Marshall Islands
Project on the Formulation of a Self-Sufficient Energy Supply System
Final Report

January, 2015

Japan International Cooperation Agency (JICA)

Okinawa Enetech Co., Inc.

IL
JR
15-001

Marshall Islands

Project on the Formulation of a Self-Sufficient Energy Supply System in the Marshall Islands

Final Report

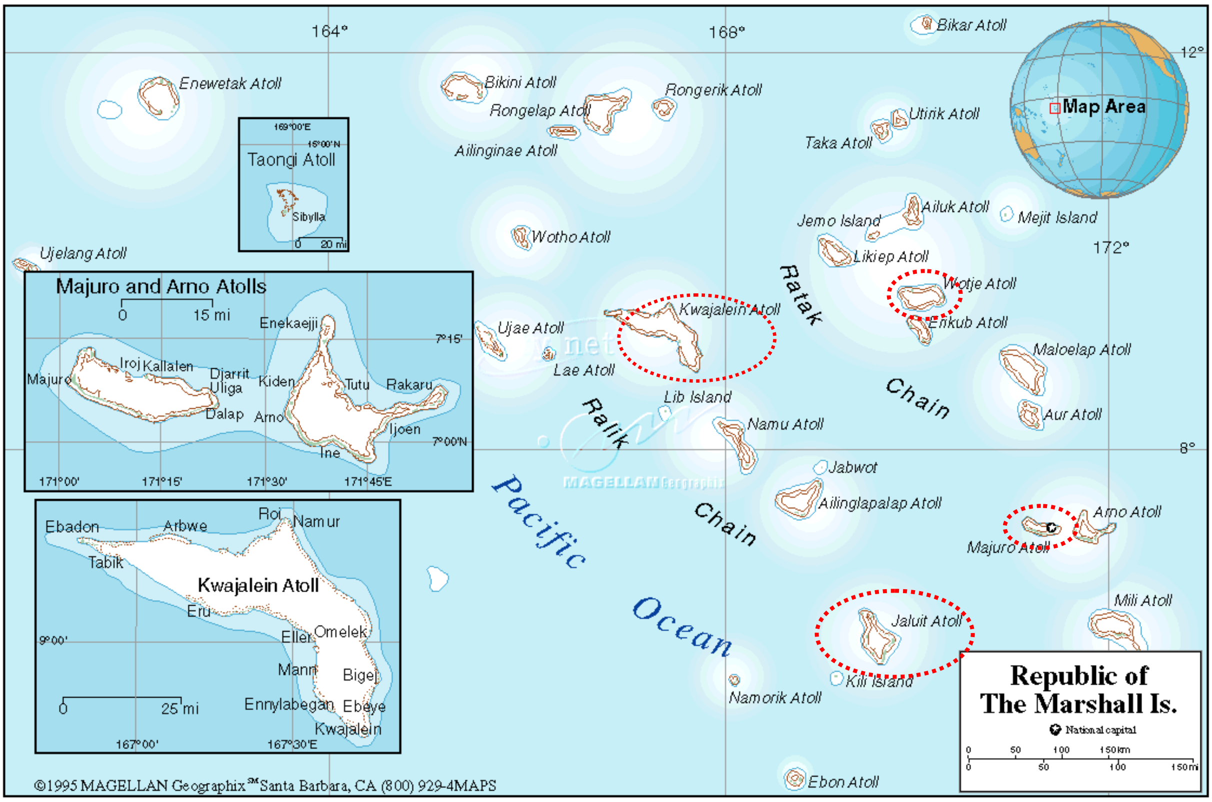
Contents

Attachments

Contents - Appendix Tables

Contents - Appendix Figures

http://thehungarybuddha.com/2013/06/30/the-marshall-islands/



http://mecrmi.net/mec%20facilities.htm

1 ⬭: Indicates survey areas for the project（Majuro Atoll, Wotje Atoll, Jaluit Atoll, Ebeye Isaland）

Facility verification with CP, Mr. Ian

Majuro Unit 7 fuel flow measurement
Verified data with CP

Installed measuring instrument for Wotje Power Plant load rejection test

Survey of potential PV installation site on WotjeAtoll

Survey of potential PV installation site on JaluitAtoll

Meeting on how to conduct load rejection test at EbeyePower Plant

Final presentation of survey results to CP

Presentation of survey results to Japanese Embassy

Abbreviations

Abbreviation	Official name
ACP-EU	ACP-EU Joint Parliamentary Assembly
ADB	Asia Development Bank
ALC	Automatic Load Control
AFC	Automatic Frequency Control
AusAID	Australian Agency for International Development
AUT	Australia
ADMIRE	Action for the Development of Marshall Islands Renewable Energy
BDEW	Bundesverband derenergie- und Wasserwirtschaft
BGR	Bulgaria
B/S	Balance Sheet
CMI	College of the Marshall Island
Compact	Compact Of Free Association
C/P	Counterpart
CT	Current Transformer
DC	Direct Current
DERlab	Distributed Energy resources Laboratory
DEG	Diesel Engine Generator
DER	distributed energy resources
DEU	Germany
DGR	Directional Ground Relays
DNK	Denmark
DSM	Demand Side Management
EC	European Commission
EDC	Economic Load Dispatching Control
EDIS	European DER Interconnection Standard
EE	Energy efficiency
EPD	Energy Planning Division
EPSCO	Economic Policy, Planning and Statistics Office
ESCAP	Economic and Social Commission for Asia and the Pacific
ESP	Spain
ETF	Energy Task Force
EU	European Union
EDF-10	European Development Fund 2008-2013
FEA	Fiji Electricity Authority
FRA	France
GBR	United Kingdom
GC	Grid Cord
GEF	Global Environment Facility
GDP	Gross Domestic Product
GF	Governor Free
GHG	Green House Gas

GNI	Gross National Income
GRC	Greece
F/S	Feasibility Study
FIT	Feed-in Tariff
HV	High Voltage
IEEE	The Institute of Electrical and Electronics Engineers, Inc.
IMF	International Monetary Fund
ICDF	International Cooperation and Development Fund
IOM	International Organization for Migration
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
IRR	Iternal rate of return
ITA	Italy
ITC	Investment tax credit
IUCN	International Union for Conservation of Nature and Natural Resources
JET	Japan Electrical Safety & Environment Technology Laboratories
JFPR	Japan Fund for Poverty Reduction
KAJUR	Kwajalein Atoll Joint Utility Resources
LED	Light Emitting Diode
LFC	Load Frequency Control
MEC	Marshall Energy Company
M/M	Minutes of Memorandum
MOMI	Mobile Oil Micronesia
MOF	Ministry of Finance JAPAN
MOU	Memorandum of Understanding
MRD	Ministry of Resources and Development
MV	MiddleVoltage
MWSC	Majuro Water and Sewage Company
NASA	National Aeronautics and Space Administration
NEP	National Energy Policy
NISA	NIHON Individual Savings Account
NLD	Netherlands
North REP	North Pacific ACP Renewable Energy and Energy Efficiency Project
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
OEPPC	Office of Environmental Planning and Policy Coordination
OTEC	Ocean Thermal Energy Conversion
OFR	Over Frequency Relay
OVR	Over Voltage Relay
O&M	operations and management
PALS	Pacific Appliance Labeling and Standard Program
PCS	Power Conditioner System
PEC	Pacific Environment Community
PIF	Pacific Islands Forum

PII	Pacific International Incorporated
P/L	Plofit & Loss Statement
POL	Poland
PPA	Pacific Power Association
PPA	Power Purchase Agreement
PT	Potential Transformer
PTC	Production tax credit
PV	Photovoltaic
R/D	Record of Discussions
RE	Renewable Energy
RMI	Republic of the Marshall Islands
RO	Reverse Osmosis Membrane
ROI	Return on investment
RPS	Renewable Portfolio Standard
RRE	Robert Reimers Enterprise
SHS	Solar Home System
SIDS	Small Island Developing States
SIEA	Solomon Islands Electricity Authority
SOPAC	SECRETARIAT OF THE PACIFIC COMMUNITY
SPC	Secretariat of the Pacific Community
TOBOLAR	TOBOLAR COPRA PROCESSING PLANT, INC.
Tr	Transformer
UFR	Under Frequency Relay
UNDP	United Nations Development Programme
UNEP	United Nations Environment programme
USAid	United States Agency for International Development
USDA	United States Department of Agriculture
UVR	Under Voltage Relay
VCB	Vacuum Circuit Breaker
WHO	World Health Organization,
WG	Working Group
WTI	West Texas Intermediate
WT	Wind turbine

Chapter 1　Survey Outline

1.1 Background of the Project

The Republic of the Marshall Islands (hereafter RMI), established the "National Energy Policy and Energy Action Plan" in September 2009, and set ① more efficient oil use and ② the electrification of 100% of households in urban areas and 95% in remote islands and atolls by 2015 (approx. 93% of households on Majuro Atoll as of 2009), and ③ the supply of 20% of all energy with RE (6% as of 2009) as its goal.　Under this plan, Japan, United States, EU, ADB, and others are making progress in the improvement of distribution networks and the introduction of renewable energy in the remote islands, but as of 2011, no regulation exists for connecting any power sources (including RE) to the existing distribution networks. Therefore, to further spread RE, the development of legal systems concerning agreements such as those between individuals and Marshalls Energy Company (MEC) remains an issue. Also, RMI which is dependent on diesel fuel for nearly all of its approximately 16 MW of power generation capacity, which is expensive, despite setting electric charges at approx. 33 US cents/kWh, which is higher than in Japan in the same year (approx. 26 US cents/kWh in 2011), MEC, the implementing organization, has been and is currently in deficit, and the advancement of economically optimal operation of existing diesel generators has also become a pressing issue.

Under such circumstances, the RMI Government filed a request to Japan for technical cooperation in December 2011 for the following purposes: ① assistance in developing a legal system for introducing RE, ② assistance in developing an evaluation method to determine the maximum permissible amount of RE that can be connected to the distribution network, ③ assistance in the planning and design of hybrid systems in remote islands, and ④ minimization of loss at facilities through optimal operation management.　Having received this project, the organizations involved conducted a detailed planning survey from 6/9/2013 to 6/15/2013, prioritized the country's issues, and agreed on the framework of the project with the RMI Government.

1.2 Purpose, Support Items and Results

Based on the above background, in order to achieve the goals set forth in the "National Energy Policy and Energy Action Plan" established by RMI in September 2009, the purpose and outcome of this project are as follows.

The Purpose of the Project

> The purpose of the project is to provide implementation support for the construction of a self-sufficient energy supply system in the Marshall Islands and to propose methods for improving the operation of existing diesel generators.

Support matters for the project

1. Assist in developing a legal system　for the introduction of RE
2. Assist in developing an evaluation method to determine the maximum allowable amount of RE that can be connected to the distribution network
3. Technical assistance with planning and design of a hybrid (PV/diesel power generation) system
4. Technical assistance on minimizing loss by optimizing power plant operation management

Project outcome

1. Not only will the method for developing a legal system relating to the introduction of RE be transferred, but a proposal and guidelines for a legal system will be put in place, and an operation plan will be presented as well.
2. Not only will the maximum permissible amount of RE that can be connected to the distribution networks be evaluated, but the evaluation methods will be transferred as well.
3. Example plans and designs of hybrid systems (photovoltaic-diesel generation) will be presented, and the design technology will be transferred as well.
4. The proposal for improving power plant efficiency by improving power plant operation and efficiency improvement test results will be presented, and optimization technology will be transferred as well.

1.3 Implementation Period

This project will be carried out in two stages: Term 1 and Term 2. "Collection and analysis of relevant data and information" will be conducted in Term 1, and "assistance in developing a legal system for introducing RE and technical assistance relevant to improving the supply-side energy efficiency" will be conducted in Term 2.

- Term 1: Dec. 2013 – Mar. 2014
- Term 2: May 2014 – Jan. 2015

1.4 Related Agencies and Authorities

Agencies concerned: Ministry of Resources and Development (MRD), Marshalls Energy Company (MEC)

Implementing agency: Marshalls Energy Company (MEC)

1.5 Survey Areas

＜Survey area＞

Majuro Atoll, Ebeye Island, Jaluit Atoll, Wotje Atoll

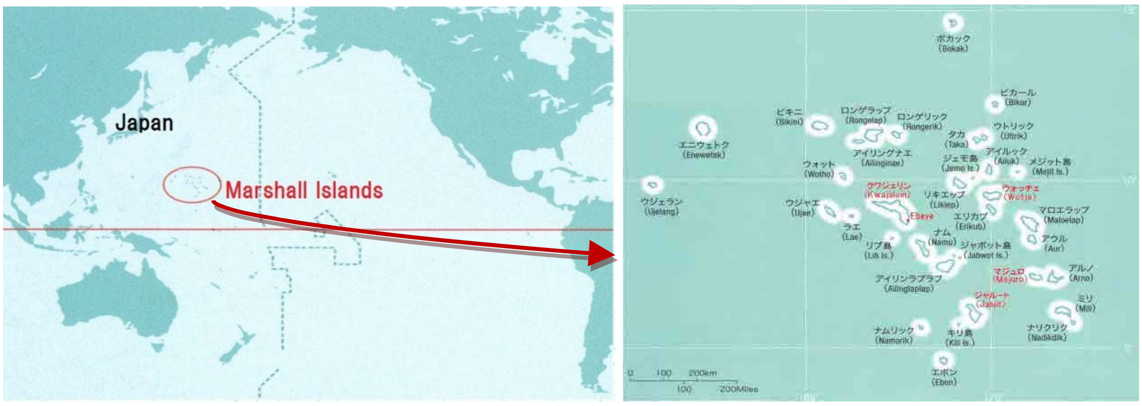


Fig. 1.5-1 Map of Marshall Islands (survey areas)[2]

[2] Source: Marshall Islands Travel Guide (Marshall Islands Visitors Authority)

1.6 Organization of Survey Personnel

Table 1.6-1 Implementation member structure

No.	Name	Field	Company
1	Luis Kakefuku	Coordinator	Okinawa Enetech Co., Inc.
2	Chihiro Tobaru	Grid analysis	Okinawa Enetech Co., Inc.
3	Jun Hagihara	Legal system design A	Individual consultant
4	Leon Roose	Legal system design B	HNEI(Hawaii Natural Energy Institute)
5	Naoto Higa	RE grid connection technology A	Okinawa Enetech Co., Inc.
6	Sadao Asato	RE grid connection technology B	Okinawa Enetech Co., Inc.
7	Hirotsune Gibo	Diesel power generation operation efficiency A	Okinawa Enetech Co., Inc.
8	Yuma Uezu	Diesel power generation operation efficiency B	Okinawa Enetech Co., Inc.

1.7 Survey Schedule

This project was carried out in two stages, 1st Year and 2nd Year. In the 1st Year, we conducted preliminary work in Japan, the 1st Field Survey, and the 1st Analysis in Japan. In the 2nd Year, we conducted three field surveys (the 2nd-4th Field Survey) and three analysis in Japan.

See attachment for details on the process and the field survey schedule.

■ Work Schedule for the 1st Year

- Preliminary work in Japan：December 19, 2013 - January 11, 2014
- 1st Field Survey：January 11, 2014 - February 2, 2014
- 1st Analysis in Japan : February 3, 2014 - March 7, 2014

■ Work Schedule for the 2nd Year

- 2nd Field Survey：June 1, 2014 - June 22, 2014
- 2nd Analysis in Japan : June 23, 2014 - August 08, 2014
- 3rd Field Survey：August 9, 2014 - August 31, 2014
- 3rd Analysis in Japan：September 1, 2014 - November 10, 2014
- 4th Field Survey：November 11, 2014 - November 23, 2014
- 4th Analysis in Japan : November 24, 2014 - January 20, 2015

Chapter 2 Overview of Energy Conditions and Energy Sector in Marshall Islands

2.1 Overview of Social and Economic Conditions

2.1.1 Political Conditions

2.1.1.1 Political aspects in the historical background

In 1947, with the United Nation's approval, Marshall Islands became one of the trust territories of the US, alongside with Palau, Federated States of Micronesia and Commonwealth of the Northern Mariana Islands. Later in 1982, the Compact of Free Association[3] was arranged with the US, and in 1986 Marshall Islands became an independent country as one of the US's COFA countries. According to the compact, RMI's autonomy is acknowledged, and mutual obligation with the US is stipulated.

Upon the compact, RMI is provided financial aids, rights of residence (not permanent) and work in the US. Instead of these rights, RMI gives over the rights of defense and also rights regarding security assurance (the US's right to utilize military bases in RMI. is prohibited to enter any US military bases located in third countries).

RMI is accomplished as an independent country, as having affiliated with the UN in 1991. RMI has diplomatic relationship with over 70 countries, and affiliated with international organizations such as International Monetary Fund (IMF), World Bank, and also with regional organizations such as ACP/EU, and also with Economic and Social Commission for Asia and the Pacific (ESCAP), Pacific Islands Forum (PIF) and Asian Development Bank.

Also, RMI is a member nation of many international treaties, and has its representative ambassador in the United Nations headquarters. RMI has foreign embassies in the US (Washington DC), Japan (Tokyo), Fiji (Suva), Taiwan (Taipei), and a general consulate is located in Honolulu, Hawaii.

The country is under the intense influence from the US, and the vote at the UN general assembly tends to be exactly the same with the US's.

2.1.1.2 National mechanism

RMI is an independent, democratic nation which is in free alliance with the US. The country has the system based on representative democracy, and the constitution is built on concepts and ideas from governance acts of the US and the UK.

The legislative body is organized by 33 councilors of the parliament Nitijela. The councilors are selected from the 24 inhabited atolls and islands. The president is selected by vote, and needs to get a majority of the councilors. The parliament is unicameral, and the councilors are selected every four years by direct election by the citizens. The president concurrently serves as the president and also as the prime minister, and appoints the cabinet which is organized by 10 personnel from the Nitijela (presidential assistant and ministers of finance, foreign affairs, health and environment, home affairs, justice, public works, development of resources, transportation and communication). Nitijela is held twice a year, and the overall term of session is 50 days.

[3] The related countries simply called it the Compact. It was later revised in 2004, and the revised free association (Second Compact) is valid until 2023.

Also, a conference of chiefs called Iroji is comoposed of 10 chiefs, and it manages traditional and conventional matters. The national constitution specifies equality of all the citizens, and lawfully assures the security of foreigners. A land tenure system and traditional laws are preserved by the national constitution.

The legislative body is centralized, and there are no administrative boundaries by regions and states. Local autonomous bodies are organized in the inhabited atolls and islands, and the mayors and councils are selected every four years.

2.1.2 Social Conditions

2.1.2.1 Population

RMI has a population of 50,840 according to the latest statistics in 1999. The average population growth rate is 1.6%, and 68% of the population is in the capital Majuro and in Kuwajalein atoll. The other 32% of the population is dispersed over all the outer islands. The US military presently has large scaled installation in Kuwajalein atoll. The unofficial statistics in 2011 shows that the total population is 53,158, the average population growth rate is 0.4% and the 74% of the population is centered in Majuro atoll and Ebeye Island (part of the Kuwajelein atoll).

In the 30 years from 1958 to 1988, RMI's population grew tremendously (average population growth rate 3.9%), and this reflects the improvement in quality of life and financial prosperity. In 1988, the rate decreased to 3.7%, and in the next 10 years from '88 to 99, it further decreased to 1.5%. The assumed reason is that the decreased birth rate (7.23% in '88, 5.71% in 5.71 and 4.1% in 2011). Also, the immigration of many citizens to the US is also considered as a major reason, considering that an estimated 11,000 people immigrated to the US between 1999 and 2011.

Table 2.1.2-1 Population and land area of RMI (2011, unofficial)

Unofficial population census (2011)	Population	Compared with data of 1999 (%)	Land area (km^2)	Population density (/km^2)
Marshall Islands	**53,158**	**0.4**	**181.5**	**293**
Ailinglaplap	1,729	-1.1	14.7	118
Ailuk	513	-3.5	5.4	63
Arno	1,794	-1.2	12.9	139
Aur	499	-0.6	5.6	89
Bikini	9	-3.1	6.0	2
Ebon	706	-2.1	5.7	123
Enewetak	664	-2.1	5.9	114
Jabat	84	-1.0	0.6	148
Jaluit	1,788	0.6	11.3	158
Kili	548	-2.9	0.9	588
Kwajalein	6,624	0.4	16.4	696
Lae	237	0.6	1.5	239
Lib	98	0.4	0.9	166
Likiep	481	-2.3	10.3	39
Majuro	27,797	1.4	9.7	2,862
Maloelap	682	-1.9	9.8	70
Mejit	348	-1.5	1.9	187
Mili	738	-2.8	15.9	46
Namdrik	508	-3.5	2.8	193
Namu	780	-1.2	6.3	124
Rongelap	79	12.1	8.0	10.0
Ujae	364	-1.6	1.9	195
Ujelang	-	-	1.7	-
Utirik	435	0.0	2.4	179
Wotho	97	-3.4	4.3	22
Wotje	859	-0.1	8.18	105

＊Colored are the target survey areas

2.1.2.2 Culture and Social Structure

The Marshall Islands has generally even culture overall, but different cultures and languages are seen in Ratak and Ralik atolls. Majuro atoll belongs to the Ratak islands, and Kuwajelein is belongs to the Ralik islands.

People in the Marshall Islands have a maternal society and strongly keep family ties and mutual dependency even under influence from foreign societies. Family-oriented units are broadly discerned, and family ties are quite tight. According to the statistics of 2011, the average family consists of 6.78 people.

Churches and religions played important roles in forming the people's lifestyles and attitudes after missionaries begun their activities in the 1830s. People in Marshall Islands are generally reverential and peaceful, having benevolent attitudes toward people. Their lives are generally simple and slow-paced. In recent years, financial activities based on cash payment are becoming active because of increased salaries gained from non-conventional work. As a result of the monetized economy, imported foods are consumed ever more. However, the more imported foods are consumed, the worse their dietary habits become. Their traditional nutrient sources were breadfruits, coconuts, pandanus, taro, fish, chicken and pork. However, these are being replaced by canned foods and processed foods.

Alcohol consumption, smoking and drug abuse are seen among the younger generations. Drinking alcohol on the streets is prohibited in recent years. Life style changes caused the increase in diseases such as diabetes and other diabetic disorders. According to the document from WHO issued in 2012[4], the leading cause of death is diabetic disorders. Rates of illness and death are quite high. Currently, the death rate from non-infectious diseases is higher than infectious diseases.

2.1.3 Economic Conditions

As other countries in Micronesia, the economy is sustained by financial aid from Compact and income related to the US military bases. In 2006, 31% of GNI and 62% of governmental revenue are made of financial aid from the US and others[5], and the scale of annual budget is highly depended on financial aid from donors and other forms of support. The country does not have its own currency, and the US dollar is the currency in circulation. Therefore, it is not influenced by foreign currency fluctuations.

According to the World Bank's statistics in 2011, GNI per person is 3,910 dollars, economic growth rate is 5.0%[6], and the inflation rate is 1.5%. The major industries are agriculture (copra, and coconut oil) and fishery, but the environment is not suitable for agriculture because the land is limited and marginal, and also water usage is dependent on harvested rain water, and government-related expenditures dominated 65% of the GDP (2006). The country is a tax haven inviting 'ships with a flag of convenience', and is also one of the world's open registry countries.

The country is aiming for economic independence by achieving economic growth from economic reform, mainly by training private sectors especially seafood processing and tourism.

About 20% of the population is engaged in agriculture and fishery, and 58% is working for the government and related authorities, and 20% is engaged in fish and coconut processing jobs.

---

4 http://www.wpro.who.int/countries/mhl/who_pacific_marshall_island.pdf
5 World bank (http://data.worldbank.org/indicator/NY.GNP.ATLS.CD?page=1) and RMI, EPPSO (http://www.spc.int/prism/country/mh/stats/economic/GovtFinance/govtexp.htm)
6 2009-1.9％ 2010-5.2%

2.2 Geography and Climate

2.2.1 Geography

RMI is located coordinates east longitude 160 – 173 degrees and north latitude 4 – 14 degrees (north-south 1.200km, east-west 1,300km). As shown in the figure 1.5-1, the country is composed of 34 atolls having containing 1,156 islands making its land territory about 181.3 km^2. Its exclusive economic zone (within 200 sea miles) spans 194 million km^2 of marine area, and its inner atoll marine area covers 11,670 km2 in total. The average altitude is 2.0m above sea level. The lowest altitude is 0m, and the highest point at Likiep is 10.0m. Majuro, in where the capital is located. It has an altitude of 3m at its highest point and is a flat coral area. There are almost no fertile lands or rivers in the territory.

2.2.2 Climate

The country is in the area of oceanic tropical climate, and the weather is hot and humid throughout the year. Annual rainfall is 2,000 mm in the northern area and 4,000 mm in the southern area. The climate conditions in the capital Majuro, is shown in the figure 2.2.2-1.

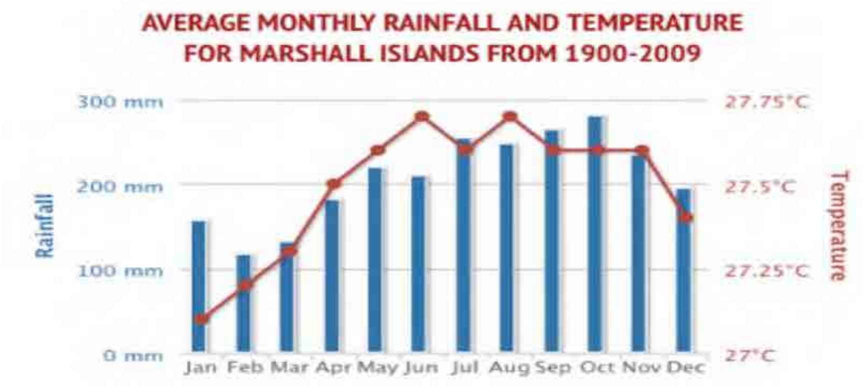


Figure 2.2.2-1 Monthly rainfall and temperature in RMI
(average from 1900 to 2009)(World Bank)[7]

As seen above, the temperature in Majuro is around 27 – 28℃, and there are no large temperature differences. The amount of rainfall is about 100 – 200 mm in the dry season (between December and April), and in the rainy season it reaches over 250 mm. Annual rainfall is 1.8 times that of Tokyo.

As the altitude is low, it is vulnerable to disaster from high tide water. However, it is rarely affected by typhoons as it does not lie on their path. Majuro incurred damaged by height tide water and cyclonic rainstorms in 1958, and in the same year, some of their buildings were damaged by a typhoon. There are no historical records of earthquakes in RMI.

[7] http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Australia&ThisCCode=MHL

2.3 Overview of Energy Sector

2.3.1 Overall Energy Conditions

Energy policy in RMI is coordinated by Ministry of Resource and Development (MRD). MRD has divisions of Agriculture, Trade Investment, Energy Planning and Finance. The Energy Planning Division (EPD) is the department in charge of energy introduction, utilization, promotion. They are also in charge of promoting RE and energy conservation. EPD is composed by two officers and a national energy adviser through the Pacific Technical Assistance Mechanism (PACTAM-AusAID) funding from Australia.

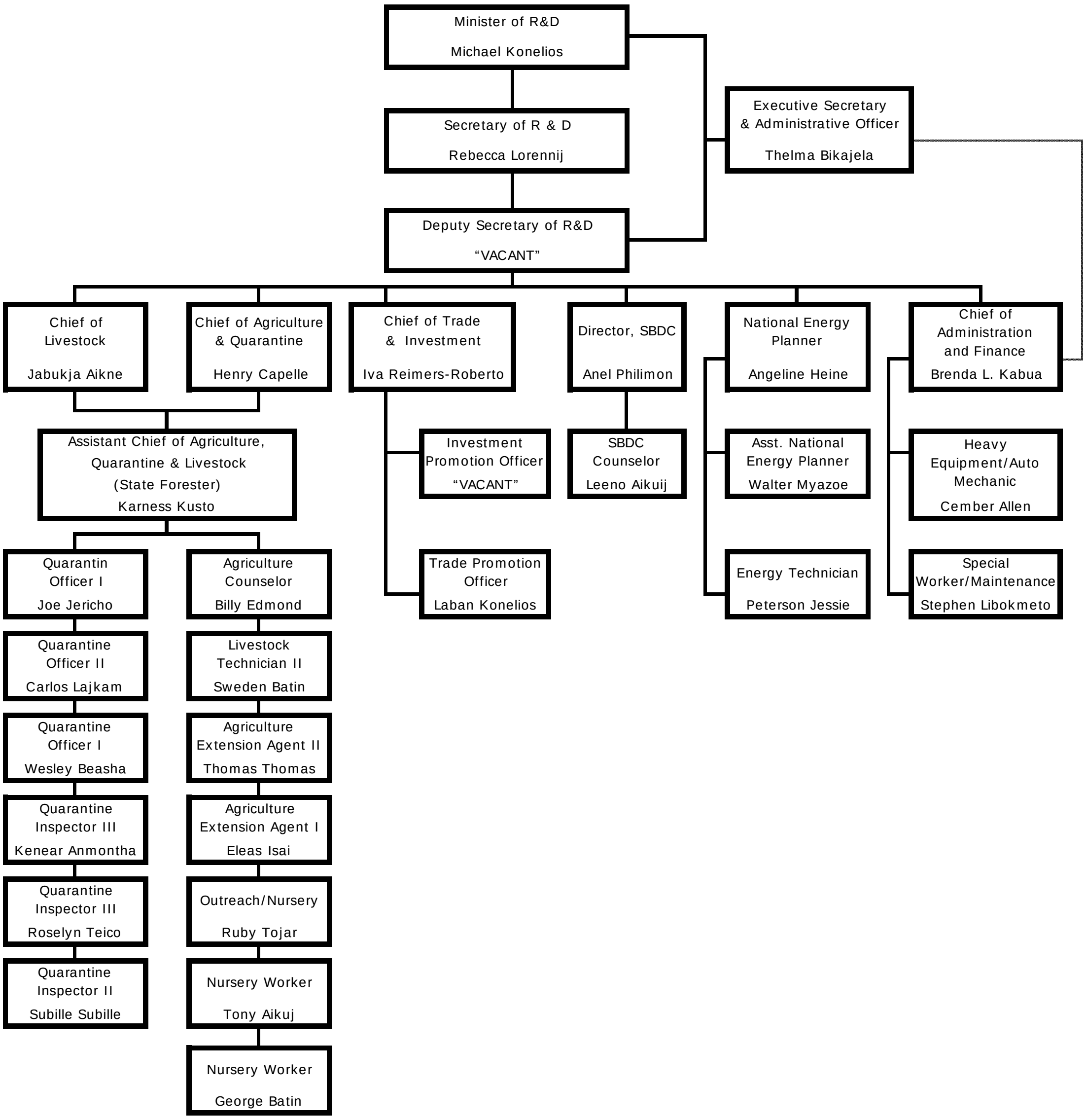


Figure 2.3.1-1 MRD Organization Chart[8]

[8] Obtained from MRD

Also, the Office of Environmental Planning and Policy Coordination (OEPPC) which is in charge of environmental considerations, and the Economic Policy, Planning and Statistics Office (EPSCO) is in charge of economic policies and strategic planning. These divisions are the direct institution of the oval office.

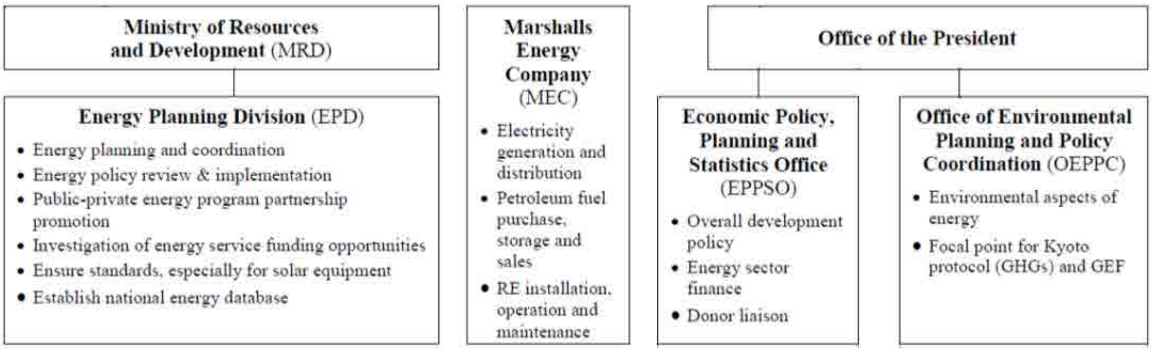


Figure 2.3.1-2　Authorized organizations in RMI energy sector[9]

The Energy Action Plan states that besides these organizations indicated in the figure above, the Ministry of Foreign Affairs, Home Affairs, and Finance will also play important roles, and the Energy Task Force (ETF) should be recognized as an important part of the project. The items stated below are defined as the main tasks for each office:

(1) Ministry of Foreign Affairs

- Managing database regarding donors and funding opportunities by development organizations

(2) Ministry of Resources and Development

- Technical advice regarding imported fuel and quality of domestic biofuel
- Arrangement of contracts in fuel provision and providing human resource development and training in regard to the management of related contracts
- Develop survey report on fuel price and management

(3) Ministry of Finance

- Evaluate MEC's fuel storage and marine fuel feeding service
- Taxation on fuel for land transportation(diesel is given preferential treatment over gasoline)
- Imposing tariff on inefficient home electric appliances
- Provision of low-interest loans for improvement of energy efficiency in government facilities
- Provision of grants, low-interest loans and implementing preferential treatment for solar thermal water heaters

(4) ETF

- Develop a consistent governmental policy regarding PV power generation project

Marshall Energy Company (MEC) is an organization, independent of government agencies, engaged in the electric industry. MEC is in charge of overall electric business, including power generation, distribution, import and sales. Details on MEC are provided in 2.4 – 2.5.

[9] Republic of the Marshall Islands National Energy Policy and Energy Action Plan VOLUME 2:　ENERGY ACTION PLAN (September 2009 – August 2012)

90% of energy provision in RMI is dependent on imported fuels, and the rest is provided from biomass. Fluctuating fuel prices can greatly influence the energy supply and economic situation in the country, and it makes energy security vulnerable. Besides MEC, a private company called Mobile Oil Micronesia (MOMI) is engaged in fuel import and sales. The consumption breakdown in 2003 is as follows: 68% for transportation, 30% for power generation, and rest is for commercial enterprises and private homes.

The rate of electrification in Majuro atoll and Ebeye island are 93 & and 97% each (2006). However, propane and petroleum are still broadly used for cooking.

Table 2.3.1-1 Energy for cooking in city areas[10]

Main Energy Source for Urban Cooking, 2008			
Fuel	Both Atolls	Majuro	Ebeye
Propane	38%	35%	43%
Kerosene	22%	20%	27%
Biomass	21%	24%	13%
Electricity	19%	20%	17%

2.3.2 Status on RE Usage and Implementation

(1) Biomass

Biomass energy in the country is produced from waste materials, coconut stalks and copra (coconuts oil), and used for cooking and water heating in households.

In 2008, 5.3ML of copra is produced within RMI, copra is more expensive than diesel fuel at present. If the cost of copra becomes less expensive in the future, and the price is about same as diesel fuel, then copra will be broadly utilized as a new energy source. At present, some trials of power generation and reduction in the burning of diesel fuel using copra are being conducted with ADB aid, but these have still not been put in practical use.

(2) PV (Solar Energy)

Regarding PV power generation, about 1,300 of standalone PV systems (SHS : Solar Home System) were installed in remote island areas by the year 2008. These were conducted with financial aids from TU, Taiwan and other donors. Details are shown in the table below.

In January 2014, during the implementation of this survey, another shipment of SHS arrived and was set to be installed in remote island areas.

[10] Republic of the Marshall Islands National Energy Policy and Energy Action Plan VOLUME 1: NATIONAL ENERGY POLICY

Table 2.3.2-1 Number of stand-alone PV generation system (SHS) installations[11]

Donor	Installed Year	Atoll / Island	No. of Installation	Category
EU	2002	Mejit	81	Household
EU	2004	Namdrik	121	Household
US	2007	Wotje	36	Household
EU	2009	Ailinglaplap	412[12]	Household
US	2007	Wotho	25	Household
EU	2009	Ine, Arno Atoll	1	Elementary school
EU	2009	Mejit, Mejit Atoll	1	Elementary school
EU	2009	Majkin, Namu Atoll	1	Elementary school
Taiwan	2007-2008[13]	Arno	359	Household
		Likiep	107	
		Ebon	98	
Taiwan	2012	Majuro	116	Street light
Taiwan	2012	Majuro	78	Basket ball court
US	2011	Utrik	1	RO membrane desalination system
US	2013	Ailuk	1	RO membrane desalination system
US	2013	Ujae	1	RO membrane desalination system
Taiwan	2014	Kuwajalein	356	Household

MEC manages financial aid from each donor, and is planning to install more SHS – 2,445 SHS with aids from Taiwan and EU and US and France, and 60 – 70 units of street lights and RO coat desalination system with aid from Japan.

On the other hand, a 57kW PV system was installed in CMI (College of Marshall Islands) with aid from the US in 2009. This system is grid connected, and all the power generated by it is to be consumed within the premises according to the contract. However, occasional reverse power flow to the grid occurs on days with extremely low loads such as holidays, as no backward flow protection device is installed. An additional PV system of 54kW was installed with aid from Taiwan, by Speedtech. Also, a 209kW PV system was installed on the roof of Majuro Hospital in July 2012 with financial aid from JICA. Power generated by this system is not used within the hospital, but rather sent to the grid.

Some shops in Majuro sell LED lanterns powered by PV panel (few watts), but most of them are made in China. Durable PV equipments are not available for sale in Majuro. However, there is one shop that specializes in PV called Island Eco. It sells PV panels, storage batteries, inverters and related parts/devices for stand-alone systems, but not for grid connection. In addition, Island Eco[14] is contracted by the U.S. Department of Agriculture to install SHS and PV desalination systems.

(3) Wind Power Generation

There are some wind turbines in the Marshall Islands. One is a 7kW turbine installed near Robert Reimers Enterprise (RRE)[15] in Majuro, and two turbines of 100W are installed at an elementary school near the airport. None of these are connected to the grid and are owned by individuals for private use. The 7kW turbine[16] near RRE is 240V and 50Hz[17], and is used to charge ship batteries.

[11] Obtained from MEC
[12] Another resource shows the number of 420 units
[13] Another resource shows 930 units in three islands.
[14] http://www.islandeco.com/about/marshall-islands-solar-resources
[15] It also operates other busiesses such as hotels, shops, and shipping.
[16] http://www.youtube.com/watch?feature=player_embedded&v=9Epmp95X-lg#t=0s

Until last year, wind conditions and solar radiation was observed in Wotje atoll and Jaluit atoll to grasp the amount of RE available, and six months of data on wind conditions was released on MEC's website[18].

Figure 2.3.2-1 RRE 7kW wind turbine

Figure 2.3.2-2 Elemenatary School 100W wind turbine

2.3.3 National Energy Policy and Action Plan (2009 Ver.)

RMI created the National Energy Policy and Energy Action Plan in September 2009, and the items below were set as the goals:

① Achieve 100% electrification for households in urban areas and 95% in remote islands (as of 2009, 93% of households in Majuro island had electricity) by 2015.

② Supply 20% of all energy with renewables by 2020 (6% as of 2009).

③ Improve energy efficiency by 50% in households and businesses and 75% in government related buildings by 2020.

④ Reduce supply-side loss at MEC by 20% by 2015.

Even though there is no Energy Act, RMI developed a National Energy Policy and Strategic Action Plan in 2008, which were endorsed by cabinet in 2009. On 21-23 January 2014, a workshop "Review of the National Energy Policy (2009) and Energy Action Plan (2009-2012)" was held in Majuro and its current position/progress was discussed. Table 2.3.3-1 shows the review of RE at the workshop.

Table 2.3.3-1 Energy Policy Administration and Implementation: Renewable Energy

	KEY STRATEGIC AREA 1: ENERGY POLICY ADMINISTRATION AND IMPLEMENTATION		
	STRATEGIES, ACTIVITIES UNDER REFERENCED DOCUMENTS	RAN KING	REASONS/ADDITIONAL COMMENTS
	NATIONAL ENERGY POLICY (2009)		
	Broad Goals of NEP 2009		

17 The country's electric power system is 120 V, 60 Hz.

18 http://www.mecrmi.net/renewable%20energy.htm

1	The provision of 20% of energy through indigenous renewable resources by 2020;	2	RMI has a peak demand of around 12MW. MEC has a supply capacity of 24.4MW. The only grid connected PV systems are the 205 kW on the hospital and the CMI 50kW PV system. Acceleration of the uptake of grid PV systems need to be pursued to meet this target by 2020, however this will be dependent on the grid stability study currently being done by JICA.
	Cross-cutting Issues		
1	***Climate change.*** Climate change will severely test the resiliency of the RMI's institutions and infrastructure, with expectations of increased flooding, longer periods of drought, changing patterns of disease and serious issues of access to clean water. This energy policy is consistent with, and supportive of, national efforts to address climate change. All new energy investment decisions and investments, including design and construction of new buildings, must consider resilience for adapting to climate change, which will also result in longer term savings to the government and people of the RMI.	2	Office of the President through OEPPC has been pursuing RE interventions in particular for OTEC in light of climate change mitigation. MRD's pursuance has been more energy focused rather than taking into account the climate change mitigation. These two sectors need to be streamlined they complement each other
2	***Governance.*** Development of transparent decision-making processes, appropriate legal tools and regulations, and consistent enforcement of regulations. Performance-based budgeting within the government is needed including energy criteria as performance measures for each government ministry and agency.	1	Whilst MRD is the leading agency for the energy sector, OEPPC has in recent years taken up an active role for RE. There is no coordination in the decision making processes or legal tools and regulations to enforce
3	***Social and environmental sustainability.*** Development of mechanisms to improve the likelihood of long-term sustainable operation, minimal production of pollutants; and reduced emissions of greenhouse gases (GHG) per unit of energy produced. Although the RMI has no legal obligation to reduce GHG emissions, which are practically nil, it plans to do so whenever practical.	2	For the outer islands electrification programme, this has been pursued through North REP. IUCN funding for $200, 000 towards environmental sustainability (in the pipeline) (ADB & ADMIRE & AUSAID on alternative fuels)
4	***Gender awareness.*** Assurance of equal access by women and men to training opportunities (e.g. community-level solar system management) and decision-making (e.g. management and boards).	2	Pursued under North REP for the Outer Islands Electrification Programme Biofuels testing /Wind monitoring
5	***Capacity building.*** Strengthening of a range of public, private, civil society and academic institutions so agreed initiatives can be effectively implemented. Strengthened public/private partnerships in energy production and efficient use.	2	Whilst it has been pursued on an ad-hoc basis for various projects, there is no formal programme at training institutions for RE (solar, biofuels)
6	***Education and information dissemination.*** Developing and disseminating appropriate public awareness materials and school curricula on energy issues.	2	Public awareness materials continued to be developed and disseminated, however there is no school curricula on energy issues
7	***Data development.*** Developing and maintaining appropriate databases on energy imports, resources, production and consumption, that are easily accessed and suitable for more effective decision-making.	2	RE assessment, implementation, operational data has been collaged and stored in separate locations. No central RE database
8	***Appropriate technology choice.*** Choice of energy production and energy efficiency equipment that is commercially available and proven in small island environments.	3	Fulfilled. Solar PV technologies has been aggressively pursued. Not as yet for other renewable energy technologies – still under assessment stage (biofuels, wind, wave, OTEC, etc)
9	***User pays principle.*** Adoption and consistent application of the principle that the urban end-user pays at the full costs of energy and outer atoll end-users pay at least all O&M costs for renewable energy services	2	Pursued through North REP For the Outer Islands Electrification Programme. (more information for urban end-user)

	RE Policy Statement		
1	take the lead in the use of indigenous energy to replace imported petroleum with a goal of a 40% total reduction in energy from petroleum fuels within government by the end of 2020 (from RE Policy Statement)	2	In progress. Acquire fuel data to ensure that this is realistic and achievable policy statement (should be reflected overall energy sector broad goals or under policy, planning, administration – targets are confusing -replacing imported petroleum as opposed to improved EE/grade of fuel, etc, alternative forms of fuels – biofuels, etc)
	Objectives		
1	Improved capacity within the RMI to plan, develop, implement and manage renewable energy systems (small and medium-scale rural; large scale urban)	1 (2)	Focus is more technology oriented and dependent on development partners rather than financial and human resources within RMI Capacity building – trainings were provided for all the RE projects implemented on the ground.
2	provision of 20% of electrical energy through indigenous renewable resources by 2020	2	Refer to first item – broad goals
3	Outer island energy development to be through indigenous energy sources where technically practical and economically attractive	2	Aggressively being pursued through North REP for households, schools. Other ministries have also implemented RE technologies to cater for their needs.
	Strategies		
1	Arrange wind measurements over 12- 18 months and obtain an independent analysis of the wind energy potential for Majuro	3	Been relocated to the outer islands
2	Arrange independent assessment of the technical, environmental and economical feasibility of waste to energy conversion for Majuro	3	Feasibility study done in 2009 by ADB
3	Develop and implement training of trainers programs covering PV system design, installation and management; develop training programs for village level O&M	2	Developed through North REP for solar home systems only. Not for other PV developments.
4	Develop and implement consistent mechanisms for the design and O&M of PV systems of different ministries to provide for consistent management, operational and financial mechanisms	2	Mechanisms are in place but no payments have been done .e.g. MOE Other Government ministries have their own O&M for PV systems
5	Develop and implement a program for solar water heating, particularly in Majuro, Ebeye and the hotel industry to replace electricity based water heating	1	No progress
6	Continue the program of outer island household solar energy installations and develop a mechanism for covering full user costs (through user fees and possibly a sustainable RE fund)	3	Fulfilled
7	Arrange with donor support a pilot program to introduce renewable energy into the MEC or KAJUR grids to gain experience in integrating RE into the grid	3	Fulfilled
8	Assess options for RE development that do not require access to private land (i.e.. at government facilities, possibly reef-based installations)	1	No progress Actual installations in Government facilities, etc
9	Ensure Cabinet is kept up-to-date regarding the capabilities of and progress in renewable energy technologies, particularly ocean energy from waves, tides and ocean thermal gradients (OTEC)	2	OTEC has been pursued by OEPPC, other RE developments by MRD
	Public Consultation		
1	Establish and fund a genuine National Energy Fund for fuel and renewable energy, with a real monetary injection, not just apparent funding	1	Not fulfilled (Cooperation fund – Japan). Existing NESA fund with MOF for Jaluit and Wotje, but no national energy fund.
2	Strengthen public/private partnerships for renewable energy and energy efficiency	2	In progress, but national RE standards yet to be developed and adopted

	Majuro Energy Declaration		
1	National Government strengthen its Renewable Energy (RE) and Energy Efficiency (EE) programs as much as possible;	2	In progress technically, but no progress for financial, human, etc capacity
2	Explore and utilize alternative energy sources, including appropriate renewable energy technologies and energy efficient measures, to mitigate against economic hardship while promoting sustainable environmental practices.	2	In progress for solar home systems, other PV related technologies
3	National Government promotes investments and promotes awareness about alternative energy technologies that can transform women's lives;	1	No progress
4	Incorporate "green" energy options wherever possible and that we identify early in the process who will develop, implement, and enforce guidelines for green options;	2	Different wording….ensure consistency in language…no enforced guidelines but in progress
5	Explore using waste and ocean as sources of energy; and	2	In progress. Refer to earlier comments about OTEC and assessment on waste energy has been undertaken
6	Explore how we can increase copra production to use the oil as a renewable energy source.	2	Tobolar, MEC and MRD currently working together and pursuing this initiative
7	RMI adopt renewable energy technologies as a high priority, as the RMI has already done with its impressive solar program;	3	Fulfilled through solar PV only.
8	Provide renewable energy assistance (e.g. solar panels) to urban families in addition to outer islands	1	Not fulfilled. Taking into consideration the solar streetlights in heavily populated areas like Rita, urban families have benefitted.
	ENERGY ACTION PLAN (2009-2012)		
1	1.1 Review existing data and carry out a proper wind energy resource survey for Majuro utilizing two widely separated masts each with two wind measuring instruments, one at 15 meters and the other at either 30 or preferably 50 meters with data logging as needed for proper modeling of the island wind regime. Placement should be in an open area with no trees more than 5 meters tall within a 50 meter radius. Data will need to be taken continuously for at least one full year.	3	NRG systems installed in Wotje and Jaluit instead of Majuro.
2	1.2 Engage a firm to analyze the wind data and prepare a wind energy assessment report including a wind map for Majuro and recommendations for the specifications of the wind turbine types that are most appropriate for Majuro. Provide an estimate of the kWh that could be produced each year per installed kW of wind turbine.	1	No progress.
3	1.3 Using the masts and dataloggers installed for wind measurements, install two good quality solarimeters (pyranometers) and log readings for at least one full year. Ensure that the instruments are located such that at no time of the year can the shadow of the pole fall on the solarimeter.)	3	Same as 1.1
4	1.4 Review the prior work done by SOPAC, EC and others in determining the present and potential coconut oil resource of RMI. Update those reports using more recent information and, where needed, visit outer islands and do on site surveys of the existing and potential resource that can be made available for biodiesel production (total production less production needed for human or animal food).	1	No progress
5	1.5 Using data available within SOPAC,* estimate the monthly wave energy potential for Majuro and	1	No progress

	Ebeye		
6	1.6 Using data available to SOPAC,* determine the areas around Majuro and Kwajalein most suitable for OTEC development (depth of water, slope to reach deep water, temperature gradient, etc.)	2	In progress, not through SOPAC but with other development partners
7	2.1 Complete electrification of outer island homes	3	Fulfilled through North REP
8	2.2 Continue with solar based electrification of outer island schools and other public facilities	2	In progress. 10 more schools will be electrified through North REP
9	3.1 Install at least 160 kWp of grid connected solar equipment on the Majuro hospital (or at an appropriate location)l	3	Fulfilled
10	3.2 Prepare a feasibility study and project proposal for an additional 400 kWp of grid connected solar for Majuro schools and government offices with draft designs for each selected site showing a matching air conditioning or other load.	1	No progress
11	3.3 Develop a consistent framework among all government agencies for the development and implementation of solar projects (standardization of design procedures, standardization of components where practical, elimination of duplicative efforts, etc.)	2	In progress through solar streetlights standards/specs, SHS, PV systems for schools, etc…which will lead on to developing a overall framework.
12	4.1 Based on the results of the resource study and the population distribution, select an atoll as a pilot area for local biofuel production and its use as their energy source for electrification and lagoon transport. Prepare a detailed project proposal for implementation	3	Fulfilled. Undertaken for Ebon Atoll
13	4.2 Implement the project proposed in 4.1	1	No progress
14	5.1 Through site visits and analysis of project records, evaluate the performance of solar energy systems on the outer islands relative to the professed needs of the residents and agencies receiving services and the requirements of the project management for cost coverage through collected fees. Prepare recommendations as needed for technical and institutional changes to improve the match of needs and services and to improve cost recovery.	3	Fulfilled through North REP
15	5.2 Monitoring and evaluation of CMI solar and wind installations. Add any needed data logging and instrumentation to the CMI solar and (soon to be installed) wind systems to measure: 1. Solar received at each site using PV type solarimeters set at the same tilt as the associated panels measured at no more than 10 minute intervals 2. Energy output from the panels at each site measured on the same time parameter as solar energy 3. Operating parameters of each installed wind machine including energy production measured at no more than 10 minute intervals 4. If reef mounted are to be installed, prior to installation carry out a detailed survey of life forms and their populations within a 1 km segment of the reef having the wind machine sites at the center. A second but smaller control area should also be surveyed at the same time. 5. Re survey the same areas of reef at the same time of the year for each of 5 years following	2 3 3 3 1 1 1	In progress Asssessment stage (1-3) collecting wind & solar data No progress at all for the wind developments (on reefs)

	installation or more often if deemed appropriate by the researchers. 6. Analyze the results of the surveys and report on the changes, if any, of the ecosystem in the area of the wind turbine installations.	1	
16	6.1 Provide finance for the installation of solar water heaters on existing homes and businesses presently using electricity for water heating using finance terms that allow the home owner to install and operate the solar water heater at a monthly cost of finance equivalent to the approximate monthly cost of electricity for the operation of the electric water heater being replaced. May be managed through renting the solar water heater from MEC with rental payments equal or lower than the cost of electric water heating for the household at the time of installation. Payments to be included in the electric bill.	1	
17	6.2 Provide incentives for the installation of solar water heaters in lieu of electric water heating on new homes and commercial buildings. Incentives may include rebate of the purchase cost, reduced interest financing, and/or tax based incentives for businesses.	2	Tax rebates in place for RE & EE equipment
18	1 Independent assessment, feasibility study and project design for the production and use of biofuels on outer islands as a fuel for transport and electricity generation. Study to consider: 1. Requirements for and cost of replacement of senile coconut trees 2. Existing requirement for coconuts for human and animal food 3. Land tenure arrangements on outer islands 4. Human resource requirements for collection, transport and processing of coconuts 5. Economic and local use of oil production waste products 6. Local requirement for biofuel produced 7. Feasibility of generating surplus biofuel for sale to urban areas 8, Sensitivity of findings to fossil fuel price changes If technically and economically feasible, prepare a pilot project design for one atoll that is accessible by air for monitoring.	1	No progress

RANKING KEY

1 – NO PROGRESS 2 – CURRENTLY IN PROGRESS 3 – FULFILLED

2.4 Overview of Energy Sector

2.4.1 Policy, Laws and Regulations

There is no Electric Power Act in the country, but instead MEC Regulations (revised several times) sets forward that MEC[19], which is a government-managed company, will exclusively supply electricity for all of Majuro.

MEC is the sole utility responsible for electric power generation and distribution on Majuro, Jaluit and Wotje, and works in close collaboration with the EPD in the installation, operation and maintenance of RE installations in remote areas. However, MEC is not under MRD, but under the Ministry of Public Works. To solve this confusing situation and many other issues, there has been an idea on establishing a National Energy Board, but it has not yet been established.

In Ebeye, KAJUR is co-managed with the local government for power generation and distribution. Most Atolls have a Development Authority overseeing all operations on that particular atoll. KAJUR was run by KADA (Kwajalein Atoll Development Authority), which was closed down in the late 90's. The RMI government took control of KAJUR after a private management company left around 2005, and later, according to cabinet minutes, the government directed the MEC board of Directors, to oversee the daily operations of KAJUR. Currently, KAJUR is susidiary of MEC. However, it is an independent company with its own power system and facilities.

MEC is responsible for not only supplying energy to urban areas, but it is also responsible for importing fuel, storing fuel, supplying fuel to ships, and the SHS program for island areas shown in Table 2.3.2-1. Under these circumstances, MEC is an important organization in RMI. Regarding RE generation such as SHS, MRD and MEC entered into a Renewable Alternative Energy Systems Franchise Agreement on April 15, 2003. According to this agreement, MEC is to implement all RE business from management to maintenance.

Besides the MEC regulations, there are some laws and regulations that regulate pricing of energy. In Chapter 11 (title 10, revised version of '98) in the Retail Price Monitoring Act 1992, establishing a committee to monitor retail values is mentioned, but it has not been implemented yet, so there are no official means to control fuel prices. On the other hand, Chapter 3 title 20 of the Unfair Business Act states that the attorney general can monitor uncompetitive practice, and it is the legal ground for monitoring electricity and fuel prices. Also, Chapter 4 title 20 of the Consumer Protection Act (1998) states that any person who commits any unfair acts against customers can be examined by the attorney general, and can be fined 10,000 dollars. In addition, Chapter 6 title 20 of the Bulletin Boards and Price List Act has the same effect as that of of Retail Price Monitoring Act 1992 regarding fuel prices in remote island areas.

Chapter 3 title 35 of the Alternative Energy Fund Act, which concerns alternative energy, energy efficiency, and environmental protection, mentions the establishment of a fund for alternative energy development, its related marketing and operation. However, it is unclear whether this fund has been established.

[19] http://mecrmi.NET/ There are terms for private ownership of MEC, but currently, it is 100% government-owned.

Chapter 1 title 48 of the Import Duties Act 1989 was revised in 2001[20], and it stated that a tax of 8% of the CIF price is to be imposed on all imported articles with some exceptions. In 2010, the Import Duty Act was revised to make high-energy efficient (EE) appliances and renewable energy (RE) equipment duty-free. The EPD has power and authority in approving tax exemptions for EE and RE equipment, such as A/C, LED lighting, PV, wind turbines and etc. Application for tax exemption shall be submitted to the EPD, and if approved, an authorization letter with the signature of the responsible EPD personnel shall be sent to the customer.

Title 35 of the Environmental Protection Act aims to promote the sustainable use of domestic natural resources. It also states that the National Environmental Protection Authority has the authority to restrict land use, pollution and emission control, but it is unclear whether this agency has been established or not.

However, there are no other approvals and licenses on electricity. If off-grid, everyone can have in-house power generation system without any application and/or approval.

2.4.2 Long-Term Power Source Development Plan and Transmission Plan by MRD and MEC

There is a a great need for electrification of remote island areas utilizing SHS, but electric demands in Majuro, Jaluit, Wotje and Ebeye, which are supplied by diesel power generation and the grid, are decreasing as described in 2.5. Currently, there is little need for new power plants and the expanion of the transmission network to electrify areas without electricity. Therefore, neither a long-term power source development plan nor a transmission plan has been formulated. It is considered more important to improve the electrification rate, RE ratio and energy efficiency than to expand the existing grid which would lead directly to the increase in the consumption of imported fuel. Particularly, further utilization of RE is considered important as it can reduce the amount of diesel burned.

On the other hand, countermeasure to reduce supply loss is necessary, as supply loss increases due to the shrinking demand and load on distribution facilities. Regarding generation facilities, the recovery of Units 3 and 4 which were damaged by fire in 2006, as well as Unit 7 which was out of order to to its rotor being damaged and improvement of energy efficiency of auxiliary machineries to reduce loss within the power plant are necessary.

2.4.3 Status of Support from Other Donors

Japan has been approved to provide RO membrane osmosis equipment (850,000 dollars) to 15 remote islands with Pacific Environment Community (PEC) funds, and also applied to provide 80 street lights utilizing PV panels.

Many donors are providing support for the introduction of PV generation and improvement of energy efficiency, as described below:

[20] Bill No.75 P.L2001-43

2.4.3.1 The US

According to "FY 2012 U. S. CLIMATE FINANCE," the US is not providing as much support as Japan and Taiwan even though they are intensely committed to climate change issues in countries in Pacific areas including RMI. The US organizations are involved in the activities described below:

(1) NREL

NREL is a research institute under the US energy department, and they are involved in supporting the country since 2012. Two researchers visited the country in December 2012, and announced that they would make intellectual contributions for three years, and prepared a draft report in September 2013.

(2) USAid

USAid has provided an RO membrane osmosis system utilizing PV and wind power generation to Utirik atoll. They also provided maintenance and management training. Also they have provided equipment to introduce the same system to Ailuk and Ujae atoll in March 2013. This system is a product of Moana Marine Corporation[21], and the company has an office in Majuro.

(3) Clinton Foundation

The foundation entered into a MOU with the government of MA, provided financial aid and collaborated with OEPPC to address climate change. The advisor at the foundation is financed by US funds and will continue for the next two years.

(4) USDA

USDA applied to the Rural Utilities Service for a grant (total 29,000 dollars), to upgrade the distribution grid in addition to the Rural Areas Development Program. As a background of the application, USDA is considering the introduction of a large scale grid-connected PV power generation facility. They are also indicating the possibility of obtaining funds to introduce large scale grid-connected PV power generation facility. They were awarded 23,000 dollars by the same organization to repair generator 7 of Majuro Power Plant in the past.

(5) Export-Import Bank of the United States, Ex-Im Bank)

The organization is considering funding an 800kW PV system that MEC is planning to use commercially.

2.4.3.2 Taiwan

Taiwan has mainly provided PV-related equipment support. They are now considering providing assistance by offering a low-interest loan worth $200,000 in 2015 targeting PV and energy-saving.

(1) Street lights

Taiwan installed 116 PV powered street lights in Rita of Majuro atoll in 2012. The budget was 400,000 dollars, and the cost per light was 3,000 dollars. In FY 2014, they installed an additional 57 lights each in Majuro and Ebeye.

(2) Light of basketball court

---

[21] It also provides equipment to http://moanamarine.com/ USAID and the IOM (International Organization for Migration).

Taiwan installed PV powered lights and electric display boards in 13 locations including remote islands.

(3) Personal computers

Taiwan provided 63 PV powered laptop PCs and 21 PV powered printers to 21 schools in 2012.

(4) PV power generation system for CMI

A Taiwanese company, Speedtech, installed a 54kW system with a 200,000 dollar budget in 2014.

(5) Solar Home System (SHS)

Taiwan installed 930 SHS mainly in the remote islands of Likiep atoll, Ebon atoll and Arno atoll in 2007 – 2008. The budget was about 3,000,000 dollars.

(6) Exchanging equipment with high-efficiency equipment and providing a loan for PV introduction for general housholds

ICDF is going to provide MEC a loan assistance (30 years, 1-2%) , to replace equipment with high-efficiency equipment, and providing revolving loans to introduce PV power generating equipment for general households. The budget is about 20 million dollars, and lights and air conditioners will be made more efficient first. Later, PV generation systems with the most appropriate capacity will be introduced. This program will start from the beginning of 2015. However, as of November 2014, although Taiwan's policy for this assistance has been set, implementation is still being considered, so implementation at the beginning of 2015 is unlikely.

2.4.3.3 Australia

Australia has made financial aid mainly for energy efficiency improvements, rather than for RE introduction, and there are no actual links to this project.

(1) Demand Side Management (DSM)

Australia has provided aid to introduce high-efficiency air conditioners to governmental offices as part of DSM support promoted by MRD.

(2) Dispatching advisers

The post of advisor at MRD (Mr. Robert Leo) is financed by the Australian government. Also in 2013, Australia dispatched one volunteer engineer to MEC’s Distribution Division for a year.

(3) Pre-paid Meter

With about 600,000 dollars, Australia supported the installation of 1,600 pre-paid meters in 2012 to contribute to achieving reasonable power utilization and reduce non-technical losses.

(4) Energy efficiency labeling

Along with other island countries, RMI participated in Pacific Appliance Labeling and Standard Program (PALS), the action in Oceania regions. Through PALS, Australia is supporting energy efficiency action of refrigerators, air conditioners and light bulbs, and also labeling promotions with Secretariat of the Pacific Community (SPC). The labeling activity is under discussion of the National Taskforce Committee in RMI.

2.4.3.4 EU

(1) EDF-9: European Development Fund

The EU installed 420 SHS (for remote island use) in Ailinglaplap atoll, starting from 2008.

(2) Additional support of EDF-9

In 2012, a budget of 1,260,000 dollars was approved, and in 2013, an additional 1,500 SHS will be installed mainly in remote islands. The project has three terms, and 500 SHS will be installed in each term. 500 SHS are already installed in remote islands. By 2012, SHS were deployed in 11 remote atolls, and when the project of all the three terms has completed, all the remote islands will have SHS installed. In this plan, another 1,000 will be installed in 2013, but it is going to be delayed until 2014. Also, the EU asked SPC (office located Fiji) to coordinate with MRD of RMI and provide support through SPC.

(3) EDF-10

$1,260,000 was approved in 2012, and 500 units per quarter over three quarters (a total of 1,500 new SHS units) were to be installed in 2013 mainly in remote islands, but at this stage all installations had not been completed, and as of 1/2014 they are still ongoing. The EU requested SPC, which has an office in Fiji, to make arrangements with MRD, and it is providing aid via SPC.

2.4.3.5 Global Environmental Facility (GEF)

GEF is a trust fund in the World Bank. World Bank, UNDP and UNEP are implementing environmental projects utilizing GEF funds. Several years ago, a support called Action for the Development of Marshall Islands Renewable Energy (ADMIRE) with GEF funds of 2,560,000 dollars was initiated, and the project is implemented mainly by UNDP. They are providing promotional activities regarding RE (providing leaflets, T-shirts and education campaign such as science camps), software componentry (coordination with organizations and donors), and also providing transport fees for PV panels that the EU has procured.

2.4.3.6 ADB

ADB plans to provide assistance for a demonstration of running diesel generators on biofuel (copra) using Unit 3 in Majuro Power Plant which is under repair due to fire damage. They plan to do the demonstration only after Unit 3 is operated normally (on diesel) without problems for 6 months after being repaired. For other assistance, it plans to conduct a muti-phased water project. Planning for phase 1 has been completed, and it plans to continue with phase 2 equipment installation in the future. ADB's future assistance strategy will focus mainly on social infrastructure, so it is not considering energy-related assistance. In addition, it is making adjustments so that the contents of the assistance do not overlap with JFPR (the Japan Fund for Poverty Reduction).

2.4.3.7 Pacific Power Association (PPA)

PPA is an inter-governmental agency made up of power utilities in the Pacific region, and it established in 1992. Currently it has a membership of 25 electricity utilities operating in 22 Pacific Island Countries and has a Secretariat Office located in Suva, Fiji. The PPA’s objective is to improve the quality of power in the region through a cooperative effort among the utilities, private sector and regional aid donors.

Its main activity is holding a conference annually to for technical training and exchange, and the 23rd conference was held this year. The next conference is scheduled to be held in Majuro from July 13 to 17 in 2015.

For other assistance for RMI, it is working with MEC to prepare reports, etc. such as a data handbook of electric power facilities, etc.

2.4.3.8 International Renewable Energy Agency (IRENA)

IRENA is an international organization established to promote RE and the sustainable utilization of RE technologies. MRD is hoping to get RE assessment through grants rather than through finance loans. Also, from April 8 to 12, 2013, IRENA, SPC and Pacific Power Association (PPA) co-hosted a workshop on grid stabilization in Palau.

2.4.3.9 SIDS-DOCK

SIDS-DOCK was established by Small Island Developing States (SIDS), and the organization takes part in activities such as fund development and project implementation in the RE field. Japan has also committed in supporting SIDS-DOCK in the 6th PALM in 2012.

2.4.3.10 UAE

UAE-Pacific Partnership Fund will provide 5 million dollars for a feasibility study and EPC project for a 500kW PV system at a water catchment near Majuro International Airport.

Table 2.4.3-1 Donor Aid in Recent Years

	Technical aid	Equipment aid	Funds Loans
Japan	○	○	−
US	△	○	○
Taiwan	−	○	△
Australia	○	○	−
EU	○	○	△
GEF	−	−	○
ADB	−	○	○
IRENA	○	−	−
SIDS-DOCK	△	△	−
UAE	−	△	−

○ : Aid implementation
△ : In talks for aid or planning for aid in the future

2.5 Outline of Electrical Industry Structure

2.5.1 Implementation Structure of MEC

2.5.1.1 MEC operation management structure

MEC operation management structure is shown in figure 2.5.1-1. The main managers are Chief Technical Officer, Jaluit Manager, Wotje Manager, Fuel Marketing Manager and Internal Auditor & Control. These seven officers work under the General Manager, and they are under the management of the MEC Board of Directors.

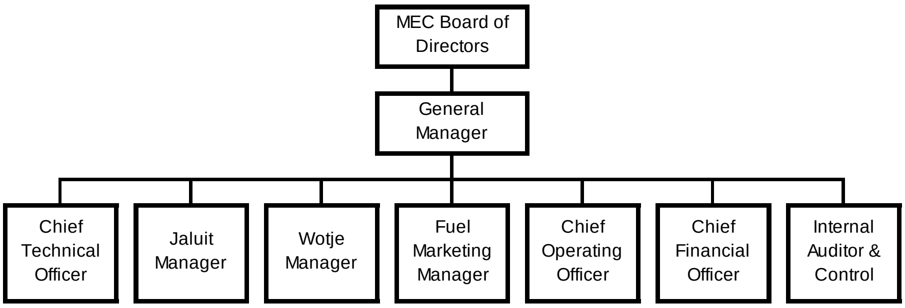


Figure 2.5.1-1 MEC business management structure[22]

2.5.1.2 MEC operation division management structure

MEC operation division management structure is shown in figure 2.5.1-2. This division has sections of Customer Services, A/R Fuel Sales, Fuel Sales, Senior Meter Reader, Cleaner and Security 1, 2.

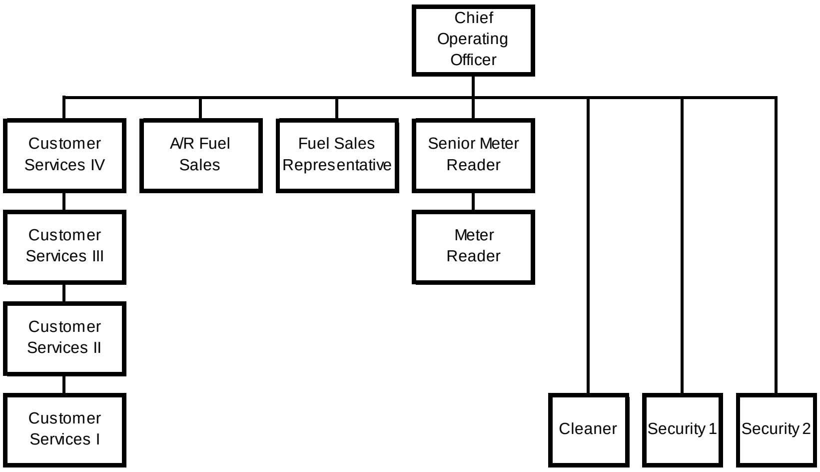


Figure 2.5.1-2 MEC operation division management structure[23]

2.5.1.3 MEC technical division structure

MEC technical division system is shown in figure 2.5.1-3. This division is under the Chief Technical Officer. The following are the main operation division: RE System for SHS operation and management in remote islands, Generation Superintendent for operative and maintenance sections, and Distribution Superintendent. There are staffing divisions such as electricity, machinery, training and GIS.

[22] Obtained from MEC
[23] Obtained from MEC

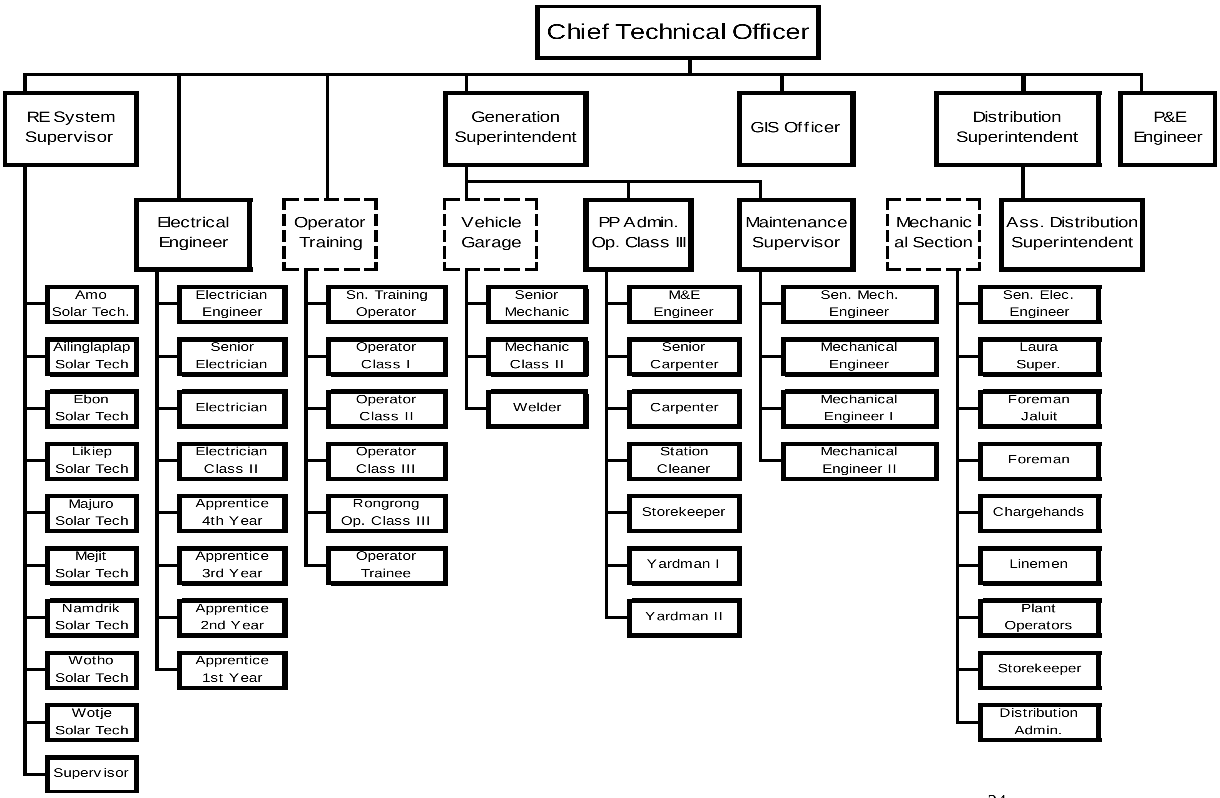


Figure 2.5.1-3 MEC technical division management structure[24]

2.5.1.4 MEC financial division structure

The financial responsibility is taken by not only MEC, but also by MWSC (Majuro Water & Sewer Company) and KAJUR (Kwajalein Atoll Joint Utility Resources). As seen in figure 2.5.1-4, billing supervisor & analyst, and the director who manages receivables / payables are working under procurement supervisor and financial controller.

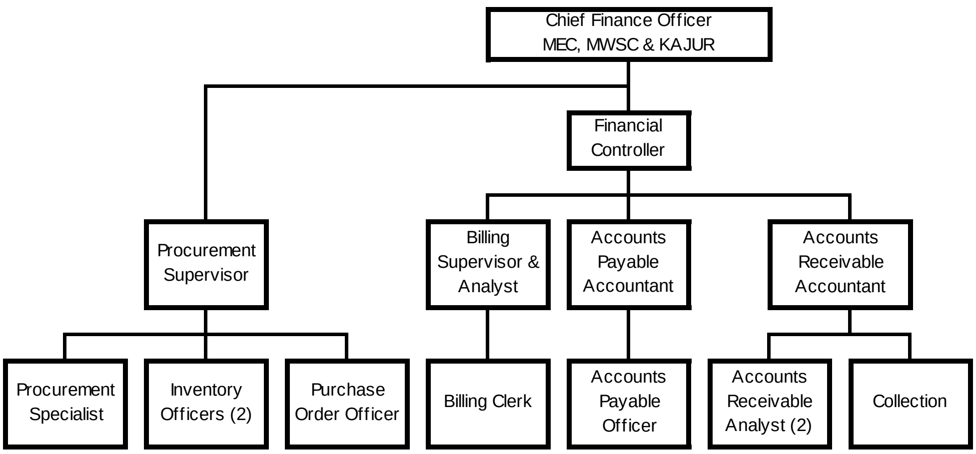


Figure 2.5.1-4 MEC financial division management structure[25]

[24] Obtained from MEC
[25] Obtained from MEC

2.5.1.5 MEC financial status

Power related items are listed in the Table 2.5.1-1 taken from MEC's 2013 Financial Report.

Table 2.5.1-1 Financial status of MEC (Power business)[26]

Financial Statement 2013, Draft Copy [May 24 2013]
Statements of Revenues, Expenses and Changes in Net Deficiency
Years Ended September 30, 2012 and 2011 (Page 3)

	2012	2011	
Assets	18,762,754	23,941,243	$
Utility plant	7,294,148	7,657,924	$
Othe non-current asset	100,000		$
Current asset	11,368,606	16,283,319	$
Cash	686,696	592,436	$
Account Receivable	8,559,467	6,717,983	$
Electricity	7,249,255	7,083,943	$
Fuel and supplies	1,740,265	8,972,900	$
Net deficiency and liabilities	18,762,754	23,941,243	$
Net deficiency	**-10,232,820**	**-12,400,415**	$
Total liabilities	28,995,574	36,341,658	$
Non-current liabilities	14,399,733	13,925,892	$
Current liabilities	14,595,841	22,415,766	$
Account payable - Fuel	7,359,557	12,350,811	$
Utility operations:			
Operating revenues:			
Electricity sales	20,794,441	19,045,398	$
Other	95,829	78,862	$
	20,890,270	19,124,260	$
Less Provision for doubtful accounts	-753,744	-1,077,246	$
Total net operating revenues	20,136,526	18,047,014	$
Operating expenses:			
Cost of fuel	13,323,084	13,024,474	$
Cost of Power	3,291,979	3,390,621	$
Administrative and general	1,475,185	1,232,460	$
Distribution operations	1,226,284	1,326,092	$
Depreciation and amortization	1,603,211	1,320,592	$
Total operating expenses	20,919,743	20,294,239	$
Operation loss from utility operation	**-783,217**	**-2,247,225**	$

In FY2012, MEC had approx. a 10 million dollars deficit. Although MEC operates not only power, but fuel oil and water business, its power business had a deficit of approx. 780 thousand dollars deficit.

[26] Obtained from MEC

2.5.1.6 Electricity tariff and subsidy

Electricity tariff is determined by MEC, cabinet and president. MRD does not have any role and responsibility on this issue. Current tariff is adjusted based on imported diesel price as shown in Table

In addition to the power plants on Majuro Atoll, MEC manages power plants on Wotje Atoll, Jaluit Atoll, and through KAJUR, a subsidiary, Ebeye Island, and the electric rates are set uniformly on all islands.

Change in the tariff system are shown in Table 2.5.1-3

Table 2.5.1-2 Electricity pricing template of MEC[27]

CURRENT TARIFF TEMPLATE				
23-Mar-09				
MARSHALLS ENERGY COMPANY, Inc.				
Diesel Price per Barrel MOPS $	Government $/kWhr	Commercial $/kWhr	Residential $/kWhr	Life Line $/kWhr
40.00	0.260	0.250	0.190	0.170
45.00	0.272	0.262	0.202	0.182
50.00	0.284	0.274	0.214	0.194
55.00	0.296	0.286	0.226	0.206
60.00	0.308	0.298	0.238	0.218
65.00	0.320	0.310	0.250	0.230
70.00	0.332	0.322	0.262	0.242
75.00	0.344	0.334	0.274	0.254
80.00	0.356	0.346	0.286	0.266
85.00	0.368	0.358	0.298	0.278
90.00	0.380	0.370	0.310	0.290
95.00	0.392	0.382	0.322	0.302
100.00	0.404	0.394	0.334	0.314
105.00	0.416	0.406	0.346	0.326
110.00	0.428	0.418	0.358	0.338
115.00	0.440	0.430	0.370	0.350
120.00	0.452	0.442	0.382	0.362
125.00	0.464	0.454	0.394	0.374
130.00	0.476	0.466	0.406	0.386
135.00	0.488	0.478	0.418	0.398
140.00	0.500	0.490	0.430	0.410
145.00	0.512	0.502	0.442	0.422
150.00	0.524	0.514	0.454	0.434
155.00	0.536	0.526	0.466	0.446
160.00	0.548	0.538	0.478	0.458
165.00	0.560	0.550	0.490	0.470
170.00	0.572	0.562	0.502	0.482
175.00	0.584	0.574	0.514	0.494
180.00	0.596	0.586	0.526	0.506
185.00	0.608	0.598	0.538	0.518
190.00	0.620	0.610	0.550	0.530
195.00	0.632	0.622	0.562	0.542
200.00	0.644	0.634	0.574	0.554

There is no direct subsidy for lower electricity tariff, but many governmental suppots for power sector are provided as follows. The resource of the entire subsidy is the US Compact.

① No tax on MEC's imported fuel

② 800,000USD to MEC annually to supply fuel and power to Wotje and Jaluit atolls (National Energy Support Fund, NESF)

③ All the land owners (approx. 700+) receive 1,000USD per month, for providing their lands for various power equipment and distribution lines

④ Electricity is free of charge for the owners of land used by power stations

[27] Obtained from MEC

Table 2.5.1-3 Transition of MEC electricity pricing[28]

		Government		Commercial		Residential		Life Line	
Notes	Date of Increase	From	To	From	To	From	To	From	To
1	1-Jan-05		$0.180		$0.180	$0.120	$0.140	$0.120	$0.130
2	1-Sep-05	$0.180	$0.205	$0.180	$0.205	$0.140	$0.150	$0.130	$0.140
3	1-Nov-05	$0.205	$0.225	$0.205	$0.225	$0.150	$0.170	$0.140	$0.160
	1-Jul-06	$0.225	$0.245	$0.225	$0.245	$0.170	$0.190	$0.160	$0.180
	1-Oct-06	$0.245	$0.255	$0.245	$0.255	$0.190	$0.200	$0.180	$0.190
4	1-Jan-07	$0.255	$0.280	$0.255	$0.270	$0.200	$0.210	$0.190	$0.190
5	1-Jun-07	$0.280	$0.290	$0.270	$0.280	$0.210	$0.220	$0.190	$0.200
6	1-Jul-07	$0.290	$0.300	$0.280	$0.290	$0.220	$0.230	$0.200	$0.210
7	1-Dec-07	$0.300	$0.350	$0.290	$0.340	$0.230	$0.255	$0.210	$0.235
8	1-Mar-08	$0.350	$0.350	$0.340	$0.340	$0.255	$0.280	$0.235	$0.260
	1-Apr-08	$0.350	$0.400	$0.340	$0.390	$0.280	$0.330	$0.260	$0.310
	1-Jun-08	$0.400	$0.480	$0.390	$0.470	$0.330	$0.410	$0.310	$0.390
	1-Nov-08	$0.480	$0.400	$0.470	$0.390	$0.410	$0.330	$0.390	$0.310
	1-Jan-09	$0.400	$0.310	$0.390	$0.300	$0.330	$0.240	$0.310	$0.220
9	1-Feb-10	$0.310	$0.368	$0.300	$0.358	$0.240	$0.298	$0.220	$0.278
	1-May-10	$0.368	$0.392	$0.358	$0.382	$0.298	$0.322	$0.278	$0.302
	1-Jan-11	$0.392	$0.416	$0.382	$0.406	$0.322	$0.346	$0.302	$0.326
	1-Feb-11	$0.416	$0.428	$0.406	$0.418	$0.346	$0.358	$0.326	$0.338
	1-Apr-11	$0.428	$0.488	$0.418	$0.478	$0.358	$0.418	$0.338	$0.398
	1-Apr-12	$0.488	$0.500	$0.478	$0.490	$0.418	$0.430	$0.398	$0.410

Notes

1	This increase was approved by Cabinet before the tariff template was introduced
2	This increase was approved by Cabinet before the tariff template was introduced
3	First increase using the automatic tariff template
4	First increase using the revised automatic tariff template
5	Increase 1 June 2007
6	Increase 1 July 2007
7	Increase 1 December 2007. Full flow on of Template $0.05 for Gov & Com. Half $0.025 for Res & Life Line
8	- Balance of $0.025 to pass on to Residential and Life Line 1 Jan 2008
9	Cabinet approved revised tariff template

As shown in Table 2.5.1-3, current electricity tariff rates are 0.50$/kWh for government, 0.49$/kWh for commerce, 0.43$/kWh for residential and 0.41$/kWh for life-line (low income earners), which are very expensive.

These rates are about 2.4 times that of rates before revision due to the implementation of MEC's electricity rates template (before September 2005). Rates had never been revised until November 2014.

On the other hand, production costs in Majuro Atoll are 0.296$/kWh for fuel, 0.072$/kWh for cost of power, 0.032$/kWh for administration and general, 0.027$/kWh for distribution operations and 0.035$/kWh for depreciation and amortization, and total cost is 0.460$/kWh. With this cost MEC has a little profit in governmental and commercial sectors, but a loss in residential and life-line sectors.

2.5.1.7 Electricity tariff and Demand trends

Figure 2.5.1-5 shows the transition of MEC electricity rates and WTI oil prices,[29] and Figure 2.5.1-6 shows the transition of MEC electricity rates and peak power on Majuro's system.

[28] MEC website (http://mecrmi.net/tariffs.htm)

[29] WTI stands for West Texas Intermediate and refers to high-quality crude oil which contains little sulfur produced in the West Texas region and from which a large amount of gasoline can be refined. As representative indexes for crude oil prices in addition to WTI, there are North Sea Brent producing in Europe and Dubai producing in the Middle East. These are said to be three major crude oil indexes of the world.

Figure 2.5.1-5 suggests that MEC electric rates transition in conjunction with the WTI crude oil price fluctuations. Therefore, it is clear that since the introduction of the automatic electric rate adjustment system in 2005 based on the import price of diesel fuel, electricity rates have been impacted greatly by WTI crude oil prices.

MEC's diesel fuel oil import prices in recent years are about US $3.2-3.5/Gal (US $132.4-147/barrel), and like WTI crude oil prices, they remained at high levels.

You can see from Figure 2.5.1-6 that the peak load has been decreasing every year since 2006. The effect of customers' incentive to save energy due to the introduction of the automatic electric rate adjustment system and recent high diesel fuel prices leading to rising electricity rates and the loss of two large scale customers (a major fisheries company and a supermarket) in Majuro since 2006 are the major factors for the drop in demand.

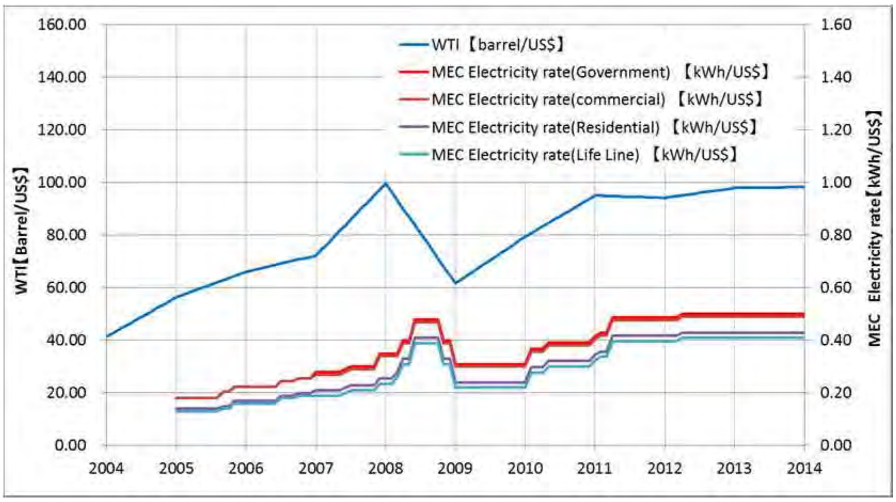


Figure 2.5.1-5 Transition of MEC electricity rates and WTI oil prices

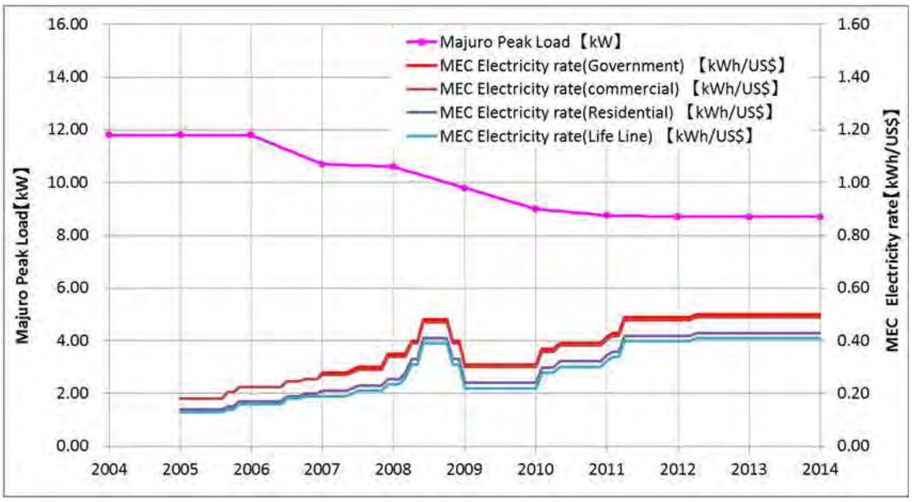
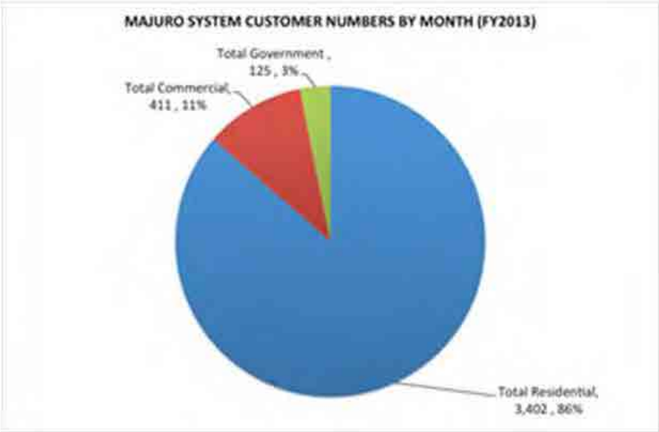


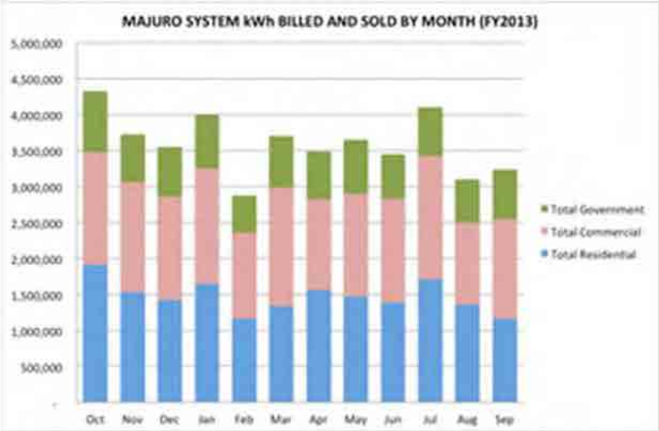
Figure 2.5.1-6 Transition of MEC electricity rates and Majuro's peak system load

2.5.1.8 Demand structure

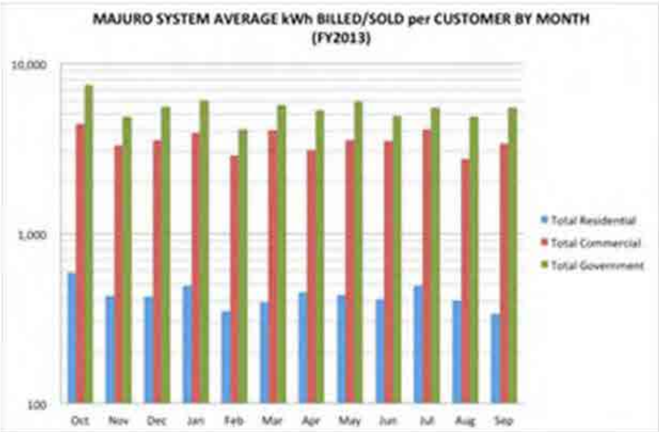
Demand structures in Majuro Atoll are shown in Figure 2.5.1-5 below.



(a) Customer numbers



(b) Monthly sold energy sold



(c) Monthly energy per customer

Figure 2.5.1-7 Demand structures in Majuro Atoll

Residential sector, which is 86% in customer numbers, accounts for 41% of energy sold. Governmental and commercial sectors accounts 11% and 3% in customer number, and 40% and 19% in sold energy respectively. Average monthly sold energy per customer is 133kWh for residential, 3,526kWh for business and 5,458kWh for government.

Major large consumers are shown in Table 2.5.1-4. In this table customers in the gray cells are governmental, and the remaining are commercial. These large consumers in Majuro receive power in LV via MEC's transformer, which converts 13.8kV to LV at/near their sites. There is no consumer receiving power at 13.8kV. Average load of Capitol Building is approx. 200kW, for example. They may be potential installers of PV system, if condition is right.

Table 2.5.1-4 Top 20 of large consumers (2013/5-2014/4)

Account Name	Total(kWh)
K＆K ISLAND PRICE SUPERMARKET	1,538,000
Capitol Building Cnmplex	1,365,200
Tobolar Tobolar Proc. Plant	878,600
MIR－EAST	725,280
RRE Complex. 3 Office	471,040
Mifv Inc.(Former Ting Hong)	461,000
MIR－WEST	401,040
Mifv NEW Ice Machine	360,641
Formosa Shopping Center M1	279,040
RRE Store.2	263,920
Jane Corp. Long Is. Hotel[30]	243,240
Formosa Supermarket	226,240
PII Rock Crusher 2 (3 Phese)	194,580
RRE PACIFIC PURE WATER	193,440
K＆K ISLAND PRICE SUPERMARKET #1	162,080
Majuro Interna. Convention Center	147,200
MSTCO REEFER BLOCK.	139,980
Rairok Elementery School (New Bld)	101,680
RRE Kabins	100,859
Education Main Office	100,757

In residential sector, there are separated areas for rich and poor peoples, and some of the former may install their own PV system, if grid connection is allowed.

Ebeye has two 13.8kV feeders, but the other two islands have no HV and only have a 4.16kV distribution system. Potential large-scale PV system owner in Ebeye is Payless Supermarket (refer to Figure 5.1-1), who has an emergency generator now.

In Wotje and Jaluit, most consumers are residential and small shops, except for schools, governmental fishery facility with freezer/refrigerator and MEC power station. It will take long term for such small residential user to have PV system, and only a few rich people may have it.

Figure 2.5.1-8 Payless Supermarket in Ebeye Island

[30] Jane Corp. Long Is. Hotel went out of business in the summer of 2014, and was sold to The University of Southern Pacific.

2.5.2 Main Power Source and Distribution Facilities

Diesel generators are installed in the islands shown in figure 2.5.2-1. Installation by MEC (including the subsidiary KAJUR) are only for the four locations - Majuro, Jaluit, Wotje and Ebeye. In other atolls and islands, electricity is produced by generators installed by other organizations and SHS promoted by MRD/MEC.

Diesel Power Plants (MEC) ▲
Diesel Power Plants (KAJUR-under MEC control) △
Diesel Power Plants (not MEC) ○

Figure 2.5.2-1 Diesel power plant in Marshall Islands

2.5.2.1 Majuro power plant

There are two power plants (Majuro Power Station No.1、No.2) in Majuro atoll. All the electricity produced in both plants is from diesel generators. Majuro Power Station No.1 has 5 units and Majuro Power Station No.2 has 2 units. However, as described in 2.4.2, 2 units out of 5 in the station no. 1 are out of operation because of the damage from fire in 2006, and have not been restored since then.

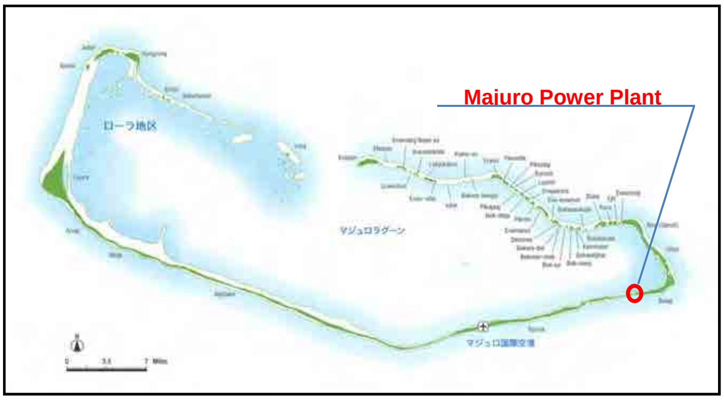


Figure 2.5.2-2 Map of Majuro Atoll(location of Majuro power plant)[31]

[31] Source: Marshall Islands Travel Guide (Marshall Islands Visitors Authority)

Figure 2.5.2-3 Majuro Power Plants[32]

(1) Generator capacity

The total capacity of the existing generators is 22.8 MW (excluding Units 3 and 4), but the actual output capacity is 116.47 MW since Unit 7 is out of order, and many generators are decrepit and their output is limited. Power demand is decreasing due to soaring electricity rates in recent years, but for the present power load (8 MW-7 MW), if the base unit in the current unit configuration were to fail, power supply would not be able to keep up with the demand.

MEC is planning to repair Unit 7 in March 2015, but until it is back in operation, they are working with a tightrope operation in terms of supply-demand balance.

(2) Generator operation

In operating generators, usually units in station no. 2 are used as base load, and units in station no.1 are used as absorber equipment for fluctuations.

(3) Control method

Droop control method is adopted for generator governors, and for mid load fluctuation by minutes are followed by operator's manual governor control. Other controls such as AFC are not used, and starting up and shut down of generator are done by operator's manual handling with heuristic rules.

[32]Source: MEC WebSite (http://www.mecrmi.net/MAJ1_Facility.htm)

Table 2.5.2-1 Generator specifications in MAJURO Power Plants No.1, No.2[33]

MEC	Substation	Station NO.1					Station NO.2	
	Engine#	1	2	3	4	5	6	7
GENERATOR DETAILS	ENGINE MAKE	Pielistick	Pielistick	Pielistick	Pielistick	Caterpiller	Deutz	Deutz
	ENEGINE MODEL	10PC2VMK2	10PC2VMK2	10PC2VMK3	10PC2VMK4	3616	BV16M640	BV16M640
	ENEGINE SERIAL NUMBER	18191	18192	18193	18194	1P00048	16010114	16010115
	NAME PLATE RATING(kW)	3,275	3,275	3,275	3,275	3,485	6,400	6,400
	Maximum output (kW)	1,500	1,500	–	–	2,700	6,000	–
	SPEED(RPM)	450	450	450	450	720	600	600
	FUEL TYPE	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
	YEAR INSTALLED	1982	1982	1982	1982	1992	1999	1999
ALTERNATOR DETAILS	MAKE	BRUSH	BRUSH	BRUSH	BRUSH	KATO	DEUTZ	DEUTZ
	TYPE	Brushless	Brushless	Brushless	Brushless	Brushless	Brushless	Brushless
	MODEL NO.	31846A4G	31846A5G	31846A6G	31846A7G	A25247	1120LP12	1120LP12
	SERIAL NO.	31846-1G	31846-2G	31846-1G	31846-2G	98350	455-9308	455-9309
	VOLTAGE(V)	13,800	13,800	13,800	13,800	13,800	13,800	13,800
Remarks				Fire trouble	Fire trouble		Base generator	Major generator failure (Repair planned for 3/2015)

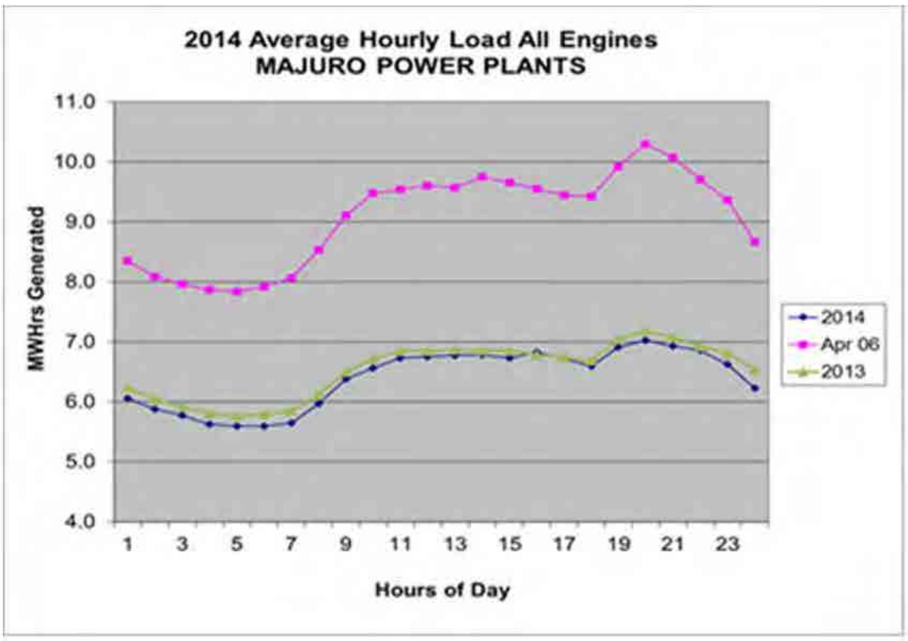


Figure 2.5.2-4 Majuro system daily load curve in (2013, 2014, 2006)[34]

＊Compared to loads prior to decrease in power demand (2006), the current curve shows a decrease of 2-3 MW.

33 Obtained from MEC
34 Obtained from MEC


Power Plant No.1 gen. 2,3,4


Power Plant No.1 gen. 5


Power Plant no.2 gen 6


Power Plant no.2 gen 7


Power Plant No.1_central control room
generator control board


Power Plant No.2 central control room
generator control board and monitoring board


Power Plant No.2
Engine room auxiliary machinery


Power Plant No.2
Engine cooling radiator

Figure 2.5.2-5　Conditions of power plant installation in Majuro

(4) Distribution equipment

Power system in Majuro is transmitted by three feeders of 13,800V from the power plant. The feeder 1 is extended north from the power plant, and the lines are laid underground across the airport area. The transmitted voltage is 13,800V up to Wotje area and 4,160V to Laura area which is transformed at the Laura substation. Feeder 2 is extends underground to the east area, and transformed to 4,160V at the Jenrok substation, and thereafter sent to Junrok area and Rita area, and furthermore to Ejit island through submarine cable. Feeder 3 is transmitting to the city area and Uliga through underground feeder. Feeders are controlled for spillout protection and VCB for power release for maintenance purposes are installed in seven locations. For low-voltage users, electricity is transformed to single phase 208V, or three phases / four lines of 208V / 120V and then provided in these conditions.

Currently, most of the existing transmission facilities are at least 30 years old, so they need to be replaced as they have become decrepit.

Transmission loss is about 18%. This value is increasing every year as transformer capacity relative to demand load is excessive amid the continuously declining demand which leads to increased transformer loss.

Power plant Feeder lead in pole

Laura Sub

Airport VCB building

Tentative transmission line

Figure 2.5.2-6 Conditions of electric distribution installation in Majuro

Figure 2.5.2-7 Utility power grid chart in Majuro[35]

35 MEC WEBSITE (http://mecrmi.net/statistics.htm)

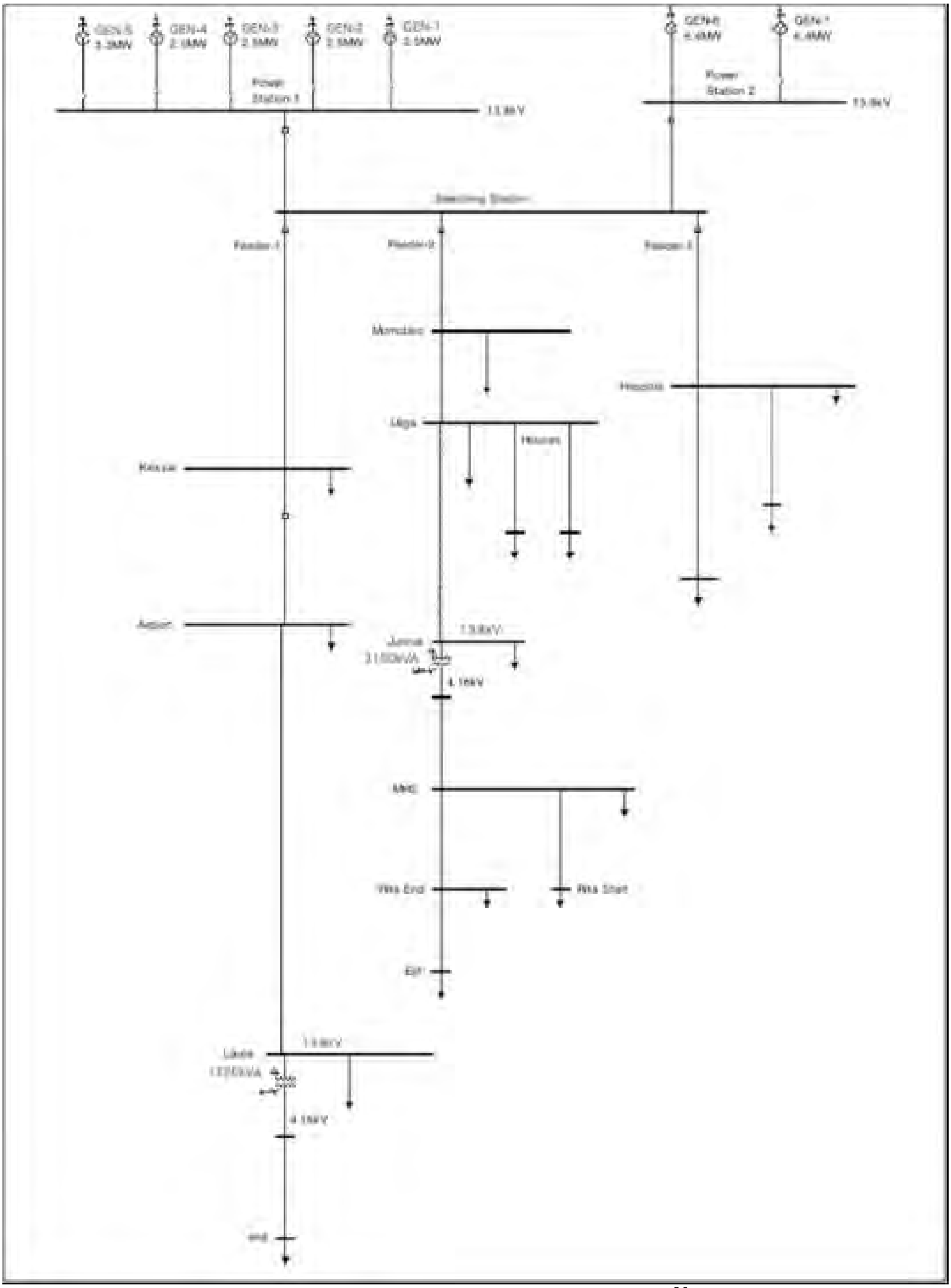


Figure 2.5.2-8 Utility grid chart in Majuro[36]

[36] Obtained from MEC

2.5.2.2 Wotje power plant

There is one power plant in Wotje atoll, and all the electricity for the user units in the island is produced at this plant. The plant was built in August 2002 with aid from Taiwan. A plant that was built before WW2 by Japanese army was destroyed by the war, and the island was unelectrified for a long time.

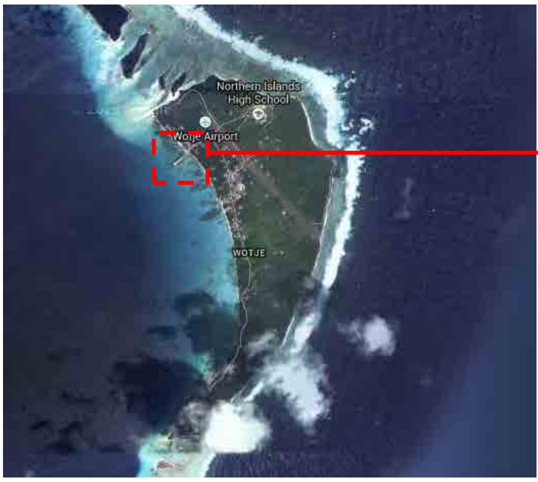


Figure 2.5.2-9 Location of power plant in Wotje

Figure 2.5.2-10 Power plant in Wotje

(1) Generation equipment

Principal specifications of generation equipment in Wotje power plant are shown in table 2.5.2-2. The power plant has two diesel generators with rated capacity of 275kW. The scale of electricity demand in the island is about 60-120kW, therefore one generator is providing electricity fairly enough for the area, and in fact usually one generation is in operation to provide electricity.

Switching of generators is timed by 300 hours of operation. A generator is switched to another one after 300 hours of continued operation, and it is checked after shut down.

Table 2.5.2-2 List of generator equipments in Wotje[37]

Engine#	1	2
ENGINE MAKE	Wartsila	Wartsila
ENEGINE MODEL	UD25	UD25
NAME PLATERATING(kW)	275	275
Maximum output (kW)	275	275
SPEED(RPM)	1200	1200
YEAR INSTALLED	2003	2003
Governor Control	Isochronous	Isochronous
Synchronous capability	Aavailable	Available

(2) Load on power system

Annual load on power system in Wotje is shown in figure 2.5.2-11. The maximum load is 120kW. One of the large-scale users is a high school, and its demand tends to decrease down to 40kW from 60kW during the summer holidays from June to August.

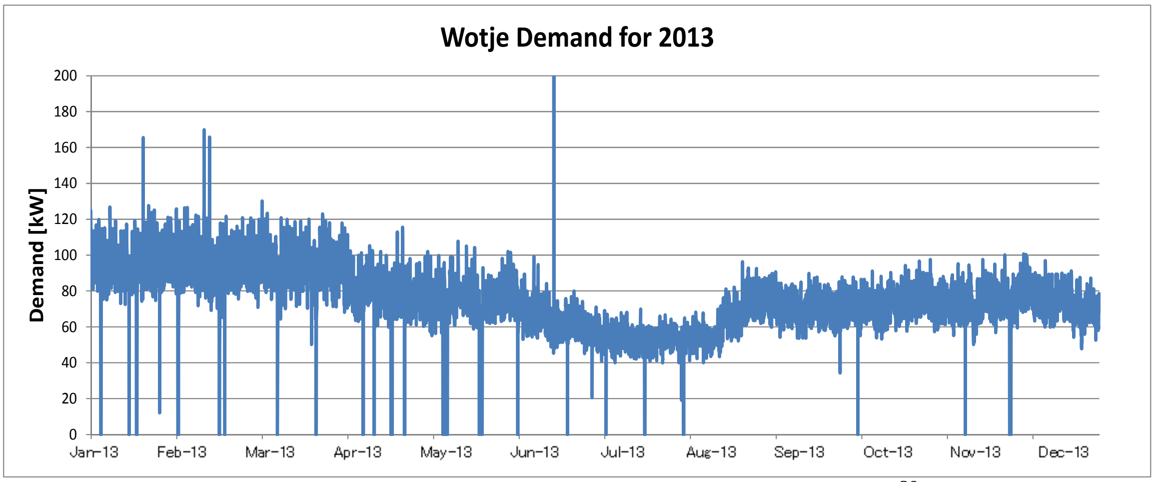


Figure 2.5.2-11 Annual grid load for Wotje(2013)[38]

(3) Control method

The control of both generators is done with isochronous control, and the responsiveness by this method is quite well to single period load fluctuation. However, frequency tends to fluctuate because general users' fluctuation can be relatively great for a small-scaled system. The detailed description regarding this fluctuation will be made in 3.0.

Other controls such as ALC are not used, and starting up and shut down of generator are done by operator's manual handling with heuristic rules.

(4) Distribution equipment

Electricity produced at the Wotje Power Plant is transformed up to 4,160V from 480V, and sent to each area through the main feeder underground. Electricity to each user is led in through a temporary line from ground-based transformer which is receiving electricity from underground feeders.

[37] Obtained from MEC
[38] Obtained from MEC

The island has 150 households in total, but 100 out of 150 are electrified. As in Majuro, pre-paid meter is adopted to use in Wotje as well.

(5) Fuel consumption

Fuel consumption at the Wotje power station for 2013 is shown in figure 2.5.2-12.The data provided by the station did not have data for January, May, Jun and July. The average per month is about 5,000 gallons.

Fuel is received using 9,000 gallon tanker from Majuro, and they receive fuel every two months.

Wotje power station has two fuel tanks of 10,000 gallons.

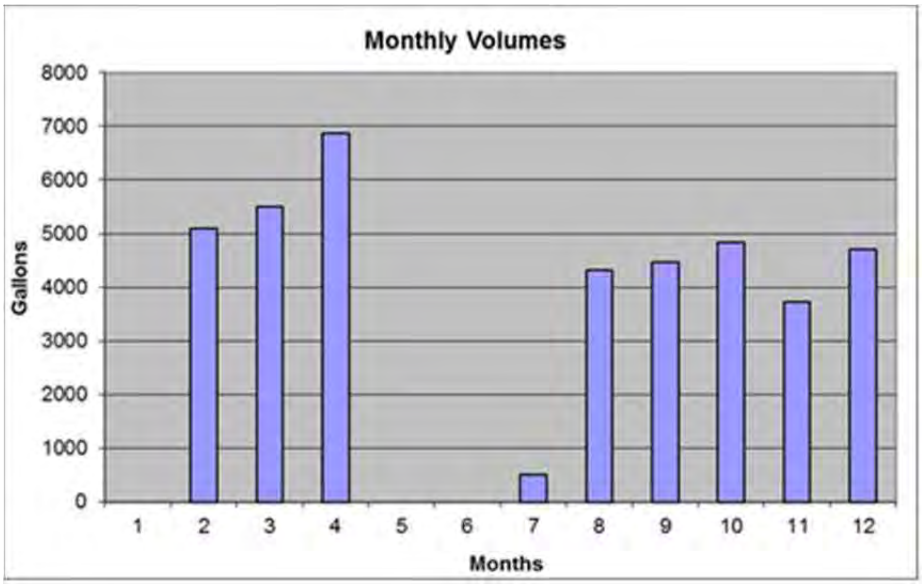


Figure 2.5.2-12 Fuel consumption in 2013[39]

[39] Obtained from MEC

Generator No. 1, 2

Generator control board

Generator bootable BT, BT charger

Service tank (500 Gallon)

Fuel tank

Radiator

Distribution line transformer box

Pre-paid meter

Figure 2.5.2-13 Conditions of power plant installation in Wotje

2.5.2.3 Jaluit power plant

Jaluit atoll has one power plant, and all the electricity for the user units in the island is produced at this plant. The plant is over 20 years old, and some equipment are outdated. Wotje atoll and Jaluit was unelectrified before the plant was built.

Figure 2.5.2-14 Location of power plant in Jaluit

Figure 2.5.2-15 Power plant in Jaluit

(1) Generation equipment

Principal specifications of generation equipment in Jaluit power plant are shown in table 2.5.2-3. The station has two diesel generators with a rated capacity of 300kW. The scale of electricity demand on the island is about 80 -120kW, therefore one generator is providing electricity fairly enough for the area, and in fact, usually only one generator is in operation to provide electricity.

A generator is replaced by another one after 300 hours of continued operation. There is scheduled outage of about 30 min. twice a month to inspect the generator.

Table 2.5.2-3 List of generator equipments in Jaluit[40]

Engine#	1	2
ENGINE MAKE	Wartsila	Wartsila
ENEGINE MODEL	UD25	UD25
NAME PLATERATING(kW)	300	300
Maximum output (kW)	300	300
SPEED(RPM)	1200	1200
YEAR INSTALLED	1993	1993
Governor Control	Droop	Droop
Synchronous capability	Unavailable	Unavailable

(2) Load on power system

Annual load on power system in Jaluit is shown in figure 2.5.2-16. The maximum load is 140kW. One of the large-scale users is high school, and their demands tend to decreases down to 50kW from 80kW, during the summer holidays between June and August.

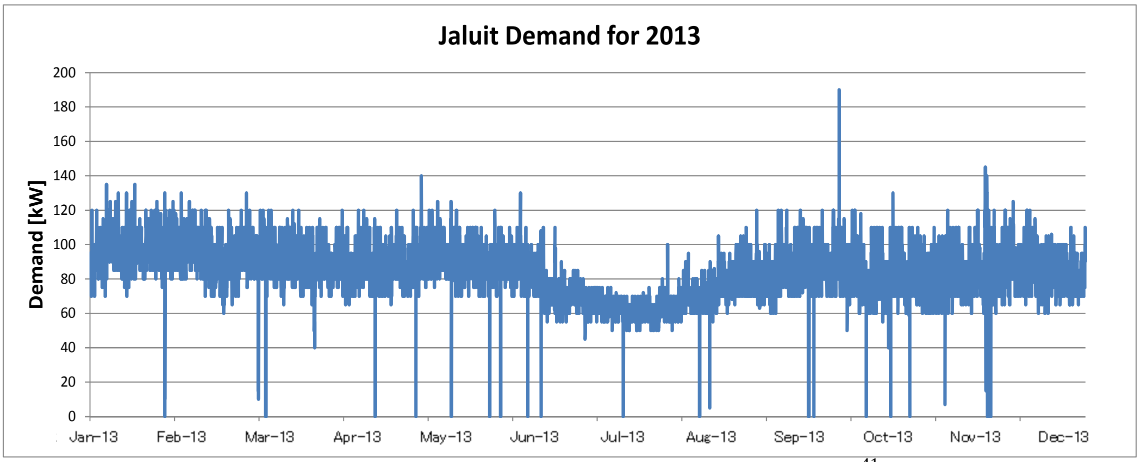


Figure 2.5.2-16 Annual grid load for Jaluit(2013)[41]

(3) Control method

Droop control method is adopted for generator governors, and for mid load fluctuation by minutes are followed by operator's manual governor control. Other controls such as ALC are not used, and starting up and shut down of generator are done by operator's manual handling with heuristic rules.

(4) Distribution equipment

Electricity produced at Jaluit power station is transformed up to 4,160V from 480V at s substation located in the power station, and sent to each area through tentative power lines. Electricity supply to each user is made through ground-based transformer or pole transformer. As in Majuro, pre-paid meter is adopted to use in Jaluit as well.

[40] Obtained from MEC
[41] Obtained from MEC

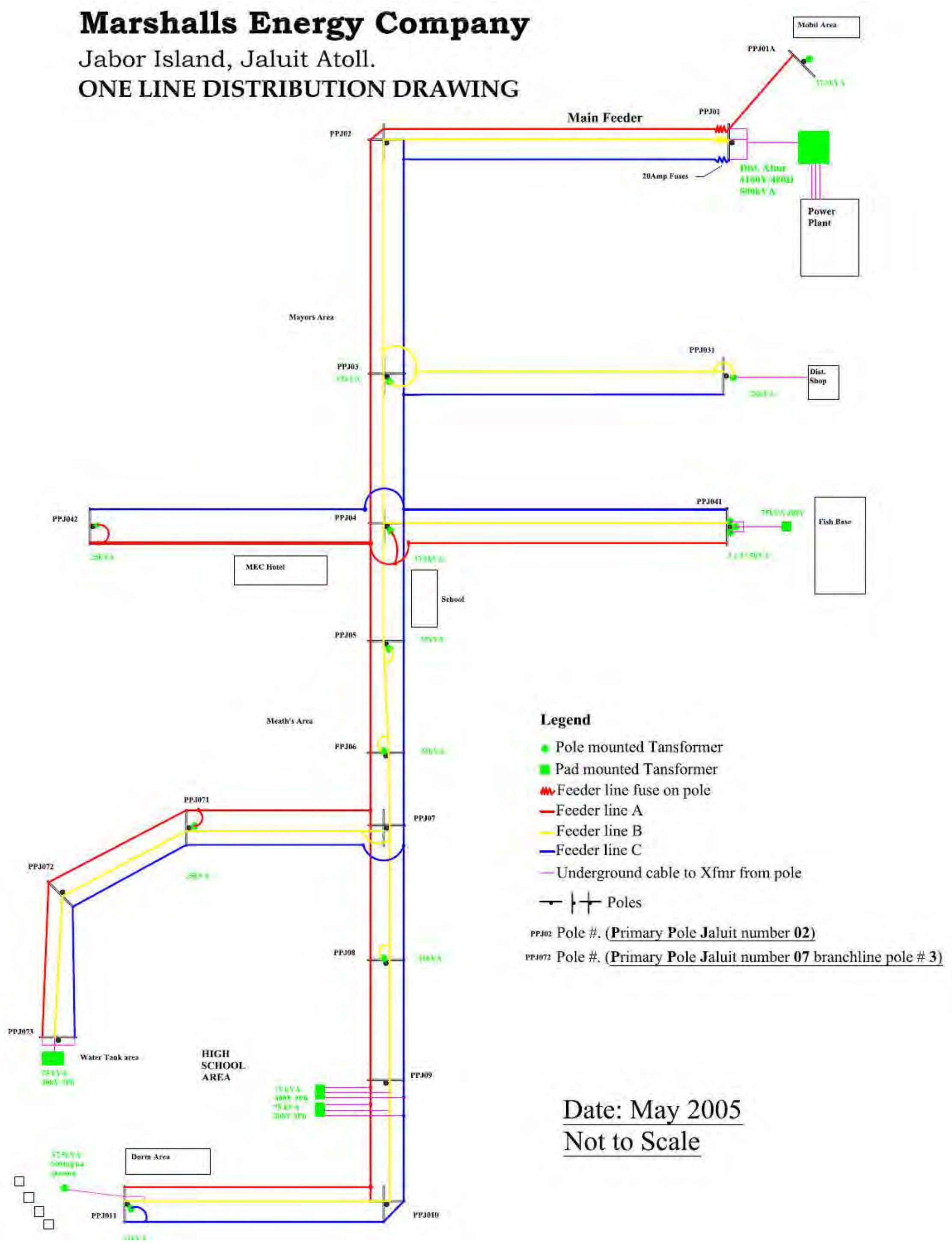


Figure 2.5.2-17 Utility grid chart in Jaluit[42]

(5) Fuel consumption

Daily fuel consumption is 17-0 gallons, and monthly 5,000 gallons.

[42] Obtained from MEC

Generator No. 1, 2

Generator control room


Generator control board


Transformer located in power plant
(4,160/480V)

Fuel tank


Service tank No. 1, 2


Transformer board for users


Distribution line and lead-in
Transformer box for users

Figure 2.5.2-18 Conditions of power plant installation in Jaluit

2.5.2.4 Ebeye power plant

Ebeye Island is located within the Kwjalein atoll. A power station located in Ebeye supplies all the adjacent islands. The operative management is conducted by KAJUR, a subsidiary of MEC.

Figure 2.5.2-19　Location of power plant in Ebeye

Figure 2.5.2-20　Power plant in Ebeye

(1) Generation equipment

The new power plant is built adjacent to the old power plant within the premises. A wasted generator is still left in the old plant. Principal specifications of generation equipments in Ebeye power plant are shown in table 2.5.2-4.　Three diesel generators with 1,286kW are installed in the new power station. There used to be four available, but one is out of operation at the moment. The demand scale of the island is about 2,000kW, therefore two generators are enough to cover the load unless there is loss from system malfunctioning.

Table 2.5.2-4 List of generator equipments in Ebeye[43]

Engine#	2	3	4
ENGINE MAKE	Cummins	Cummins	Cummins
ENEGINE MODEL	—	—	—
NAME PLATERATING(kW)	1,286	1,286	1,286
Maximum output (kW)	1,286	1,286	1,286
SPEED(RPM)	1,800	1,800	1,800
YEAR INSTALLED	—	—	—
Governor Control	Isochronous	Isochronous	Isochronous
Synchronous capability	Available	Available	Available

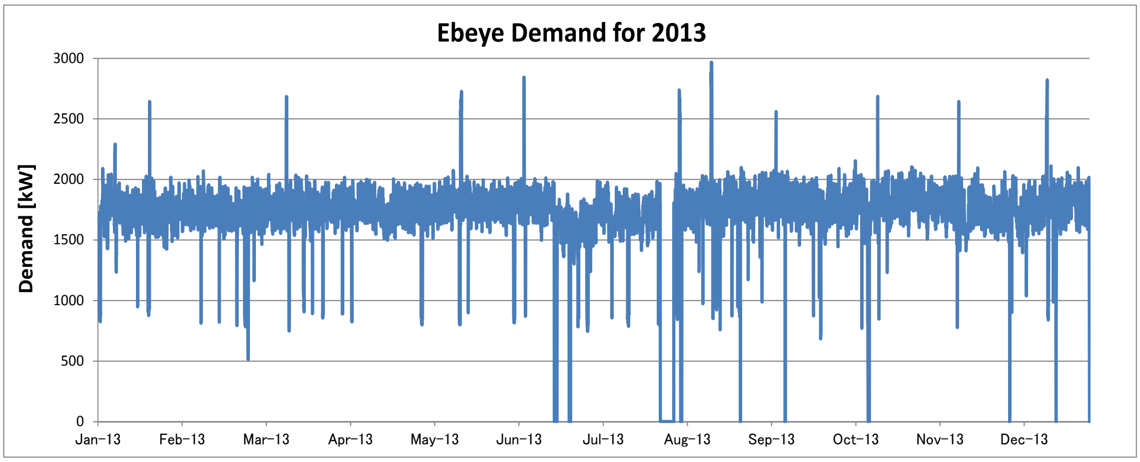


Figure 2.5.2-21 Annual grid load for Ebeye(2013)[44]

(2) Control method

Governor control method is isochronous control, and output is done with load sharing control method with same output value.

(3) Distribution equipment

Power system of Ebyeye is consisted with two feeders. Electricity produced at the station is transformed up to 13.8kV from 480V and sent to each area through tentative lines and underground transformers. Electricity is supplied to each user after lowered by ground based transformer or pole transformer.

Households with electricity are about 1,200.

[43] Obtained from KAJUR
[44] Obtained from KAJUR

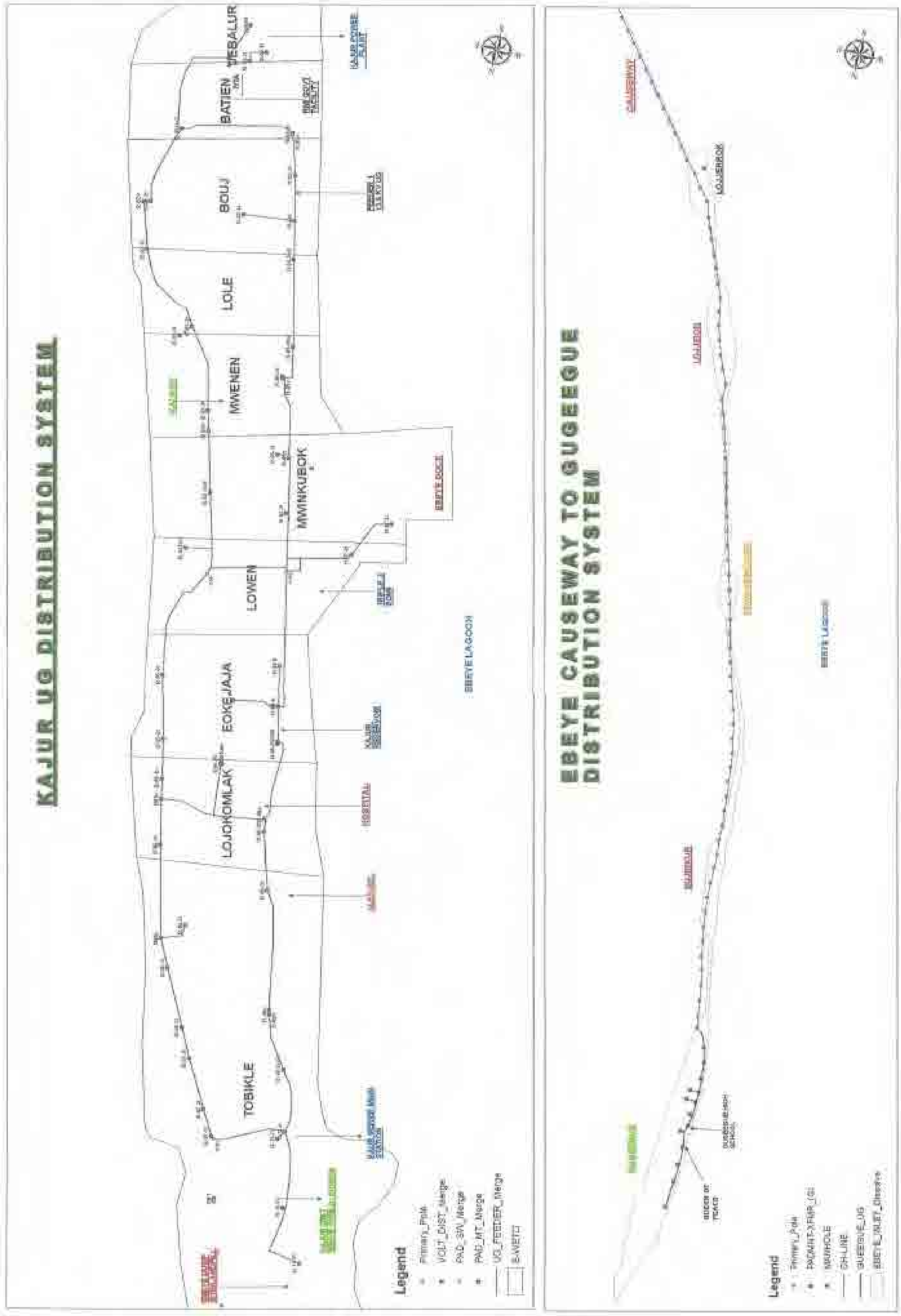


Figure 2.5.2-22 Utility grid chart in Ebeye[45]

[45] Obtained from KAJUR


Generator 2 and 3


Feeder pressure transformer(13,800/480V)


Generator control board


Electric room


Fuel tank


Tentative distribution line(Lead-in for user)


Lead-in transformer box for users


Tentative distribution line(13. 8kV)

Figure 2.5.2-23　Conditions of power plant installation in Ebeye

Chapter 3 Survey results

The survey results for “Assist in developing a legal system for the introduction of renewable energy,” “Assistance in developing an evaluation method to determine the maximum permissible amount of renewable energy that can be connected to the distribution network,” “Assist in planning and designing solar power-diesel hybrid power generation facilities,” and “Improve power plant efficiency by improving power plant operation,” which are the items for this project, are described below.

3.1 Assistance in Developing a Legal System for the Introduction of RE

3.1.1 Grid code

If a power generation system connected in a distributed manner to the power transmission and distribution system provides power to the grid side (reverse power flow), the failure of the distributed power system as well as the amount and quality of the power generated by it affect the grid of the power company and the consumers supplied with electricity from the same power company will also be affected. Therefore, regarding the installation and operation of distributed power sources, prescribed standards must be met, and the owner must make efforts to ensure quality of the generated power for public safety. For these reasons, guidelines for grid connection will be established.

The main requirements as defined herein are as follows.

3.1.1.1 Major requirements in grid code[45]

(1) Targeted facility

Generally requirements on grid connection varies depending on voltage level and configuration of distribution network, maximum capacity, type of connected generator (inverter, synchronous/inductive generator, etc.), with or without reverse power flow and others.

(2) Voltage management

In the distribution system, the voltage of the power that consumers receive throughout the system must be maintained at a constant predetermined range (101 ± 6V, 202 ± 20V in Japan). This is accomplished by adjusting the delivery voltage of the distribution substation in accordance with the load condition. However, if a power source with reverse flow is connected to the distribution line, power flows in the direction of the substation and causes voltage to rise from the middle of the distribution line which may result in deviation from the prescribed voltage at the terminal point of the line. If there is such risk, automatic voltage regulators such as "phase advanced reactive power control functions" and "output control functions" is required. In addition, instantaneous voltage fluctuations and voltage flickering should be kept in mind and measures may be required.

(3) Islanding operation detection

If there is no distributed power, in the event of an accident, measures were taken so that the distribution

[45] Takaaki Kai and Toshiro Fujimoto, Grid Connection for Solar and Wind Generation, Ohm Publishing Co. (in Japanese)

line is brought to a no-voltage state by opening a circuit breaker on the delivery side of the distribution substation to prevent electrical fires and shock while responding to the accident. However, if a distributed power supply is connected to the distribution line, there is a possibility that the distributed power supply continues islanding operation during an accident on the grid side, so a distribution line which should have no voltage becomes charged. To avoid this situation, functions for power cut-off on the grid side, distributed power to detect islanding operation on its own, and automatic parallel off from the grid are required.

However, for small systems, since voltage change and frequency change tend to occur due to supply and demand fluctuations (sudden voltage phase change), the islanding operation prevention function is prone to unnecessary detections during normal times. Therefore, the value for this detection function must be set after getting a good understanding of the characteristics of the power system in RMI.

If the islanding operation prevention function is activated by unnecessary detection, RE that is connected to the grid is simultaneously shut down, power supply and demand balance is disturbed, and due to voltage drop and frequency fluctuation in the distribution line associated with this, the whole grid is at risk of becoming unstable.

(4) Power factor

In power systems, there is a need to manage active power as well as reactive power, but if loads with a lot of reactive power increase (load power factor becomes poor), current increases resulting in increased power loss. Also regarding distributed power equipment, just as load, power factor at the network connection point must be kept above a certain level and must not become a leading power factor as seen from the system side.

(5) Harmonic wave

If system voltage is distorted by harmonic waves, it may cause malfunction of equipment, and in some cases, cause the power capacitor to burn. The AC-DC converter for the PV generation equipment (Power Conversion System, PCS) is one power electronics equipment and is prone to become the source of harmonic current. Provisions for current distortion are required.

(6) Protection coordination

A protection function which meets the demands for the following 4 requirements is required.

- For its own failures, in order to prevent the spread of their impact to the grid, the power generation equipment should parallel off from the grid immediately.
- For grid failures, the equipment shall parallel off quickly and reliably to prevent islanding operation.
- When automatic reclosing occurs during grid failures, power generation equipment should absolutely be paralleled off from the grid.
- When accidents other than those of the interconnected grid occur, and for momentary voltage drops on the grid side, the system should be designed so that the power generation equipment can continue operation without parallel off or automatically recover.

3.1.1.2 Grid codes in the world

(1) Japan

Japanese "Grid-interconnection Code" was formulated in August 1986 by a circular notice from the department manager of Public Utility Industry, Resource and Energy Agency, and was rearranged in "Interpretation of Technical Standards for Electrical Equipment" and "Grid-connected Technical Requirements Guidelines related to Power Quality Assurance" and announced officially in October 2004. And the Japan Electro-technical Standards and Codes Committee has compiled necessary and related parts for RE grid connection in these two codes into "Grid-interconnection Code (JEAC9701-2012)". It shows general principle, definition of words, requirements for grid connection in LV (600V and smaller). HV (600V – 7kV), spot network and extra-HV (>= 7kV), advance consultation with utility and required documents.

Furthermore, for protection device of solar generation system less than 20kW installed at residential house, Japan Electrical Safety & Technical Laboratories validate it and issue certification mark (Figure 3.1.1-1) in compliance with the Grid Code and the Interpretation of Technical Standards for Electrical Equipment[46].

Figure 3.1.1-1
JET certification

(2) United States

U.S. energy sector has two features. One is difference of control body of transmission lines and distribution lines[47], and the other is existence of numerous electric power suppliers[48]. Grid code changes slightly among control bodies, but most of them are based on Institute of Electric and Electronics Engineers (IEEE) 1547 series codes, "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, 28 July, 2003". This provides requirements on performance, operation, testing, safety considerations, and maintenance of the interconnection. IEEE1547 has the following four relevant standards.

(a) 1547.1-2005, IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems
- Specifies the type, production, and commissioning tests
- System control: Output levels, start/stop
- Electrical protection: Abnormal protection
- Steady-state control: V, I, VAR, power factor

(b) 1547.2-2008, IEEE Application Guide for IEEE Standard 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems
- Local protection
- Commerce functions (metering)
- Enterprise energy control

---

[46] http://www.jet.or.jp/products/protection/

[47] The main organization with jurisdiction over the power transmission system (crossing state borders) is the Federal Government, and each state government has jurisdiction over its distribution system (not crossing state borders).

[48] Combining private, regional municipal, Federal, and cooperative operated organizations, there are 3,000 or more.

- Local control
- Coordinated protection and control (requiring communication)

(c) 1547.3-2007, IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected With Electric Power Systems

It describes functionality, parameters and methodologies for monitoring, in formation exchange and control for the interconnected distributed resources with, or associated with electric power systems.

(d) 1547.4-2011: IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems

- Radial Distribution System: Power only flows from utility to load.
- Micro-grid or Intentional Island: Depending on configuration, power flows only within micro-grid or can export power to utility.
- Networked Distribution System w/2-way power flow: Distribution in which the secondaries of the distribution transformers are connected in a grid, typically energized at the customers' utilization voltage, to serve multiple loads.

Based on these IEEE 1547 series standards, each utility in US establishes its own grid code.
And similar to JET certification in Japan, US have UL1741 for inverters. Grid connection of inverters with UL1741 easily approved without detailed check in US[49].

(3) Australia

Australia has the following three codes for grid connection.

(a) AS 4777.1: Grid connection of energy systems via inverters – Installation Requirements
(b) AS 4777.2: Grid connection of energy systems via inverters – Inverter requirements

This is the requirement on power factor, harmonic current, voltage fluctuations and flicker, impulse protection, transient voltage limits, DC current injection and data logging and communication

(c) AS 4777.3: Grid connection of energy systems via inverters – Grid protection requirement

This is the requirement on disconnection devise, voltage and frequency limits (passive anti islanding protection), active anti-islanding protection, reconnection procedure and security of protection settings

And Clean Energy Council publishes approved equipment and retailer/installers for solar system on its web site[50].

3.1.1.3 Small island countries

Current position and outline on grid code in Maldives, Tonga, Solomon, Malta, Mauritius, Palau and Fiji, which are similar to RMI with small population and small grid, are shown below.

---

[49] If you enter QIKH for UL Category Code and search at http://database.ul.com/cgi-bin/XYV/cgifind.new/LISEXT/1FRAME/index.html, a list of inverters that are UL1741 certified will be displayed.
[50] http://www.solaraccreditation.com.au/

(1) Maldives

Maldives has 298km^2 of land area and approx. 300,000 populations, and then the population density is 1,006.7/km^2. GDP is 2,220 million USD and per capita is 6,567USD.[51]

"Guidelines on Technical Requirements for Photovoltaic Grid-connection" was released in February 2013 and specifies the followings[52]:

- Metering method
- Power factor
- Voltage fluctuation (Normal, Instantaneous)
- Protection relay
- Islanding operation detection (Active, Passive)
- Automatic recovering function
- Automatic load limiting and power generation suppression

And Maldives Energy Authority released "Manual for Photovoltaic Grid-connection Application" in February 2013[53]. It specifies:

- Application procedure/flowchart to introduce grid connected PV system
- Form, screening and inspection sheet
- For 1Ø 230V, 3Ø 400V, 3Ø 11kV
- With or without reverse power flow protection relay
- OVR, UVR, OFR, UFR, IOD (active/passive)

Furthermore "POWER PURCHASE AGREEMENT[54] " for 3Ø 11kV was prepared but it is still final draft.

(2) Tonga

Tonga has 720km^2 of land area and approx. 100,000 populations, and then the population density is 145.8/km^2. GNI is 370 million USD and per capita is 3,580USD. Energy use per capita 567kgoe in 2007.

"POLICY FOR THE CONNECTION OF EMBEDDED GENERATION" was released in March 2013 by Tonga Power Limited (TPL) [55] and specifies net-billing (Net metering) policy with dual meter system and application process/form for more than 10kW and 10kW and smaller RE. It refers the following standards and requires 50Hz +/-1.5% and 230V +/-10%.

- AS/NZS 3000 Wiring Standards
- AS/NZS 5033 Installation of Photovoltaic (PV) Arrays
- IEEE 1547 Standards for Interconnecting distributed Resources with Electric Power Systems
- EN50160 in regards to power quality
- IEC 61000-6-2 (EMC Immunity) and -4 (EMC Emission)

[51] RMI has 180km^2, 53,000 populations, 294.4/km^2, GNI180 million USD, GNI per capita 4,040USD and energy consumption per capita 613.6kgoe.

[52] http://www.mea.gov.mv/v1/wp-content/files/downloads/Guideline_for_Grid-connected_PV_System_-_Feb_2013.pdf

[53] http://www.mea.gov.mv/v1/wp-content/files/downloads/Manual_for_PV_Grid-connectin_Application_-_Feb_2013.pdf

[54] http://www.mea.gov.mv/v1/wp-content/files/downloads/Draft_Standard_Power_Purchasing_Agreement.pdf

[55] http://www.tongapower.to/Portals/2/Docs/TPL%20Net%20Billing/TPL%20Net-Billing%20Policy.pdf

- AS 4777.1 Grid connect – Installation
- AS/NZS 1768 Lightning Protection
- IEC 61730 PV modules
- Pricing methodology

(3) Solomon

Solomon has 28,900km^2 of land area and approx. 550,000 populations, and then the population density is 19.0/km^2. GDP is 1,000 million USD and per capita is 1,130USD. Energy use per capita 130kgoe in 2007.

"Solar Arrangements: Technical Arrangements for Grid Connection of Photovoltaic Systems via Inverters" is under discussion in parliament and not yet authorized. Solomon Islands Electricity Authority (SIEA) prepared the draft (Version 0.5, 20 October 2013) and shows the followings:

- 10kVA and smaller for 1Ø 230V and, 0kVA and smaller for 3Ø 400V
- Basically without batteries
- Refer Australian standard
- Inverter: AS4777, maintained with AS5033
  - Approved one on Clean Energy Council website
  - Listed on application form of SIEA
  - Approved designers/suppliers on Clean Energy Council website
- Islanding detection
- Trip at 210V, 270V (1Ø) 470V, 370V (3Ø), 54Hz, 46Hz
- Metering Arrangement

SIEA also prepares "Photovoltaic Inverter Network Connection Agreement, For Connection to SIEA Grid" as draft version 0.5 on 20 Oct 2013. It shows flowchart for smaller than or equal 30kVA PV with two attachments.

- Attachment A: Licensing of Standby and Independent Generation
- Attachment B: Interconnected Solar Array Generation, POLICY

However it declares that SIEA will not pay any excess dollar for array output that may be injected back into the grid.

(4) Palau

According to Palau 2012, "Palau Net Metering Act approved: by Clint Wachi", it says "The Palau Net Metering Act that will facilitate a system of customer-based renewable energy generation was approved into law Friday. The new law, which is authored by Senator Paul Ueki and designated as RPPL No. 8-39, allows consumers of electricity to establish renewable energy-powered generation system to produce electricity for their own use and to supply excess electricity to the electric service provider…IT"[56]. However more detailed information is not available and further investigation is needed.

(5) Fiji

[56] http://palau2012.wordpress.com/2012/03/21/palau-net-metering-act-approved-by-clint-wachi/

Fiji has 18,270km^2 of land area and approx. 868,000 populations, and then the population density is 47.5/km^2. GDP is 3,190 million USD and per capita is 6,680USD. Energy use per capita 627.3kgoe in 2007.

There is some news on grid code in Fiji. The first one is the tender No. MR 102/2011 by Fiji Electricity Authority (FEA) on "Grid Code Review".[57]

And the second one is information on the University of Southern Pacific (USP), "Electricity provider willing to consider net-metering".[58] It says, "The Fiji Electricity Authority (FEA) - the only state owned electricity utility in Fiji - is keen to buy electricity from grid-connected systems through net-metering, and has the legislations in place to do so". This was revealed by FEA's Chief Information Officer, Mr Anand Nanjangud during the Small Developing Island Renewable Energy Knowledge and Technology Transfer Network-Project DIREKT - organized workshop held at The University of the South Pacific on 16 March 2012. However more detailed information is not available and further investigation is needed.

(6) Malta

Malta has 316km^2 of land area and approx. 410,000 populations, and then the population density is 1,297/km^2. GDP is 84.15 million USD and per capita is 19,740USD. Energy use per capita 2,057.9kgoe in 2007.

Malta government focuses on dissemination of solar energy and has clear grid code "The Network Code, Enemalta, Approved by the Malta Resources Authority, Version 1, October 2013" [59]. It specifies the followings:

- Protection requirements and earthing
- Voltage regulation and control
- Short-circuit levels
- Voltage disturbances
- Islanding, Standby generators
- Metering
- Demand forecasting, if it appropriate
- Demand control
- Safety co-ordination

(7) Mauritius

Mauritius has 2,045km^2 of land area and approx. 1,300,000 populations, and then the population density is 635.7/km^2. GNI is 10,340 million USD and per capita is 8,040USD. Energy use per capita 947.3kgoe in 2007.

Central Energy Board (CEB) has "CEB, Grid Code for Small Scale Distributed Generation (SSDG), 9 Dec 2010", "Customer Guidelines for Grid Connection of Small Scale Distributed Generators (SSDG) up to 50 kW, 9 Dec 2010", "CEB, SSDG Application Form" and "CEB, SSDG Connection Agreement[60]" .

[57] http://www.fea.com.fj/userfiles/file/MR%20102-2011.pdf
[58] http://www.usp.ac.fj/news/story.php?id=986
[59] http://www.enemalta.com.mt/index.aspx?cat=2&art=5&art1=71
[60] http://ceb.intnet.mu/grid_code/project.asp

The guideline specifies the followings:

- LV, less than 17kW for 1Ø and less than 50kW for 3Ø
- Total 2MW or 200 sites, 1MW for residential
- 230/400V +/-6%, 50Hz +/-1.5%
- Protection requirement
- Network islanding, reconnection
- Power quality, power factor
- Safety, Metering

3.1.2 Legal system for RE promotion and dissemination

In RMI, governmental PV projects have been implemented so far, such as, grid connected PV system at Majuro Hospital and College of Marshall Islands (CMI), and Solar Home System (SHS) in outer islands. To have broader diffusion in RE utilization, development of RE generation in private sector is essential and the government has to provide incentives for private sector. That is, it is necessary to enhance aid scheme for RE, not only tax exemption of imported RE equipment. In this section, outline of various schemes in the world are reviewed, with focusing small island countries.

3.1.2.1 Aid scheme for RE diffusion

As shown in Figure 3.1.2-1, purpose of aid scheme from the energy cost viewpoint is to mitigate increasing cost risk with fossil fuel, by investing to improve energy infrastructure with RE utilization.[61]

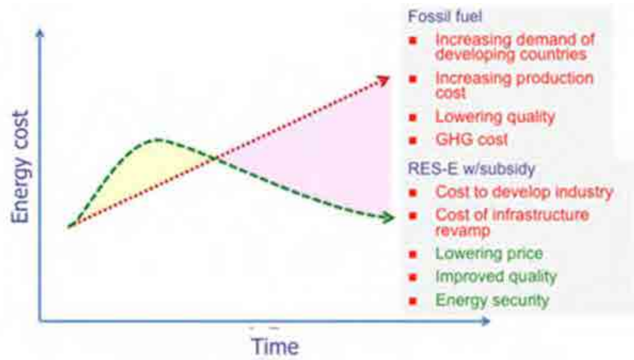


Figure 3.1.2-1 Purpose of aid from the viewpoint of energy cost

It is hard to stop fossil fuel cost rise, and faced with growing consumption in developing countries, cost up in digging, lowering quality, CO_2 emission cost. Therefore even though inviting higher initial cost, financial aids for RE development can be a tool to improve energy infrastructure, to pursue lower energy cost in future.

There are some aid schemes as shown in Figure 3.1.2-2 and two major approaches, Quota and Feed-in Tariff (FIT).

[61] Keiichiro Sakurai, 2011, Intrroduction to FIT: Renewable Energy: Trump card of Dissemination (in Japanese) http://ksakurai.nwr.jp/R/slides/WhyFIT/WhyFIT-v5.pdf

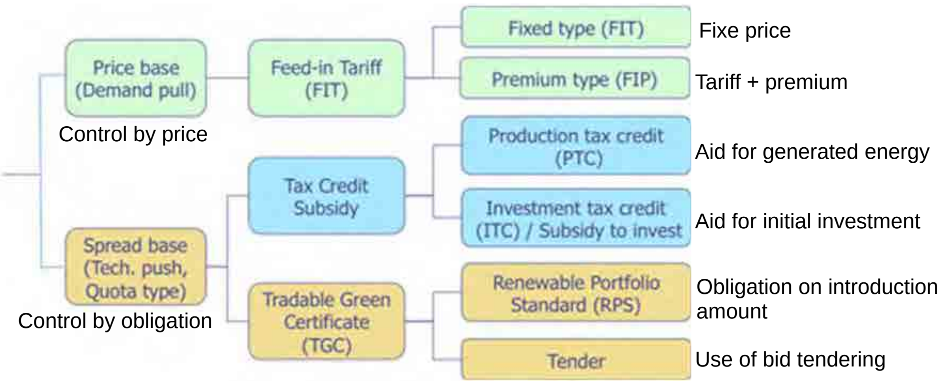
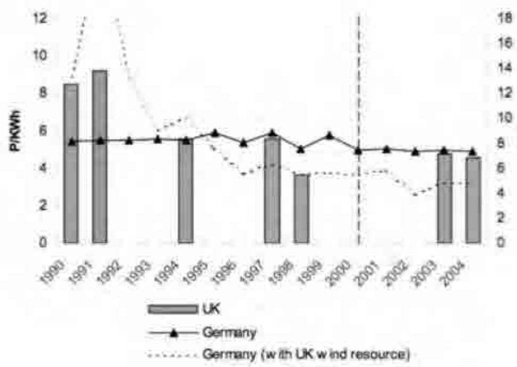


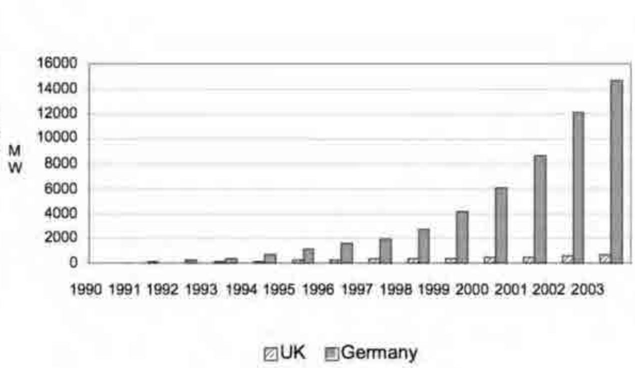
Figure 3.1.2-2 Categories of major promotion plans

Quota system is based on volume, and as typified by Renewable Portfolio Standard (RPS) or Tendering system, which impose obligation on RE introduction amount. It is applied with financial support for generated volume (Production tax credit, PTC), for acquiring initial capital (Investment tax credit, ITC), and/or others. On the other hand, FIT is based on price, and purchases RE power at fixed price or with premium added on electricity tariff. In practice, these schemes can be applied in mix, so Figure 3.1.2-2 is a simplified classification for easy understanding.

So far many efforts have been made to diffuse RE in the world, and FIT results in better performance rather than Quota system.



(a) Cost per kWh



(b) Cost per kWh

Figure 3.1.2-3 Comparison between wind power generation in Germany (FIT) and UK (tendering → RPS)

Figure 3.1.2-3 shows a comparison in change of cost and installed volume of wind generation in Germany and UK.[62] The former applied FIT and the latter applied Quota (Tendering and then RPS). Although UK has better wind condition than Germany, Germany has greater installed volume. And assuming similar wind condition, cost curve in Germany is as shown in dotted line in 3.1.2-3 (a) and Germany got better result.

However, depending on FIT scheme design, penetration of RE may proceed rather than designer's expectation. Actually also in Japan, Okinawa prefecture is obliged to refuse further application of grid connected PV system by fast and vast installation so far.

[62] Lucy Butler and Karsten Neuhoff, 2004, Comparison of Feed in Tariff, Quota and Auction Mechanisms to Support Wind Power Development https://www.repository.cam.ac.uk/bitstream/handle/1810/131635/ep70.pdf?sequence=1

3.1.2.2 Mechanism of FIT

To assure returns in private investment in RE, FIT guarantees purchasing price of power from RE and contract period (10 – 20 years) at initial stage of RE project.

Figure 3.1.2-4 Mechanism of FIT

To adjust introduced volume, generally purchasing price is lowered in accordance with increasing installed volume. Price for Mr. B, a latecomer, is lower than one for Mr. A. Since degressive price is not applied for Mr. A, he can have assured investment return at pre-fixed price for contract period (refer to Figure 3.1.2-4). In designing FIT system, various options can be set to correspond to specific national/regional condition[63].

3.1.2.3 World trend

Japan has started FIT from July, 2012 and its outline is shown in Table 3.1.2-1.[64] Outline of FIT (in 2014) in various countries is summarized in Table 3.1.2-2.[65] These are very informative in considering FIT for RMI, but we have to check one for small island countries too. Mauritius and Malta have had FIT already and some developing island countries have formulated it. However purchased price in Tonga is 0, and in Fiji and Cook Islands price is under their electricity tariff and specified without clear contract period. Table 3.1.2-3 is a summarized table of FIT with demand, existing PV, tariff in those small island countries.

[63] Toby D. Couture, Karlynn Cory, Claire Kreycik and Emily Williams, 2010, A Policymaker's Guide to Feed-in Tariff Policy Design http://www.nrel.gov/docs/fy10osti/44849.pdf

[64] Resources and Energy Agency, 2013, FIT guidebook for renewable energy http://www.enecho.meti.go.jp/category/saving_and_new/saiene/data/kaitori/kaitori_jigyousha2013.pdf

[65] Legal Sources on Renewable Energy, http://www.res-legal.eu/search-by-country/

Table 3.1.2-1 FIT in Japan (2014)

Power source	Classification	Purchased price (JPY/kWh)		Period (Years)
		w/ tax	w/o tax	
Solar	>= 10kW	34.56	32.00	20
	< 10kW (surplus)	-	37.00	10
	< 10kW (double gen. surplus)	-	30.00	
Wind onshore	>= 20kW	23.76	22.00	20
	< 20kW	59.40	55.00	
Wind offshore	-	38.88	36.00	20
Geo-thermal	>= 15,000kW	28.08	26.00	15
	< 15,000kW	43.20	40.00	
Hydro	>= 1,000kW, < 30,000kW	25.92	24.00	20
	>= 200kW, < 1,000kW	31.32	29.00	
	< 200kW	36.72	34.00	
Hydro for headrace	>= 1,000kW, < 30,000kW	15.12	14.00	20
	>= 200kW, < 1,000kW	22.68	21.00	
	< 200kW	27.00	25.00	

Power source	Biomass type	Purchased price (JPY/kWh)			Period
		Classification	w/ tax	w/o tax	
Bio-mass	Gasification (sewage sludge)	Methane fermentation gasified biomass	42.12	39	20
	Gasification (livestock excreta)				
	Solid fuel burning (unused wood)	Unused wood	34.56	32	
	Solid fuel burning (other wood)	Wood, including palm shell	25.92	24	
	Solid fuel burning (general wastage)	Wastage biomass (non-wood)	18.36	17	
	Solid fuel burning (other biomass)				
	Solid fuel burning (construction wastage)	Recycled wood	14.04	13	

Table 3.1.2-2 System outline in countries have already implemented FIT (2014)

Country		Tariff level in 2014 (Euro cents/kWh) and duration of support for different technologies						
		Small hydro	Wind onshore	Wind offshore	Solid biomass	Biogas	PV	Geothermal
Austria (fixed)		4.97-10.55 13 yrs	9.45 13 yrs	-	5.74-20.0 15 yrs	4.95-19.5 15 yrs	10.0-12.5 13 yrs	7.43 13 yrs
Bulgaria (fixed)		4.8-12.14 15 yrs	4.9-7.0 12 yrs	-	8.4-12.8 20 yrs	4.6-19.8 15 yrs	6.7-10.8 20 yrs	20 yrs
Cyprus (fixed)		-	-	-	-	-	Net-Metering	-
Czech Republic	(fixed)	9.1-11.8 30 yrs	7.3 20 yrs	-	4.8-12.1 20 yrs	7.1-12.9 20 yrs	9.0-11.1 20 yrs	12.0 20 yrs
	(premium)	6.1-8.8 30 yrs	5.6 20 yrs	-	1.7-9.0 20 yrs	4.1-9.8 20 yrs	6.8-8.9 20 yrs	8.9 20 yrs
Denmark	(fixed)	Net-Metering	Net-Metering	Net-Metering	Net-Metering	Net-Metering	Net-Metering	-
	(premium)	1.0-17.0 20 yrs	3.0-14.0 20 yrs	3.0-8.0 10 yrs	2.0-11.0 10 yrs	11.0-17.0 10 yrs	8.0-19.4 10 yrs	-
Estonia (Premium)		5.37 12 yrs	5.37 12 yrs	5.37 12 yrs	5.37 12 yrs	5.37 12 yrs	5.37 12 yrs	5.37 12 yrs
France (Fixed)		6.07-15 20 yrs	2.8-8.2 15 yrs	-	4.34-12.05 20 yrs	8.121-9.745 15 yrs	6.98-28.91 20 yrs	20.0-28.0 15 yrs
Germany (fixed)		3.23-12.45 20 yrs	4.72-8.66 20 yrs	3.5-19.0 20 yrs	5.76-13.73 20 yrs	5.71-24.5 20 yrs	8.92-12.88 20 yrs	25.0 20 yrs
Hungary (fixed)		4.0-12.0 -	4.0-10.0 -	-	3.0-12.0 15 yrs	3.0-12.0 15 yrs	3.0-10.0 -	3.0-12.0 -
Ireland (fixed)		8.8 15 yrs	6.95-7.2 15 yrs	6.95-7.2 15 yrs	8.91-14.68 15 yrs	8.54-15.7 15 yrs	-	-
Italy	(fixed)	15.5-25.7 20 yrs	14.9-29.1 20 yrs	17.6 25 yrs	18.1-25.7 20 yrs	14.0-23.6 20 yrs	-	13.5 20 yrs
	(premium)	-	-	-	-	-	27-36 25 yrs	-
Latvia (fixed)		Net-Metering	Net-Metering	-	Net-Metering	Net-Metering	Net-Metering	Net-Metering
Lithuania (fixed)		6.4-7.8 12 yrs	6.4-8.1 12 yrs	6.4-8.1 12 yrs	5.5-8.7 12 yrs	9.0-15.3 12 yrs	13.3-20.0 12 yrs	-
Luxembourg (fixed)		12.5-18.0 15 yrs	9.2 15 yrs	-	11.8-16.3 15 yrs	15.3-19.2 20 yrs	26.4 15 yrs	-
Netherland (fixed)		Net-Metering	Net-Metering	Net-Metering	Net-Metering	Net-Metering	Net-Metering	Net-Metering
Portugal (fixed)		9.1-26.0 15-25 yrs	7.4 15 yrs	7.4 15 yrs	10.2-11.9 25 yrs	10.2-11.7 15 yrs	6.6-38.0 15-20 yrs	27.0 12 yrs
Slovakia (fixed)		9.798-11.127 15 yrs	7.03 15 yrs	-	9.209-12.61 15 yrs	7.034-12.529 15 yrs	9.894 15 yrs	15.513 15 yrs
Slovenia (fixed)		8.234-10.547	9.538	-	19.053-25.21	6.167-16.555	7.277-10.428	15.247
		Agreed and laid down in the contract						
United Kingdom (fixed)		4.08-25.98 20 yrs	4.2-21.9 20 yrs	4.2-21.9 20 yrs	-	11.7-15.3 20 yrs	7.8-17.7 20 yrs	-

Table 3.1.2-3 FIT in small island countries

	Load (MW)	Grid connected PV (kW)	kWh / capita[66]	Electricity tariff (/kWh) for business[67]	Grid code	FIT		Remark
						/kWh	year	
Marshalls Energy Company	Ave. 7.0 Max. 8.5	257	1,032	0.40USD	no	no		
Tonga Power Limited	6.4 (12:00) 7.0 (20:00) [67]	1,300	487	0.945TOP (0.509USD)	yes[68]	yes, but free now[68]	-	
Fiji Electric Authority	111[69]	10[69]	850	0.3947FJD (0.209USD)	yes[70]	0.23FJD (0.121USD)	?	
Solomon Islands Electric Authority	14 (15:00)	0	142	6.418SBD (0.879USD)	under preparation	no		
Maldives Energy Authority	106[71]	> 90.4[71]	2,283	3.65MVR (0.240USD) [72]	yes	under revision		
Cook Islands, Te Aponga Uira: Rarotonga	Approx. 5.0 [67]	367.12 [67]	1,235	0.78USD [73]	yes	0.45USD[73]	?	Net metering [67]
FSM: Kosrae Utility Authority	2.0 [67]	51.26 [67]	560	0.528USD[74]	under consideration[70]	no		
Nauru Utility Authority	3.3[67]	70[67]	2,057	0.25-0.50AUD (0.22-0.44 USD) [67]	being prepared[70]	no		
Palau Public Utilities Corporation	Approx. 10.0[67]	600[67]	3,372	0.405USD[67]	Yes[70]	no		
Mauritius, Central Electricity Board	430[75]	300[76]	1,941	10.01MUR (0.333USD) [77]	yes[78]	15MUR (0.499USD) [79]	15[79]	16% is from biomass [66]
Malta, Enemalta	360[80]	18[80]	4,423	0.16EUR (0.217USD) [81]	yes[82]	0.2EUR (0.271USD) [81]	20[81]	

66 RENEWABLE ENERGY COUNTRY PROFILES: Special edition on the occasion of the renewables and Islands http://www.irena.org/DocumentDownloads/Publications/Country_profiles_special_edition-islands.pdf
67 renewable energy opportunities and challenges in the Pacific Islands region http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=353
68 TONGA POWER LIMITED POLICY FOR THE CONNECTION OF EMBEDDED GENERATION http://www.tongapower.to/Portals/2/Docs/TPL%20Net%20Billing/TPL%20Net-Billing%20Policy.pdf
69 PPA/e7 renewable Energy Workshop for Southern Utilities: FEA http://www.globalelectricity.org/projects/fiji/Attendees_fichiers/Presentation%20Fiji%20Electricity%20Authority.pdf
70 Accelerating renewable Energy Deployment in the Pacific SIDS http://www.irena.org/DocumentDownloads/events/Workshop_Accelerated_renewable_Energy_Deployment/Session2/S2_2_Solomone_Fifita_accelerating_re_Deployment.pdf
71 RENEWABLE ENERGY IN THE MALDIVES: Current situation and a way forward http://www.irena.org/DocumentDownloads/events/Workshop_Accelerated_renewable_Energy_Deployment/Session1/S1_3_Ibrahim_Nashid_IRENA_Sydney_2011.pdf
72 MALDIVES ENERGY AUTHORITY APPROVED TARIFF http://www.mea.gov.mv/v1/wp-content/files/lawsandregulations/revised_MEA_APPROVED_TARIFF-ALL_10_2013.pdf
73 Te Aponga launches new solar opportunities http://www.cookislandsnews.com/2013/December/Wed18/environment.htm
74 Kosrae Utilities Authority: Tariff Rate, Effective April 2nd 2013 http://kosraepower.com/tariff.html
75 DEMAND FORECAST FOR MAURITIUS http://ceb.intnet.mu/CorporateInfo/IEP2013/Chapter4_Demand%20Forecast%20for%20Mauritius.pdf
76 Renewable Energy Potential in Mauritius and Technology Transfer through the DIREKT Project http://psrcentre.org/images/extraimages/1012223.pdf
77 Central Electricity Load: Tariffs http://ceb.intnet.mu/
78 GRID CODE: MEDIUM SCALE DISTRIBUTED GENERATION (MSDG): Greater than 200kW but not exceeding 2MW http://ceb.intnet.mu/msdg/document/MSDG200kW2MWVer2.1.pdf
79 FEED IN TARIFF (FIT) for 15 years http://ceb.intnet.mu/grid_code/feedin.asp
80 Malta Indicative National Energy Efficiency Target for 2020 in accordance with Article 3 of Directive 2012/27/EU http://ec.europa.eu/energy/efficiency/eed/doc/ewporting/2013/mt_2013ewport_en.pdf
81 Enemalta: New Feed-in Tariffs announced http://www.enemalta.com.mt/newsDetails.aspx?id=17868
82 Enemalta: The Network Code http://www.enemalta.com.mt/enemaltastorage/images/files/network%20code/network%20code%20emc%20approved%20%20october%202013.pdf

3.1.3 Approach to establish legal system for RE in Marshall Islands

3.1.3.1 Cooperation system with counterpart

It is hard to develop RE aid scheme including FIT, only with engineer level in counterpart, since it requires some management and financial knowledge. And also in considering technical requirement for grid code, since there are a few engineers who know operation and protection system of entire MEC grid, it is necessary to involve not only power system engineers but also generation ones. To cope with these constraints, without focusing on any particular individual, a committee and two working groups have been established as shown in Figure 3.1.3-1.

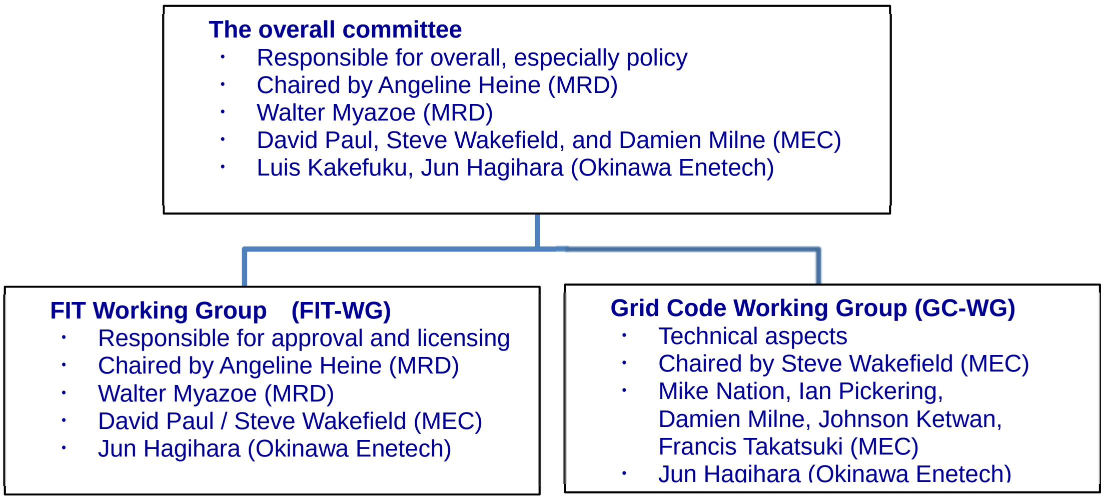


Figure 3.1.3-1 Committee structure

The committee arranges/solves various issues, which affects both politics/management and technical operation, and is responsible for the total output.

3.1.3.2 Schedule and points of concern

Contents of survey and discussion held in each mission are summarized as shown in Table 3.1.3-1. Fundamental knowledge of grid code was studied with "A Guidebook On Grid Interconnection and Islanded Operation of Mini-Grid Power Systems Up to 200kW" published by Lawrence Berkeley National Laboratory,[83] and one for FIT was "A Policymaker's Guide to Feed-in Tariff Policy Design" by NREL.[84]

Table 3.1.3-1 Tasks in each mission

Mission	CG–WG	FIT-WG
Jan. 2014	・Facility survey including outer islands ・Study of fundamentals ・Review of examples in other countries	・Study of various support mechanism ・Study of FIT fundamentals ・Review of examples in other countries
Jun. 2014	・Survey of facility and customer ・Discussion on power quality and safety	・Study with FIT simulator ・Impact analysis on MECside
Aug. 2014	・Survey of facility and customer ・Discussion on protection coordination ・Prepare initial draft	・Discussion on issues around FIT scheme and its feasibility in RMI
Nov. 2014	・Final report and Q&A ・Symposium (open to public)	

83 http://www.cleanenergyministerial.org/Portals/2/pdfs/A_Guidebook_for_Minigrids-SERC_LBNL_March_2013.pdf
84 http://www.nrel.gov/docs/fy10osti/44849.pdf

And during analysis and identifying issues, the following should be kept in mind.

① It is an island country and the electricity grid is small sized and independent.

② RE installation among private sectors might progress even without incentives as the grid power is expensive.

③ An increase in energy demand is not expected as the economy is currently stagnant.

As for item ①, it will be reviewed using examples in Okinawa and Hawaii which have a lot of experience in similar circumstances as reference.

3.1.3.3 Basic principle

Basic principles based on discussions with the counter part are shown below.

(1) Grid code

- In RMI, industrial standard for electrical facility and equipment is U.S. NEC/IEEE. Therefore its grid code should be based on IEEE1547 and shall use gird code of island utility in U.S., such as Hawaii, as a reference.
- As the first step, only PV facility in Majuro Atoll shall be focused.
- Grid connection shall be made with low voltage line, since all the consumers are connected with it. And max capacity at one site shall be 30kW[85], tentatively.
- For residential house, reverse power flow is basically not allowed, and for commercial and residential sector, its surplus reverse flow is permitted, if small quantity.
- No IPP is permitted.

(2) Financial support

- Although FIT proven in developed countries is investigated, the purpose of this work is not to establish FIT scheme, but to understand FIT's concept, mechanism and design methodology. RMI is expected to gain an understanding and skills to design FIT scheme, if necessary.
- This kind of measure and policy is heavily relates to land owner and regional governments, and is easily got trapped in political issues. Such an issue shall not be investigated in this project.
- Issues and possibility of RMI's FIT scheme shall be investigated, and based on them, what FIT is feasible in RMI shall be studied, if necessary.

3.1.4 Grid code for RMI

3.1.4.1 Initial draft of RMI's grid code

Draft of RMI's grid code, which was prepared based on reviews of Hawaiian Electric Company (HECO) Rule 14[86] and discussions with MEC. Although it is based on Rules 14 and IEEE1547, the following points are amended, in considering RMI's singularity.

① Max allowable capacity to be connected with grid is 30kW.

② Targeted generator is just PV with inverter.

③ Grid connection is made with low voltage line.

[85] HECO requests utility grade specification for generating facility with over 30kW capacity.

[86] http://www.hawaiianelectric.com/vcmcontent/FileScan/PDF/EnergyServices/Tarrifs/HECO/HECORules14.pdf

④ Access to isolating device such as breaker shall be secured for MEC staffs.
⑤ Normal voltage fluctuation is ±5%.
⑥ Normal frequency fluctuation is ±1%.
⑦ Reclose shall be made after at least 20 minutes later returning to normal grid condition.

Developed grid code is not completed, since it should be maintained and revised based on environmental change, technological progress and RE penetration. That is, it should not be provided by others, but a self product as its own rule. In this project, priority is placed at co-work and discussion with counter part in preparing grid code, we think RMI can easily maintain, revise and develop it.

Version 0.08a

Grid Code for RMI

1. Purpose of the Grid Code

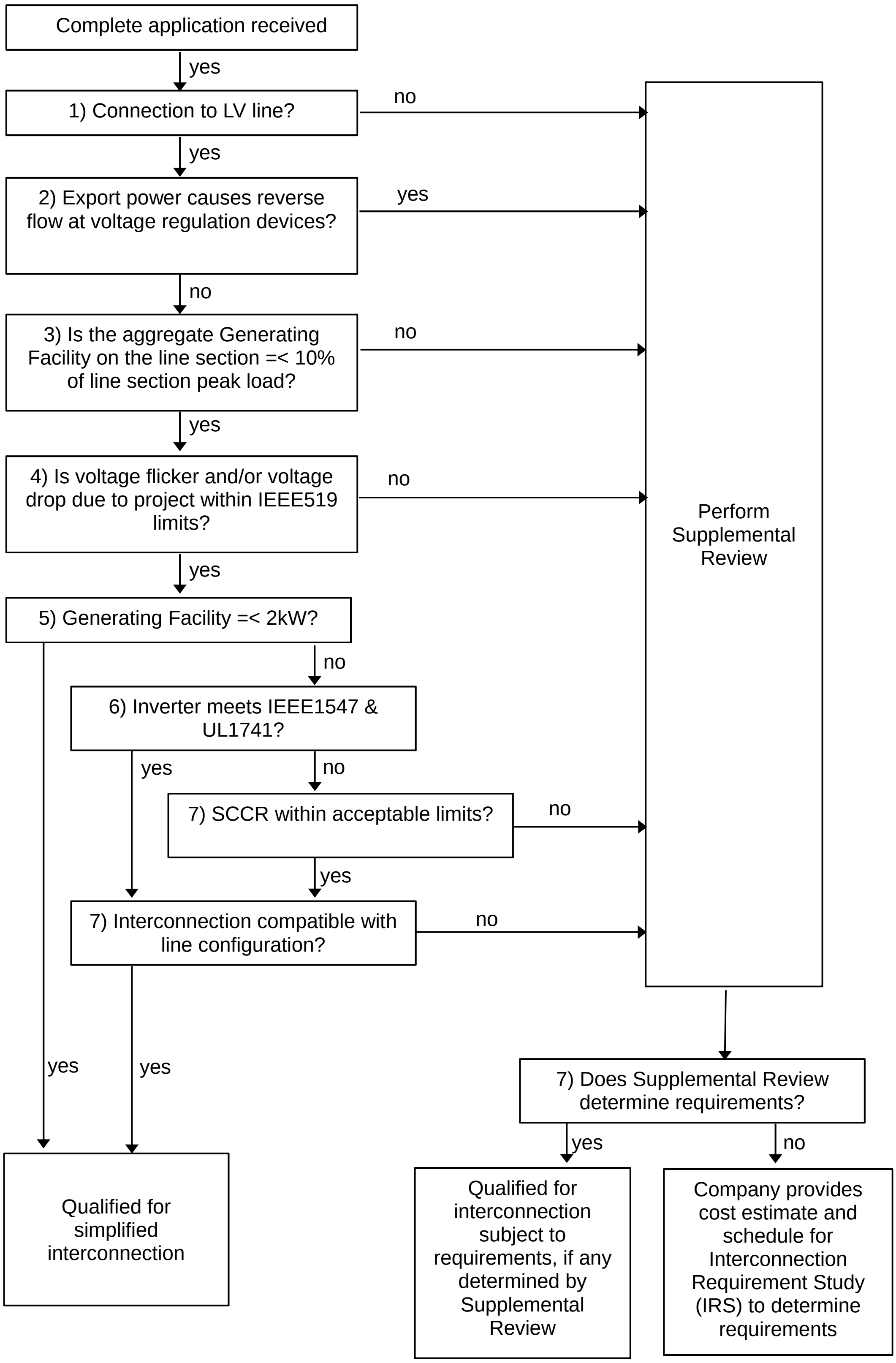
The following interconnection standards are intended to provide general technical guidelines and procedures to facilitate the interconnection and parallel operation of distributed generating facilities of capacity less than 30kW with Marshall Energy Company's (MEC) electrical distribution system. These technical interconnection requirements have been established to maintain safety, reliability, and power quality standards for all utility customers and personnel under the objectives described below:

The criteria and requirements in this document are applicable to the following distributed resource technologies, interconnected to MECs at typical secondary distribution voltages.

- Photovoltaic (PV)

This standard does not prescribe generating facility self-protection or all operating requirements for generating facility units.

2. Connecting Distributed Generating Facility to the Grid



3. Interconnection Requirements and Safety Aspects

3.1 Interconnection Facility Characteristics

The generating facility is connected to the MEC's Low Voltage distribution line.

- 480V 3ϕ 4 wire/277V 1ϕ
- 240V double phase (1ϕ 3 wire /120V 1ϕ
- 208V 3ϕ 4 wire/120V 1ϕ
- Metering is to be performed at low voltage (LV).

3.2 Interconnection Facility Design Parameters

The generating facility shall have the following design parameters. The generating facility has to functions and protects itself within the following range of the voltages, currents and frequencies existing in the MEC grid.

Table 1: Normal operating parameters of the MEC grid

Description	Range
Statutory Voltage range (LV)	120V±5% 1ϕ 208V±5% 3ϕ 240V±5% double phase (1ϕ) 480V±5% 3ϕ
Normal Frequency	60Hz
Statutory frequency deviation	60Hz±1%
Operating frequency range	58.8Hz -61.2Hz

3.3 Protection Requirements

3.3.1 Availability of Protection

The generating facility shall, at a minimum, provide adequate protective devices which include over/under voltage trip, over/under frequency trip, reverse power relay (for non-export generating facilities), and a means for automatically disconnecting the generating facility from MEC distribution system whenever a protective device initiates a trip. Based upon the results of the Initial Technical Review and/or Supplemental Review by MEC, additional protective devices may be required. Photovoltaic generating systems are to follow the guidelines set by UL1741 standard (or latest version). Typical equipment and protective device requirements for inverter generator is illustrated in Figures 1 in 4.1.

Applicable circuit breakers or interrupting devices at the generating facility must be capable of interrupting the maximum available fault current at the site, including any contribution from the generating facility. For generating facilities, the interrupting device must be accessible to MEC personnel at all times.

3.3.2 Loss of Protection

Failure of the generating facility interconnection protection equipment, including loss of control power, shall result in the automatic disconnection of the generating facility from MEC distribution system until such time that the interconnection protection equipment has been restored. Such failure shall initiate a signal to trip a generating facility circuit breaker or shutdown an inverter.

3.3.3 Trip Settings

3.3.3.1 Instantaneous Voltage Regulation

The generating facility shall be equipped with protective equipment designed to automatically disconnect the generating facility from MEC distribution system for voltages outside the normal operating range within the clearing time as indicated in Table 2 below, and remain disconnected until the voltage and frequency have stabilized (see Section3.3.5). The protective equipment shall measure the RMS (root-mean-square) voltage at the Point of Interconnection.

Table 2: Interconnection system response to abnormal voltage

Voltage (% of base voltage[87])	Clearing Time (s)
V < 50	0.16
50 ≤ V < 88	2.00
110 ≤ V < 120	1.00
120 ≤ V	0.16

3.3.3.2 Frequency

When the system frequency is in a range given in Table 3, the generating facility shall cease to energize MEC grid within the clearing time as indicated. Clearing time is the time between the start of the abnormal condition and the generating facility ceasing to energize MEC grid.

Adjustable under-frequency trip settings shall be coordinated with MEC grid operations.

Table 3: Interconnection system response to abnormal frequencies

Frequency range (Hz)	Clearing Time (s)
> 61.0	0.16
< 57.0	0.16

[87] Base voltages are the nominal system voltages stated in ANSI C84.1-1995, Table 1.

3.3.4 Unintentional Islanding

For an unintentional island in which the generating facility energizes a portion of MEC grid through the PCC, the generating facility interconnection system shall detect the island and cease to energize the MEC grid within two seconds of the formation of an island.[90] [IEEE1547, 4.4.1]

3.3.5 Re-connection and Synchronization

The generating facility shall be equipped with automatic means to prevent reconnection of the generating facility with MEC distribution system until MEC service voltage and frequency are within MEC tariff normal operating ranges and stable for at least 20 minutes, unless earlier directed by MEC.

Upon connection, the generating facility shall synchronize with MEC distribution system. Synchronization means that at the Point of Interconnection, the frequency difference shall be less than 0.2 Hz from rated frequency, the voltage difference shall be less than 5% of nominal voltage, and the phase angle difference shall be less than 10 degrees.

3.3.6 Grounding Requirements

The grounding scheme of the generating facility interconnection shall not cause over voltages that exceed the rating of the equipment connected to the MEC grid and shall not disrupt the coordination of the ground fault protection on the MEC grid.

3.4 Power Quality

3.4.1 DC Injection

The generating facility and its interconnection system shall not inject dc current greater than 0.5% of the full rated output current at the point of interconnection.

3.4.2 Flicker

The generating facility shall not create objectionable flicker for other customers on MEC grid.[91]

---

[90] Some examples by which this requirement may be met are:
1. The generating facility aggregate capacity is less than one-third of the minimum load of MEC.
2. The generating facility is certified to pass an applicable non-islanding test.
3. The generating facility installation contains reverse or minimum power flow protection, sensed between the Point of generating facility Connection and the PCC, which will disconnect or isolate the generating facility if power flow from MEC to MEC reverses or falls below a set threshold.
4. The generating facility contains other non-islanding means, such as a) forced frequency or voltage shifting, b) transfer trip, or c) governor and excitation controls that maintain constant power and constant power factor.

[91] Flicker is considered objectionable when it either causes a modulation of the light level of lamps sufficient to be irritating to humans, or causes equipment misoperation. For guidance, refer to IEEE Std 519^{TM}-1992 [B5], IEEE P1453^{TM}, IEC/TR3 61000-3-7, IEC 61000-4-15, IEC 61400-21.

3.4.3 Harmonics

When the generating facility is serving balanced linear loads, harmonic current injection into MEC grid at the point of common coupling (PCC) shall not exceed the limits stated below in Table 4. The harmonic current injections shall be exclusive of any harmonic currents due to harmonic voltage distortion present in MEC grid without the generating facility connected.

Table 4: Maximum harmonic current distortion in percent of current (I)[92]

Individual harmonic order h (odd harmonics)[93]	h < 11	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h < 35	35 ≤ h	Total demand distortion (TDD)
Percent (%)	4.0	2.0	1.5	0.6	0.3	5.0

3.4.4 Surge Withstand Capability

The interconnection system shall have the capability to withstand voltage and current surges in accordance with the environments defined in IEEE Std C62.41.2-2002 or IEEE Std C37.90.1-2002 as applicable.

3.5 Power Factor

The generating facility shall not adversely impact the power factor at the Point of Interconnection. Generating facilities shall operate at a power factor minimum 0.9 (lagging).

3.6 Safety, Isolation and Switching

The generating facility shall not energize MEC when MEC is de-energized.

3.6.1 Isolation Device

The generating facility shall have a manual isolation device that has a visible break to isolate their generating facility from MEC distribution system. The isolation device shall either be a disconnect switch or a breaker with rack-out capability. The device must be accessible to MEC personnel and be capable of being locked by utility personnel in the open position. For generating facilities that do not have a circuit breaker or interrupting device, the isolation device must be capable of interrupting load.

[92] I = the greater of the Local EPS maximum load current integrated demand (15 or 30 minutes) without the DR unit, or the DR unit rated current capacity (transformed to the PCC when a transformer exists between the DR unit and the PCC).

[93] Even harmonics are limited to 25% of the odd harmonic limits above.

3.6.2 Disconnection of Generating Facility for MEC Reasons and Safety

Upon providing prior notice, MEC may require the generating facility to temporarily disconnect from MEC's system when necessary for MEC to construct, install, maintain, repair, replace, remove, investigate, test, or inspect any of its equipment or other MEC customer's equipment, or any part of its system. The generating facility shall not energize a de-energized MEC line under any circumstances, but may operate isolated from MEC system with an open tie point in accordance with Section 3.6.3.

MEC may disconnect the generating facility from MEC's system, without prior notice to the customer: (a) to eliminate conditions that constitute a potential hazard to MEC's personnel or the general public; (b) if pre-emergency7 or emergency conditions5 exist on MEC system; (c) if a hazardous condition relating to the generating facility is observed by MEC's inspection; (d) if the generating facility interferes with MEC's equipment or equipment belonging to other utility customers (including non-MEC generating equipment); or (e) if the customer or a party with whom the customer has contracted for ownership and/or operation of the generating facility has tampered with any protective device. The generating facility shall remain disconnected until such time as MEC is satisfied that the endangering condition(s) has been corrected, and the utility shall not be obligated to allow parallel operation of the generating facility during such period.

3.6.3 Inadvertent Energization, Operation During Utility System Outage

The generating facility shall not energize a de-energized MEC circuit for any reason. The generating facility may be operated isolated from MEC system during a MEC outage or system emergency only with an open tie breaker or disconnect device which isolates the generating facility from MEC system. This shall generally be done through automatic isolation device in addition to that required under Section 3.6.1. Where operator of generating facility desire the ability to manually or automatically isolate their generating facility from MEC system by themselves, MEC will consider alternative designs proposed by the generating facility that will prevent inadvertent energization of a de-energized MEC circuit.

3.6.4 Protection from electromagnetic interference

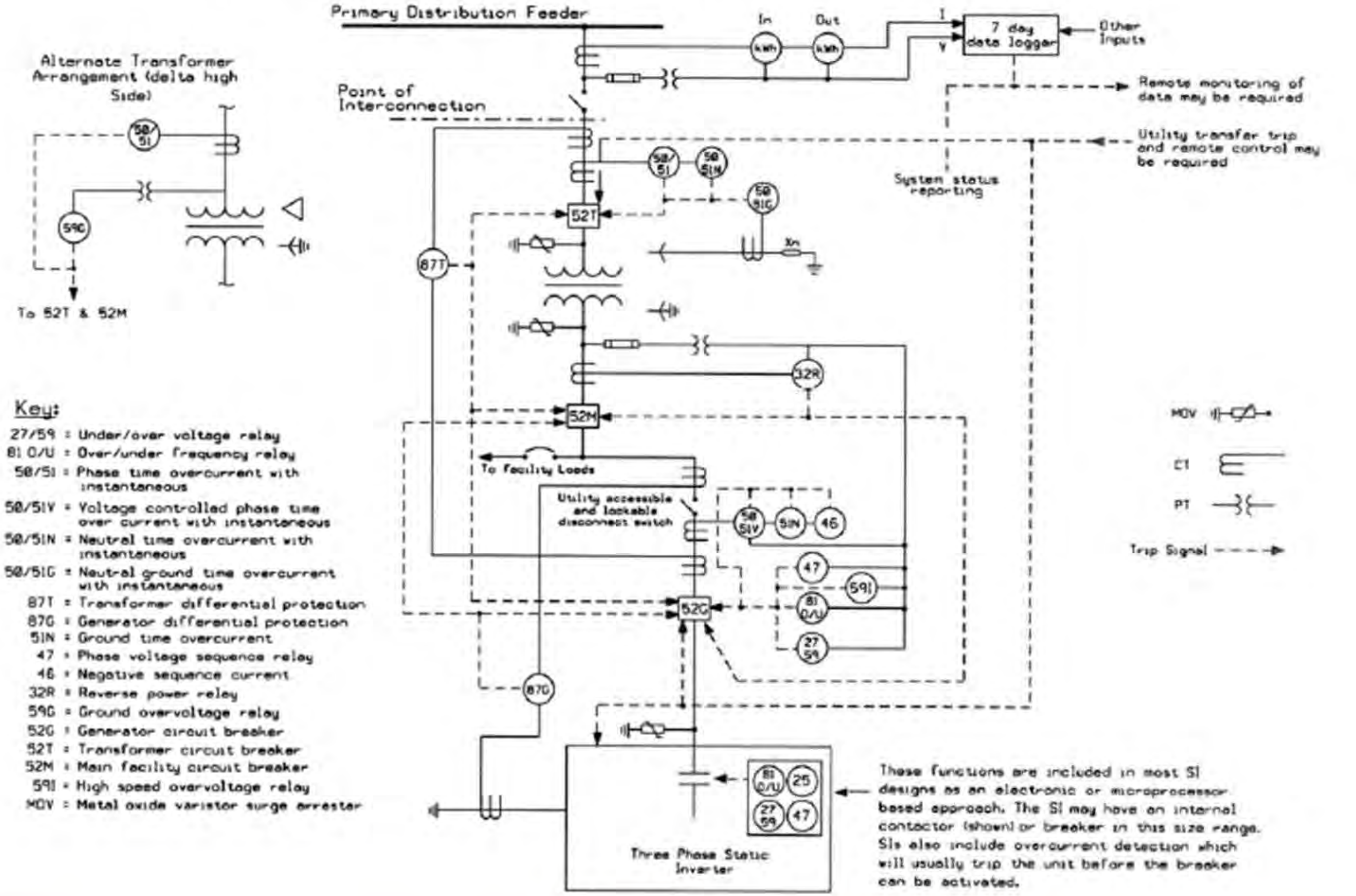
The influence of electromagnetic interference (EMI) shall not result in a change in state or misoperation of the generating facility interconnection system.

4 ANNEX

4.1 ANNEX 1 – Figure 1 – Typical Requirement and Protective Device Requirements for Large Inverter Generators (Non-Export)

Large Static Inverter (Non-export)

Typical Equipment and Protective Device Requirements



3.1.4.2 Remarks on reviewing process of grid connection application

It is necessary to review and evaluate application's compliance with grid code. The followings are major technical check points to be investigated in this process.

(1) Reverse power flow protection for residential sector

The followings shall be satisfied.

- Reverse power flow relay (32R) shall be equipped, or
- Inverter with UL1741 certificates shall be used, or
- Appropriate anti-islanding protection function (active and/or passive type) shall be equipped.

(2) Anti-islanding protection for commercial and governmental sector

The followings shall be satisfied.

- Inverter with UL1741 certificates shall be used, or
- Appropriate anti-islanding protection function (active and/or passive type) shall be equipped.

(3) Protection relay coordination

Relay coordination should be made with protection system of MEC's grid. Major checkpoints are summarized in the following table.

Table 3.1.4-1 Relay protection coordination

PV site	MEC's VCB or SS
OCR-H (51)	OCR (50/51)
OVGR (59G)	DGR (67G)
UVR (27)	OCR (50/51)

Current setting parameters of OCR in MEC's grid are shown in Figure 3.1.4-1, for the reference. Red three parameters in this figure are Long Delay Pickup, Short Delay Pickup and Instantaneous from top to bottom.

Setting parameters of existing PV system at Hospital and CMI are shown in Table 3.1.4-2 and 3.1.4-3 (as of August, 2014). There are some differences in frequency fluctuation. It's highly recommended to change these parameters in accordance with the initial grid code shown above.

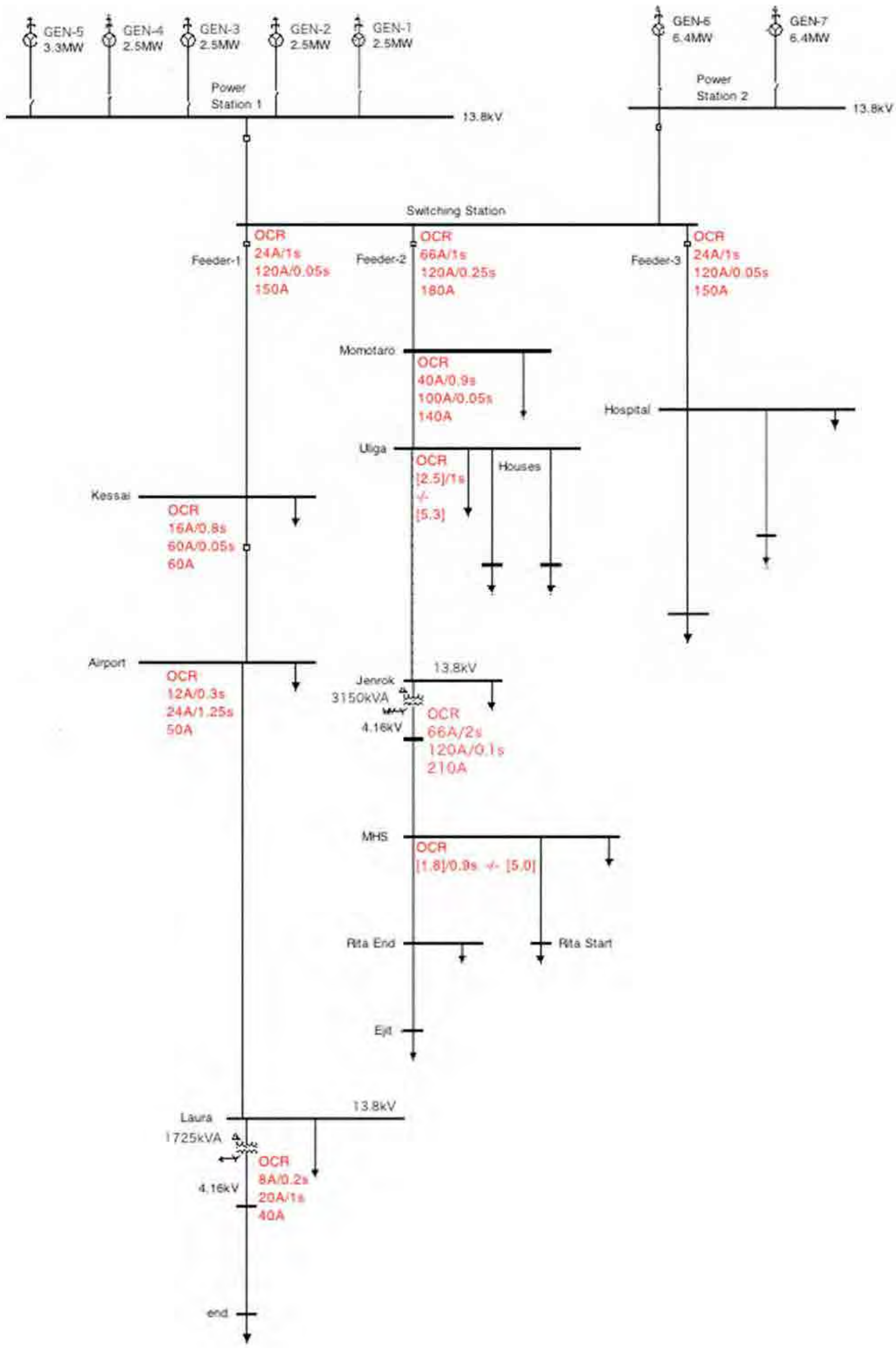


Figure 3.1.4-1 OCR parameters in MEC grid

Table 3.1.4-2 Voltage fluctuation parameters of existing PV system

IEEE1547 (HECO)	Hospital	CMI	
Voltage (% of base voltage) Clearing Time (s)	209kW	Old 57kW	New 54kW
V < 50% 0.16 sec		V < 50% Max 0.1602 sec	V < 50% Max 0.1602 sec
50% ≦ V < 88% 2.00 sec	V < 89% 1.00 sec	50% ≦ V < 88% Max 2.002 sec	50% ≦ V < 88% Max 2.002 sec
110% ≦ V < 120% 1.00 sec	109% ≦ V 1.00 sec	110% ≦ V < 120% Max 1.001 sec	110% ≦ V < 120% Max 1.001 sec
120% ≦ V 0.16 sec		120% ≦ V Max 0.1602 sec	120% ≦ V Max 0.1602 sec

Note) Hospital is connected with high voltage line. OCR parameters at 13.8kV line are as follows;

Time delayed: 4.0A, time multiplier is 2.0.

Instantaneous: 50A

Table 3.1.4-3 Frequency fluctuation parameters of existing PV system

	IEEE1547 (HECO)	Hospital	CMI	
	Frequency range (Hz) Clearing Time (s)	209kW	Old 57kW	New 54kW
≦ 30kW	> 60.5 Hz 0.16 sec	-	-	-
	< 59.3 Hz 0.16 sec	-	-	-
> 30kW	> 60.5 Hz 0.16 sec	> 60.6 Hz 1.00 sec	> 64.5Hz 0.16 sec	> 60.49 Hz 0.16 sec
	< {59.8 – 57.0} (adjustable set point) Adjustable 0.16 to 300 sec	< 59.4 Hz 1.00 sec	< 57 Hz 0.16 sec	< 59.31 Hz 0.16 sec
	< 57.0 Hz 0.16 sec	-	-	-

(4) Short circuit capacity

In IEEE1547, Short Circuit Contribution Ratio (SCCR) is used in checking short circuit capacity. SCCR is a ratio of contribution ratio of generator and one of grid at high voltage side of distribution transformer, which is connected to grid connection point, in three-phase short circuit fault.

$SCCR = SC_{DR} / SC_{AreaEPS}$

where,

- $SC_{AreaEPS}$ = Contribution ratio of related grid (including all other generators) in short circuit fault (kVA)
- SC_{DR}= Contribution ratio of the generator under investigation, in short circuit fault (kVA)

Aggregated SCCR should be less than 10%. And also, comparison between short circuit current of the generator and capacity of the disconnecting device is necessary for secured disconnection in faults.

(5) Voltage fluctuation at distribution line

In the case of reverse power flow, its influence should be checked. Even in the case of no reverse flow, voltage fluctuation at sudden and many PV disconnection is possible, and such a influence should be checked also. For some situations, voltage compensator such as capacitor may be required.

(6) Over load of upstream side of distribution line by reverse flow

Checking should be made in the most severe case, to avoid over load in distribution system.

(7) Communication with PV system installers

Especially with commercial and governmental installers, who may have large scale PV system, MEC shall have secured communication way to responsible persons of installers.

3.1.4.3 Other necessary tasks to establish and enforce grid code

To establish grid connection scheme, application form sheet, standard contract, in-house manual and other related documents should be prepared. In developing these materials, those attached with HECO Rule 14 serve as useful references.

And to understand effects of PV installation quantitatively, MEC should keep daily load curves of customer and distribution line. Weekday and holiday daily load curves are kept and updated in MEC for typical commercial and governmental customer, who are possible PV system installer, typical residential customers and low voltage distribution lines.

3.1.5 Assistance in establishing RE development financial scheme

3.1.5.1 Introduction

FIT is abbreviation of Feed-in Tariff, and has precisely the following two systems, depending on treatment of self-consumption of generated power. However FIT is used as full amount purchase system, frequently.

① Full amount purchase system: Whole generated power is once purchased by utility, and customer purchase power from grid separately. This is widely applied in Germany and so on.

② Surplus electricity purchase system: Only surplus power, which is remaining balance of generated power after deduction of in-house consumption, is purchased by utility. Therefore consumed energy at the site has same value as grid energy.

In the case of lower purchase price than electricity tariff, an installer gets benefit by self-consumption of generated power, and then it is had to establish full amount purchase system. In many developed countries, FIT price is higher than tariff and this promotes IPP without regard to its size. However in small island countries, which has higher tariff, much more higher FIT price invites cash-laden investors (in many case foreign capitals), who aim to get higher return in investment. If a country has large population and larger grid, it may be reasonable to accept such an (foreign) IPP to accelerate RE penetration. However in the case of small island countries such as RMI with smaller grid, electricity tariff is high, and even lower FIT price than tariff may be able to provide good investment chance in PV installation. If higher FIT price rather than tariff is provided, it may be leak of national wealth and cause a problem in fairness.

Actually, new PV system at CMI costs approx. 200 thousand USD for installation, and even with 40c/kWh purchased price, which is lower 10c than tariff, it is possible to recoup the investment in 12 years[94]. Its IRR is 10.25%, and ROI is 16.1% in 20 years. If installer can have higher FIT than tariff, it can be very profitable investment. If not, it is clear for the investor to have larger benefit by consuming generated power in-house.

Therefore in RMI, it is not feasible to have full amount purchase system with higher FIT price than tariff, and then surplus purchase system with lower price than tariff can be a realistic system. Really it is reported that Fiji and Cook Islands have lower purchasing price than tariff.

One more option of incentives to promote RE in private sector is, however precisely it is not FIT, to pay for all the generated power by PV with or without reverse flow. This price becomes lower than one for surplus power. Since it can provide a support to installers without surplus power, it is investigated as an alternative in this project.

3.1.5.2 FIT simulator

To make understanding of FIT deeper, FIT simulator was developed and provided to RMI. With this simulator, a user can evaluate the influence on both investor’s (PV installer’s) payback schedule and MEC’s financial status, by changing various input parameters such as amount of initial investment, tariff and FIT price/period, and then can investigate/design better FIT scheme.

In the following sections, FIT simulator is shown by an example with micro finance scheme by Taiwan loan (now under preparation) for small residential PV system. In this example, support scheme pays for all the generated power.

(1) Overall view of FIT simulator

Overall view of FIT simulator is shown in Figure 3.1.5-1. Upper left part is input parameter, green cells in lower left is simulator output such as IRR and NPV, upper right is investor’s payback schedule and lower right is MEC’s balance. Green cells are important output from the simulator. Each part is explained in detail below.

[94] Discount rate is assumed as 6%.

Solar Worksheet	Idea 2 for Micro-finance FIT for generated power	
COSTS		
System Size (kW)	1.5	
Installed Cost/Watt	$4.00	
System Installed Cost		$6,000.00
ADJUSTMENTS (Optional)		
State Rebate/W	$0.00	
Maximum State Rebate	$10,000.00	
State Rebate Total		$0.00
Total Install less rebates		$6,000.00
Governmental ITC Rate	0.00%	
Maximum Governmental ITC	$250,000.00	
Governmental ITC Total		$0.00
RATES		
Discount Rate	6.00%	
Base Energy Rate $/kWh (FIT)	$0.12	for generation
Annual Energy Rate escalation	0.00%	
FIT Term (year)	5	
MEC tariff Base $/kWh	$0.43	
MEC tariff Escalator	0.00%	
MEC fuel Cost $/kWh	$0.296	
MEC other cost $/kWh	$0.167	
Capacity Factor (CF)		
Base Capacity Factor	16.00%	
Annual Degradation	0.80%	
Ratio of sold energy to MEC (Surplus)	0.00%	
Financing		
Percent Equity Before ITC	20.00%	
Loan Amount	$4,800.00	
APR (Annual Percentage Rate)	4.00%	
Term (years)	5	
O&M		
Annual Cost (per kW)	$25.00	
Inverter replacement at 10 years (per watt)	$0.50	
IRR&ROI		
Internal Rate of Return (End of FIT)	-56.99%	
Internal Rate of Return (10)	15.96%	
Internal Rate of Return (20)	22.68%	
ROI	96.36%	
Net Installed Cost	$1,200.00	
Total with NPV O&M	$372.02	

CUSTOMER PAYBACK SCHEDULE										FINANCING			
YEAR	FIT Energy Rate	MEC Energy Rate	Generated Energy kWh	Sold Energy to MEC kWh	In-house Consumption kWh	FIT income	Consumed Energy Value	State Rebate + ENERGY VALUE	Capital + O&M Cost	Annual Payment	Annual Net	Annual ROI	NPV
0				0%	100%				-$1,200.00		-$1,200.00		
1	$0.120	$0.430	2,102.40	0.00	2,102.40	$252.29	$904.03	$1,156.32	-$37.50	-$1,078.21	$40.61	3.4%	-$1,095.90
2	$0.120	$0.430	2,085.58	0.00	2,085.58	$250.27	$896.80	$1,147.07	-$37.50	-$1,078.21	$31.36	2.6%	-$1,069.60
3	$0.120	$0.430	2,068.90	0.00	2,068.90	$248.27	$889.63	$1,137.89	-$37.50	-$1,078.21	$22.18	1.8%	-$1,052.55
4	$0.120	$0.430	2,052.34	0.00	2,052.34	$246.28	$882.51	$1,128.79	-$37.50	-$1,078.21	$13.06	1.1%	-$1,042.26
5	$0.120	$0.430	2,035.93	0.00	2,035.93	$244.31	$875.45	$1,119.76	-$37.50	-$1,078.21	$4.05	0.3%	-$1,039.40
6	$0.000	$0.430	2,019.64	0.00	2,019.64	$0.00	$868.44	$868.44	-$37.50	$0.00	$830.94	69.2%	-$486.78
7	$0.000	$0.430	2,003.48	0.00	2,003.48	$0.00	$861.50	$861.50	-$37.50	$0.00	$824.00	68.7%	$30.21
8	$0.000	$0.430	1,987.45	0.00	1,987.45	$0.00	$854.61	$854.61	-$37.50	$0.00	$817.11	68.1%	$513.85
9	$0.000	$0.430	1,971.55	0.00	1,971.55	$0.00	$847.77	$847.77	-$37.50	$0.00	$810.27	67.5%	$966.30
10	$0.000	$0.430	1,955.78	0.00	1,955.78	$0.00	$840.99	$840.99	-$750.00	$0.00	$90.99	7.6%	$1,014.23
11	$0.000	$0.430	1,940.14	0.00	1,940.14	$0.00	$834.26	$834.26	-$37.50	$0.00	$796.76	66.4%	$1,410.20
12	$0.000	$0.430	1,924.61	0.00	1,924.61	$0.00	$827.58	$827.58	-$37.50	$0.00	$790.08	65.8%	$1,780.62
13	$0.000	$0.430	1,909.22	0.00	1,909.22	$0.00	$820.96	$820.96	-$37.50	$0.00	$783.46	65.3%	$2,127.14
14	$0.000	$0.430	1,893.94	0.00	1,893.94	$0.00	$814.40	$814.40	-$37.50	$0.00	$776.90	64.7%	$2,451.32
15	$0.000	$0.430	1,878.79	0.00	1,878.79	$0.00	$807.88	$807.88	-$37.50	$0.00	$770.38	64.2%	$2,754.57
16	$0.000	$0.430	1,863.76	0.00	1,863.76	$0.00	$801.42	$801.42	-$37.50	$0.00	$763.92	63.7%	$3,038.27
17	$0.000	$0.430	1,848.85	0.00	1,848.85	$0.00	$795.01	$795.01	-$37.50	$0.00	$757.51	63.1%	$3,303.65
18	$0.000	$0.430	1,834.06	0.00	1,834.06	$0.00	$788.65	$788.65	-$37.50	$0.00	$751.15	62.6%	$3,551.92
19	$0.000	$0.430	1,819.39	0.00	1,819.39	$0.00	$782.34	$782.34	-$37.50	$0.00	$744.84	62.1%	$3,784.16
20	$0.000	$0.430	1,804.83	0.00	1,804.83	$0.00	$776.08	$776.08	-$37.50	$0.00	$738.58	61.5%	$4,001.42
TOTAL			39,000.66	0.00	39,000.66	$1,241.42	$16,770.28	$18,011.70	-$2,662.50	-$5,391.05	$9,958.15		
NPV								$10,811.29	-$1,913.19		$4,001.42		
								Total O&M	-$1,482.50				
								O&M NPV	-$827.98				

MEC BALANCE										
YEAR	FIT Energy Rate	MEC Energy Rate	Generated kWh	MEC Purchas Energy kWh	MEC Reduced Fuel Cost	MEC Income by re-selling to Others	MEC FIT Cost	MEC Other Cost	MEC Balance	MEC Total Balance
0				0.00%						
1	$0.120	$0.430	2,102.40	0.00	$622.31	$0.00	-$252.29	-$351.10	$18.92	$18.92
2	$0.120	$0.430	2,085.58	0.00	$617.33	$0.00	-$250.27	-$348.29	$18.77	$37.69
3	$0.120	$0.430	2,068.90	0.00	$612.39	$0.00	-$248.27	-$345.51	$18.62	$56.31
4	$0.120	$0.430	2,052.34	0.00	$607.49	$0.00	-$246.28	-$342.74	$18.47	$74.78
5	$0.120	$0.430	2,035.93	0.00	$602.63	$0.00	-$244.31	-$340.00	$18.32	$93.11
6	$0.000	$0.430	2,019.64	0.00	$597.81	$0.00	$0.00	-$337.28	$260.53	$353.64
7	$0.000	$0.430	2,003.48	0.00	$593.03	$0.00	$0.00	-$334.58	$258.45	$612.09
8	$0.000	$0.430	1,987.45	0.00	$588.29	$0.00	$0.00	-$331.90	$256.38	$868.47
9	$0.000	$0.430	1,971.55	0.00	$583.58	$0.00	$0.00	-$329.25	$254.33	$1,122.80
10	$0.000	$0.430	1,955.78	0.00	$578.91	$0.00	$0.00	-$326.62	$252.30	$1,375.10
11	$0.000	$0.430	1,940.14	0.00	$574.28	$0.00	$0.00	-$324.00	$250.28	$1,625.37
12	$0.000	$0.430	1,924.61	0.00	$569.69	$0.00	$0.00	-$321.41	$248.28	$1,873.65
13	$0.000	$0.430	1,909.22	0.00	$565.13	$0.00	$0.00	-$318.84	$246.29	$2,119.94
14	$0.000	$0.430	1,893.94	0.00	$560.61	$0.00	$0.00	-$316.29	$244.32	$2,364.26
15	$0.000	$0.430	1,878.79	0.00	$556.12	$0.00	$0.00	-$313.76	$242.36	$2,606.62
16	$0.000	$0.430	1,863.76	0.00	$551.67	$0.00	$0.00	-$311.25	$240.43	$2,847.05
17	$0.000	$0.430	1,848.85	0.00	$547.26	$0.00	$0.00	-$308.76	$238.50	$3,085.55
18	$0.000	$0.430	1,834.06	0.00	$542.88	$0.00	$0.00	-$306.29	$236.59	$3,322.14
19	$0.000	$0.430	1,819.39	0.00	$538.54	$0.00	$0.00	-$303.84	$234.70	$3,556.84
20	$0.000	$0.430	1,804.83	0.00	$534.23	$0.00	$0.00	-$301.41	$232.82	$3,789.67
TOTAL			39,000.66	0.00	11,544.19	0.00	-$1,241.42	-$6,513.11	$3,789.67	$3,789.67

Figure 3.1.5-1 Overall view of FIT simulator

(2) Input and output part

For a simulation, user specifies/changes input parameter value, which is yellow cell in Table 3.1.5-1. From top, there are PV capacity (in the figure, 1.5kW [the same hereinafter]), cost per kW (4$/kW), subsidy (0 $), discount rate (6%), FIT price (12c/kWh) and period (5 years), tariff (43c/kWh), MEC's fuel cost (29.6c/kWh), other cost (16.7c/kWh), CF[95] (16%), loan (4,800$, 5 years, 4%), annual O&M cost (25$), and inverter replacement cost at 10 years later (0.5$/kW).

In this example, the installer gets 4,800 USD loan from micro finance under Taiwan loan, and installs 1.5kW PV for residential house. Then with 12c/kWh and 5 years FIT, it is shown what does happen in investor side and MEC. User can evaluate schemes by changing FIT parameters.

Investor's IRR and ROI are shown in lower part of this table.

[95] Capacity Factor

Table 3.1.5-1 Input and output section of FIT simulator

Solar Worksheet	Idea 2 for Micro-finance	
	FIT for generated power	
COSTS		
System Size (kW)	1.5	
Installed Cost/Watt	$4.00	
System Installed Cost		$6,000.00
ADJUSTMENTS (Optional)		
State Rebate/W	$0.00	
Maximum State Rebate	$10,000.00	
State Rebate Total		$0.00
Total Install less rebates		$6,000.00
Governmental ITC Rate	0.00%	
Maximum Governmental ITC	$250,000.00	
Governmental ITC Total		$0.00
RATES		
Discount Rate	6.00%	
Base Energy Rate $/kWh (FIT)	$0.12	for generation
Annual Energy Rate escalation	0.00%	
FIT Term (year)	5	
MEC tariff Base $/kWh	$0.43	
MEC tariff Escalator	0.00%	
MEC fuel Cost $/kWh	$0.296	
MEC other cost $/kWh	$0.167	
Capacity Factor (CF)		
Base Capacity Factor	16.00%	
Annual Degradation	0.80%	
Ratio of sold energy to MEC (Surplus)	0.00%	
Financing		
Percent Equity Before ITC	20.00%	
Loan Amount	$4,800.00	
APR (Annual Percentage Rate)	4.00%	
Term (years)	5	
O&M		
Annual Cost (per kW)	$25.00	
Inverter replacement at 10 years (per watt)	$0.50	
IRR&ROI		
Internal Rate of Return (End of FIT)	-56.99%	
Internal Rate of Return (10)	15.96%	
Internal Rate of Return (20)	22.68%	
ROI	96.36%	
Net Installed Cost	$1,200.00	
Total with NPV O&M	$372.02	

(3) Investor’s payback schedule

Table 3.1.5-2 shows investor’s payback schedule. Its gain comes from no more purchase of grid power and FIT scheme. But the loss is O&M cost and repayment of debt. The condition of this loan, 5 years and 4%, is assumed in the micro finance under Taiwan loan. Annual balance is positive but in the first 5 years profit is made by FIT scheme. And if no FIT, it comes out negative. NPV turns to positive 7 years later.

(4) MEC’s balance

Table 3.1.5-3 shows MEC’s balance. MEC does not have income because the installer can get power from PV, but it has a benefit from decreased fuel consumption. It is assumed that other cost (cost of power, administration and general cost, distribution operations cost and depreciation and amortization) does not change with or without PV. In the first 5 years, MEC has to bear FIT cost, but it is smaller than reduced fuel cost, and then its balance comes to positive.

As shown above, user can design basic FIT scheme easily, by evaluating outputs that are changing with input parameter (FIT price and term, tariff, loan interest). In this example, payment is made for generated power. Also user can simulate surplus electricity purchase system easily.

All FIT-WG members used this simulator on their own PC, designed FIT, shared knowledge among WG members, made Q&A and then deepen their understanding.

Table 3.1.5-2 Investor's payback schedule section of FIT simulator

CUSTOMER PAYBACK SCHEDULE										FINANCING			
YEAR	FIT Energy Rate	MEC Energy Rate	Generated Energy kWh	Sold Energy to MEC kWh	In-house Consumption kWh	FIT income	Consumed Energy Value	State Rebate + ENERGY VALUE	Capital + O&M Cost	Annual Payment	Annual Net	Annual ROI	NPV
0				0%	100%				-$1,200.00		-$1,200.00		
1	$0.120	$0.430	2,102.40	0.00	2,102.40	$252.29	$904.03	$1,156.32	-$37.50	-$1,078.21	$40.61	3.4%	-$1,095.93
2	$0.120	$0.430	2,085.58	0.00	2,085.58	$250.27	$896.80	$1,147.07	-$37.50	-$1,078.21	$31.36	2.6%	-$1,069.60
3	$0.120	$0.430	2,068.90	0.00	2,068.90	$248.27	$889.63	$1,137.89	-$37.50	-$1,078.21	$22.18	1.8%	-$1,052.03
4	$0.120	$0.430	2,052.34	0.00	2,052.34	$246.28	$882.51	$1,128.79	-$37.50	-$1,078.21	$13.08	1.1%	-$1,042.26
5	$0.120	$0.430	2,035.93	0.00	2,035.93	$244.31	$875.45	$1,119.76	-$37.50	-$1,078.21	$4.05	0.3%	-$1,039.40
6	$0.000	$0.430	2,019.64	0.00	2,019.64	$0.00	$868.44	$868.44	-$37.50	$0.00	$830.94	69.2%	-$486.78
7	$0.000	$0.430	2,003.48	0.00	2,003.48	$0.00	$861.50	$861.50	-$37.50	$0.00	$824.00	68.7%	$30.21
8	$0.000	$0.430	1,987.45	0.00	1,987.45	$0.00	$854.61	$854.61	-$37.50	$0.00	$817.11	68.1%	$513.85
9	$0.000	$0.430	1,971.55	0.00	1,971.55	$0.00	$847.77	$847.77	-$37.50	$0.00	$810.27	67.5%	$966.30
10	$0.000	$0.430	1,955.78	0.00	1,955.78	$0.00	$840.99	$840.99	-$750.00	$0.00	$90.99	7.6%	$1,014.23
11	$0.000	$0.430	1,940.14	0.00	1,940.14	$0.00	$834.26	$834.26	-$37.50	$0.00	$796.76	66.4%	$1,410.20
12	$0.000	$0.430	1,924.61	0.00	1,924.61	$0.00	$827.58	$827.58	-$37.50	$0.00	$790.08	65.8%	$1,780.62
13	$0.000	$0.430	1,909.22	0.00	1,909.22	$0.00	$820.96	$820.96	-$37.50	$0.00	$783.46	65.3%	$2,127.14
14	$0.000	$0.430	1,893.94	0.00	1,893.94	$0.00	$814.40	$814.40	-$37.50	$0.00	$776.90	64.7%	$2,451.32
15	$0.000	$0.430	1,878.79	0.00	1,878.79	$0.00	$807.88	$807.88	-$37.50	$0.00	$770.38	64.2%	$2,754.57
16	$0.000	$0.430	1,863.76	0.00	1,863.76	$0.00	$801.42	$801.42	-$37.50	$0.00	$763.92	63.7%	$3,038.27
17	$0.000	$0.430	1,848.85	0.00	1,848.85	$0.00	$795.01	$795.01	-$37.50	$0.00	$757.51	63.1%	$3,303.65
18	$0.000	$0.430	1,834.06	0.00	1,834.06	$0.00	$788.65	$788.65	-$37.50	$0.00	$751.15	62.6%	$3,551.92
19	$0.000	$0.430	1,819.39	0.00	1,819.39	$0.00	$782.34	$782.34	-$37.50	$0.00	$744.84	62.1%	$3,784.16
20	$0.000	$0.430	1,804.83	0.00	1,804.83	$0.00	$776.08	$776.08	-$37.50	$0.00	$738.58	61.5%	$4,001.42
TOTAL			39,000.66	0.00	39,000.66	$1,241.42	$16,770.28	$18,011.70	-$2,662.50	-$5,391.05	$9,958.15		
NPV								$10,811.29	-$1,913.19		$4,001.42		
								Total O&M	-$1,462.50				
								O&M NPV	-$827.98				

Table 3.1.5-3 MEC's balance section of FIT simulator (1)

MEC BALANCE										
YEAR	FIT Energy Rate	MEC Energy Rate	Generated kWh	MEC Purchas Energy kWh	MEC Reduced Fuel Cost	MEC Income by re-selling to Others	MEC FIT Cost	MEC Other Cost	MEC Balance	MEC Total Balance
0				0.00%						
1	$0.120	$0.430	2,102.40	0.00	$622.31	$0.00	-$252.29	-$351.10	$18.92	$18.92
2	$0.120	$0.430	2,085.58	0.00	$617.33	$0.00	-$250.27	-$348.29	$18.77	$37.69
3	$0.120	$0.430	2,068.90	0.00	$612.39	$0.00	-$248.27	-$345.51	$18.62	$56.31
4	$0.120	$0.430	2,052.34	0.00	$607.49	$0.00	-$246.28	-$342.74	$18.47	$74.78
5	$0.120	$0.430	2,035.93	0.00	$602.63	$0.00	-$244.31	-$340.00	$18.32	$93.11
6	$0.000	$0.430	2,019.64	0.00	$597.81	$0.00	$0.00	-$337.28	$260.53	$353.64
7	$0.000	$0.430	2,003.48	0.00	$593.03	$0.00	$0.00	-$334.58	$258.45	$612.09
8	$0.000	$0.430	1,987.45	0.00	$588.29	$0.00	$0.00	-$331.90	$256.38	$868.47
9	$0.000	$0.430	1,971.55	0.00	$583.58	$0.00	$0.00	-$329.25	$254.33	$1,122.80
10	$0.000	$0.430	1,955.78	0.00	$578.91	$0.00	$0.00	-$326.62	$252.30	$1,375.10
11	$0.000	$0.430	1,940.14	0.00	$574.28	$0.00	$0.00	-$324.00	$250.28	$1,625.37
12	$0.000	$0.430	1,924.61	0.00	$569.69	$0.00	$0.00	-$321.41	$248.28	$1,873.65
13	$0.000	$0.430	1,909.22	0.00	$565.13	$0.00	$0.00	-$318.84	$246.29	$2,119.94
14	$0.000	$0.430	1,893.94	0.00	$560.61	$0.00	$0.00	-$316.29	$244.32	$2,364.26
15	$0.000	$0.430	1,878.79	0.00	$556.12	$0.00	$0.00	-$313.76	$242.36	$2,606.62
16	$0.000	$0.430	1,863.76	0.00	$551.67	$0.00	$0.00	-$311.25	$240.43	$2,847.05
17	$0.000	$0.430	1,848.85	0.00	$547.26	$0.00	$0.00	-$308.76	$238.50	$3,085.55
18	$0.000	$0.430	1,834.06	0.00	$542.88	$0.00	$0.00	-$306.29	$236.59	$3,322.14
19	$0.000	$0.430	1,819.39	0.00	$538.54	$0.00	$0.00	-$303.84	$234.70	$3,556.84
20	$0.000	$0.430	1,804.83	0.00	$534.23	$0.00	$0.00	-$301.41	$232.82	$3,789.67
TOTAL			39,000.66	0.00	11,544.19	0.00	-$1,241.42	-$6,513.11	$3,789.67	$3,789.67

3.1.5.3 Decreased fuel cost

There is a controversial issue in Table 3.1.5-1～3. That is the treatment of reduced fuel cost. From the simple view point of MEC's income and cost, after PV installation, MEC has no income but remaining other cost and FIT cost. To check this point, Table 3.1.5-4 (before PV installation) and Table 3.1.5-5 (after PV installation), MEC's balance (2), are prepared. Please note that discussion is made without FIT, to make it simple.

Table 3.1.5-4 MEC balance of FIT simulator (2) [before PV installation]

MEC BALANCE (before PV)						MEC BALANCE (before PV)			
YEAR	FIT Energy Rate	MEC Energy Rate	MEC Sold Energy kWh	MEC Income	MEC Fuel Cost	MEC FIT Cost	MEC Other Cost	MEC Profit/Loss	MEC Total Balance
0									
1		$0.430	2,102.40	$904.03	-$622.31		-$351.10	-$69.38	-$69.38
2		$0.430	2,085.58	$896.80	-$617.33		-$348.29	-$68.82	-$138.20
3		$0.430	2,068.90	$889.63	-$612.39		-$345.51	-$68.27	-$206.48
4		$0.430	2,052.34	$882.51	-$607.49		-$342.74	-$67.73	-$274.20
5		$0.430	2,035.93	$875.45	-$602.63		-$340.00	-$67.19	-$341.39
6		$0.430	2,019.64	$868.44	-$597.81		-$337.28	-$66.65	-$408.04
7		$0.430	2,003.48	$861.50	-$593.03		-$334.58	-$66.11	-$474.15
8		$0.430	1,987.45	$854.61	-$588.29		-$331.90	-$65.59	-$539.74
9		$0.430	1,971.55	$847.77	-$583.58		-$329.25	-$65.06	-$604.80
10		$0.430	1,955.78	$840.99	-$578.91		-$326.62	-$64.54	-$669.34
11		$0.430	1,940.14	$834.26	-$574.28		-$324.00	-$64.02	-$733.37
12		$0.430	1,924.61	$827.58	-$569.69		-$321.41	-$63.51	-$796.88
13		$0.430	1,909.22	$820.96	-$565.13		-$318.84	-$63.00	-$859.88
14		$0.430	1,893.94	$814.40	-$560.61		-$316.29	-$62.50	-$922.38
15		$0.430	1,878.79	$807.88	-$556.12		-$313.76	-$62.00	-$984.38
16		$0.430	1,863.76	$801.42	-$551.67		-$311.25	-$61.50	-$1,045.89
17		$0.430	1,848.85	$795.01	-$547.26		-$308.76	-$61.01	-$1,106.90
18		$0.430	1,834.06	$788.65	-$542.88		-$306.29	-$60.52	-$1,167.42
19		$0.430	1,819.39	$782.34	-$538.54		-$303.84	-$60.04	-$1,227.46
20		$0.430	1,804.83	$776.08	-$534.23		-$301.41	-$59.56	-$1,287.02
TOTAL			39,000.66	16,770.28	-$11,544.19	$0.00	-$6,513.11	-$1,287.02	-$1,287.02

Table 3.1.5-5 MEC balance of FIT simulator (2) [after PV installation]

MEC BALANCE (after PV)						MEC BALANCE (after PV)			
YEAR	FIT Energy Rate	MEC Energy Rate	Generated kWh	MEC Income	MEC Fuel Cost	MEC FIT Cost	MEC Other Cost	MEC Profit/Loss	MEC Total Balance
0									
1	$0.000	$0.430	2,102.40	$0.00	$0.00	$0.00	-$351.10	-$351.10	-$351.10
2	$0.000	$0.430	2,085.58	$0.00	$0.00	$0.00	-$348.29	-$348.29	-$699.39
3	$0.000	$0.430	2,068.90	$0.00	$0.00	$0.00	-$345.51	-$345.51	-$1,044.90
4	$0.000	$0.430	2,052.34	$0.00	$0.00	$0.00	-$342.74	-$342.74	-$1,387.64
5	$0.000	$0.430	2,035.93	$0.00	$0.00	$0.00	-$340.00	-$340.00	-$1,727.64
6	$0.000	$0.430	2,019.64	$0.00	$0.00	$0.00	-$337.28	-$337.28	-$2,064.92
7	$0.000	$0.430	2,003.48	$0.00	$0.00	$0.00	-$334.58	-$334.58	-$2,399.50
8	$0.000	$0.430	1,987.45	$0.00	$0.00	$0.00	-$331.90	-$331.90	-$2,731.41
9	$0.000	$0.430	1,971.55	$0.00	$0.00	$0.00	-$329.25	-$329.25	-$3,060.66
10	$0.000	$0.430	1,955.78	$0.00	$0.00	$0.00	-$326.62	-$326.62	-$3,387.27
11	$0.000	$0.430	1,940.14	$0.00	$0.00	$0.00	-$324.00	-$324.00	-$3,711.27
12	$0.000	$0.430	1,924.61	$0.00	$0.00	$0.00	-$321.41	-$321.41	-$4,032.68
13	$0.000	$0.430	1,909.22	$0.00	$0.00	$0.00	-$318.84	-$318.84	-$4,351.52
14	$0.000	$0.430	1,893.94	$0.00	$0.00	$0.00	-$316.29	-$316.29	-$4,667.81
15	$0.000	$0.430	1,878.79	$0.00	$0.00	$0.00	-$313.76	-$313.76	-$4,981.57
16	$0.000	$0.430	1,863.76	$0.00	$0.00	$0.00	-$311.25	-$311.25	-$5,292.82
17	$0.000	$0.430	1,848.85	$0.00	$0.00	$0.00	-$308.76	-$308.76	-$5,601.58
18	$0.000	$0.430	1,834.06	$0.00	$0.00	$0.00	-$306.29	-$306.29	-$5,907.86
19	$0.000	$0.430	1,819.39	$0.00	$0.00	$0.00	-$303.84	-$303.84	-$6,211.70
20	$0.000	$0.430	1,804.83	$0.00	$0.00	$0.00	-$301.41	-$301.41	-$6,513.11
TOTAL			39,000.66	0.00	0.00	$0.00	-$6,513.11	-$6,513.11	-$6,513.11

For residential sector, since electricity tariff itself is below cost, MEC has 60-70 USD annual deficits for the demand in discussion, even before 1.5kW PV installation (refer to table 3.1.5-4).

After PV installation, as shown in Table 3.1.5-5, deficit grows to 350～300 USD. The important point is the deficit becomes larger WITHOUT FIT, for other cost reasons.

Figure 3.1.5-2 (Original data is shown in Table 3.1.5-6.) shows MEC's P/L in the case of 500 installations of this 1.5kW PV system. Basic data comes from 2012 financial report (Table 2.5.1-1) and some values are changed based on impact by PV installation. Deficit of MEC grows from 780 to 920 thousand USD.

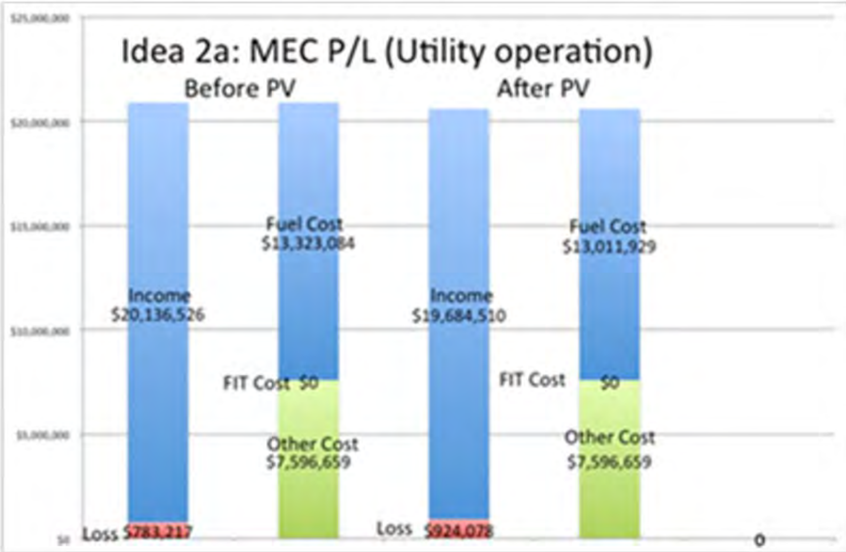


Figure 3.1.5-2 Change of MEC P/L

In the calculation of Table 3.1.5-3, reduced fuel cost is treated as plus explicitly, but in the P/L table in accounting it disappears. Reduced fuel cost affects on capital/asset and/or debt in balance sheet. That is, reduced fuel cost gives slower deceasing speed of cash in hand, or makes no new debt to purchase fuel (refer to Figure 3.1.5-3). However on P/L, MEC has decreased sales and decreased profit, even without FIT, if private PV installations grow.

Generally, progress of private RE penetration under national policy invites reduced fuel cost, but it takes a chance of sales and certain profit out of utility company[96].

Reduced fuel cost is so called “avoidable cost”. Generally “avoidable cost” and surcharge tacked on electricity tariff are applied to FIT resource. This approach is in the right, but we have to acknowledge it may make utility company’s P/L worse.

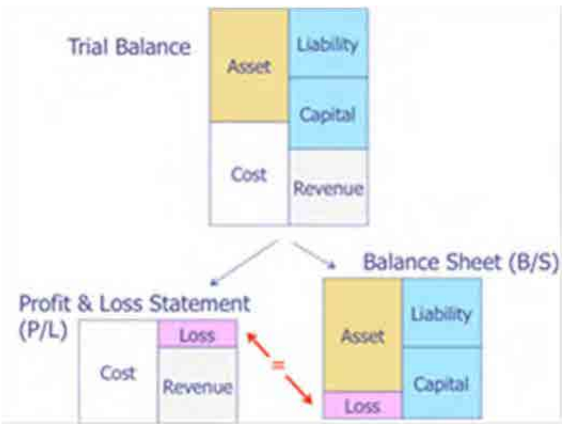


Figure 3.1.5-3 B/S and P/L

[96] Inapplicable to MEC with deficit balance. It will have larger loss.

And furthermore, the definition of "avoidable cost" is very controversial issue. That is, what is "avoidable cost"? Fuel cost is unquestioned. It is a big questioned if we can assume other cost (cost of power, administration and general cost, distribution operations cost and depreciation and amortization) does not change after and before PV installation. If these costs can be smaller after PV installation, it should be "avoidable cost".

Let's assume other cost can be decreased with the ratio in fuel reduction. Then MEC's P/L becomes as shown in Table 3.1.5-6 and Figure 3.1.5-4, and its deficit can get lower even if MEC bears some FIT cost. That is, if MEC accept same deficit as in the previous year, the decline in deficit (approx. 36,600 USD) can be used as FIT resource.

However, to reach this point, we had a few assumptions as follows, and the reality is that it is very hard.

① Other cost can be decreased with the rate of fuel reduction
Other cost is cost of power, administration and general cost, distribution operations cost and depreciation and amortization. Even with PV installation, utility has to supply power in night, cloudy and rainy days, so O&M cost of generators and distribution line does not change so much. Administration and general cost, depreciation and amortization are almost same but to have precise knowledge it is necessary to investigate in more detail[97].

② Small declining in deficit
It is not zero but small, so realistically it is not enough for FIT resource.

③ Priority should place to make deficit small rather than to use for FIT resource.
If MEC's balance can be improved, MEC should make best effort to do so. Even if MEC is national enterprise, deficit is not allowed basically.

Table 3.1.5-6 MEC's P/L after 500 1.5kW PV system installation

	2012 Financial Statement	w/1.5kW * 500 PV Avoidable cost is only fuel	Assuming same rate of reduction for other costs	
Utility operations:		Decreased Sales		
Operating revenues:		-452,016		
Electricity sales	20,794,441	20,342,425	20,342,425	
Other	95,829	95,829	95,829	
	20,890,270	20,438,254	20,438,254	
Less Provision for doubtful accounts	-753,744	-753,744	-753,744	
Total net operating revenues	20,136,526	19,684,510	19,684,510	
Operating expenses:				Cut rate
Cost of fuel	13,323,084	13,011,929	13,011,929	97.7%
Cost of FIT		0	0	
Other cost	7,596,659	7,596,659	7,419,242	
Cost of Power	3,291,979	3,291,979	3,215,096	97.7%
Administrative and general	1,475,185	1,475,185	1,440,733	97.7%
Distribution operations	1,226,284	1,226,284	1,197,645	97.7%
Depreciation and amortization	1,603,211	1,603,211	1,565,769	97.7%
Total operating expenses	20,919,743	20,608,588	20,431,171	
Operation loss from utility operation	-783,217	-924,078	-746,661	

[97] MEC has many possibilities in improving its operational efficiency. But it is another issue. It is important to identify "avoidable" work or payment by private PV penetration.

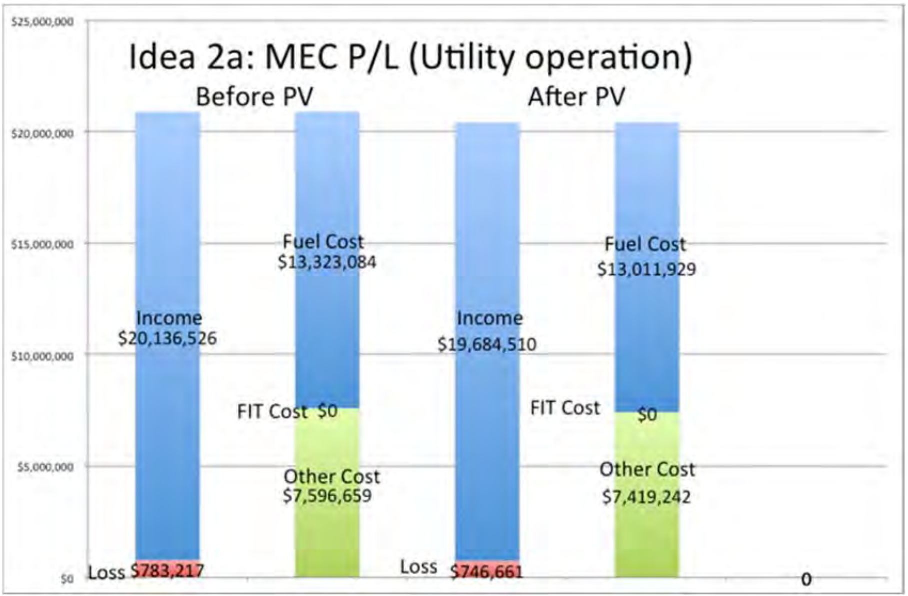


Figure 3.1.5-4 Change in MEC's P/L in the case of "avoidable" other cost

3.1.5.4 Issues of FIT scheme in RMI

Except for political issues, big problem in introducing FIT is from where we bring FIT resource. Electricity tariff is around 0.5 USD/kWh, so we can not add surcharge on it. If we assume "avoidable cost" is only fuel cost, FIT degrades MEC's financial status. Therefor last resort is donor's fund, but according to MRD, it may be very hard to use it for FIT resource.

RMI will need some kind of financial support mechanism, if it has negative response after allowing grid connection without economical incentives. Then RMI is obliged to have negotiation with donors.

So far discussion was made about FIT resource. What about other supporting mechanism, such as subsidy or investment tax reduction? Of course they need resource and we have same conclusion as FIT. Therefore we have to say that economically reasonable financial support mechanism is very hard to be established in RMI.

However without such a support, high electricity tariff provides a good investing environment, where investor can be paid back if he can make the initial investment and maintain PV system well in 20 years. The question is how many such a qualified investors are in RMI.

And furthermore RMI has one more underlying issue. Does RMI need to promote private PV installation by providing incentives such as FIT? RMI has existing 209kW PV at hospital, 54+57kW PV at CMI and is going to have 500kW PV with UAE fund. It comes out 820kW in total. On the other hand, from the survey result about max allowable PV capacity (refer to Section 3.2), RMI can have 890kW under the constraints of 1Hz and 2σ. Remaining capacity is just only 70kW PV. It means that only 47 sets of 1.5kW PV system by Taiwan loan can be allowed. To provide financial support just for them is not realistic.

3.1.5.5 Example of possible FIT

FIT is a financial incentive to promote private PV installation. If it is economically reasonable to install PV without FIT, people will install it voluntary. In above mentioned example (input parameter in Table

3.1.5-1), FIT price is 12c/kW. Now without FIT, that is 0c/kW, the investor’s payback schedule turns as shown in Table 3.1.5-7 (The investor’s payback schedule with 12c/kW is shown in Table 3.1.5-2.).

Table 3.1.5-7 Payback schedule without FIT

CUSTOMER PAYBACK SCHEDULE									FINANCING			
YEAR	FIT Energy Rate	MEC Energy Rate	Generated Energy kWh	In-house Consumptic kWh	FIT income	Consumed Energy Value	State Rebate + ENERGY VALUE	Capital + O&M Cost	Annual Payment	Annual Net	Annual ROI	NPV
0				100%				-$1,200.00		-$1,200.00		
1	$0.000	$0.430	2,102.40	2,102.40	$0.00	$904.03	$904.03	-$37.50	-$1,078.21	-$211.68	-17.6%	-$1,320.47
2	$0.000	$0.430	2,085.58	2,085.58	$0.00	$896.80	$896.80	-$37.50	-$1,078.21	-$218.91	-18.2%	-$1,504.27
3	$0.000	$0.430	2,068.90	2,068.90	$0.00	$889.63	$889.63	-$37.50	-$1,078.21	-$226.08	-18.8%	-$1,683.35
4	$0.000	$0.430	2,052.34	2,052.34	$0.00	$882.51	$882.51	-$37.50	-$1,078.21	-$233.20	-19.4%	-$1,857.61
5	$0.000	$0.430	2,035.93	2,035.93	$0.00	$875.45	$875.45	-$37.50	-$1,078.21	-$240.26	-20.0%	-$2,026.99
6	$0.000	$0.430	2,019.64	2,019.64	$0.00	$868.44	$868.44	-$37.50	$0.00	$830.94	69.2%	-$1,474.36
7	$0.000	$0.430	2,003.48	2,003.48	$0.00	$861.50	$861.50	-$37.50	$0.00	$824.00	68.7%	-$957.38
8	$0.000	$0.430	1,987.45	1,987.45	$0.00	$854.61	$854.61	-$37.50	$0.00	$817.11	68.1%	-$473.73
9	$0.000	$0.430	1,971.55	1,971.55	$0.00	$847.77	$847.77	-$37.50	$0.00	$810.27	67.5%	-$21.28
10	$0.000	$0.430	1,955.78	1,955.78	$0.00	$840.99	$840.99	-$750.00	$0.00	$90.99	7.6%	$26.65
11	$0.000	$0.430	1,940.14	1,940.14	$0.00	$834.26	$834.26	-$37.50	$0.00	$796.76	66.4%	$422.61
12	$0.000	$0.430	1,924.61	1,924.61	$0.00	$827.58	$827.58	-$37.50	$0.00	$790.08	65.8%	$793.03
13	$0.000	$0.430	1,909.22	1,909.22	$0.00	$820.96	$820.96	-$37.50	$0.00	$783.46	65.3%	$1,139.56
14	$0.000	$0.430	1,893.94	1,893.94	$0.00	$814.40	$814.40	-$37.50	$0.00	$776.90	64.7%	$1,463.73
15	$0.000	$0.430	1,878.79	1,878.79	$0.00	$807.88	$807.88	-$37.50	$0.00	$770.38	64.2%	$1,766.99
16	$0.000	$0.430	1,863.76	1,863.76	$0.00	$801.42	$801.42	-$37.50	$0.00	$763.92	63.7%	$2,050.68
17	$0.000	$0.430	1,848.85	1,848.85	$0.00	$795.01	$795.01	-$37.50	$0.00	$757.51	63.1%	$2,316.07
18	$0.000	$0.430	1,834.06	1,834.06	$0.00	$788.65	$788.65	-$37.50	$0.00	$751.15	62.6%	$2,564.33
19	$0.000	$0.430	1,819.39	1,819.39	$0.00	$782.34	$782.34	-$37.50	$0.00	$744.84	62.1%	$2,796.58
20	$0.000	$0.430	1,804.83	1,804.83	$0.00	$776.08	$776.08	-$37.50	$0.00	$738.58	61.5%	$3,013.83
TOTAL			39,000.66	39,000.66	$0.00	$16,770.28	$16,770.28	-$2,662.50	-$5,391.05	$8,716.73		
NPV							$9,764.46	-$1,913.19		$3,013.83		
							Total O&M	-$1,462.50				
							O&M NPV	-$827.98				

In this case, investor has deficit in annual net in the first 5 years, to return of the micro finance loan. And it takes 10 years to get positive NPV. The point is if the investor acknowledges this kind of anticipation, how he views this investment and especially if he expects the PV system can be operated at almost similar condition more than 10 years. The cost of inverter replacement is large. If he cannot replace it, we have to say that he will not have a profit.

Many people in RMI do not know this kind of simulation result. It may be insincere or not accountable, if RMI/MEC calls for application of grid connection without telling this simulation result. And if this is open to public, people’s response for this call may be negative. In such a case, some sort of incentive such as FIT may be necessary. As shown in Table 3.1.5-2, FIT with 12c/kWh purchase price can improve investor’s annual net in the first 5 years and provide positive NPV in 7 years.

However to implement this FIT, RMI needs financial resource, and as mentioned above, it can depend not on surcharge and reduced fuel cost but on donor’s fund. So in this Taiwan loan case, it may be practical to have half of the budget allocate for the 4% and 5 years micro finance (tentative target is around 500 sets.) and the remaining half for FIT resource.

If we can expect positive response even though the simulation result is opened, of course this kind of incentive is not required. But assuming negative response, it is recommended to investigate this kind of measure as the second best way.

3.1.6 Summary

In this chapter, general explanation on grid code, FIT and their world trend were made, and the approach for RMI in this project was described. As output, initial draft of grid code and how to design FIT scheme were provided.

Finally, issues, which RMI faces in this field, were analyzed. The RMI’s biggest issue is financial resource of supporting scheme such as FIT.

3.2 Capacity Evaluation of RE Connected to Electricity Grid

Since the output of RE represented by PV and wind power is influenced by the weather, it is difficult to ensure a constant output and control power amount as required (simultaneous equal amount control). Using unstable power supplies increases the risk of power outage due to instability of system voltage and frequency fluctuations, so careful consideration is required to promote and spread RE.

Since the power grids in RMI are small and independent, receiving backup power from other grids in case of emergencies is impossible. If a large amount of RE is introduced to such grids, in addition to power flow and voltage fluctuations, there is a high possibility of frequency fluctuations, so delicate management of power supply and demand balance in cycles is required. Therefore, in order to stably implement supply and demand operation management with large-scale introduction of RE, a supply and demand prediction technology for RE and a power storage system for high speed charging and discharging is essential. However, because these systems are expensive, implementing them in island regions with insufficient funding is difficult. In order to promote the introduction of RE to small independent power grids such as those in RMI taking into economic elements, determining in advance the threshold for RE introduction such that stable supply and demand operation management is possible is required. Moreover, preparing stepwise measures for when the limit is about to be exceeded is also important.

＜Note: The impact of frequency fluctuation＞

- Impact on consumers

  For motors, frequency and rotation speed are proportional, so fluctuations cause the motor itself to vibrate and produce heat, or irregularities in a product which is being made with the motor may occur. This would reduce the value of the product or result in the failure to meet the product's standards. In addition, clocks and automation equipment that operate based on the frequency of electricity that are connected to are also affected. For clocks, it may cause them to be early or late, and with automation equipment, it may cause product irregularities.

- Impact on the generator side

  When frequency changes, rotation speed changes, so if there is a significant change, vibrations and stress on the mechanical system become a problem. In addition, if there is a significant change in frequency, it may cause the inability of generators to continue to operate resulting in generators stopping one after the other, and ultimately lead to a major blackout.

3.2.1 Evaluation on the maximum allowable amount of RE power generation using the algebraic method

3.2.1.1 Overview of the algebraic method

The algebraic method which is a simple method commonly used in Japan, and by using allowable adjustable range, the generator's frequency response range, demand fluctuation rate, and RE output fluctuations as specifications, the maximum allowable amount that can be introduced can be calculated. Unlike a detailed generator simulation, this method does not require special tools nor a high level of knowledge and experience, and calculations can be performed with Excel. In addition, since calculation results similar to those of detailed simulations can be obtained, we provided technical training for the project in RMI by introducing the algebraic method.

A schematic diagram is shown in Fig 3.2.1-1. With this method, the maximum allowable amount of PV can be calculated using the following formula.

$$PV = \frac{\sqrt{(Frequency\ \ adjustable\ \ margin)^2 + (LFC)^2 - (Demand\ \ fluctuation)^2}}{Fluctuation\ \ Rate}$$

(Max. PV allowable)

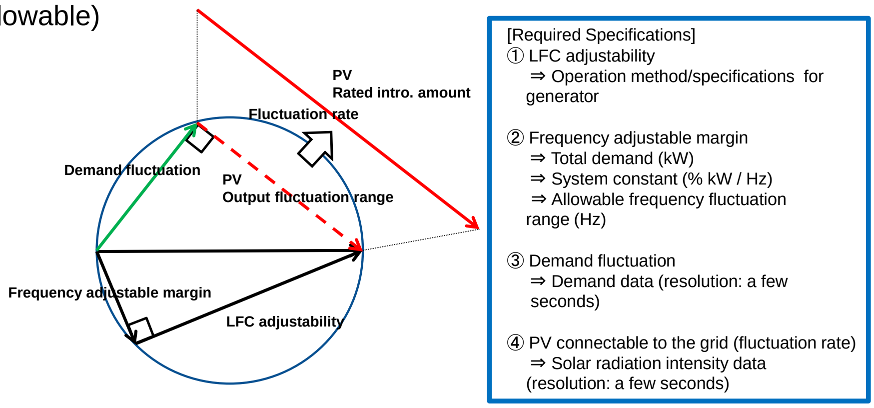


Fig 3.2.1-1 A representation of the algebraic method

＜Note: Detailed generator simulation＞

By simulating the responsiveness of the generator in detail, frequency fluctuations due to output fluctuations of RE can be quantitatively calculated. Data for modeling and a dedicated simulation tool are required in this method. In Japan, Y Method and Matlab, which are power system analysis programs developed by the Central Research Institute of Electric Power Industry and are capable of dynamic analysis of the grid, are generally used as simulation tools.

Since these tools require advanced skills and tuning of the generator model using actual past data, acquiring high level skills is required.

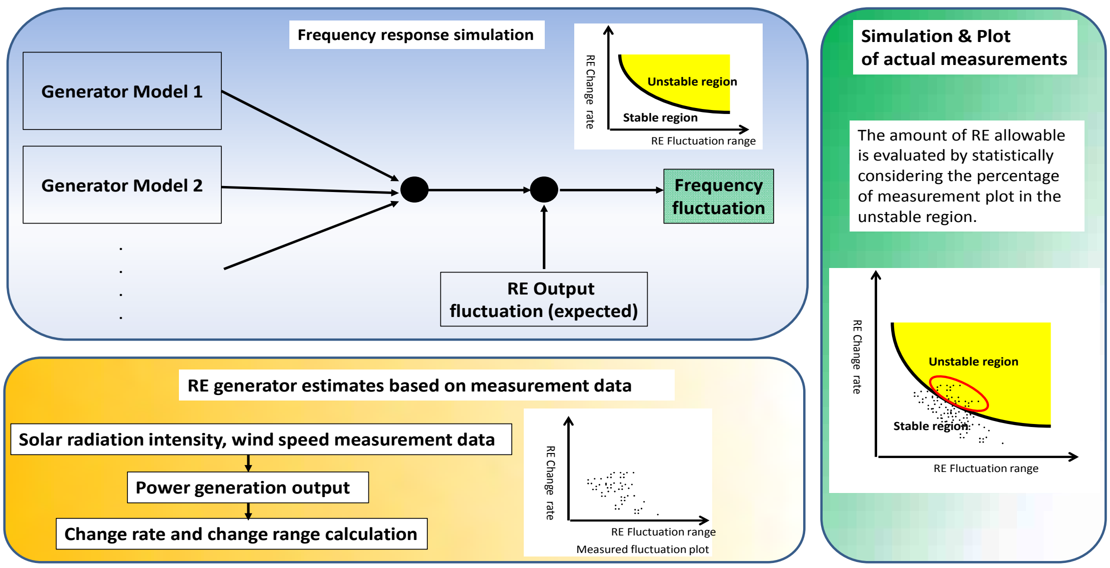


Fig 3.2.1-2 Detailed schematic diagram of generator simulation

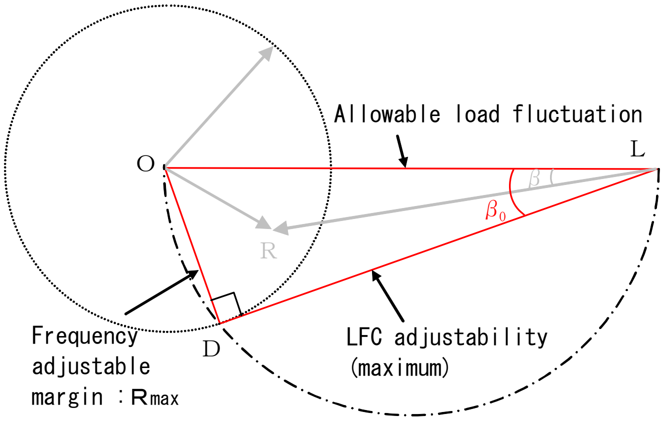
[Glossary]

- Allowable adjustable margin

  The adjustment range which the power supplying side should maintain in order to maintain power quality. For the grid in Okinawa, the adjustment range is within 60±0.3Hz. This frequency range greatly affects the value of the maximum allowable amount. A schematic diagram of the allowable adjustable margin is shown in Fig. 3.2.1-3. In addition, the allowable adjustable margin is calculated using Formula ①.

  Formula for calculating allowable adjustable margin

  Allowable adjustable margin R_{max} = system constant (%MW/Hz) × frequency range (0.3 Hz) ×total demand (MW)... ①



(See Institute of Electrical Engineers of Japan Technical Report No. 869 Figure 5.13)

Fig 3.2.1-3　The relationship among load fluctuation, LFC adjustability, and adjustable margin

- LFC adjustability

  In Japan, based on the Electric Utility Industry Law, power companies must strive to maintain a standard frequency. The purpose of LFC control is to maintain frequency. This is done by controlling the generator output automatically by determining the amount of generator adjustment required for the power area with respect to the frequency fluctuation due to demand fluctuations in roughly a 20-minute period or below. LFC control has not been implemented in RMI, and since major improvements to the control system will be required in the future, it is not clear if it will be implemented.

3.2.1.2　Definition of RE output change range

There are short and long period elements in RE, and a study needs to be conducted for each element to determine if the generator is able to track load. The study target for the algebraic method is the short period element. In Okinawa, since it is an island with a small independent power grid, the evaluation window is set at 10 minutes as this is believed to be most suitable, we assume the same time window can be used in the RMI, which is an island region, for the study.　In addition, output fluctuation range is defined as the difference between the maximum and minimum output during the evaluation time window. A schematic diagram of the evaluation time window is shown in Fig 3.2.1-4.

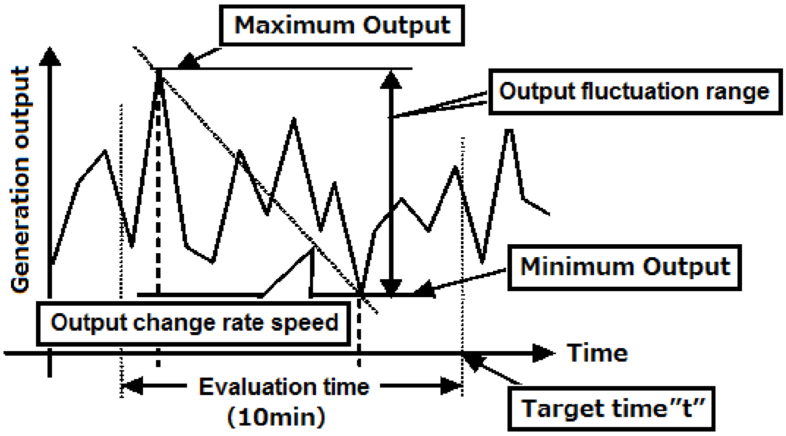


Fig 3.2.1-4　Definition of evaluation time window and output fluctuation range

3.2.1.3 Overview of the probabilistic method

If the output fluctuation range is used as defined above, rare fluctuations will be considered, so RE the output fluctuation (the rated value of RE grid connection for the output fluctuation range) becomes a large value. As a result, the maximum allowable amount of RE calculated with the algebraic method becomes small. Probabilistic processing by excluding rare events in order to maximize RE is commonly used in Japan. Frequency management in Japan is very strict, so probabilistic values are set high. The 3σ value (events that occur with a probability of 99.7% relative to all events) and 2σ value (events that occur with a probability of 95.7% relative to all events) is often used.　3σ means that there is a 99.7% probability that a frequency deviation will not occur.

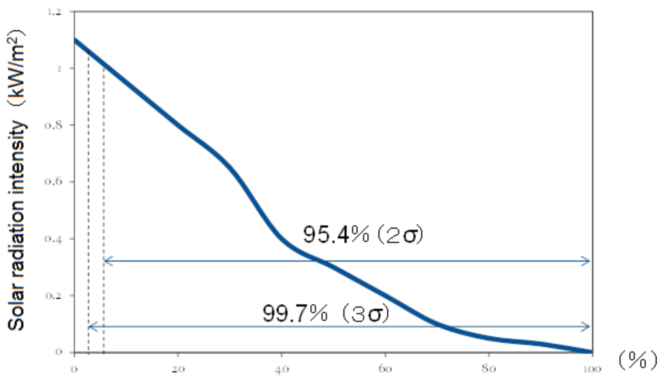


Fig 3.2.1-5　A representation of the probabilistic calculation (2σ, 3σ)

3.2.2　The RE maximum allowable amount for each remote island

The maximum allowable amount of RE for the 4 target islands for survey in this project (Majuro Atoll, Ebeye Island, Wotje Atoll, Jaluit Atoll) was calculated using the algebraic method. The parameters required for the algebraic method [system constant, demand fluctuation rate, total demand (assumed load), solar radiation intensity and wind fluctuation rate] were analyzed using the measurement data for each island. The results are shown below.

3.2.2.1 Calculating system constant (frequency fluctuation test)

The anticipated introduction of RE (solar power, wind power, etc.) is an unstable power source, so controlling it according to the demand load is difficult. The existing generators (thermal power generation, diesel generator, etc.) are essential as control devices to match demand load. The more RE is introduced, the more likely the existing generators deviate from their controllable range which increases the risk of a blackout and increases grid instability. A test which induces frequency fluctuation such as a load cutoff test is an effective means in helping to determine the load tracking capability of the existing generators, and the system constant can be calculated with the test results (% kW/Hz), and grid stability can be evaluated.

Formula (1) expresses the relationship between power fluctuation of the grid ΔP and frequency fluctuation. Here, constant value is defined as the system constant. If the system constant for the grid is is known, the amount of power fluctuation that occurred can be inversely calculated from frequency deviation. The algebraic method uses the system constant, which was estimated when conducting a load rejection test to calculate the allowable adjustable margin, to calculate the value for the maximum allowable power fluctuation. In order to convert the system constant to a PU value, power fluctuation, ΔP, is based on the generator's total rated capacity.

$$\Delta P\ (\%MW) = \Delta P\ (MW)\ /\ \text{total rated output of parallel input generators}$$
$$\Delta P / \Delta F = K\ (\text{constant value: }\%MW/Hz)\ ...\ ①$$

In a load cutoff test, one of the multiple generators which are connected to the grid is shutdown causing a load imbalance of load. By doing so, the load tracking capability of the remaining generators that are connected to the grid can be evaluated. There is a risk of inducing generator failures and blackouts with this test as it is conducted in the actual field, so we carefully carried it out with the consent of the local power plant officials. The test results and system constant calculation results for each island are shown in the following sections.

(1) Majuro

For normal operation, Unit 6 is the main unit, and when Unit 6 is undergoing maintenance, Unit 7 is operated in its place. Peak hours are from 6:00 p.m. to 21:00, and off-peak hours are late at night. One generator operation is only conducted during off-peak hours, at other times two generators are in operation. Unit 1, 2, or 5 is used as the second unit, Unit 5 is preferentially used. Therefore, the purpose of the load rejection test is to verify the load tracking capability of the generator during the daytime when two generators are in operation (Unit 5 + Unit 6 or Unit 5 + Unit 7), and the test was carried out in according to the following time schedule and patterns. Under C/P consent, the output for the generator to be shut down was set at 5%, 10%, and 15% of the total demand.

Pattern① : #2, #5, #6 generator to be shut down: #2
Pattern② : #2, #5, #7 generator to be shut down: #2

Table 3.2.2-1　Load rejection test schedule (2014/1/18)

9:00	Ready for test (Setting measurement devices)
10:00 AM	Pattern①(Shut down #2) 1)Ratio：5%　⇒check data
11:00 AM	2)Ratio：10%　⇒check data 3)Ratio：15%　⇒check data
12:00 PM	Pattern②(Shut down #2) 1)Ratio：5%　⇒check data
1:00 PM	2)Ratio：10%　⇒check data 3)Ratio：15%　⇒check data
2:00 PM	Clean up

(a)　Load rejection test results and system constant calculation results

The results of the load rejection test corresponding to the test patterns described above are shown in following sections.

(Pattern ① load rejection ratio 5%)

Test conditions

Test time	2014/1/18 11:10	
Parallel input generator	3 units (G2, G5, G6)	
Dropout generator	G2	
Rated generator output (MW)	G2	3.275
	G5	3.475
	G6	6.400
Generator output (MW)	G2	0.22
	G5	1.36
	G6	3.64
Total demand (MW)	5.22	

Test results

Original frequency (Hz)	59.91
Bottom frequency (Hz)	59.63
Frequency deviation (Hz)	0.28
Dropout generator output (MW)	0.31
Time to reach bottom frequency (s)	1.3
End frequency (Hz)	59.93

System constant calculation result

Rated output base (%MW/Hz)	11.30

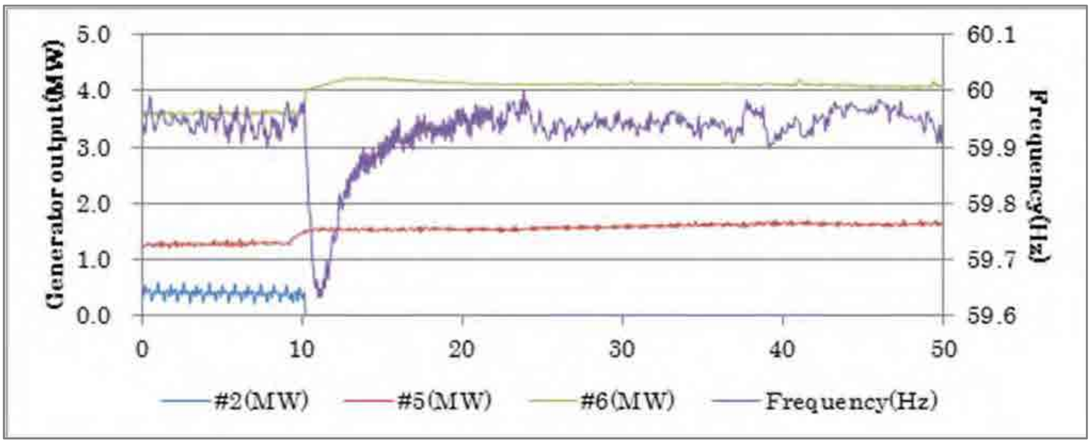


Fig 3.2.2-1　Pattern ① Generator output and frequency with 5% rejection

(Pattern ① load rejection ratio 10%)

Test conditions

Test time	2014/1/18 11:24	
Parallel input generator	3 units (G2, G5, G6)	
Dropout generator	G2	
Rated generator output (MW)	G2	3.275
	G5	3.475
	G6	6.400
Generator output (MW)	G2	0.54
	G5	1.24
	G6	3.58
Total demand (MW)	5.36	

Test results

Original frequency (Hz)	59.97
Bottom frequency (Hz)	59.44
Frequency deviation (Hz)	0.53
Dropout generator output (MW)	0.54
Time to reach bottom frequency (s)	1.3
End frequency (Hz)	59.97

System constant calculation result

Rated output base (%MW/Hz)	10.38

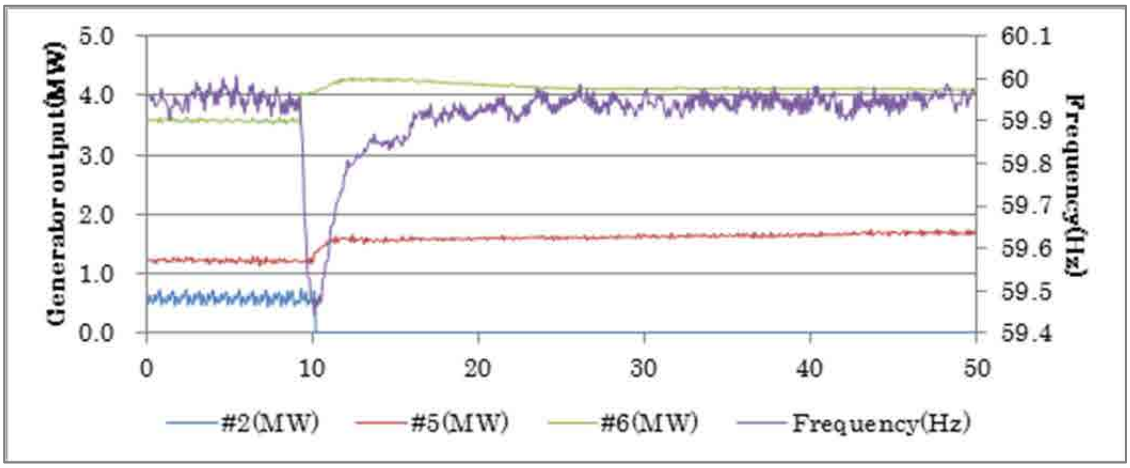


Fig 3.2.2-2 Pattern ①Generator output and frequency with 10% rejection

(Pattern ① load rejection ratio 15%)

Test conditions

Test time	2014/1/18 1:01	
Parallel input generator	3 units (G2, G5, G6)	
Dropout generator	G2	
Rated generator output (MW)	G2	3.275
	G5	3.475
	G6	6.400
Generator output (MW)	G2	1.18
	G5	0.83
	G6	3.38
Total demand (MW)	5.38	

Test results

Original frequency (Hz)	60.03
Bottom frequency (Hz)	59.08
Frequency deviation (Hz)	0.94
Dropout generator output (MW)	1.18
Time to reach bottom frequency (s)	1.3
End frequency (Hz)	59.99

System constant calculation result

Rated output base (%MW/Hz)	12.65

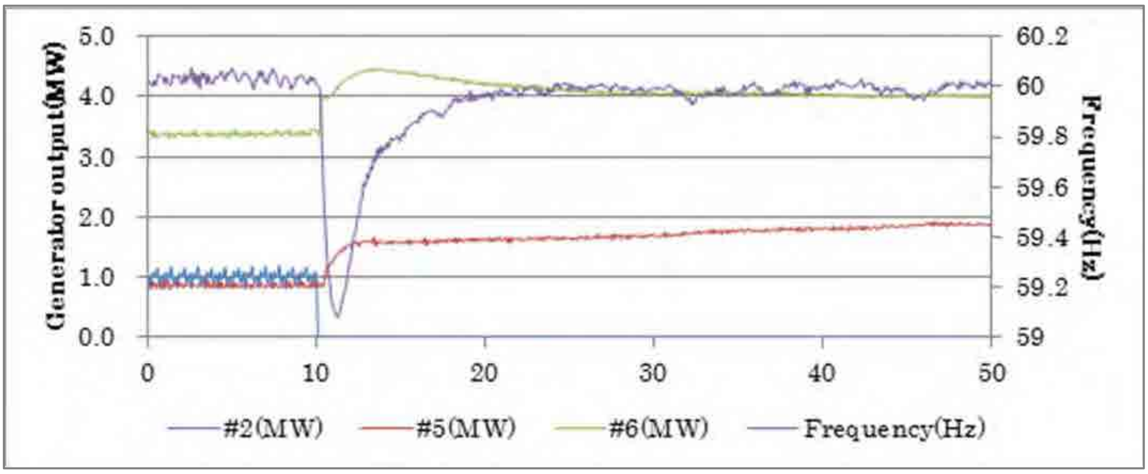


Fig 3.2.2-3 Pattern ①Generator output and frequency with 15% rejection

(Pattern ② load rejection ratio 5%)

Test conditions

Test time	2014/1/18 11:45	
Parallel input generator	3 units (G2, G5, G7)	
Dropout generator	G2	
Rated generator output (MW)	G2	3.275
	G5	3.475
	G7	6.400
Generator output (MW)	G2	0.32
	G5	1.51
	G7	3.28
Total demand (MW)	5.11	

Test results

Original frequency (Hz)	60.19
Bottom frequency (Hz)	59.89
Frequency deviation (Hz)	0.30
Dropout generator output (MW)	0.32
Time to reach bottom frequency (s)	1.1
End frequency (Hz)	60.16

System constant calculation result

Rated output base (%MW/Hz)	11.03

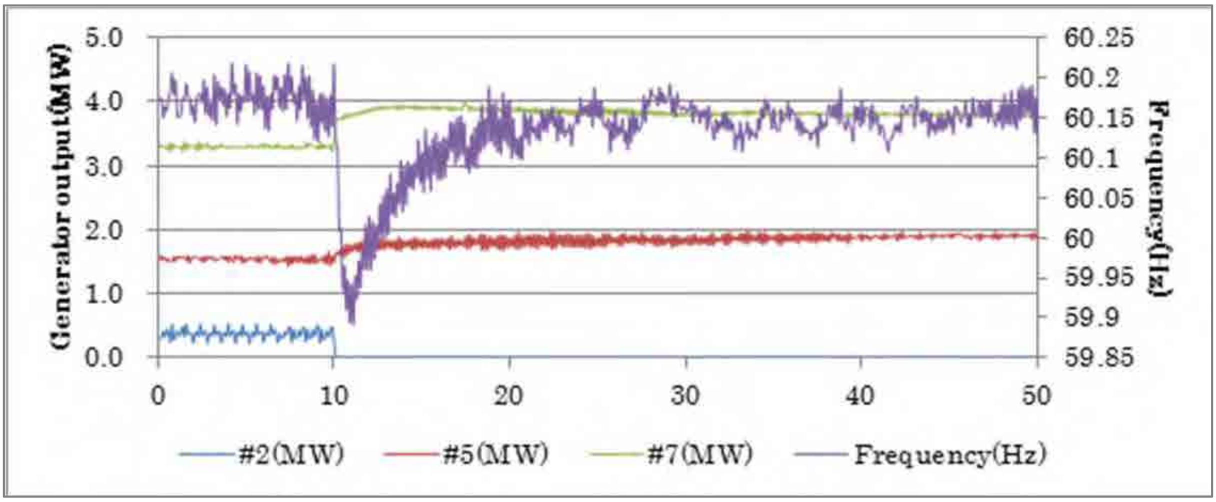


Fig 3.2.2-4 Pattern ②Generator output and frequency with 5% rejection

(Pattern ② load rejection ratio 10%)

Test conditions

Test time	2014/1/18 12:17	
Parallel input generator	3 units (G2, G5, G7)	
Dropout generator	G2	
Rated generator output (MW)	G2	3.275
	G5	3.475
	G7	6.400
Generator output (MW)	G2	0.58
	G5	1.23
	G7	3.33
Total demand (MW)	5.13	

Test results

Original frequency (Hz)	60.13
Bottom frequency (Hz)	59.68
Frequency deviation (Hz)	0.45
Dropout generator output (kW)	0.58
Time to reach bottom frequency (s)	0.8
End frequency (Hz)	60.16

System constant calculation result

Rated output base (%MW/Hz)	13.00

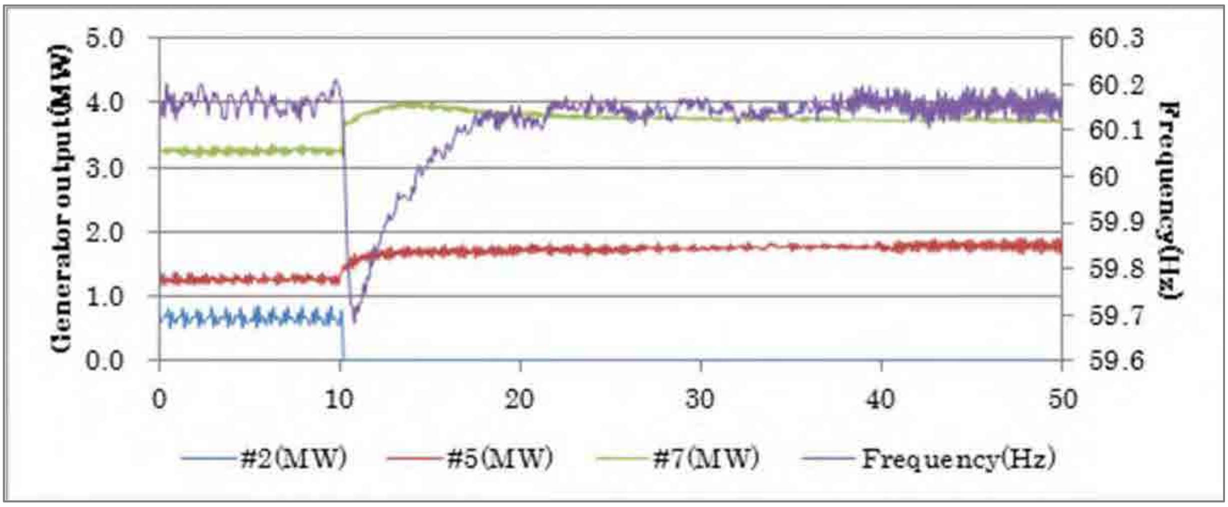


Fig 3.2.2-5 Pattern ②Generator output and frequency with 10% rejection

(Pattern ② load rejection ratio 15%)

Test conditions

Test time	2014/1/18 12:30	
Parallel input generator	3 units (G2, G5, G7)	
Dropout generator	G2	
Rated generator output (MW)	G2	3.275
	G5	3.475
	G7	6.400
Generator output (MW)	G2	1.08
	G5	0.99
	G7	3.24
Total demand (MW)	5.31	

Test results

Original frequency (Hz)	60.15
Bottom frequency (Hz)	59.38
Frequency deviation (Hz)	0.77
Dropout generator output (kW)	1.08
Time to reach bottom frequency (s)	0.8
End frequency (Hz)	60.15

System constant calculation result

Rated output base (%MW/Hz)	14.16

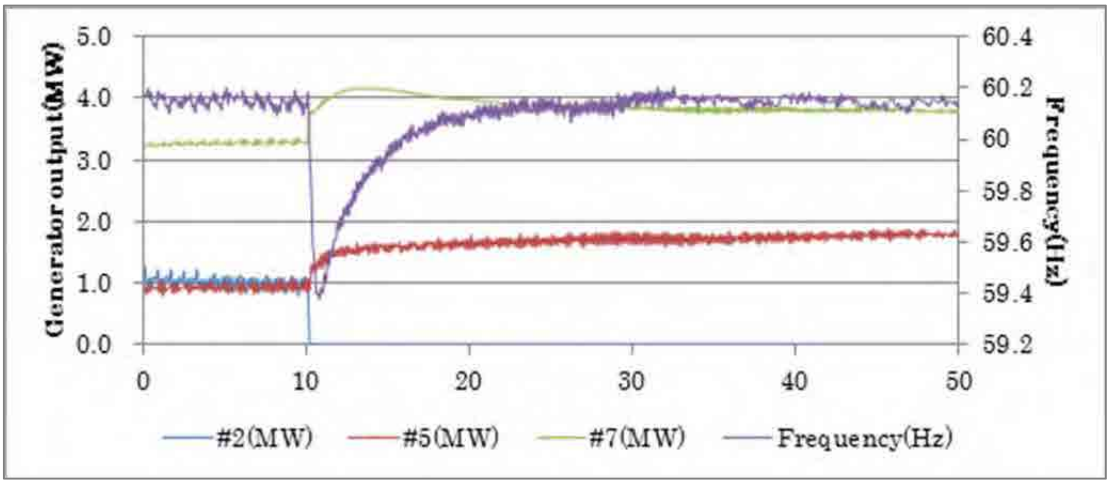


Fig 3.2.2-6 Pattern ②Generator output and frequency with 15% rejection

(b) System constant used in the algebraic method

The average value of these data are set as the system constant used in the algebraic method. The average value is shown in Table 3.2.2-2.

Table 3.2.2-2 Average value for system constant (Majuro)

System constant average value (% MW/Hz)	12.09

(2) Ebeye

Ebeye Power Plant has 3 generators with 2 operating at all times. Control system for the generators is isochronous control, and power generation output is balanced using the load sharing function. Since the rated output of the 3 generators is the same, when two generators are in operation, each is maintained at nearly the same output.

During load cutoff, the three generators were operated in parallel, and we verified the load tracking capability of Unit 2 and Unit 4 by shutting down Unit 3. Since the generators at Ebeye Power Plant have the same specifications, we decided not to test for load tracking capability for each combination (Unit2 + Unit 3, Unit 3 + Unit 4) of parallel operation for the generators.

The best place to collect data with measurement instruments is in the control panel for the generators in operation, but since the charging unit is nearby, for safety purposes, we collected PT and CT data from the control panel. Since the CT of the control panel is two-phase, the two-wattmeter method was used to measure active power. The schedule for the load rejection test is shown in Table 3.2.2-3.

Table 3.2.2-3 Load rejection test schedule (1/27/2014)

9:00	Ready for test (Setting measurement devices)
11:30 AM	Test Shut down #3 ⇒ Check data
12:30 PM	Clean up

(a) Load rejection test results and system constant calculation results

We conducted the load cutoff test twice. The results of the load cutoff test are shown in following sections.

(1^{st} time: approx. 25 kW rejection)

Test conditions

Test time	2014/1/27 11:24	
Parallel input generator	3 units (G2, G5, G7)	
Dropout generator	G3	
Rated generator output (kW)	G2	1286
	G3	1286
	G4	1286
Generator output (kW)	G2	946
	G3	1098
	G4	
Total demand (kW)	2044	

Test results

Original frequency (Hz)	59.95
Bottom frequency (Hz)	59.81
Frequency deviation (Hz)	0.14
Dropout generator output (kW)	26.5
Time to reach bottom frequency (s)	1.3
End frequency (Hz)	60.00

System constant calculation result

Rated output base (%kW/Hz)	7.38

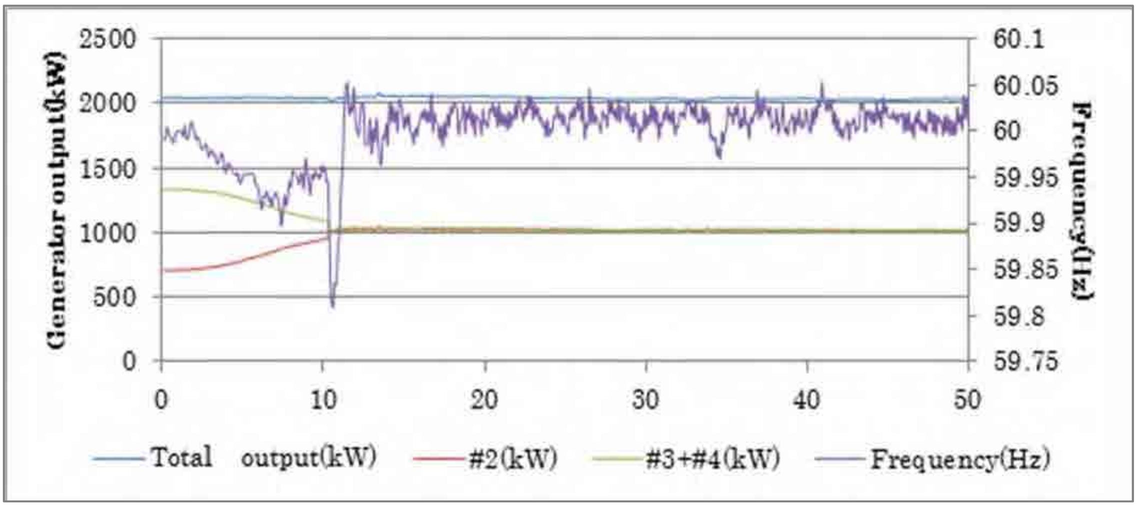


Fig 3.2.2-7 Generator output and frequency with about 25kW rejection

(2nd time: approx. 100 kW rejection)

Test conditions

Test time	2014/1/27 11:24	
Parallel input generator	3 units (G2, G5, G7)	
Dropout generator	G3	
Rated generator output (kW)	G2	1286
	G3	1286
	G4	1286
Generator output (kW)	G2	709
	G3	1330
	G4	
Total demand (kW)	2039	

Test results

Original frequency (Hz)	59.99
Bottom frequency (Hz)	59.51
Frequency deviation (Hz)	0.48
Dropout generator output (kW)	101.9
Time to reach bottom frequency (s)	0.28
End frequency (Hz)	59.98

System constant calculation result

Rated output base (%kW/Hz)	8.28

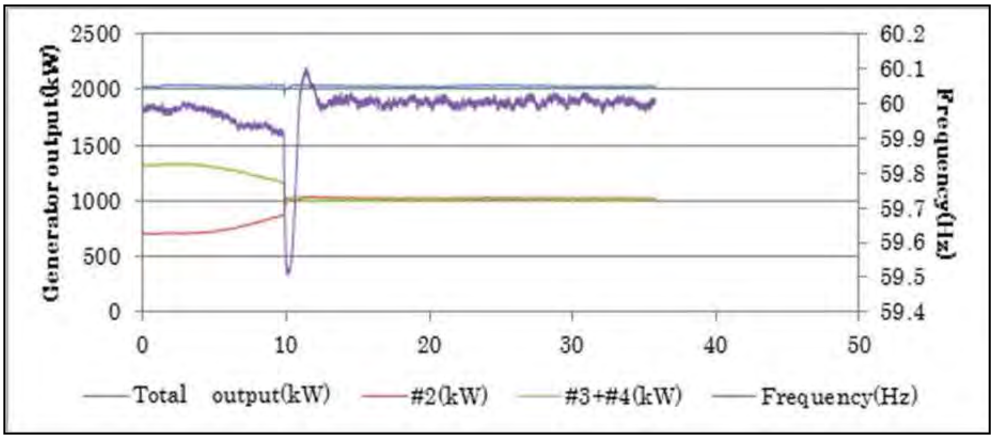


Fig 3.2.2-8　Generator output and frequency with about 100kW rejection

(b)　System constant used in the algebraic method

The average value of these data are set as the system constant used in the algebraic method. The average value is shown in Table 3.2.2-4.

Table 3.2.2-4　Average value for system constant (Ebeye)

System constant average value (% MW/Hz)	7.83

(3)　Wotje

Wotje Power Plant has two generators, but since the system load is very low, only one is in operation at all times. Since the generators use isochronous control without load sharing, the two generators cannot be operated at the same time. Therefore, we could not conduct the load rejection test. We verified the generator's response by cutting off and reclosing Feeder 2 which is not a supply feeder for critical loads (such as hospitals and schools). In carrying out the test, we obtained the consent of the power plant and notified the residents of the island.

The measurement instrument only collected CT and PT data for Unit 2 which is in operation. Measurement of Feeder 2 is needed for analysis, but since the field instruments are located outside the plant building, and there is no place where CT and PT data can be collected, we calculated the system constant by using the active power values before and after the cutoff.

Table 3.2.2-5　Load rejection test schedule (2014/1/22)

9:00	Ready for test (setting measurement devices)
15:00	Test Open F2 and Reclose F2　⇒Check data
15:30	Clean up

(a)　Load rejection test results and system constant calculation results

We verified the generator's ability to track output increase or decrease by turning on and off Feeder 2. The results are shown in the following sections.

Verification of the generator's ability to track output increase or decrease
... when Feeder 2 is cut off

Test conditions

Test time	2014/1/22 15:00	
Parallel input generator	1 Unit (G2)	
Cutoff feeder	F2	
Rated generator output (kW)	G2	275
Generator output (kW)	G2	75.46
Total demand (kW)	75.46	

Test results

Original frequency (Hz)	59.69
Maximum frequency (Hz)	60.00
Frequency deviation (Hz)	0.31
Estimated feeder cutoff load (kW)	12.58
Time to reach the highest frequency (s)	0.4
End frequency (Hz)	59.69

System constant calculation result

Rated output base (%kW/Hz)	14.67

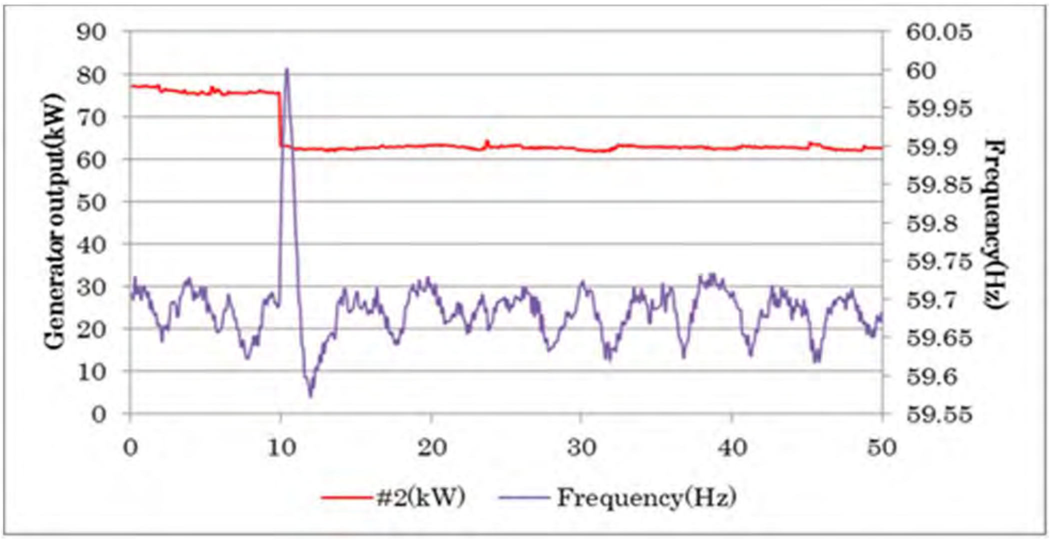


Fig 3.2.2-9 Generator output and frequency with F2 rejection

(Verification of the generator's ability to track output increase or decrease ... when Feeder 2 is reclosed)

Test conditions

Test time	1/22/2014 15:02	
Parallel input generator	1 Unit (G2)	
Reclosing feeder	F2	
Rated generator output (kW)	G2	275
Generator output (kW)	G2	67.49
Total demand (kW)	67.49	

Test results

Original frequency (Hz)	59.73
Bottom frequency (Hz)	59.19
Frequency deviation (Hz)	0.54
Estimated reclosing feeder load (kW)	18.56
Time to reach bottom frequency (s)	0.3
End frequency (Hz)	59.70

System constant calculation result

Rated output base (%kW/Hz)	12.55

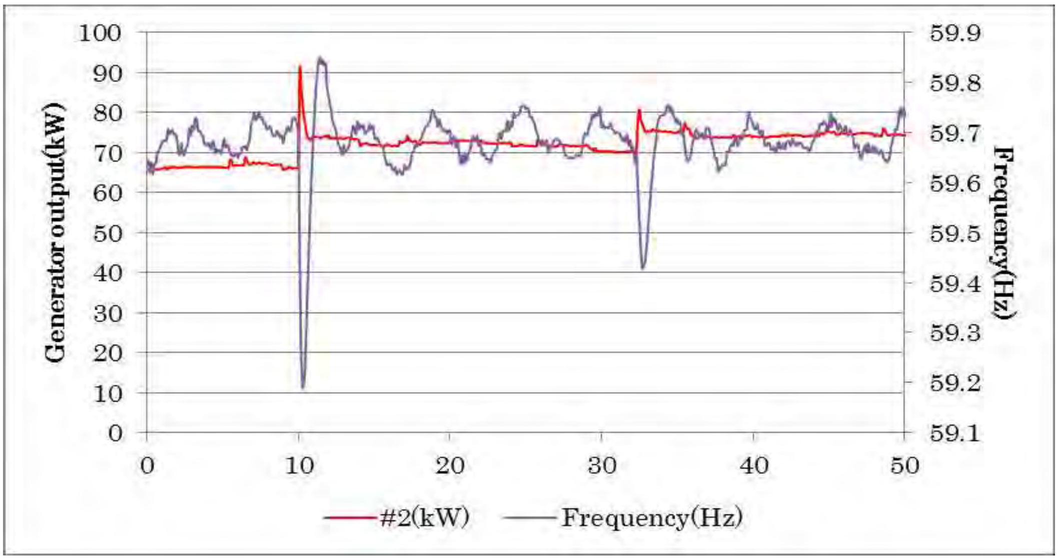


Fig 3.2.2-10　Generator output and frequency with F2 reconnection

(b) System constant used in the algebraic method

The test conditions when reclosing are the sames those for a test conducted by dropping out a generator, so 12.55% kW/Hz is used for system constant and applied to the algebraic method.

(4) Jaluit

As is the case with Wotje Power Plant, Jaluit Power Plant has two generators, and one is operated at all times to supplying power. The system load is small and the feeder only serves one grid. Therefore, since it is not feasible to conduct tests by cutting off generators or feeders, we conducted tests by cutting off transformers on the customer side.

Table 3.2.2-6　Load rejection test schedule (2014/1/27)

9:00	Ready for test (setting measurement devices)
14:00	Test Cut off Dorm transfomer ⇒Check data Cut off Waterpump transformer ⇒Check data
15:00	Clean up

(a) Load rejection test results and system constant calculation results

We verified the generator's ability to track output increase by adding a transformer. The results are shown in the following sections.

(Verification of the generator's ability to track output increase ...when the Dorm transformer is added)

Test conditions

Test time	1/27/2014 14:18	
Parallel input generator	1 Unit (G2)	
Cutoff transformer	Student dormitory	
Rated generator output (kW)	G2	275
Generator output (kW)	G2	91.07
Total demand (kW)	91.07	

Test results

Original frequency (Hz)	60.25
Bottom frequency (Hz)	59.77
Frequency deviation (Hz)	0.48
Estimate of load added (kW)	18.73
Time to reach bottom frequency (s)	0.3
End frequency (Hz)	60.20

System constant calculation result

Rated output base (%kW/Hz)	14.15

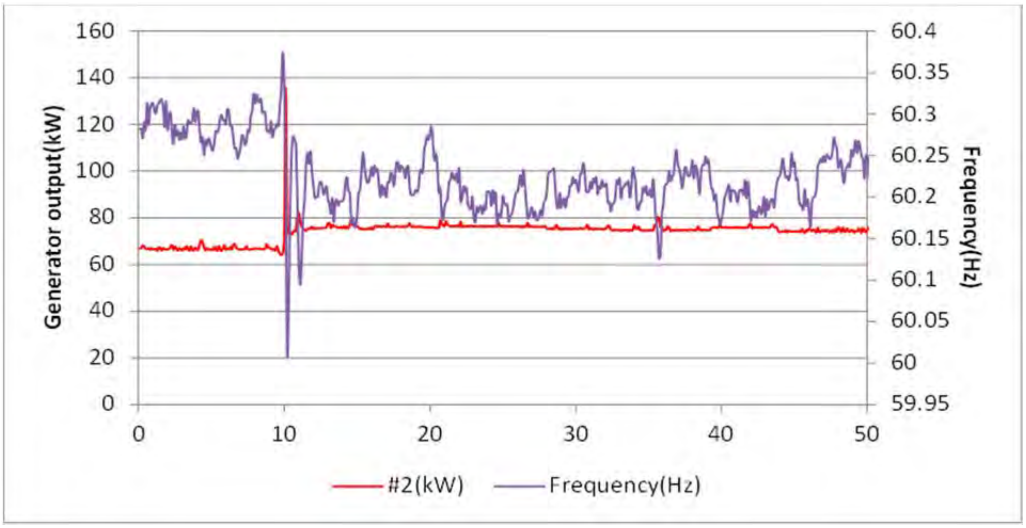


Fig 3.2.2-11 Generator output and frequency when water pump transformer is connected

(Verification of the generator's ability to track output increase ...when the water pump transformer is added)

Test conditions

Test time	1/27/2014 14:38	
Parallel input generator	1 Unit (G2)	
Cutoff transformer	Water pump	
Rated generator output (kW)	G2	275
Generator output (kW)	G2	66.29
Total demand (kW)	66.29	

Test results

Original frequency (Hz)	60.37
Bottom frequency (Hz)	60.01
Frequency deviation (Hz)	0.36
Estimate of load added (kW)	11.25
Time to reach bottom frequency (s)	0.3
End frequency (Hz)	60.21

System constant calculation result

Rated output base (%kW/Hz)	11.35

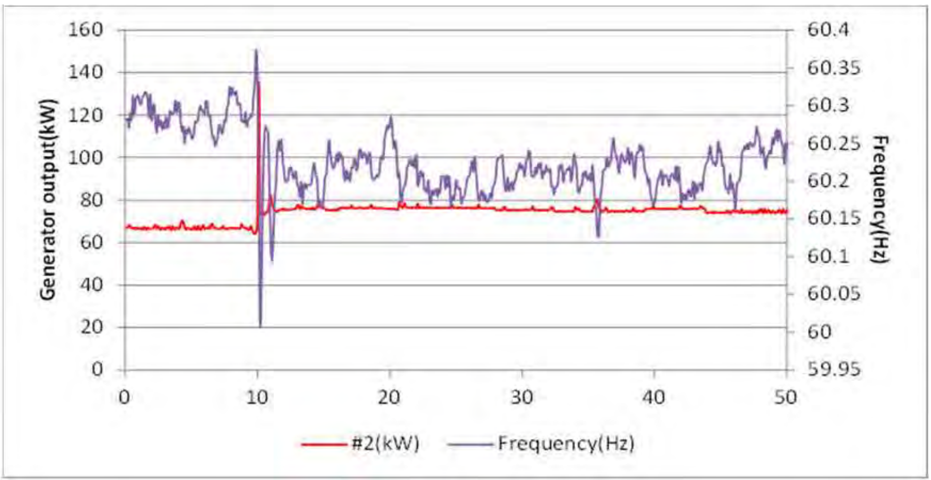


Fig 3.2.2-12 Generator output and frequency when water pump transformer is installed

(b) System constant used in the algebraic method

The average value of these data are set as the system constant used in the algebraic method. The average value is shown in Table 3.2.2-7.

Table 3.2.2-7 Average value for system constant (Jaluit)

System constant average value (% kW/Hz)	12.75

3.2.2.2 Calculating demand fluctuation rate

When the fluctuation component for demand load is extracted using Fast Fourier Transform, it results in roughly the normal distribution. When processing data using this characteristic, demand fluctuation is calculated by statistical analysis after extracting the fluctuation component within the evaluation time. An example is shown in Fig. 3.2.2-13. Assuming the fluctuation range is the difference between the 10-min moving average value (5 minutes before and after) and the actual value, and the values for 2σ and 3σ were determined from the standard deviation (σ value). The daytime hours and 24-hour analysis results are shown for the analysis of PV and wind turbine. The daily load curve and frequency trend from measurements are shown for reference.

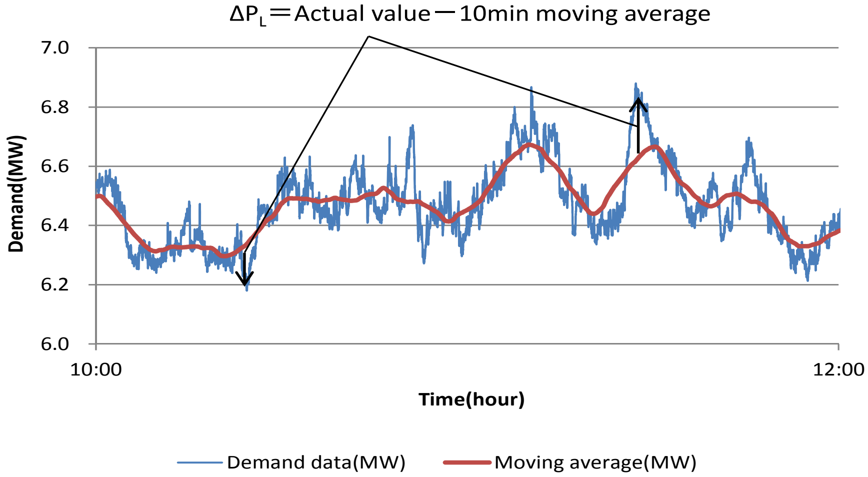


Fig 3.2.2-13 Example of demand fluctuation data processing method

(1) Majuro

(a) Daily load curve

The daily load curve is shown in Fig 3.2.2-14, and the frequency measurements are shown in Fig 3.2.2-15. Demand remained in the range of about 5 to 7 MW. Off-peak hours are from late at night to early morning while peak hours are from 20:00 to 22:00. Frequency hardly ever deviated from the operation management value of 60 ± 0.3Hz, but depending on the time, instances when it is not the standard frequency (60Hz) can be confirmed. It can be conceived that the reason the standard frequency is difficult to maintain at Majuro Power Plant is because it uses droop control.

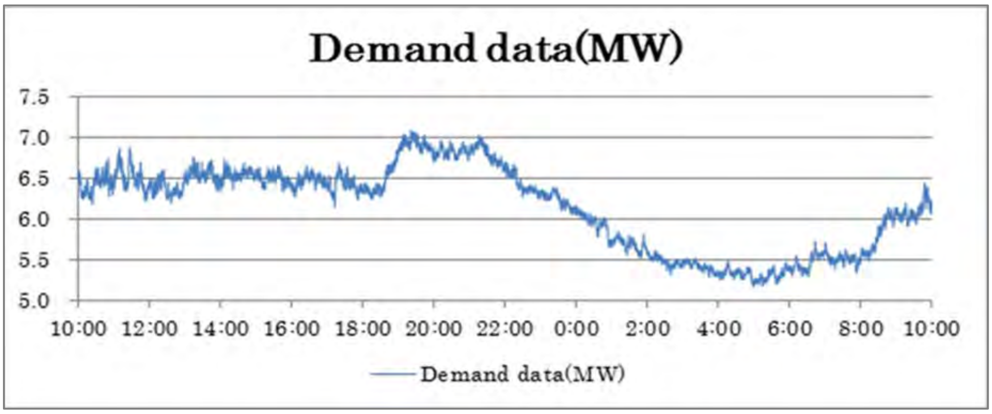


Fig 3.2.2-14 Daily load curve (Majuro)

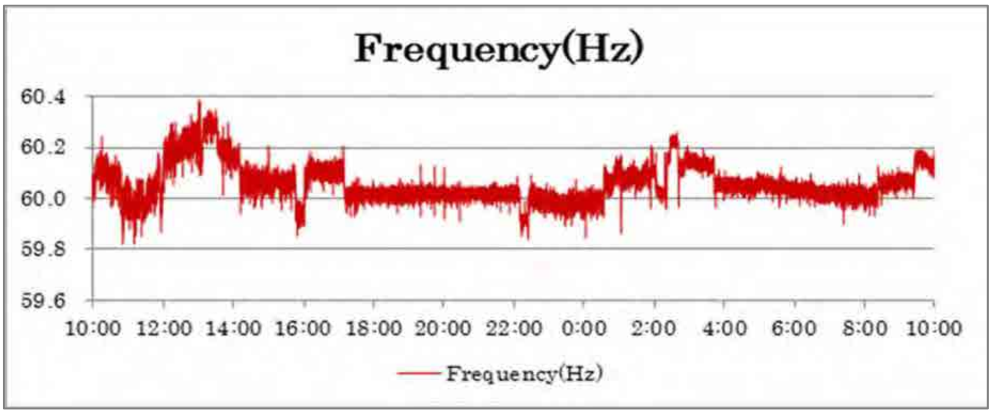


Fig 3.2.2-15 Frequency trend in a day (Majuro)

(b) Demand fluctuation rate

Table 3.2.2-8 and Table 3.2.2-9 show the demand fluctuation rate results for the PV output time zone (9:00-17:00) and wind turbine output time zone (24-hour).

Table 3.2.2-8 Demand fluctuation rate for daytime hours (9:00 to 17:00) (Majuro)

Probability	Demand Fluctuation Rate
Max (100%)	4.00%
3σ (99.7%)	1.54%
2σ(95.4%)	1.02%
σ (68.3%)	0.51%

Table 3.2.2-9 24-hour demand fluctuation rate (Majuro)

Probability	Demand Fluctuation Rate
Max (100%)	4.00%
3σ (99.7%)	1.29%
2σ(95.4%)	0.86%
σ (68.3%)	0.43%

(2) Ebeye

(a) Daily load curve

The daily load curve is shown in Fig. 3.2.2-16, and the frequency measurements are shown in Fig. 3.2.2-17. Demand is in the range of approximately 1,700 to 2,100kW. Off-peak hours are from late at night to early morning, and peak hours are around 20:00. There are almost no frequency deviations from 60 Hz. We presume the reason is that the control method used for the generators is isochronous control.

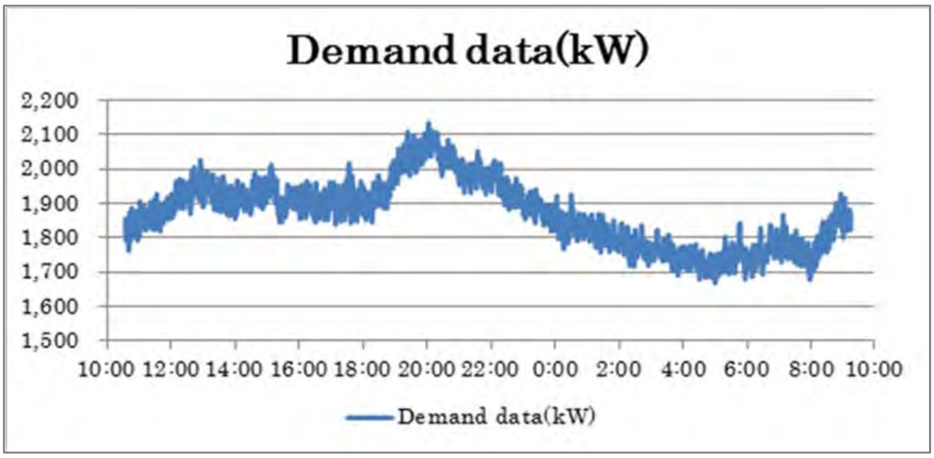


Fig 3.2.2-16 Daily load curve (Ebeye)

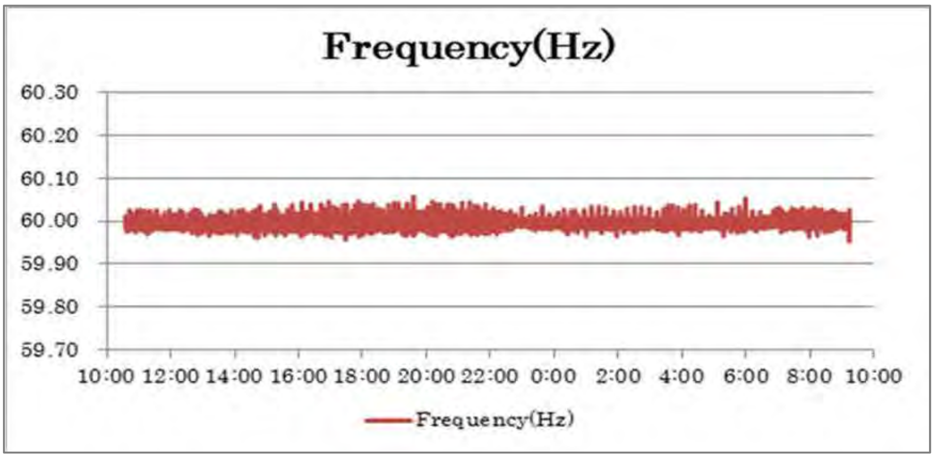


Fig 3.2.2-17 Frequency trend for in a day (Ebeye)

(b) Demand fluctuation rate

Table 3.2.2-10 and Table 3.2.2-11 show the demand fluctuation rate results for the PV output time zone (9:00-17:00) and wind turbine output time zone (24-hour).

Table 3.2.2-10 Demand fluctuation rate for daytime hours (9:00 to 17:00) (Ebeye)

Probability	Demand Fluctuation Rate
Max (100%)	4.05%
3σ (99.7%)	1.97%
2σ(95.4%)	1.31%
σ (68.3%)	0.66%

Table 3.2.2-11 24-hour demand fluctuation rate (Ebeye)

Probability	Demand Fluctuation Rate
Max (100%)	4.53%
3σ (99.7%)	2.02%
2σ(95.4%)	1.35%
σ (68.3%)	0.67%

(3) Wotje

(a) Daily load curve

The daily load curve is shown in Fig. 3.2.2-18, and the frequency measurements are shown in Fig. 3.2.2-19. Demand is in the range of approximately 60 to 90 kW. Off-peak hours are late at night, and peak hours are around 20:00. Frequency is approx. 59.7 Hz at all times deviating from 60 Hz. We presume the isochronous control has not been tuned properly. This needs to be corrected in the future to ensure stability and soundness of the grid.

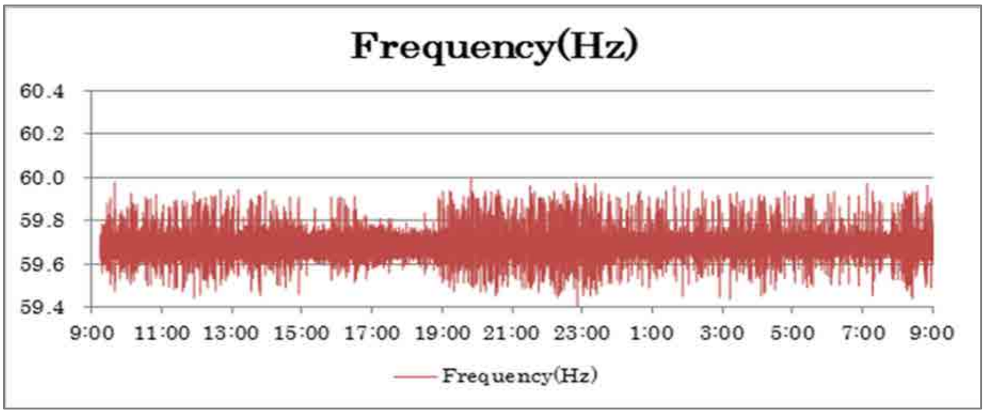


Fig 3.2.2-18 Daily load curve (Wotje)

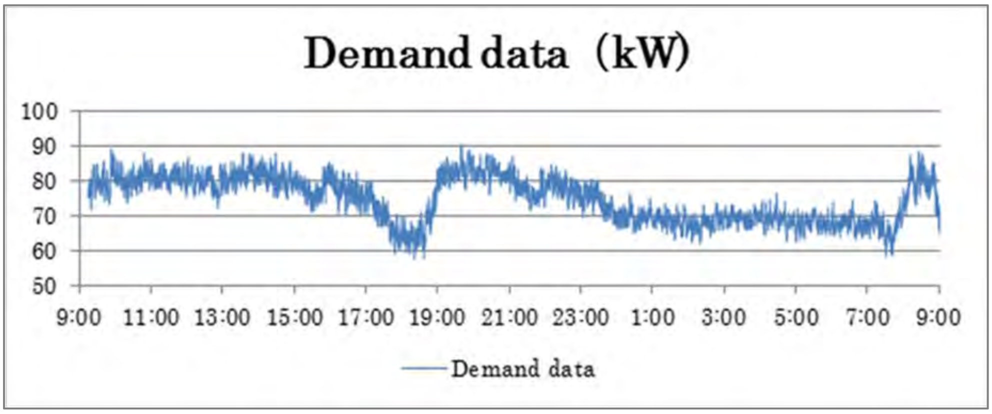


Fig 3.2.2-19 Frequency transition in a day (Wotje)

(b) Demand fluctuation rate

Table 3.2.2-12 and Table 3.2.2-13 show the demand fluctuation rate results for the PV output time zone (9:00-17:00) and wind turbine output time zone (24-hour).

Table 3.2.2-12 Demand fluctuation rate for daytime hours (9:00 to 17:00) (Wotje)

Probability	Demand Fluctuation Rate
Max (100%)	10.30%
3σ (99.7%)	4.68%
2σ(95.4%)	3.12%
σ (68.3%)	1.56%

Table 3.2.2-13 24-hour demand fluctuation rate (Wotje)

Probability	Demand Fluctuation Rate
Max (100%)	11.99%
3σ (99.7%)	4.87%
2σ(95.4%)	3.25%
σ (68.3%)	1.62%

(4) Jaluit

(a) Daily load curve

The daily load curve is shown in Fig. 3.2.2-20, and the frequency measurements are shown in Fig. 3.2.2-21. Demand is in the range of 70 to 120 kW. Off-peak hours are late at night and around 18:00, and peak hours are around 13:00 and 20:00 to 22:00. Frequency remained higher than 60 Hz at all times deviating from the standard frequency. We presume droop control is the cause.

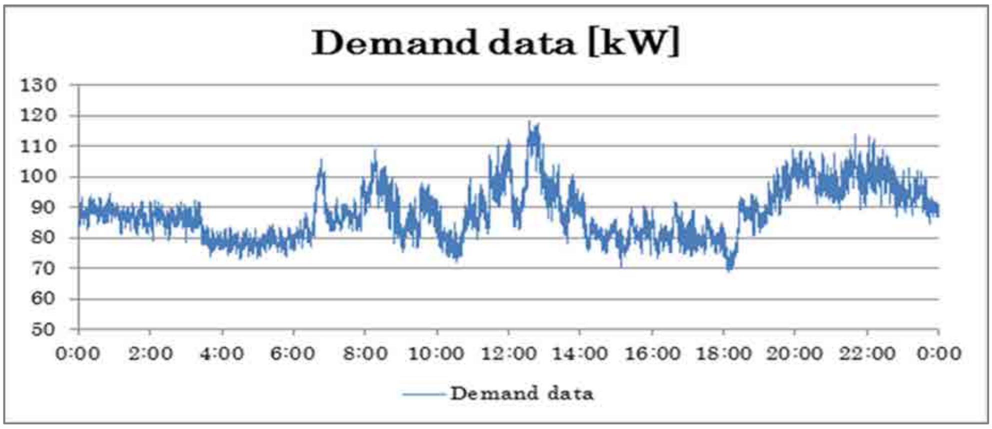


Fig 3.2.2-20 Daily load curve (Jaluit)

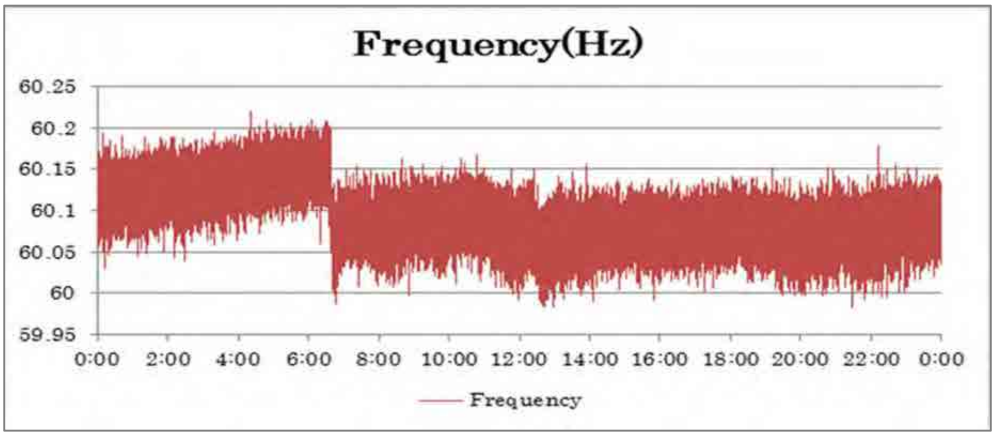


Fig 3.2.2-21 Frequency Supermarket in a day (Jaluit)

(b) Demand fluctuation rate

Table 3.2.2-14 and Table 3.2.2-15 show the demand fluctuation rate results for the PV output time zone (9:00-17:00) and wind turbine output time zone (24-hour).

Table 3.2.2-14　Demand fluctuation rate for daytime hours (9:00 to 17:00) (Jaluit)

Probability	Demand Fluctuation Rate
Max (100%)	13.77%
3σ (99.7%)	5.94%
2σ(95.4%)	3.96%
σ (68.3%)	1.98%

Table 3.2.2-15　24-hour demand fluctuation rate (Jaluit)

Probability	Demand Fluctuation Rate
Max (100%)	14.84%
3σ (99.7%)	5.72%
2σ(95.4%)	3.81%
σ (68.3%)	1.91%

3.2.2.3 Demand analysis (determining the expected load)

Analyze the demand distribution from the annual demand data to calculate cumulative distribution (σ, 2σ, and 3σ). Each power plant on each island keeps a daily operation report with demand data for every hour. The analysis will be performed based on this data. The demand distribution of Majuro is shown in Fig 3.2.2-22. Cumulative distribution is estimated from a section with high demand. Allowable adjustable margin increases with increase in demand, and thus increases the maximum allowable amount of RE. A specific example is shown below.

Example:　system constant 10% MW/Hz allowable frequency range 1Hz

①When demand is 10MW... allowable adjustable margin: 1MW (= 10MW × 10% MW/Hz × 1 Hz)

②When demand is 1MW... allowable adjustable margin: 0.1MW (= 1 MW × 10% MW/Hz × 1 Hz)

⇒As you can see, allowable adjustment margin increases with increase in demand.

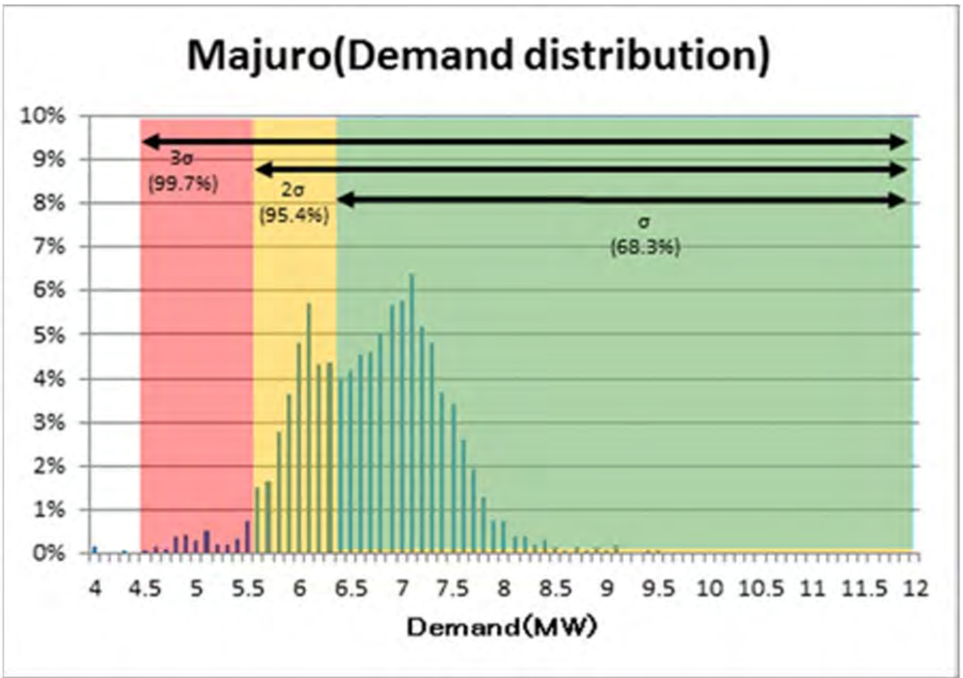


Fig 3.2.2-22　A representation of demand distribution

In order to analyze the connection of PV and wind power to the grid, it is necessary to analyze the expected load range using daytime data for PV and data for a whole day for wind power. Therefore, we analyzed the MW value distribution when demand data for daytime hours (9:00 to 17:00) and demand data for a whole day (24 hours) is extracted from the annual demand data.

(1) Majuro

Table 3.2.2-16 Daytime demand considering probability distribution (Majuro)

Min (100%)	3.60 MW
3σ (99.7%)	4.56 MW
2σ(95.4%)	5.85 MW
σ (68.3%)	6.70 MW
AVERAGE	6.88 MW

Table 3.2.2-17 24-hour demand considering probability distribution (Majuro)

Min (100%)	3.30 MW
3σ (99.7%)	4.50 MW
2σ(95.4%)	5.50 MW
σ (68.3%)	6.25 MW
AVERAGE	6.64 MW

(2) Ebeye

Table 3.2.2-18 Daytime demand considering probability distribution (Ebeye)

Min (100%)	1,027 kW
3σ (99.7%)	1,369 kW
2σ(95.4%)	1,589 kW
σ (68.3%)	1,737 kW
AVERAGE	1,780 kW

Table 3.2.2-19 24-hour demand considering probability distribution (Ebeye)

Min (100%)	1,011 kW
3σ (99.7%)	1,347 kW
2σ(95.4%)	1,559 kW
σ (68.3%)	1,702 kW
AVERAGE	1,764 kW

(3) Wotje

Table 3.2.2-20 Daytime demand considering probability distribution (Wotje)

Min (100%)	38 kW
3σ (99.7%)	44 kW
2σ(95.4%)	52 kW
σ (68.3%)	71 kW
AVERAGE	77 kW

Table 3.2.2-21 24-hour demand considering probability distribution (Wotje)

Min (100%)	33 kW
3σ (99.7%)	45 kW
2σ(95.4%)	55 kW
σ (68.3%)	73 kW
AVERAGE	80 kW

(4) Jaluit

Table 3.2.2-22 Daytime demand considering probability distribution (Jaluit)

Min (100%)	40 kW
3σ (99.7%)	50 kW
2σ(95.4%)	60 kW
σ (68.3%)	80 kW
AVERAGE	86 kW

Table 3.2.2-23 24-hour demand considering probability distribution (Jaluit)

Min (100%)	40 kW
3σ (99.7%)	50 kW
2σ(95.4%)	60 kW
σ (68.3%)	78 kW
AVERAGE	84 kW

3.2.2.4 Fluctuation in Solar Radiation intensity and Wind speed

MRD takes measurements of wind speed and solar radiation intensity in Wotje and Jaluit. The fluctuation rates for 10 minute windows for each were calculated by taking into account the probabilistic element. Since measurement data on Majuro and Ebeye were not available, data for Wotje was used instead.

(1) Wotje

(a) Solar radiation intensity

The maximum and minimum trend for solar radiation intensity in 10-minute windows is shown in Figure 3.2.2-23. At this time, the calculations were performed using 1kW/m^2 as the standard. In addition, the fluctuation rate trend at that time is shown in Figure 3.2.2-24. The results of the fluctuation rate calculated with the maximum, 3σ, 2σ and σ in are shown in Table 3.2.2-24. The data for 9:00 to 17:00 (daytime) from September 21, 2012 to August 15, 2013 was used to determine the fluctuation rate for sunlight.

Table 3.2.2-24 Sunlight fluctuation rate (Wotje)

	PV
Maximum (100%)	96.6%
3σ (99.7%)	90.2%
2σ(95.4%)	79.0%
σ (68.3%)	57.4%

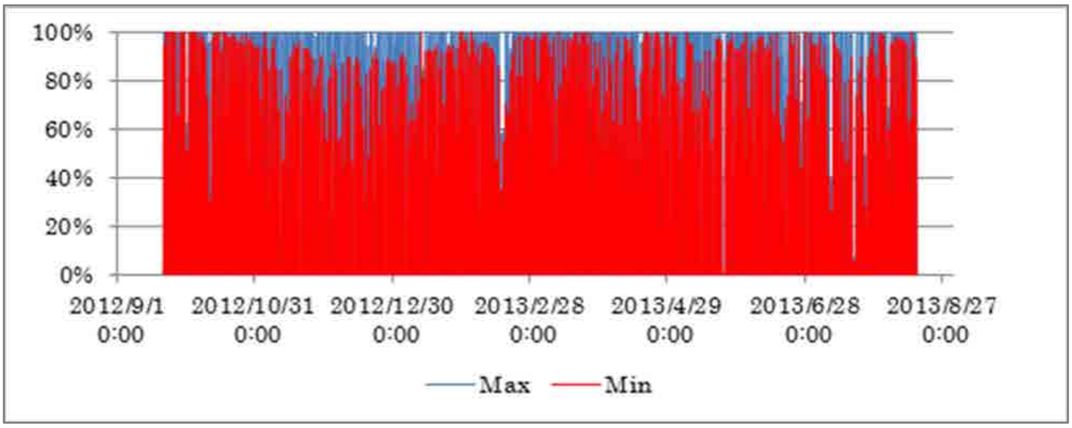


Fig 3.2.2-23 Maximum and minimum value of solar radiation intensity(Wotje)

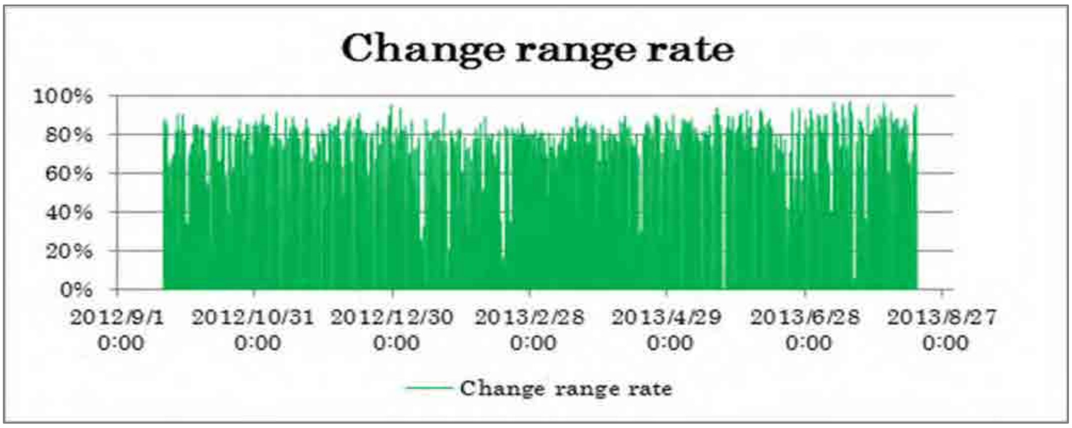


Fig 3.2.2-24 Sunlight fluctuation rate over time (Wotje)

(b) Wind speed

The maximum and minimum trend for wind speed in 10-minute windows is shown in Figure 3.2.2-25. The output for wind power generation estimated from wind speed was calculated using Homer. In addition, the fluctuation rate trend at that time is shown in Figure 3.2.2-26. The results of the fluctuation rate calculated with the maximum, 3σ, 2σ and σ in are shown in Table 3.2.2-25. The data from September 20, 2012 to August 15, 2013 was used to determine the fluctuation rate for wind power.

Table 3.2.2-25 Wind fluctuation rate (Wotje)

	WT
Maximum (100%)	100.0%
3σ (99.7%)	97.9%
2σ(95.4%)	79.5%
σ (68.3%)	55.7%

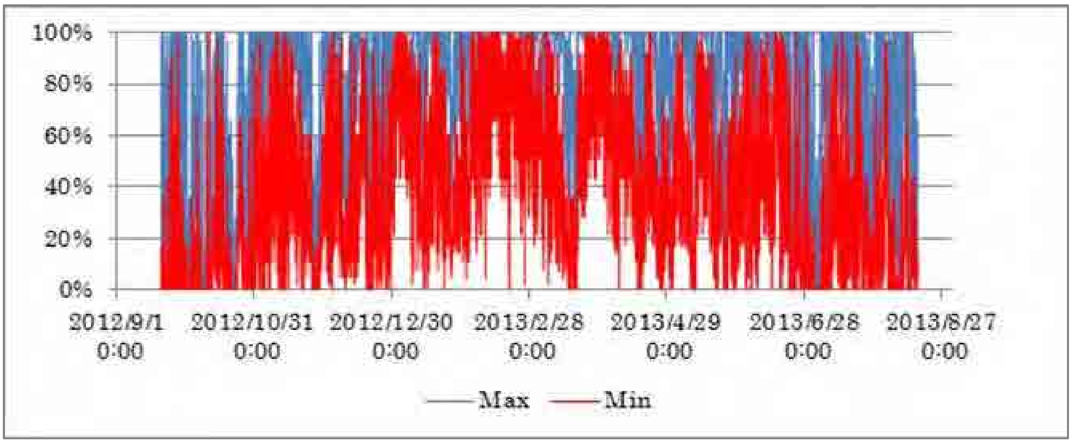


Fig 3.2.2-25　Maximum and minimum value of wind power(Wotje)

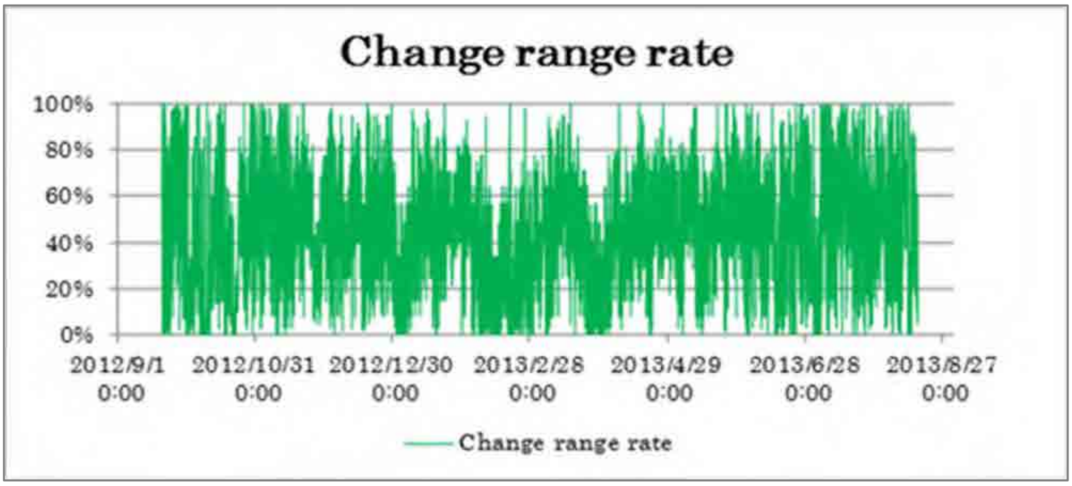


Fig 3.2.2-26　Wind power fluctuation rate over time (Wotje)

(2) Jaluit

(a) Solar radiation intensity

As in the previous section, the maximum and minimum trend for solar radiation intensity in 10-minute windows is shown in Figure 3.2.2-27. At this time, the calculations were performed using 1kW/m^2 as the standard. In addition, the fluctuation rate trend at that time is shown in Figure 3.2.2-28. The results of the fluctuation rate calculated with the maximum, 3σ, 2σ and σ in are shown in Table 3.2.2-26. The data for 9:00 to 17:00 (daytime) from September 21, 2012 to Monday, April 01, 2013 was used to determine the fluctuation rate for sunlight.

Table 3.2.2-26　Sunlight fluctuation rate (Jaluit)

	PV
Maximum (100%)	100.0%
3σ (99.7%)	86.8%
2σ(95.4%)	75.3%
σ (68.3%)	44.2%

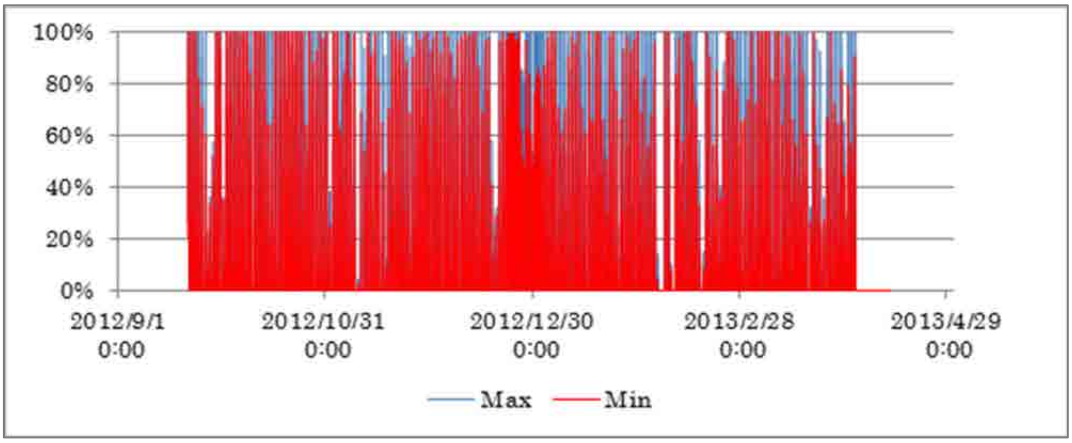


Fig 3.2.2-27 Maximum and minimum value of solar radiation intensity(Jaluit)

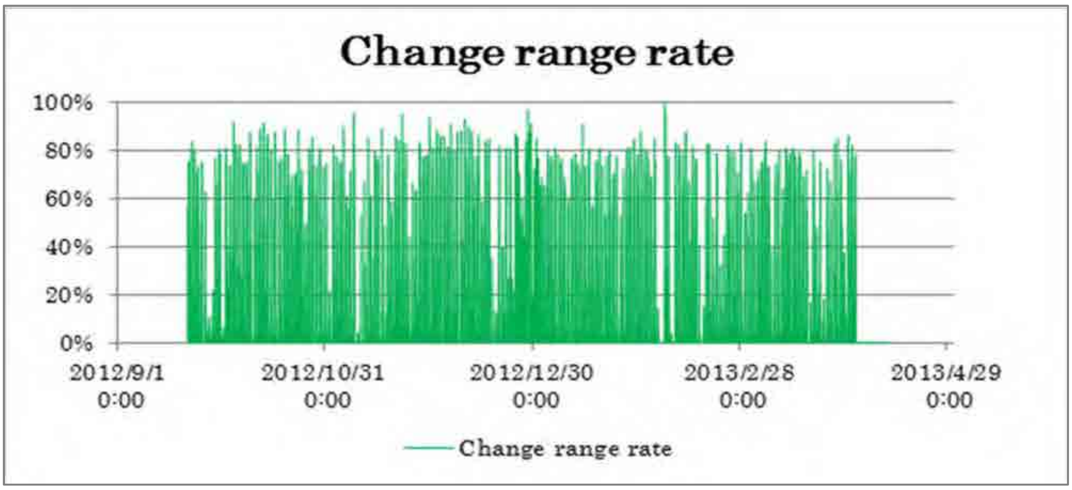


Fig 3.2.2-28 Sunlight fluctuation rate over time (Jaluit)

(b) Wind speed

As in the previous section, the maximum and minimum trend for solar radiation intensity in 10-minute windows is shown in Figure 3.2.2-29. The output for wind power generation estimated from wind speed was calculated using Homer. In addition, the fluctuation rate trend at that time is shown in Figure 3.2.2-30. The results of the fluctuation rate calculated with the maximum, 3σ, 2σ and σ in are shown in Table 3.2.2-27. The data from September 20, 2012 to Friday, April 12, 2013 was used to determine the fluctuation rate for wind power.

Table 3.2.2-27 Wind fluctuation rate (Jaluit)

	WT
Maximum (100%)	100.0%
3σ (99.7%)	99.0%
2σ(95.4%)	73.0%
σ (68.3%)	50.9%

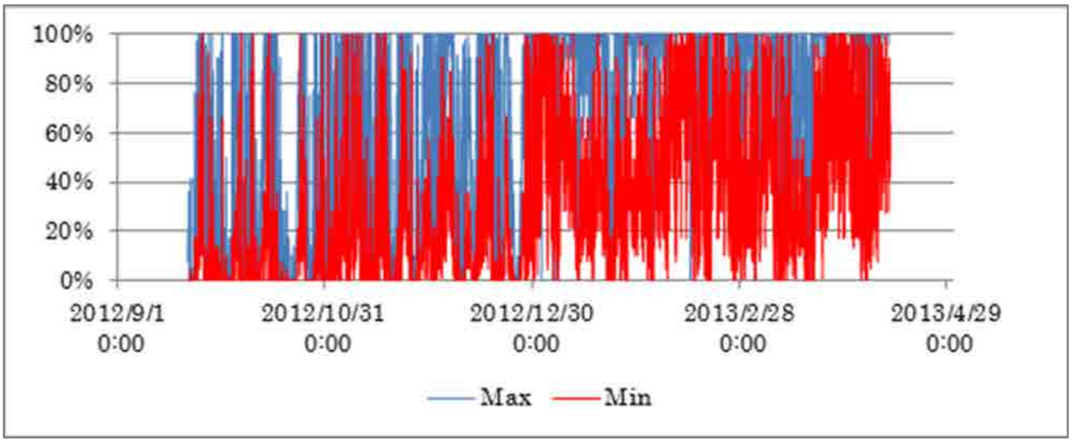


Fig 3.2.2-29 Maximum and minimum value of wind power(Jaluit)

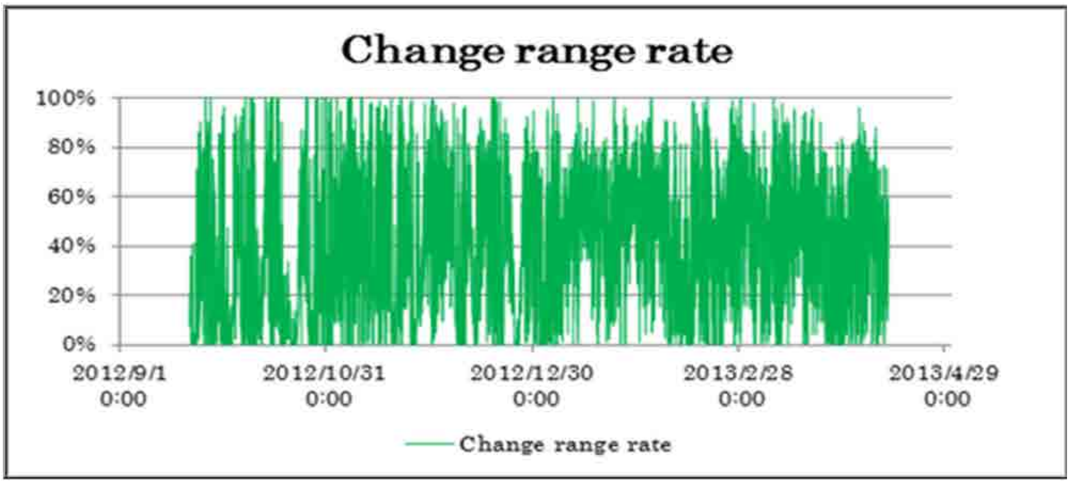


Fig 3.2.2-30 Wind power fluctuation rate over time (Jaluit)

3.2.2.5 Calculation results on the maximum allowable amount using the algebraic method

The results of maximum introduction in three different scenarios (PV only, wind turbines only, and a combination of PV and wind turbines) for each island are shown below. The GRG method (Generalized Reduced Gradient Method) was used in calculating maximum introduction.

In Japan, since frequency must be managed very strictly, calculating the introduction amount using 3σ (99.7%) or 2σ (95.4%), which is are strict conditions in terms of probability, is standard. Since using this condition as is will reduce the amount of RE that can be introduced in RMI, it is necessary to calculate the maximum allowable amount under conditions which match the needs of RMI. In this study, calculations were conducted using 3σ (99.7%), 2σ (95.4%), and σ (68.3%) as probabilistic elements. In addition, we examined three different patterns (0.3Hz, 0.5Hz, and 1.0Hz) for the allowable frequency fluctuation range. This allowable range must also be set based on the conditions in RMI.

(1) Majuro

(a) In the case of introducing only PV

In the most severe case (3σ, allowable frequency fluctuation range of 0.3Hz) the maximum allowable amount of PV is 170 kW. Almost no short period impact to the grid is expected under this condition. The total amount of PV currently introduced in Majuro is 260 kW (Majuro Hospital: approx. 209kW, Marshall Islands College:57 kW), but no short period frequency fluctuation problems have arisen. Considering this, it can be said that there would be very little impact on the grid when conforming to the results of the 3σ value.

Table 3.2.2-28 Calculation results for the maximum allowable amount of PV (Majuro)

Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
3σ (99.7%)	170 kW	300 kW	610 kW	4.56 MW
2σ(95.4%)	260 kW	440 kW	890 kW	5.85 MW
σ (68.3%)	420 kW	700 kW	1,410 kW	6.70 MW

(b) In the case of introducing only wind turbines

Table 3.2.2-29 The results in the case of introducing only wind turbines. Since wind turbines are capable of generating power at all hours, calculations were performed by expanding the time period studied to a whole day rather than only daytime hours. The reason the difference in the total demand used in this study and the total demand used in calculating the maximum allowable amount of PV is due to the difference in the time period considered.

Table 3.2.2-29 Calculation results for the maximum allowable amount of wind power (Majuro)

Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
3σ (99.7%)	160 kW	270 kW	550 kW	4.50 MW
2σ(95.4%)	250 kW	420 kW	840 kW	5.55 MW
σ (68.3%)	400 kW	680 kW	1,360 kW	6.25 MW

(c) In the case of introducing maximum PV and wind turbines

The maximum allowable amount when combining PV and wind turbines was calculated using the algebraic method and GRG method. The results are shown in Table 3.2.2-30. The calculations were performed by the setting to the daytime hours when PV power generation is possible. In addition, since there is no correlation to wind power and PV, we established that the fluctuation ranges intersect perpendicularly as shown in Fig. 3.2.2-31.

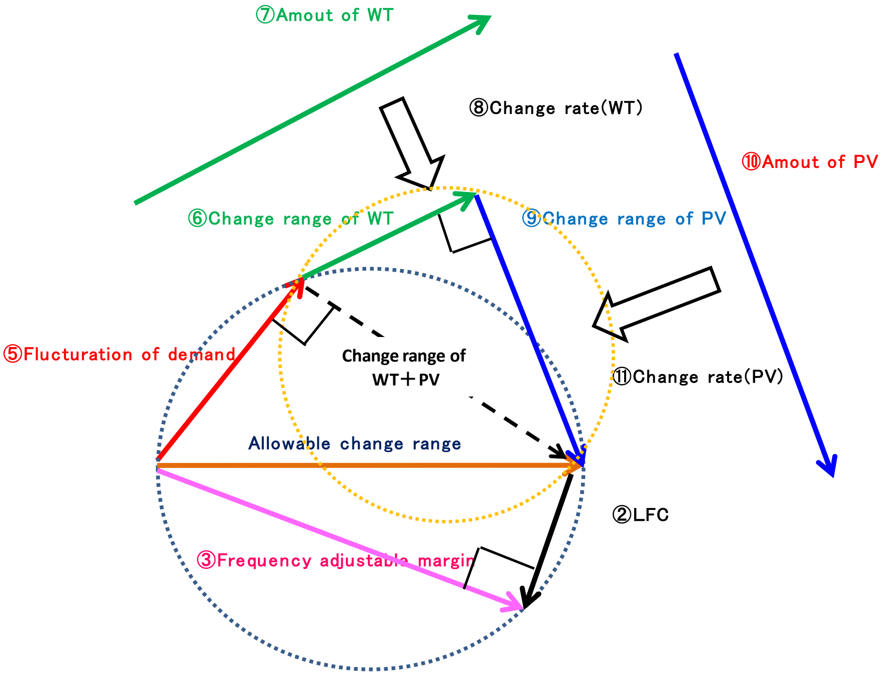


Fig. 3.2.2-31 A representation of the algebraic method when PV and wind power are combined

Table 3.2.2-30 Calculation results for the maximum allowable amount of RE

PV	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
	3σ (99.7%)	130 kW	220 kW	450 kW	4.56 MW
	2σ(95.4%)	180 kW	310 kW	630 kW	5.85 MW
	σ (68.3%)	290 kW	490 kW	980 kW	6.70 MW
WT	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
	3σ (99.7%)	110 kW	180 kW	380 kW	4.56 MW
	2σ(95.4%)	180 kW	310 kW	630 kW	5.85 MW
	σ (68.3%)	310 kW	520 kW	1,040 kW	6.70 MW
RE Total (PV＋WT)	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
	3σ (99.7%)	250 kW	400 kW	820 kW	4.56 MW
	2σ(95.4%)	360 kW	620 kW	1,260 kW	5.85 MW
	σ (68.3%)	600 kW	1,010 kW	2,030 kW	6.70 MW

(2) Ebeye

(a) In the case of introducing only PV

Table 3.2.2-31 PV maximum allowable amount (Ebeye)

Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
3σ (99.7%)	19 kW	51 kW	115 kW	1,369 kW
2σ(95.4%)	39 kW	74 kW	155 kW	1,589 kW
σ (68.3%)	68 kW	116 kW	235 kW	1,737 kW

(b) In the case of introducing only wind turbines

Table 3.2.2-32 WT maximum allowable amount (Ebeye)

Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
3σ (99.7%)	16 kW	46 kW	104 kW	1,347 kW
2σ(95.4%)	37 kW	72 kW	151 kW	1,559 kW
σ (68.3%)	68 kW	117 kW	237 kW	1,702 kW

(c) In the case of introducing maximum PV and wind turbines

Table 3.2.2-33 PV+WT maximum allowable amount (Ebeye)

	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
PV	3σ (99.7%)	14 kW	38 kW	84 kW	1,369 kW
	2σ(95.4%)	28 kW	52 kW	110 kW	1,589 kW
	σ (68.3%)	47 kW	81 kW	164 kW	1,737 kW
WT	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
	3σ (99.7%)	12 kW	32 kW	72 kW	1,369 kW
	2σ(95.4%)	27 kW	52 kW	108 kW	1,589 kW
	σ (68.3%)	50 kW	86 kW	174 kW	1,737 kW
RE Total (PV＋WT)	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
	3σ (99.7%)	26 kW	69 kW	156 kW	1,369 kW
	2σ(95.4%)	55 kW	104 kW	218 kW	1,589 kW
	σ (68.3%)	98 kW	167 kW	338 kW	1,737 kW

(3) Wotje

(a) In the case of introducing only PV

Table 3.2.2-34 PV maximum allowable amount (Wotje)

Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
3σ (99.7%)	0 kW	2 kW	6 kW	44 kW
2σ(95.4%)	1 kW	4 kW	8 kW	52 kW
σ (68.3%)	4 kW	7 kW	15 kW	71 kW

(b) In the case of introducing only wind turbines

Table 3.2.2-35 WT maximum allowable amount (Wotje)

Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
3σ (99.7%)	0 kW	2 kW	5 kW	45 kW
2σ(95.4%)	2 kW	4 kW	9 kW	55 kW
σ (68.3%)	4 kW	8 kW	16 kW	73 kW

(c) In the case of introducing maximum PV and wind turbines

Table 3.2.2-36 PV+WT maximum allowable amount (Wotje)

	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
PV	3σ (99.7%)	0 kW	1 kW	4 kW	44 kW
	2σ(95.4%)	1 kW	3 kW	6 kW	52 kW
	σ (68.3%)	3 kW	5 kW	11 kW	71 kW
WT	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
	3σ (99.7%)	0 kW	1 kW	4 kW	44 kW
	2σ(95.4%)	1 kW	2 kW	6 kW	52 kW
	σ (68.3%)	3 kW	6 kW	11 kW	71 kW
RE Total (PV＋WT)	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
	3σ (99.7%)	0 kW	3 kW	8 kW	44 kW
	2σ(95.4%)	2 kW	5 kW	11 kW	52 kW
	σ (68.3%)	6 kW	11 kW	22 kW	71 kW

(4) Jaluit

(a) In the case of introducing only PV

Table 3.2.2-37 PV maximum allowable amount (Jaluit)

Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
3σ (99.7%)	0 kW	0 kW	6 kW	50 kW
2σ(95.4%)	0 kW	4 kW	9 kW	60 kW
σ (68.3%)	5 kW	10 kW	21 kW	80 kW

(b) In the case of introducing only wind turbines

Table 3.2.2-38 WT maximum allowable amount (Jaluit)

Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
3σ (99.7%)	0 kW	1 kW	5 kW	50 kW
2σ(95.4%)	0 kW	4 kW	9 kW	60 kW
σ (68.3%)	5 kW	9 kW	18 kW	78 kW

(c) In the case of introducing maximum PV and wind turbines

Table 3.2.2-39 PV+WT maximum allowable amount (Jaluit)

	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
PV	3σ (99.7%)	0 kW	0 kW	4 kW	50 kW
	2σ(95.4%)	0 kW	2 kW	6 kW	60 kW
	σ (68.3%)	4 kW	8 kW	16 kW	80 kW
WT	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
	3σ (99.7%)	0 kW	0 kW	3 kW	50 kW
	2σ(95.4%)	0 kW	3 kW	7 kW	60 kW
	σ (68.3%)	3 kW	6 kW	12 kW	80 kW
RE Total (PV＋WT)	Allowable range	0.3 Hz	0.5 Hz	1.0 Hz	Total demand
	3σ (99.7%)	0 kW	0 kW	8 kW	50 kW
	2σ(95.4%)	0 kW	5 kW	13 kW	60 kW
	σ (68.3%)	7 kW	13 kW	28 kW	80 kW

3.2.3 Allowable frequency fluctuation and allowable risk range

The most important factors in assessing the maximum allowable amount of RE is how much fluctuation range can be allowed for frequency and to what extent risk is taken for the occurrence of frequency fluctuation. It is necessary to make the assessment taking into consideration the current achievements in RMI and how high the goals of promoting the spread of RE will be set.

【Important factors for calculating the maximum allowable amount】

①How much frequency fluctuation range will be allowed? The study must be conducted from the perspective of stable generator operation and customer needs.

②To what extent is the probability of the grid becoming unstable (risk) tolerable?

Frequency management targets for Japan's 10 electric power companies are shown in Table 3.2.3-1 and standards in Europe (EN50160) are shown in Table 3.2.3-2. In addition, allowable frequency fluctuation values according to a survey on electricity consumers in Japan are shown in Table 3.2.3-3.

After discussions in two seminars in RMI, we discovered that at 2 σ (95.4%), a frequency of 1 Hz will not disrupt the stable supply of power.

Table 3.2.3-1 Frequency management targets for Japan's 10 electric power companies

Power Company	Management target
Hokkaido	Standard frequency within ± 0.3 Hz
Tōhoku region	Standard frequency within ± 0.2 Hz
Tokyo	Standard frequency within ± 0.2 Hz
Chubu	Standard frequency within ± 0.1 Hz 【Target staying rate 95%】
Hokuriku	Standard frequency within ± 0.1 Hz 【Target staying rate 95%】
Kansai	Standard frequency within ± 0.1 Hz 【Target staying rate 95%】
Chugoku	Standard frequency within ± 0.1 Hz 【Target staying rate 95%】
Shikoku	Standard frequency within ± 0.1 Hz 【Target staying rate 95%】
Kyūshū	Standard frequency within ± 0.1 Hz 【Target staying rate 95%】
Okinawa	Standard frequency within ± 0.3 Hz

Table 3.2.3-2 EN50160 Standard

System frequency (10 sec. avg.)	Grid connection	99% of the year frequency fluctuation within ± 1%
		1% of the year frequency variation within ± 6%
	Independent grids	95% of the year frequency fluctuation within ± 2%
		5% of the year frequency fluctuation within ± 6%

Table 3.2.3-3 Allowable frequency fluctuation values according to a survey on electricity consumers in Japan

Organization	Target equipment	Allowable frequency fluctuation range (Hz)	Answers and helpful information
Japan Electrical Manufacturers ' Association (JEMA)	Induction motor	＋3%(1.5Hz) to －5%(2.5Hz)	For temporary fluctuations, ＋3%(1.5Hz) to －5%(2.5Hz) is the allowable arrange for rated frequency. But there are some with torque fluctuation like induction motors used in fans and blowers, but 3% frequency fluctuation will cause a 6.1% fluctuation. This does not cause any practical problems, but if frequency deviates for a long period of time, it will cause the temperature of the motor to rise.
	Servomotor	±5%(2.5Hz)	The allowable frequency fluctuation range for the servo is ±5%(2.5Hz). When there is a deviation from this, the servo can no longer maintain its characteristics (performance), so measures such as stopping it need to be taken.
	Power electronics equipment	±5%(2.5Hz)	No effect if within the normal operation assurance range (±5%：2.5Hz).
	Transformer	±5%(2.5Hz)	Transformation equipment must satisfy the allowable frequency values stipulated by JEC standards. In general the rated frequency is ± 0.5%(2.5Hz).
Japan Machine Tool Builders' Association (JMTBA)	Machine tools	—	The Builders' Association has not studied the effects of domestic fluctuations. Concerning products, as a countermeasure for instantaneous voltage drop, computer control units are equipped with an uninterruptible power supply, but for motor parts, etc., not measures have been taken for frequency fluctuations. As a practice in the machine tools industry, the tolerance of frequency fluctuation is hardly ever listed in catalogs. Also, devices are often divided into 50 Hz use and 60 Hz use. Proper operation is not assured, but we have confirmed operation in developing countries (frequency fluctuation of about ±5%) without any modifications to the power source.
Association for Electric Home Appliances (AEHA)	Consumer electronics	—	The impact of frequency fluctuation on consumer electronics products are considered to vary depending on the individual product, so studies like these are left to each relevant industry association, and our Association has not conducted such a study. Recent appliances can be used on both 50 and 60 Hz, and tolerance for frequency fluctuation has become large. They are less susceptible to the effects of frequency fluctuations. (Catalog analysis)
Japan Electronics and Information Technology Industries Association (JEITA)	Information appliances	—	As far as standardization, the standard pertaining to the frequency of stabilized power supply becomes a problem. Regarding this, we are working on this while referring to the IEC international standard. Adapters for electronic products are increasingly becoming universal, and they can be used for both 50 and 60 Hz. The operating range for frequency is generally secured at 47 – 63 Hz. (Catalog analysis)
Communication and Information Network Association of Japan (CIAJ)	Information appliances	—	Harmonics, voltage fluctuations, and electromagnetic interference are targets of study, but we have not had any cases where frequency fluctuations was an issue. Adapters for electronic products are increasingly becoming universal, and they can be used for both 50 and 60 Hz. The operating range for frequency is generally secured at 47 – 63 Hz. (Catalog analysis)
Japan Lighting Manufacturers Association (JLMA)	Lighting	—	We have not conducted any studies on frequency fluctuations. Inverter rectification is almost unaffected. We have conducted studies on the effect of misuse of 50 or 60 Hz for fluorescent lamp stabilizers, but almost no manufacturer has conducted a study on the effect of fluctuations below 1 Hz. There are no frequency impacts with 50/60Hz combined use for fluorescent lamps. Concerning stabilizers, frequency fluctuations over a short period of time should not be a problem for inverter-type products which have recently become popular. (Catalog analysis)
Japan Electric Measuring Instruments Manufacturers' Association (JEMIMA)	Measurement and control equipment	—	Since power protection for measurement instruments have become very robust, frequency fluctuations listed in catalogs have no impact, so no such studies have been conducted. The allowable range for input frequencies of equipment such as UPS is about 50/60Hz ±2.5 – 4.5Hz. (Catalog analysis)
NIPPON ELECTRIC CONTROL EQUIPMENT INDUSTRIES ASSOCIATION (NECA)	Measurement and control equipment	—	Since we assume we use a stabilized power supply, we have not conducted studies on the impact of frequency. The allowable range for input frequencies of equipment such as UPS is about 50/60Hz ±2.5 – 4.5Hz. (Catalog analysis)

(Source: Agency for Natural Resources and Energy, Wind Power Grid Integration Measures Subcommittee)

3.2.4 Power system measures for the expansion of RE integration

So far, we have evaluated the maximum amount of RE that can be connected to the existing grid. There is a need to enhance the grid's ability to make adjustments if the goal is to expand on this amount. Three methods for realizing this are as follows.

1) Improving the control factor for the existing diesel generators (improved GF) ⇒ system constant increase
2) AFC function addition (modification of existing diesel generators, storage battery installation) ⇒ increase in LFC
3) Reduction of RE fluctuation rate with batteries ⇒ RE fluctuation rate reduction

This section describes how to calculate using the algebraic method when the 3 methods above are applied to Majuro's grid (see Fig 3.2.4-1), and approximations of PV integration capacity for each measure are shown in Table 3.2.4-1.

The calculation conditions here are set at 2σ (95.4%) for fluctuation risk, and ± 1Hz for allowable frequency fluctuation range.

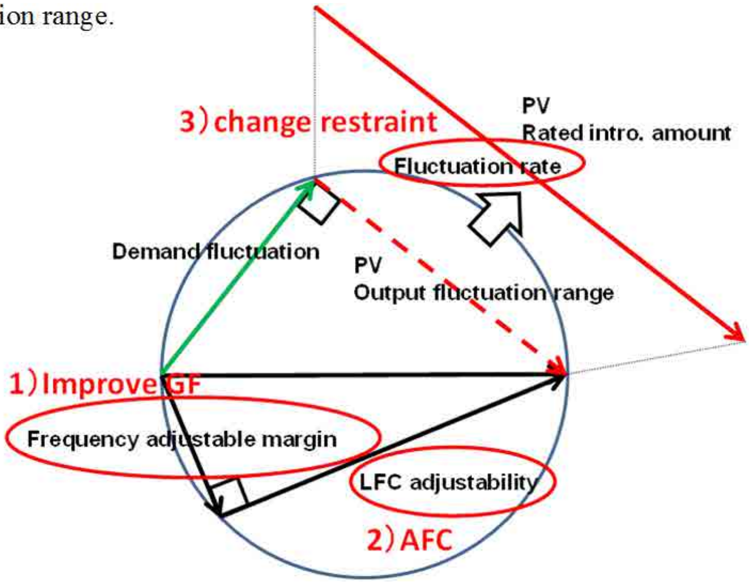


Fig 3.2.4-1 Parameter change when measures to maximize RE integration are applied to the algebraic method parameter

Table 3.2.4-1 The PV maximum allowable amount when maximization measures are taken (approx.)

Maximization Method	Allowable PV amount	Note
No measures	890 kW	-
Improve GF	1110 kW	System constant: 12.1 ⇒ 15.0
AFC (Battery or DG)	1090 kW	AFC: 0 ⇒ 500ｋW
PV output fluctuation control (Battery)	1120 kW	PV fluctuation range: 0.790 ⇒ 0.632 (Reduction ratio：80%)

(1) Improving the control factor for the existing diesel generators (improved GF)

By increasing the sensitivity of the diesel generators, sensitivity to frequency change increases. As a result, the system constant value becomes large. Therefore, when the allowable adjustable margin becomes large, the amount of RE allowable can be increased. Here, the RE maximum allowable amount calculation results are shown as an example if Majuro's system constant were improved from the current 12.1% MW/Hz to 15% MW/Hz. With the algebraic method, allowable adjustable margin (1 of Figure 3.2.4-1) increases. As a result, an additional 220 kW of PV can be introduced.

(2) AFC function addition (modification of existing diesel generators, storage battery installation)

By remodeling existing diesel generators or adding an AFC function with storage batteries, LFC adjustability (2 in Figure 3.2.4-1) will increase. Here, we assumed that 500 kW of AFC adjustability was added in performing the calculation. As a result, an additional 200 kW (approx.) of PV can be introduced.

(3) Reduction of RE fluctuation rate with batteries

We will calculate the PV maximum allowable amount, when PV output fluctuation is controlled in concert with battery output to reduce the PV fluctuation rate. When the fluctuation rate decreases (3 in Figure 3.2.4-1), the amount of PV allowable increases. Here, the calculation was carried out assuming the reduction rate for fluctuation is 80%. As a result, an additional 230 kW (approx.) of PV can be introduced.

* Note that the calculation for expansion of PV integration mentioned above is only an example. To actually consider measures, equipment specifications and costs should be considered.

3.3 Assist in planning and designing PV-diesel hybrid system

3.3.1 Basic system configuration

We will present the following 3 basic system configurations.

- PV-DEG hybrid system
- PV-WT-DEG hybrid system
- PV-Battery-DEG hybrid system

Keeping in mind that in any case, the system will be introduced to a small remote island, the configuration will consist of multiple generators.

We believe that by using a multi-unit configuration, serviceability can be enhanced on small remote islands where backup and maintenance are not easy.

(1) PV-DEG hybrid system

In most cases, a system stabilizing device such as a storage battery is incorporated in PV/diesel power generation hybrid systems. However, power system stabilizers are expensive, so if such equipment is incorporated, the economic burden on MA to introduce the system alone is heavy making it unfeasible. Therefore, in this project, we will propose and design a system that does not feature a stabilizer such as a power storage battery. An example system is described below.

＜A PV system that does not use storage batteries＞

- ■ A system with improved frequency stability through quantity control performed by the power conditioners (PCS) that comes with the PV system
- ■ A system that takes into account low-output DEG operation measures through quantity control of power conditioners (PCS)

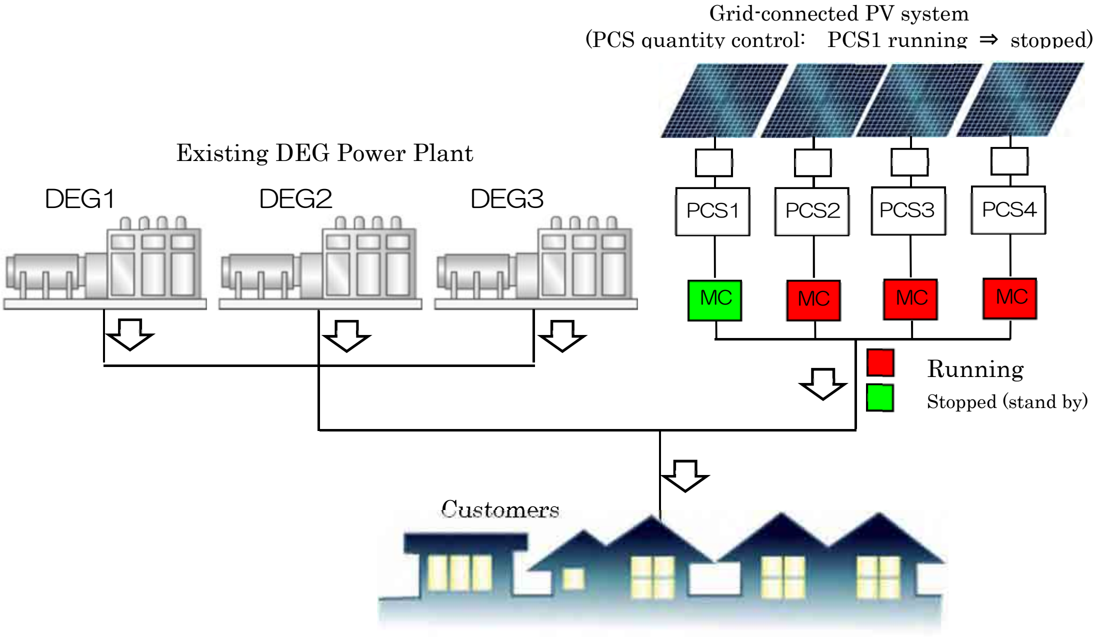


Figure 3.3.1-1 Schematic diagram of PV/DEG hybrid system (not equipped with batteries)

＜Features/advantages of the system＞

- ■ As each PCS can be switched on and off individually, limiting output can be done in a stepwise fashion.
  (Complex control equipment is not required in performing output limit control)
- ■ Mitigate the risk of total shutdown of the PV system due to PCS failure
  Even if one PCS fails, only the failed unit is cut off, and the other functional units will continue output, so it does not interfere with the operation of the whole system.
- ■ Using PCSs with low output capacity (compact and lightweight) improves workability.
  The number of PCSs installed will increase, but a foundation, anchoring, etc. for a high-capacity PCS is not required, and the installation method is simple (wall installation, etc.).

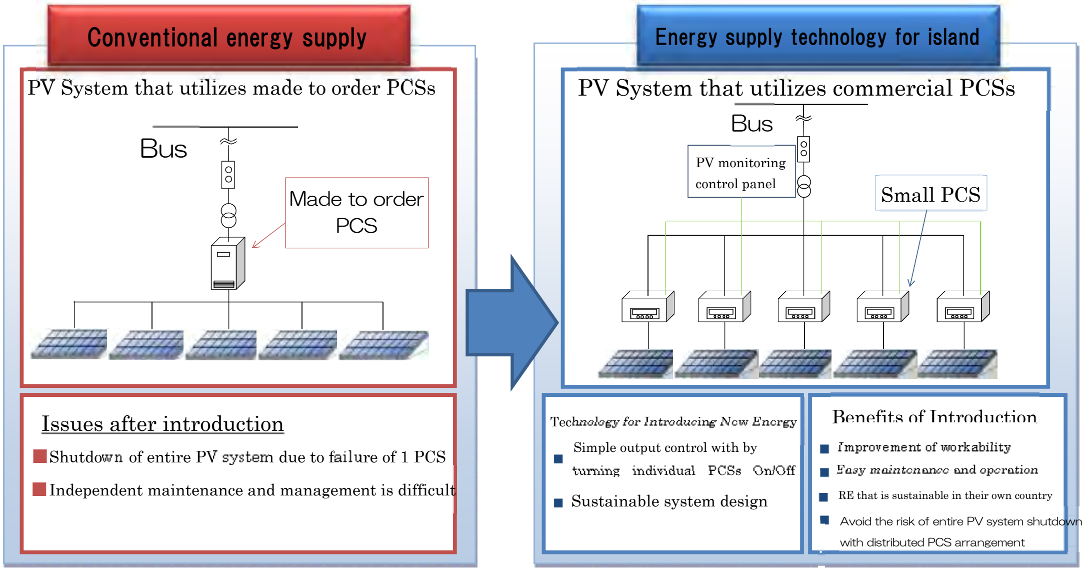


Figure 3.3.1-2　System configuration that makes operation and maintenance sustainable

Since the power supply structure in RMI is dependent on diesel fuel, it is susceptible to high oil prices which makes it very vulnerable. Power costs have become more expensive especially on remote islands . Large-scale introduction of PV systems is an effective way to resolve such issues. However, various problems such as the loss of power quality and supply reliability and low output operation of diesel generators may occur with mass introduction of PV systems, so in order to introduce PV systems, measures to prevent these problems are required. Therefore, the introduction of a hybrid system which controls the PCS units in operation depending on grid and PV system output conditions is an effective method to resolve these problems.

More specifically, when system frequency fluctuations become large due to fluctuations in PV system output, the number of PCS units operation is reduced (quantity control) to reduce the PV system output fluctuation range, and thus the grid frequency fluctuation is controlled. In addition, for low-load DG operation, DGs are monitored and when output drops below the output lower limit, quantity control is performed on the PV system to prevent low-output DG operation by reducing the number of PCS units in operation. Moreover, when DG output exceeds the output lower limit, the number of PCS units in operation is increased to enable maximize utilization of the power generated by the PV system.

Also, combining multiple commercial small capacity PCSs makes it possible for owners to handle failures on their own, so rapid recovery is possible, and increased equipment utilization can be expected. Compared to systems that use made to order type PCSs, troubleshooting costs can be reduced. It has an advantage in terms of workability as the owner can sustainably operate and maintain it independent of manufacturers.

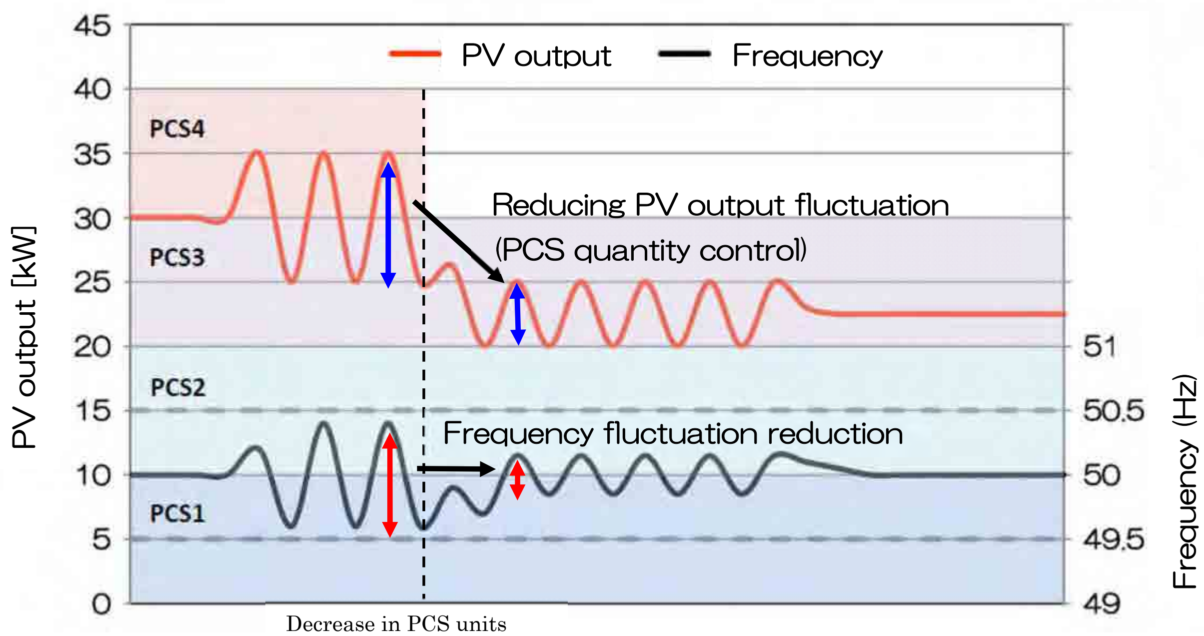


Figure 3.3.1-3 Schematic of frequency stabilization measures through PCS quantity control

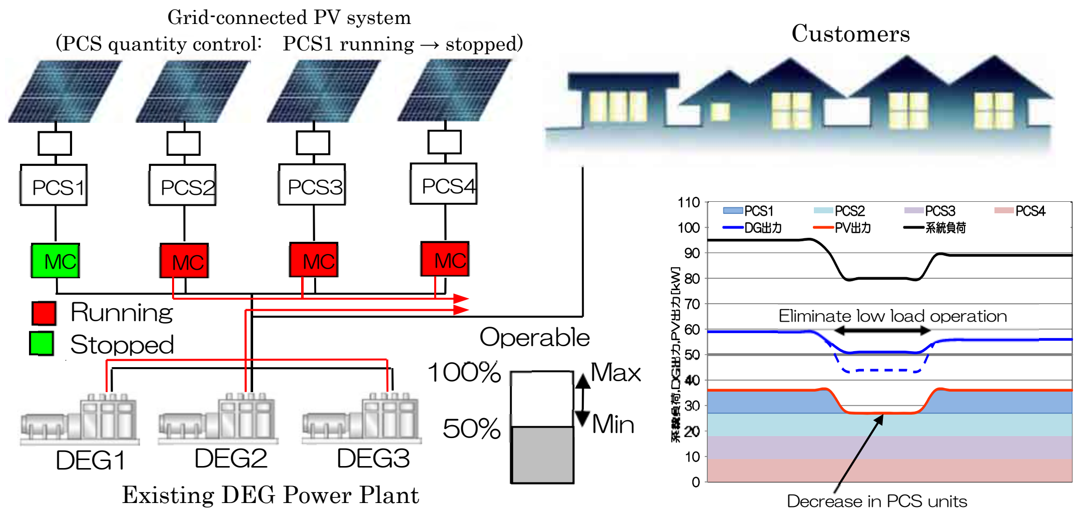


Figure 3.3.1-4 Schematic of measures for low-load DEG operation through PCS quantity control

(2) PV-WT-DEG hybrid system

This system is basically similar to the PV/diesel power generation hybrid system.

The basics of the WT is that it is small with a capacity of 5-25 kW and is capable of connecting to an inverter.

An example system is described below.

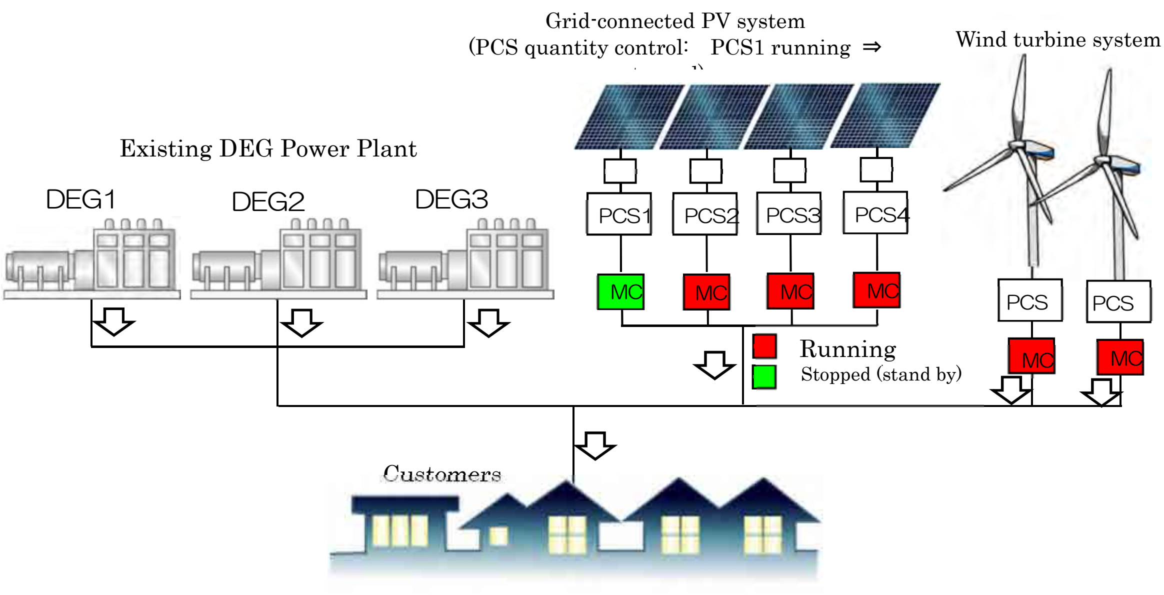


Figure3.3.1-5 Schematic diagram of PV-WT-DEG hybrid system (not equipped with batteries)

(3) PV-Battery-DEG hybrid system

This system is basically similar to the PV/diesel power generation hybrid system.

It is possible to increase the RE supply rate to a high percentage by using a battery to absorb PV fluctuations and surplus power. Some WT can also be included in the system configuration.

As a storage battery equipment is very expensive, economic study is necessary.

An example system is described below.

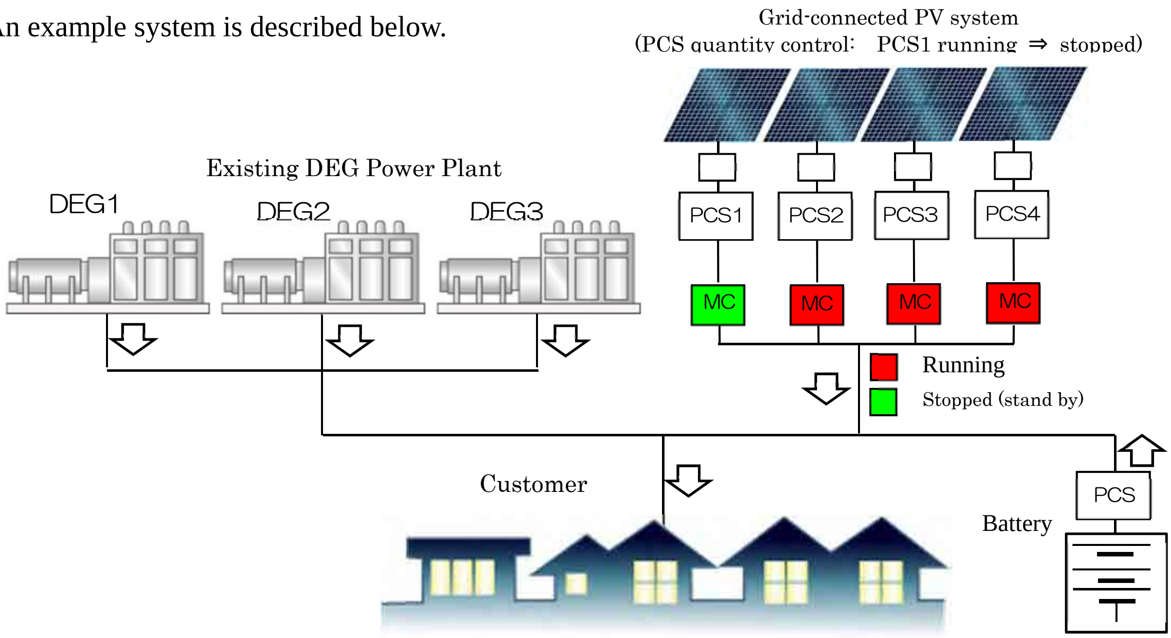


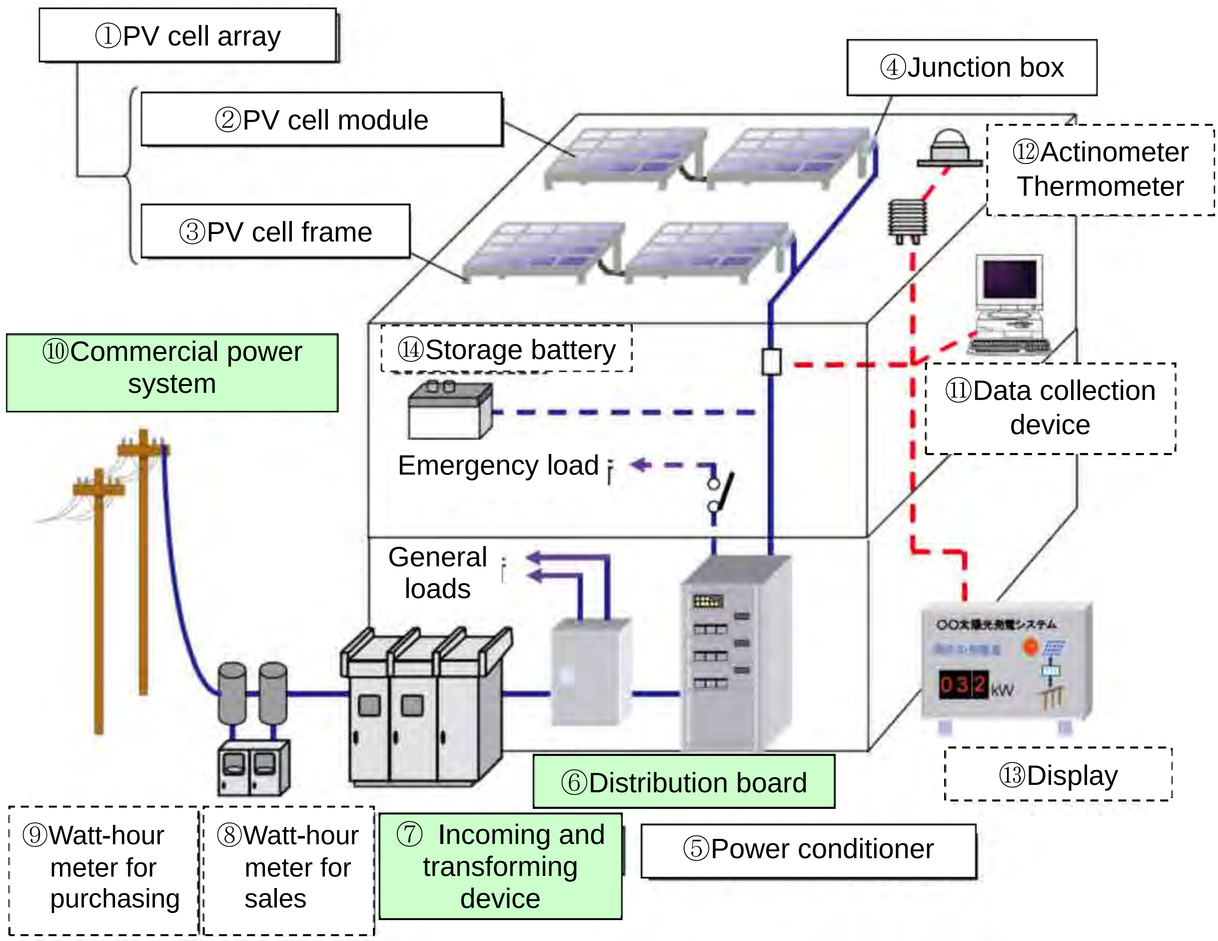
Figure 3.3.1-6 Schematic of a PV-Battery-DEG hybrid system

3.3.2 Basics of a PV system

(1) Definition of terms

Figure 3.3.2-1 is a typical system configuration of an industrial photovoltaic power system. Technical terms for this system are listed in table 3.3.2-1.

Generally, the output of a 3-phase 3-wire type power conditioner is more than 10kW, and the minimum capacity of this industrial PV power system is 10kW, which usually will only require a single power conditioner.



*Interconnection can be done at low-voltage (directly interconnect at low-voltage without connecting incoming and transforming device, or deemed as low-voltage interconnection utilizing incoming and transforming device) or high-voltage.

*Distribution board, incoming and transforming equipment, and commercial power system are existing equipment.

*Data collection device, actinometer & thermometer, display device, and storage battery may not be required.

Figure 3.3.2-1 Industrial PV Power System Diagram[95]

[95] Source:Japan Photovoltaic Energy Association, “PV power system manual” http://www.jpea.gr.jp/point/index.html

Table 3.3.2-1 Technical Terms for Industrial PV Power Systems[96]

№	System Component	Description
①	PV cell array	- A group of PV cell modules connected mechanically and electrically on a frame
②	PV cell module	- A panel, which converts photovoltaic energy directly into electric energy (AC power)
③	PV cell frame	- Base frame used to mount PV cell modules at a certain angle - Generally made of a steel or aluminum alloy - Unnecessary when using building-integrated type modules
④	Junction box	- A box which contains all of the power cables from each string of PV cell modules - Contains an embedded anti-reverse flow diode to prevent power from flowing back to the solar cell side in addition to a power switch and lightening protector for use during inspection and maintenance - Often incorporated into the power conditioner
⑤	Power conditioner	- Provides control to maximize the generation of DC power from solar cells and also converts into AC power - The interconnection protective device is normally equipped to prevent negative impact on the utility distribution system (commercial power system) - Able to operate independently supplying power for specific loads even in the event of a power outage from the commercial source
⑥	Distribution board	- Distributes power for each electrical load in the building - Interconnection point between the power conditioner output and the commercial power system - Dedicated circuit breaker is necessary for the PV system
⑦	Incoming and transforming equipment	- Receives power from the commercial power system (6.6kv, etc.) and converts it into lower voltage power (3-phase 3-wire 200V) or lighting power source (single-phase 3-wire 200/100V). - Some low-voltage receiving points don't require these devices
⑧	Watt-hour meter for power sales	- Measures power sold back to the utility company (excess power) for systems wherein reverse flow is enabled. Some utility companies obligate consumers to provide such meters at their own cost - The meter sometimes varies depending on the type of purchase agreement with the utility company
⑨	Watt-hour meter for power purchasing	- Measures purchased amount of power (demand consumption) from the utility company. The utility company should replace the conventional meter with one that has a reverse protection function
⑩	Commercial power system	- Commercial power system provided by the utility company. AC 3-phase 3-wire 6.6kv or 200v, etc.
⑪	Data collection device	- A device used to collect and store data including power output, etc. Usually, an ordinary PC is used.
⑫	Actinometer, thermometer	- Devices used to measure insolation and ambient temperature
⑬	Display device	- Indicates power output, total energy production, radiation levels, etc. for promotional purpose
⑭	Storage battery	- Allows the storage of electricity generated during the daytime and releases it at night or when there's trouble with the utility system. In that case, a controlling unit for charging / discharging and another junction box for the storage battery connection will be necessary.

* ⑪ data collection device, ⑫ actinometer, thermometer, ⑬ Display device, and ⑭ storage battery are installed as necessary depending on the situation.

[96] Source:Japan Photovoltaic Energy Association, "PV power system manual" http://www.jpea.gr.jp/point/index.html

(2) The principle of PV cells

Nowadays, many solar cells are made by the crystalline silicon semiconductor. This subsection describes the principle of PV cells made by the crystalline silicon semiconductor.

When the sunlight shines on the two kinds of different silicon semiconductor (n type and p type), the light energy will be absorbed in a solar cell and holes which are positive (+) and electrons which are negative (-) are generated. The hole is attracted to p type and the electron is attracted to n type, and if the load is connected to an electrode, a current will flow. Although it is called a battery, it won't be able to generate electricity without solar radiation, and the PV cell cannot store electricity in itself.

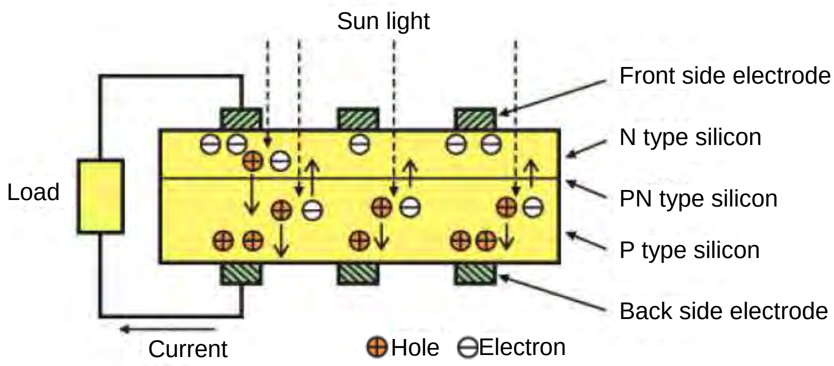


Figure 3.3.2-2 The power generation principle of PV cells[97]

(3) Type of PV panel

The manufacturing process and the characteristics of a PV cell are different depending on its material. The materials of the PV cell can be classified into silicon type, compound type and organic type like the figure 3.3.2-3. Also, the table 3.3.2-2 shows the characteristic and the application of each PV cell.

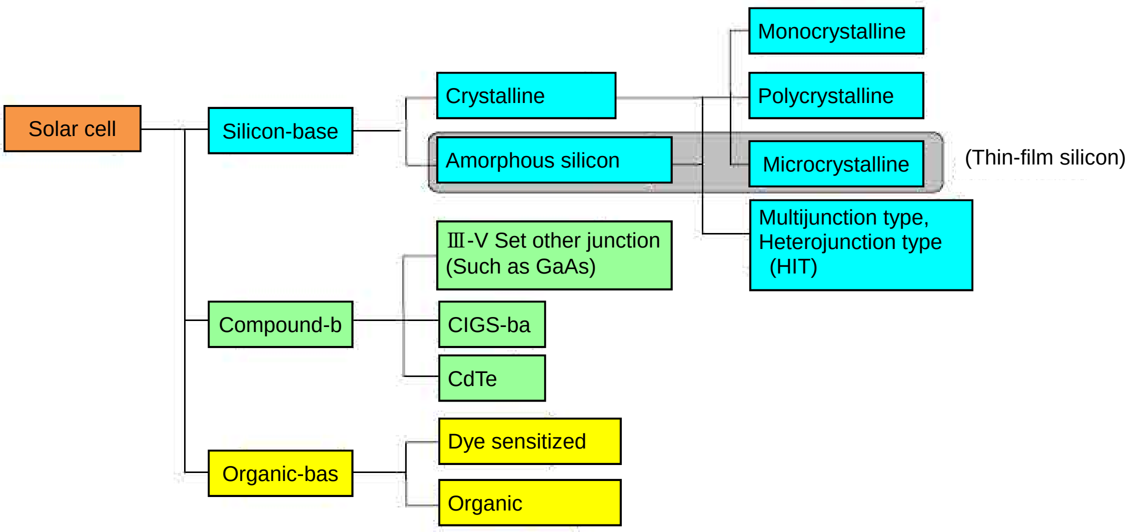


Figure 3.3.2-3 The type of PV cell[98]

[97] Source:NEDO "the manual for installation of a large-scale PV power generation system"
[98] Source:NEDO "the manual for installation of a large-scale PV power generation system"

Table 3.3.2-2 The characteristics of each PV cell[99]

Silicon	Monocrystalline Silicon	A high purity monocrystalline silicon wafer is used, it has been used most for many years. The conversion efficiency is high and excellent in reliability. However, the amount of high-purity silicon usage is high and energy and cost required for production become high. At present, conversion efficiency of commercial module is about 15% to 19%.
	Polycrystalline Silicon	This is the most popularly used PV cell now. It is PV cells that use polycrystalline silicon consist of small crystals. The module's conversion efficiency is lower than monocrystalline silicon. However, the energy required for production is less and it is excellent in energy budget, energy payback tune (EPBT), greenhouse gas emission, and reduced cost. At present, conversion efficiency of the commercial module is about 13% to 16%.
	Thin-film Silicon	This type is getting popular due to the shortage of silicon materials. It is made by forming a very thin film, about 1/100 of crystalline silicon. An amorphous or microcrystalline is used. Although the efficiency is low, it is easy to mass-produce, and the strong point is to make a lightweight and flexible module. The conversion efficiency of the commercial module is about 6% to 11%.
	Heterojunction (HIT)	This PV cell is laminated with crystalline silicon and amorphous silicon. It is resources saving and a high conversion efficiency compared with regular crystalline silicones. Temperature performance is also good. The conversion efficiency of the commercial module is about 16% to 19%.
Compound	CI(G)S	This type is made from compound such as copper (Cu), indium (In), gallium (Ga), selenium (Se) and sulfur (S), instead of silicon. It is a resource saving, and the conversion efficiency can be the same as polycrystalline silicon. The mass productivity is good, so there is a big potential for cost savings. The conversion efficiency of the commercial module is about 9% to 11%.
	CdTe	This CdTe type uses cadmium that has toxicity, but the mass productivity is good and the production cost is low. Due to these advantages, this type is used in a large-scale of PV power plant in Europe and the U.S., and it has been promoting rapidly. The conversion efficiency of the commercial module is about 9% to 11%.
	Condenser	This type is mainly used for space applications. When it collects sunlight, it performs more than 40% conversion efficiency, so this is an ultra-high performance PV cell. It has a very high production cost, but it is being studied for utilization in concentrating type system in countries and regions that have much direct sunlight.
Organic	Dye sensitizer	This is a new type of PV cell. Without using pn junction, dye adhering to titanium oxide absorbs light and emits electrons to generate. It is lightweight and colorable. Significant cost reduction is expected in future mass-production. The current challenge is its efficiency and durability. The development for practical utilization is in progress.
	Organic thin-film	This PV cell is currently under development, and it uses a semiconductor thin film contained in an organic substance. It can be made by just coating a film at room temperature, and also it can be colorful and lightweight.

[99] Source:NEDO "the manual for installation of a large-scale PV power generation system"

(4) The Structure and the composition of PV modules

(a) The structure of PV modules

The structures of PV modules are classified into following types.

1) Super-straight type

a) Crystalline silicon type

This structure connects PV cells with the lead frame, and is sealed with weather resistant fill material and film. The surface is sandwiched by a highly shock-resistant cover glass and a weather resistant film on the back.

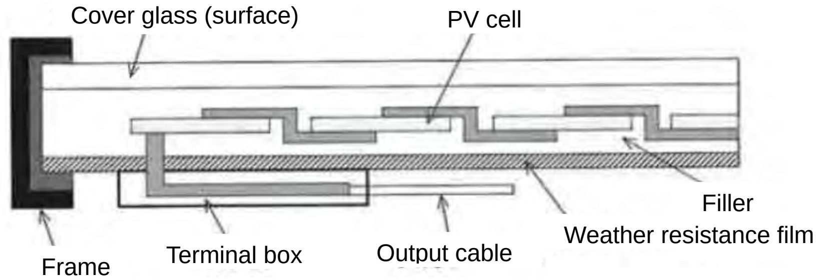


Figure 3.3.2-4 Super straight type: Crystalline silicon

b) Thin film silicon type

This structure is composed of transparent electrodes, PV cells and backside-electrodes which are all laminated by the glass cover, and sealed with fill material and weather resistant film.

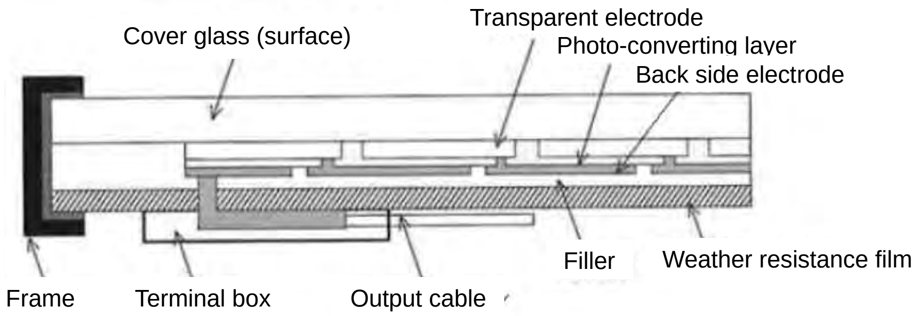


Figure 3.3.2-5 Super straight type: Thin film silicon

c) CIS/CIGS type

The structure is composed of electrodes and PV cells which are laminated on a glass substrate, and sealed with fill material, and the surface is sandwiched by cover glass and weather resistant film on the back.

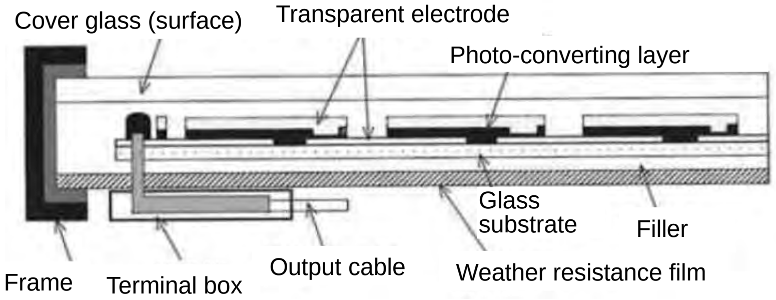


Figure 3.3.2-6 Super straight type: CIS/CIGS

2) Sub-straight type

This structure uses a transparent film on the surface side, and is reinforced by the substrate on the back.

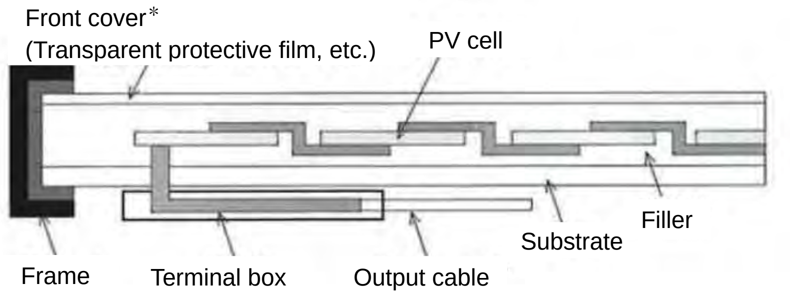


Figure 3.3.2-7 Substrate type

3) Laminated glass type

This structure uses glass on both sides, allowing sunlight, to penetrate.

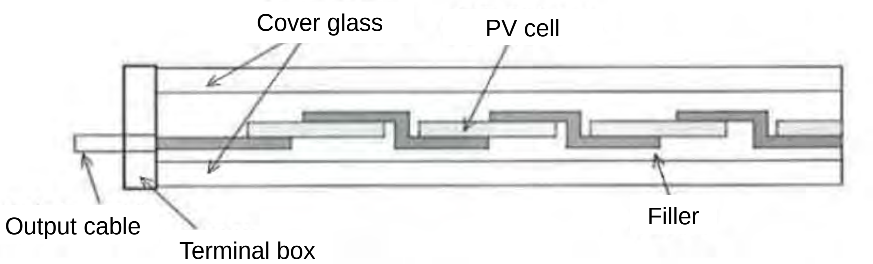


Figure 3.3.2-8 Laminated glass type

(5) Composition of PV module

(a) Front cover

A heat-treated super white glass with high shock-resistance and about 3mm thickness, maintaining transmissivity of 90% and more, is generally used for the front cover glass.

The hail test is specified by "the environmental test method and the durability test method of a crystalline PV module (JIS C8717) and "the environmental test method and the durability test method of an amorphous PV module (JIS C8938)" for quality control. It is specified that the mechanical strength to the shock by ice ball shall be examined in the hail test, but it might be replaced by the simple test that drops a hard sphere (the mass of 227±2g, and 38mm in diameter).

(b) Frame

A frame bar coated with acrylic on the surface of anodized corrosion-resistant treatment aluminum, is commonly used. The structure of long sapwood is big, and it is classified into two types: U-shaped and hollow. Although most of the ribs are mounted on the inside, there are cases when they are mounted on the outside. In particular, modules for residential use are designed to match the clamps, and the adjoining modules can be superimposed. In this way, the structure details vary depending on the module.

(c) Holes for mounting

In order to mount a module to a frame, 3 to 4 holes of approx. ϕ 6.0 mm to 9.7mm for mounting are drilled on both long sides of the frame. In addition, a hole of approx. ϕ 4.0 mm to 6.5mm for grounding or for wiring is drilled.

(d) Terminal box

Generally, the lead wire (insulation cable) that retrieves output from the module is connected to a resin terminal box. Also, an exclusive waterproof connector is attached at the tip of the lead wire (insulation cable), making it possible to connect to other modules and external cables.

(e) Lead wire (insulation cable)

The cross-linked polyethylene insulated PVC sheathed cable (CV cable) is commonly used for the lead wire. Recently, the eco-cable, which is environmentally friendly, is used. The size of the lead wire varies depending on each company's module output. Also, the polarity of a lead wire is either distinguished by cable color, marked on a cable, or indicated on the terminal box. The display by the cable color varies depending on the manufacturer, so check manufacturer specifications.

Monocrystalline module

Polycrystalline module

Thin film silicon multi-junction module

CIS type module

Figure 3.3.2-9 Samples of various PV module appearance[100]

[100] Source: Japan Photovoltaic Energy Association "PV power generation system manual" http://www.jpea.gr.jp/point/index.html

3.3.3 Basics of a wind turbine

(1) Approximate wind turbine output

(a) Approximate wind turbine output

The output of a wind turbine varies greatly depending on the wind speed, so it is difficult to intuitively determine it, but the diagram shows the output trends from market data as a guide. For example, if a wind turbine has a 4m diameter and the wind speed is 8m/s, the typical output is 1 kW.

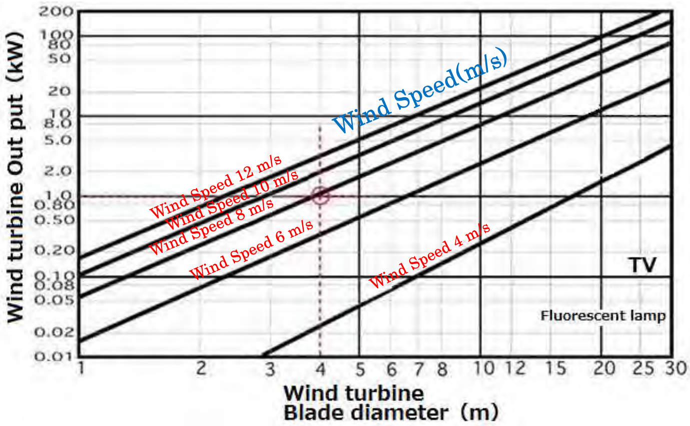


Figure 3.3.3-1 Approximate wind turbine output

(b) Separation of wind turbines

It is recommended to secure 10D (10 times the rotor diameter) of separation with respect to the main wind direction and 3D perpendicularly. If no separation is secured, an output reduction of 10 to 40% is possible.

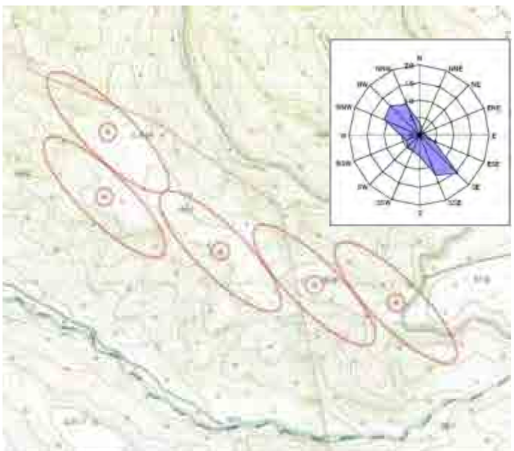


Figure 3.3.3-2 Arrangement example

Figure 3.3.3-3 Effect of wind turbine separation

Since primary wind direction is East-West in the RMI region, arrangement will basically be like the one shown below.

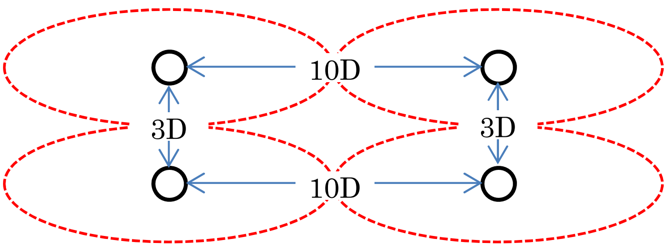


Figure 3.3.3-4
Wind direction layout drawing

(2) Small Wind Turbine 5kW

Introduced here is Evance R9000 which can be purchased in Japan or abroad (the Japanese version is Zephyr 9000).

Official retailer Evance http://www.evancewind.com/

Distributor in Japan Zephyr http://www.zephyreco.co.jp/en/products/z-9000.jsp

(a) Overview

Figure 3.3.3-5 Wind Turbine Overview

It is advantageous during construction and maintenance in remote islands as the tower can be brought down with hydraulic pumps, etc.

Figure 3.3.3-6 Wind turbine maintenance conditions

(b) Specification

Turbine Specification

Architecture	Upwind, 3 bladed rotor, self regulating
Nominal Power	5kW
BWEA Reference Power	4711W (power output at 11m/s (24.6 mph))
Annual Energy Yield	9170kWh with Annual Mean Wind Speed (AMWS) of 5m/s (11.2mph) (to IEC & BWEA Standards)
Cut-In Wind Speed	3m/s (6.7mph)
Cut-Out Wind Speed	None - continuous generation to survival wind speed
Survival Wind Speed	60m/s (134mph)
IEC Turbine Class	Conforms to IEC 61400 to Class II - AMWS up to 8.5m/s (19mph)
Control System	Patented Reactive Pitch™ control - at low to moderate wind speeds the patented pitch system, Reactive Pitch™, holds the blades in the optimum position for capturing maximum energy from the wind. At high wind speeds the R9000's Reactive Pitch™ mechanism automatically pitches the blades so it can regulate energy capture and blade speed. It therefore continues to capture - up to the full 5kW power rating.
Rotor Diameter	5.5m (18')
Rotor Speed	200rpm nominal
Blade Type	Fully optimized aerofoil ensuring maximum yield & minimum noise
Blade Material	Glass fiber reinforced composite, low reflection, UV & anti-erosion coatings
Generator	Patented brushless direct drive, air-cored high efficiency Permanent Magnet Alternator
Gearbox	None required (see generator)
Emergency Braking	Patented automatic ElectroBrake™ (with manual control for servicing). No moving parts.
Yaw Control	Passive tail vane and rotor
Design Longevity	20 years minimum. Regular maintenance inspections.
Noise	Lp,25m = 52.8dB(A). BWEA Reference Sound Level at 8m/s (17.9mph) & 25m (82') distance. Lp,60m = 45.3dB(A). BWEA Reference Sound Level at 8m/s (17.9mph) & 60m (197') distance.
Operating Temperature Range	-20˚C - +50˚C
Warranty	5 years

Electrical Installation

Rectifier	Converts AC energy from the turbine to DC
Inverter	Takes energy from the DC store & converts to grid quality electricity which can be used in the home Options: 2 x 2,500 inverters for a 3phase supply. 1 x 5,000A for a single phase supply
Grid Connection Panel	Includes generation meter and isolator switch Option for a smart meter for online/remote monitoring of generation

Tower Specification

Tower Height	10m, 12m, 15m & 18m (33', 40', 50' & 60')
Tower Types	Free-standing monopole towers designed to tilt down using hydraulic RAMS
Tower Foundation	Root, pad & rock options depending on ground
Tower Top Mass	325kg (715lbs) complete (excl tower)

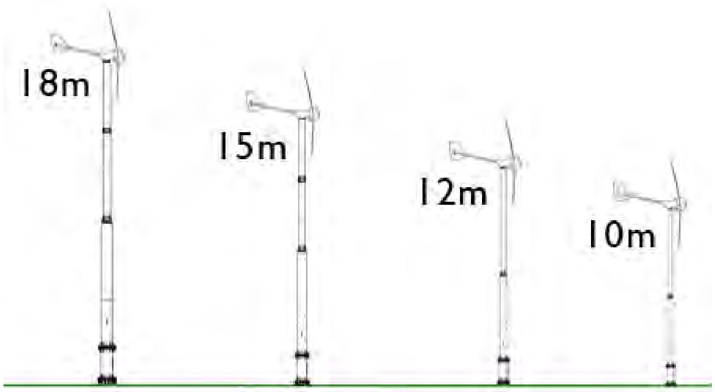


Figure 3.3.3-7 Wind turbine specifications

(c) System Performance

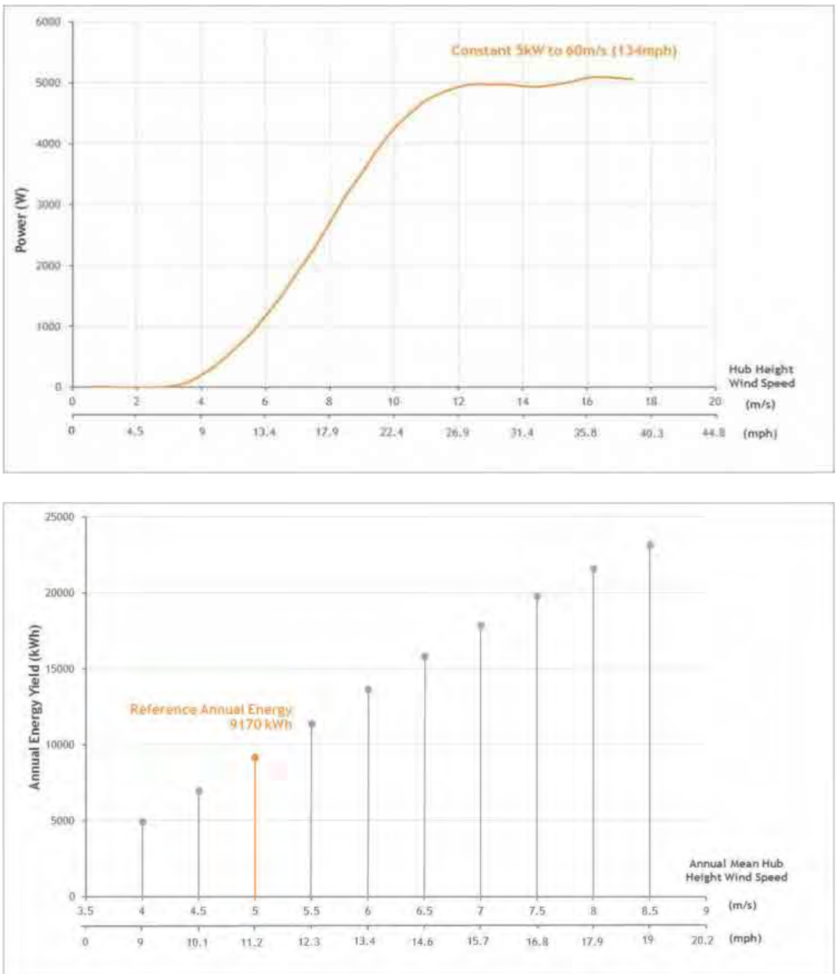


Figure 3.3.3-8 System performance

(d) Install Photos

Figure 3.3.3-9 Wind turbine installation conditions

(3) Wind Turbine 25kW

Here, a medium-sized unit with a tower that can be brought down is introduced (Viking 25).

Official retailer HSwind http://hswind.dk/en/

(a) Overview

Figure 3.3.3-10 Wind Turbine Overview

It is advantageous during construction and maintenance in remote islands as the tower can be brought down with hydraulic pumps, etc.

Figure 3.3.3-11 Wind turbine retraction conditions

(b) Specification

Specifications	
Nominal power	25 kW
Nave height	18 m
Power regulation	Stall
Start wind	4,0 m/s
Maximum wind	25 m/s
Survival wind	No limit
Pivot system	Active, automatic cable uncoiling
Operational temperature	-10 °C to +40 °C
Rotor	
Rotational direction	Clockwise
Blades	3
Coated area	133 m²
Rotor material	Fiberglass
RPM	65
Tip speed	45 m/s
Generator	
Generator	4 pole asynchronous from VEM
Voltage	3*400 + N
Frequency	50/60 Hz
Rated RPM	1525
Network connection	Yes
Gear Type	STM-EX1501/804 23,32 PAM200D M1s
Tower Type	HSWind tilt
Control System	Manufacturer: Mita-Teknik
Safety Brakes	Electromechanical fail safe MAYR 10/800.410.3

(c) System Performance

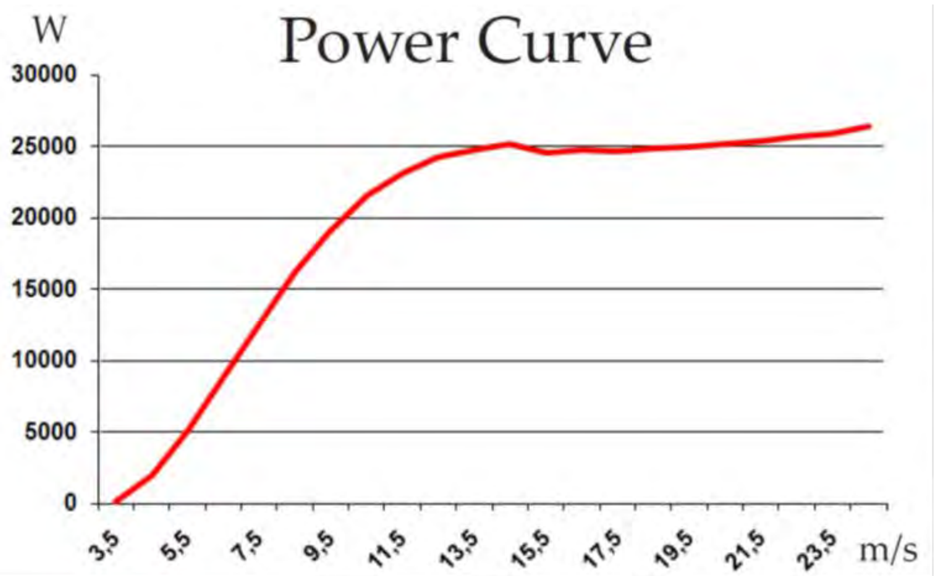


Figure 3.3.3-12 System Performance

(d) Install Photos

Below is an installation and fitting of Viking 25 kW described

Viking 25 kW is installed and lowered by means of a winch and a car battery.

By installing and lowering the turbine in this fashion, it is completely unnecessary to ever scale the tower. Everything can be attended to at ground level.

Since the heaviest lifting when installing the turbine is of the 750 kg nacelle to a height of 2 meters, no crane is necessary. A tractor or the like can easily be used to fit the nacelle.

Once the nacelle has been fitted, all that's left are the blades, cable and nacelle cover – and the turbine will be ready for installation. This work can be done by two men in one day.

Figure 3.3.3-13 Wind turbine installation conditions

3.3.4 Basic data and how to understand them

3.3.4.1 Introduction

In considering a hybrid system, there are a variety of ways to consider, but basically the amount of power supplied by the diesel generators, PV, and wind turbines for the power load of every hour must be determined, and the operational restrictions of each must be evaluated.

HOMER (introduced in the next section,), a simulation software widely used around the world, is recommended as a tool for evaluation.

With HOMER, the following data can be used to perform simulations.

Load data：Data for 8,760 hours (every hour for a year)

Solar radiation data：Data for 8,760 hours (every hour for a year). However, HOMER is equipped with this.

Wind speed data：Data for 8,760 hours (every hour for a year)

Diesel generator: rated output and low-power operating range of the diesel generator

PV: conversion efficiency, tilt angle, orientation angle

Wind turbine: output characteristics curve

To obtain highly accurate simulation results, measured values in line with reality whenever possible is desirable for each of the above data. However, if there are no such measured values, similar data or anticipated values may be used.

＜Notes＞

This simulation is a calculation for hourly load fluctuations, solar radiation, and wind speed, the so-called long-period fluctuation analysis. Since short period output changes, etc. within one hour, e.g. a few seconds or minutes, are not included, this point should be fully understood when considering the system.

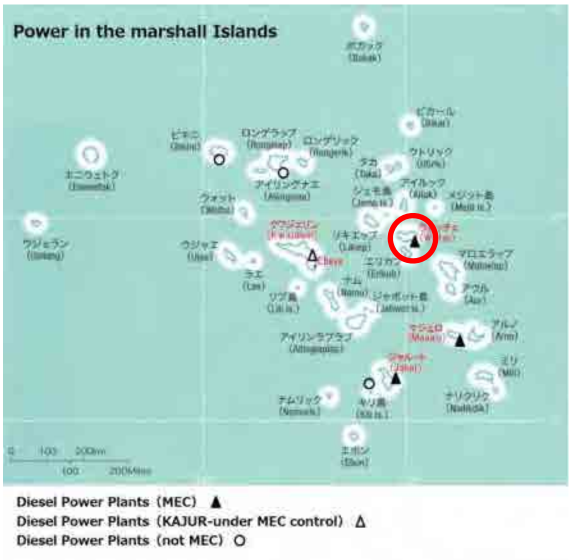
In addition, regarding whether or not such short-period fluctuations are acceptable to the power system, see "3.2 Evaluation on the maximum allowable amount of RE that can be connected to the distribution network."

3.3.4.2 Basic data for each remote island

(1) Wotje Atoll

(a) Status of the power plant

Details of the plant are as follows.



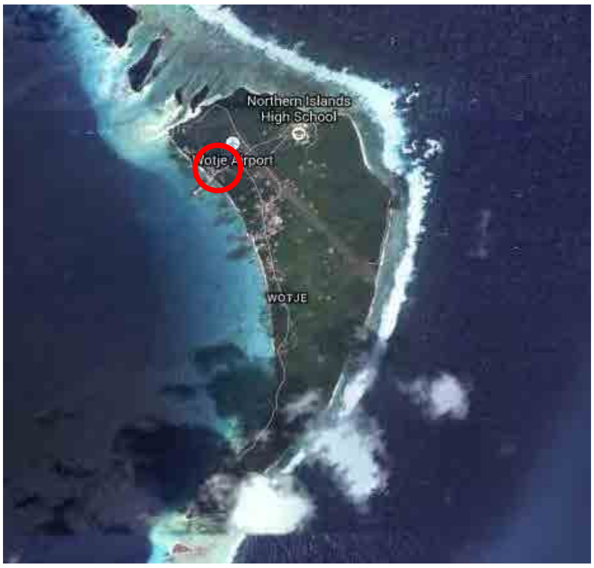


Figure 3.3.4-1 Power plant location: North 9° 27' 40" East 170° 13' 56" [GMT + 12:00]
(from Google Earth)

Table 3.3.4-1 Generator specifications (Wotje)

Engine #	1	2
Manufacturer	Wartsila	Wartsila
ENGINE MODEL	UD25	UD25
NAME PLATE RATING（kW）	275	275
Maximum output (kW)	275	275
SPEED（RPM）	1200	1200
INSTALLATION YEAR	2003	2003
Governor Control	Isochronous	Isochronous
Synchronous capability	Unavailable	Unavailable

Operation range: with load, 5-20% output and up to 100 hours (after that, 70% or more output and 100 hours or more)

With no load, up to 10 minutes (when stopped after that)

Up to 6 hours (if a load will be carried after that)

Governor control: isochronous control

Switch operation: basically 1 unit is operated and switched at 300 hours

Reference: The maximum annual load is approx. 160 kW.

It shifted between 70 and 110kW throughout the year.

There is a tendency for the load to fall to 40 - 60kW from June to August.

The load is approximately half as compared with 10 years ago.

Number of power outages (time): 24 times/year, 118 hours/year (2013)

(b) Load changes

Step 1: Obtain at least one year's worth of hourly data (8760 hours) from operating records.

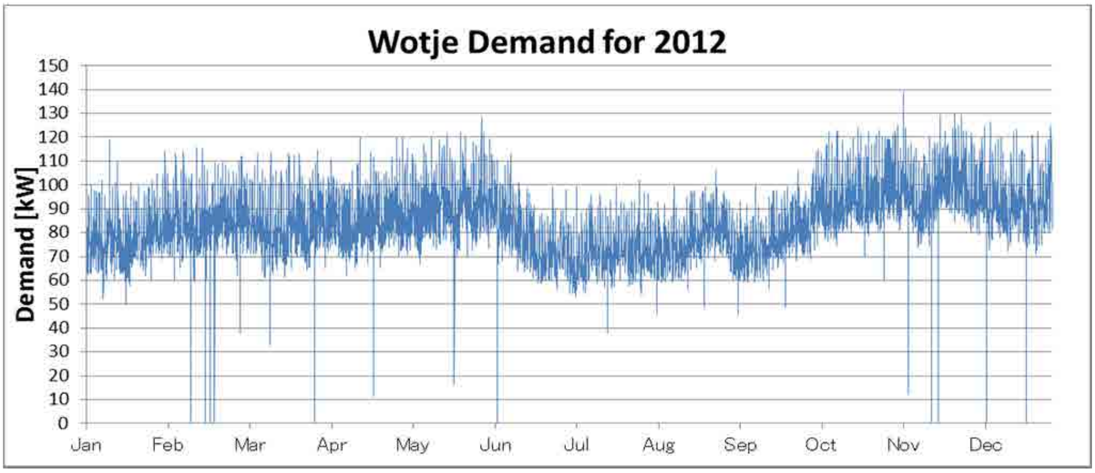


Figure 3.3.4-2 Measured load change data for Wotje (2012)

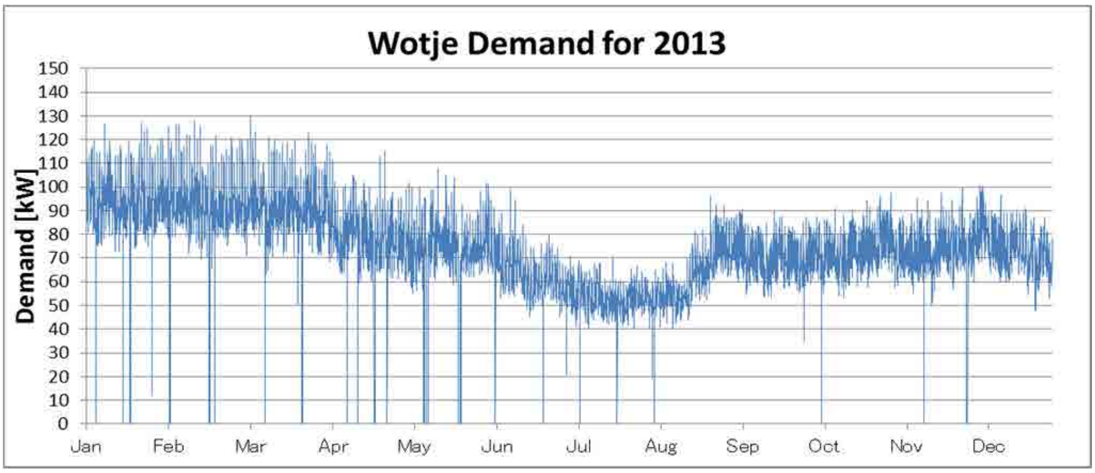


Figure 3.3.4-3 Measured load change data for Wotje (2013)

Step 2: When measurement errors and power outages occur, data shall be replaced by data values just before such events.

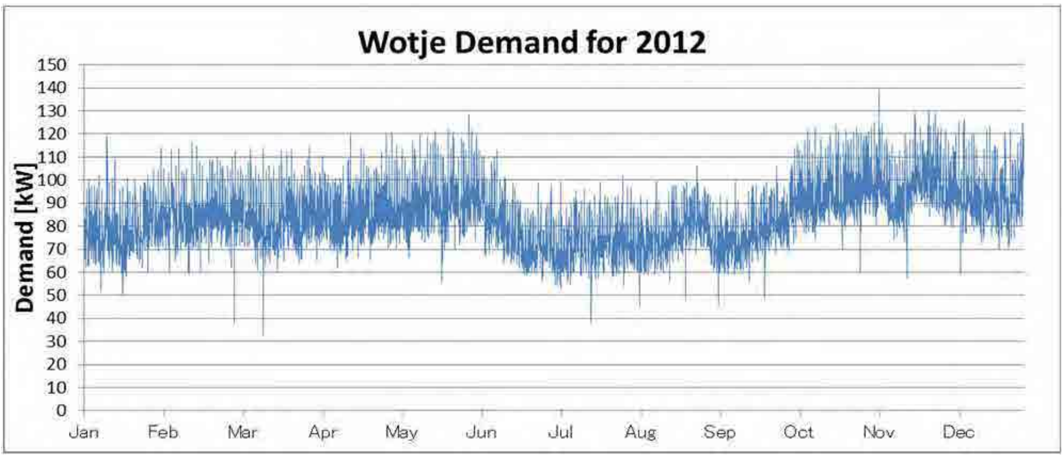


Figure 3.3.4-4 Corrected measured load change data for Wotje (2012)

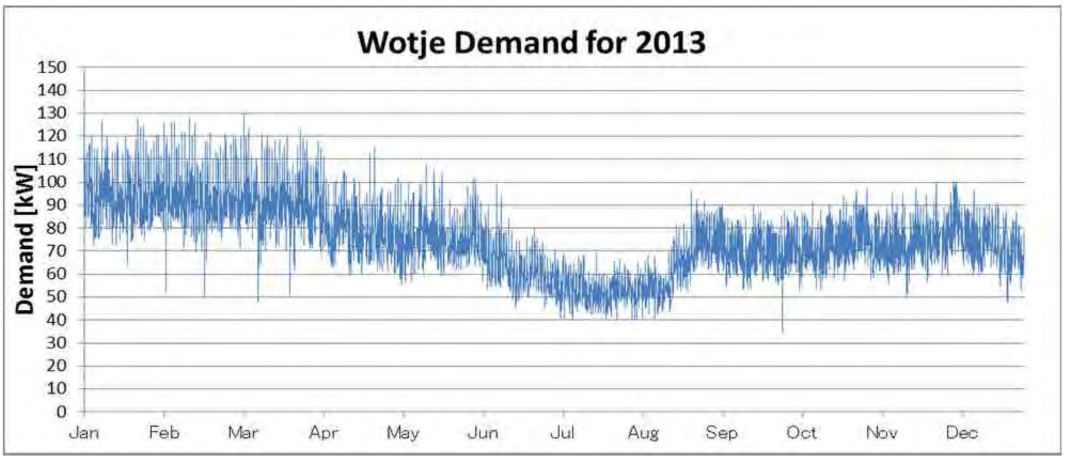


Figure 3.3.4-5 Corrected measured load change data for Wotje (2013)

Step 3: If there is data for multiple years, average them to prepare a load change graph.

If data for multiple years is unavailable, get the average for 3 hours before and after to prepare a load change graph.

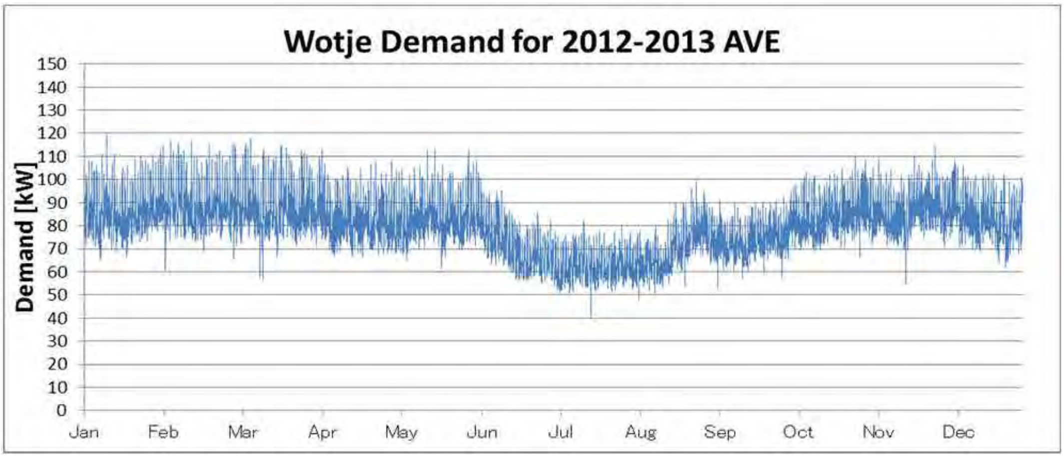


Figure 3.3.4-6 Average load change data for Wotje (2012-2013)

(c) Solar radiation data

Solar radiation data to be used are saved in HOMER, etc.

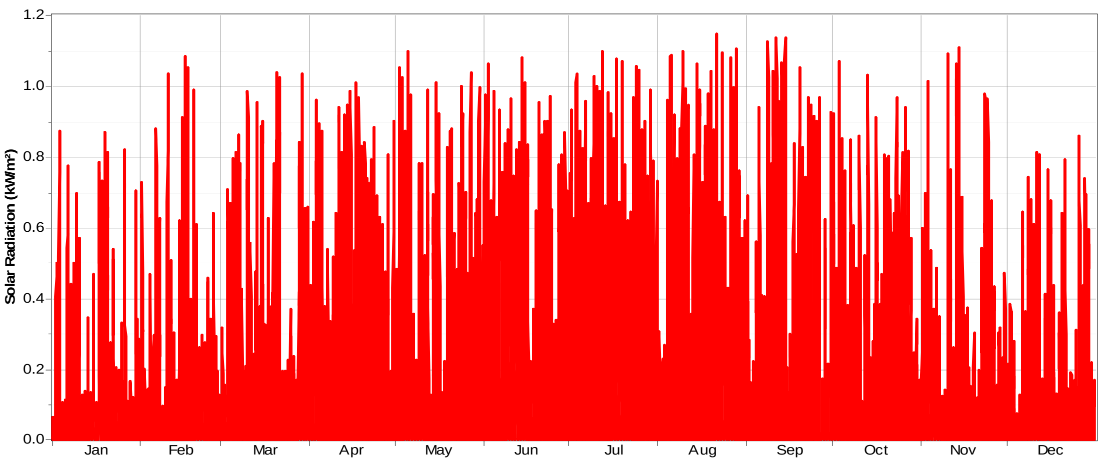


Figure 3.3.4-7 Solar radiation data for Wotje

*For solar radiation data to perform the trial calculations for the amount PV generated power, 8,760 hours worth of data for hourly values is loaded in HOMER which will be introduced later.

* The approximate PV generated power is system output [kW] x 8,760h x 13%.

(d) Wind speed data

Because wind speed has regional characteristics, it is necessary to actually measure wind conditions. Wind speed data recorded from 9/20/2012 to 8/16/2013 in Wotje will be used.

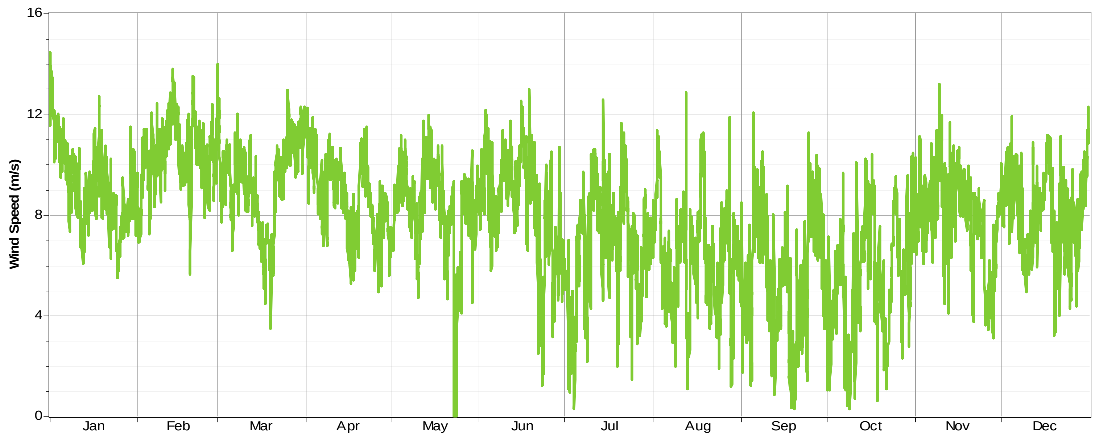


Figure 3.3.4-8 Wotje wind speed data

* Wind speed varies depending on the height at which it is measured. The height of the observation point shall be reflected by adjusting the wind turbine hub height with the simulation software (HOMER).

(2) Jaluit Atoll

(a) Status of the power plant

Details of the plant are as follows.

Figure 3.3.4-9 Power plant location: North 5° 55' 11" East 169° 38' 37" [GMT + 12:00]

(Source Google Earth)

Table 3.3.4-2 Generator specifications (Jaluit)

Engine #	1	2
ENGINE MAKE	Wartsila	Wartsila
Manufacturer	UD25	UD25
ENGINE MODEL	300	300
NAME PLATE RATING（kW）	300	300
Maximum output (kW)	1200	1200
SPEED（RPM）	1993	1993
INSTALLATION YEAR	Droop	Droop
Governor Control	Unavailable	Unavailable
Synchronous capability		

Operation range: with load, 5-20% output and up to 100 hours (after that, 70% or more output and 100 hours or more)

With no load, up to 10 minutes (when stopped after that)

Up to 6 hours (if a load will be carried after that)

Governor control: isochronous control

Switch operation: basically 1 unit is operated and switched at 300 hours

Reference: The maximum annual load is approx. 180kW.

It shifted between 80 and 100kW throughout the year.

There is a tendency for the load to fall to 40 - 60kW from June to August.

The load is approximately half as compared with 10 years ago.

Number of power outages (time): 18 times/year, 45 hours/year (2013)

(b) Load changes

Step 1: Obtain at least one year's worth of hourly data (8,760 hours) from operating records.

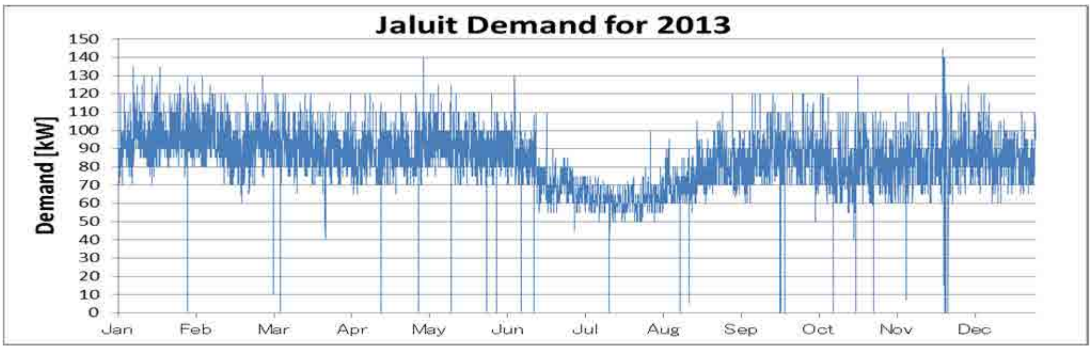


Figure 3.3.4-10 Measured load change data for Jaluit (2013)

Step 2: When measurement errors and power outages occur, data shall be replaced by data values just before such events.

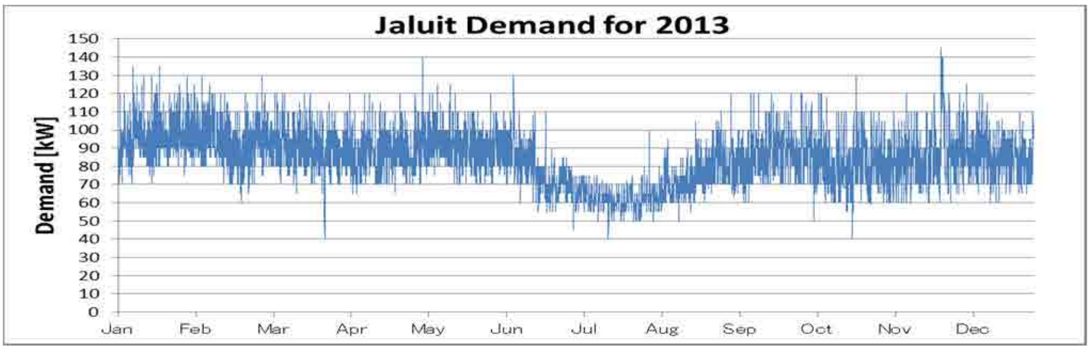


Figure 3.3.4-11 Corrected measured load change data for Jaluit (2013)

Step 3: If there is data for multiple years, average them to prepare a load change graph.

If data for multiple years is unavailable, get the average for 3 hours before and after to prepare a load change graph.

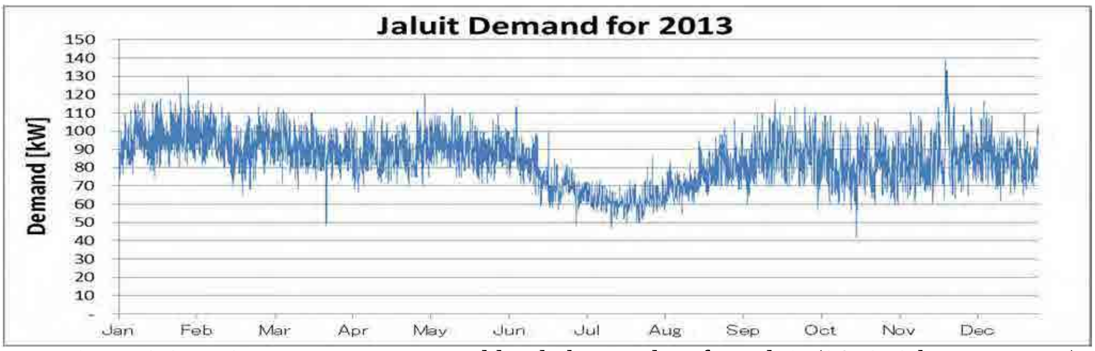


Figure 3.3.4-12 Average measured load change data for Jaluit (2013, 3 hour average)

(c) Solar radiation data

Solar radiation data to be used are saved in HOMER, etc.

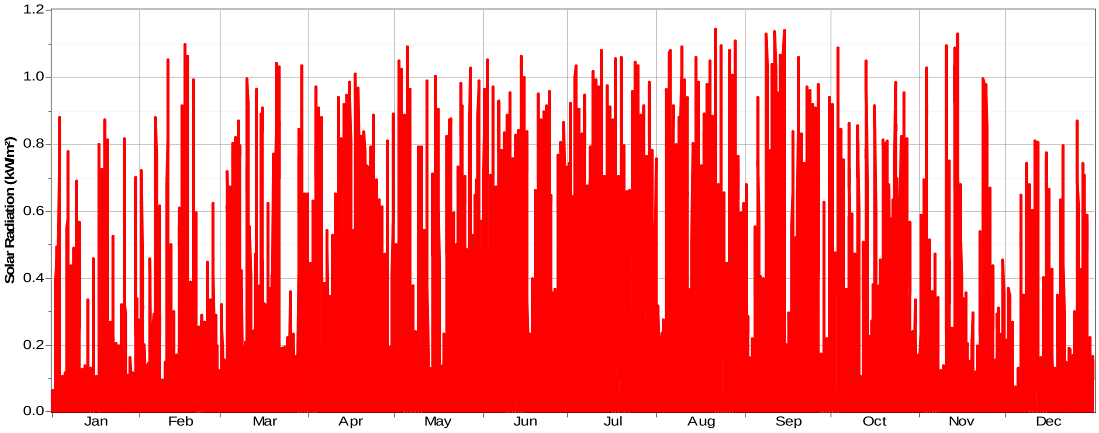


Figure 3.3.4-13 Solar radiation data for Jaluit

*For solar radiation data to perform the trial calculations for the amount PV generated power, 8,760 hours worth of data for hourly values is loaded in HOMER which will be introduced later.

* The approximate PV generated power is system output [kW] x 8,760h x 13%.

(d) Wind speed data

Because wind speed has regional characteristics, it is necessary to actually measure wind conditions. Wind speed data recorded from 9/20/2012 to 8/16/2013 in Wotje will be used.

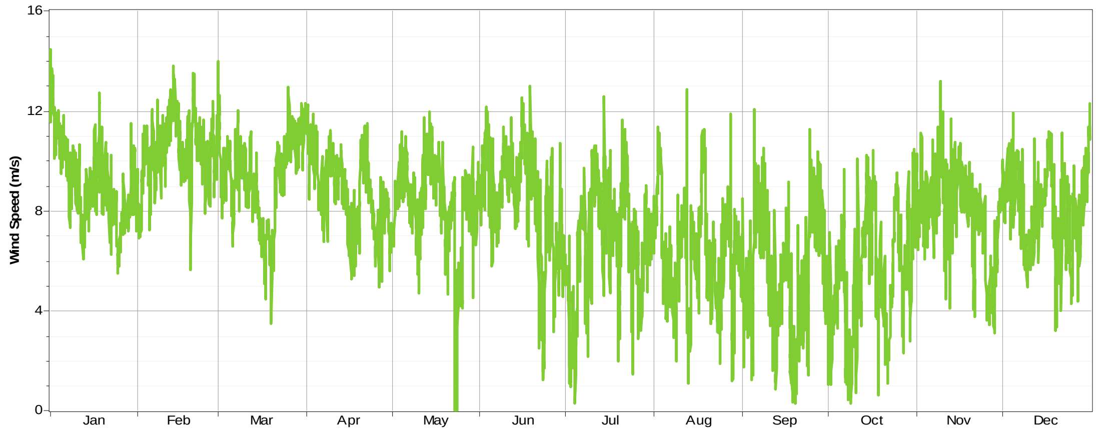


Figure 3.3.4-14 Wotje wind speed data

* Wind conditions in Jaluit were measured from 9/21/2012 to 4/12/2013, but since there is a lack of approx. 5 months of data, using this data is difficult.

* Wind speed varies depending on the height at which it is measured. The height of the observation point shall be reflected by adjusting the wind turbine hub height with the simulation software (HOMER).

(3) Ebeye Island

(a) Status of the power plant

Details of the plant are as follows.

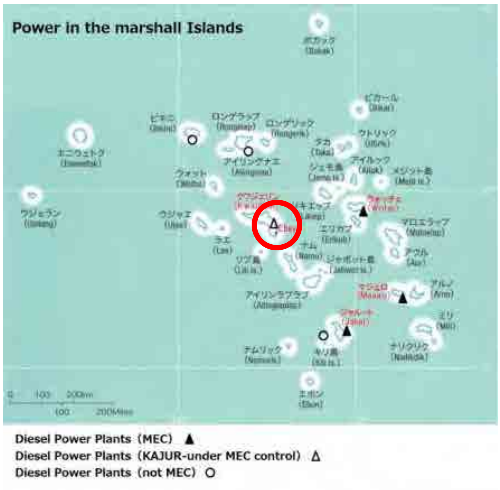


Figure 3.3.4-15 Power plant location: North 8° 46' 26" East 167° 44' 20" [GMT + 12:00] (from Google Earth)

Table 3.3.4-3 Generator specifications (Ebeye)

Engine #	2	3	4
ENGINE MAKE	Cummins		
ENGINE MODEL	—	—	—
NAME PLATERATING (kW)	1,286	1,286	1,286
Maximum output (kW)	1,286	1,286	1,286
SPEED (RPM)	1,800	1,800	1,800
YEAR INSTALLED	—	—	—
Governor Control	Isochronous		
Synchronous capability	Available		

Operating range: Unknown However, estimated at 35% or more based on 2013 operating data for each unit.

35% output
450kW

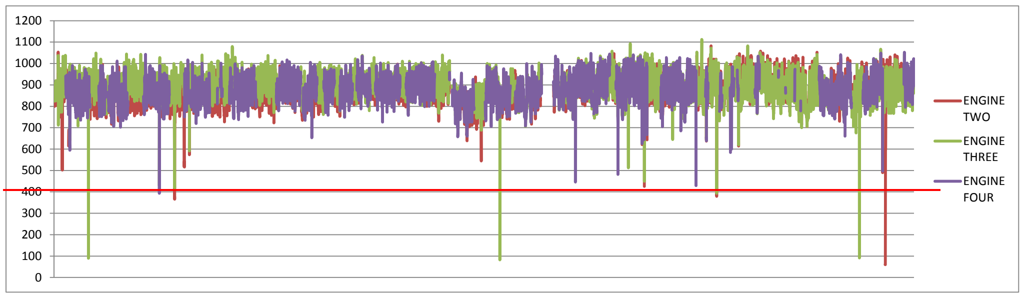


Figure 3.3.4-16 Operation data for each unit

Governor control: isochronous control ＋ load sharing control

Switch operation: basically 2 units are operated

Reference: The maximum annual load is approx. 180kW.

It shifted between 1600 and 1900kW throughout the year.

Number of power outages (time): 10 times/year, 185 hours/year

(b) Load changes

Step 1: Obtain at least one year's worth of hourly data (8,760 hours) from operating records.

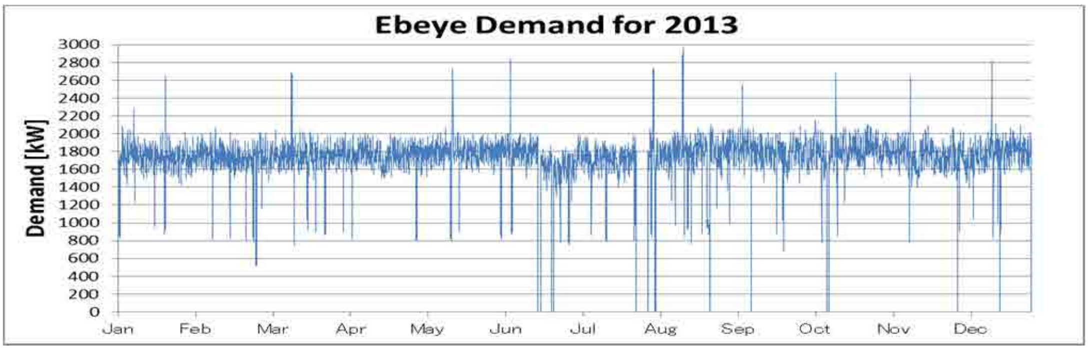


Figure 3.3.4-17 Measured load change data for Ebeye (2013)

Step 2: When measurement errors and power outages occur, data shall be replaced by data values just before such events.

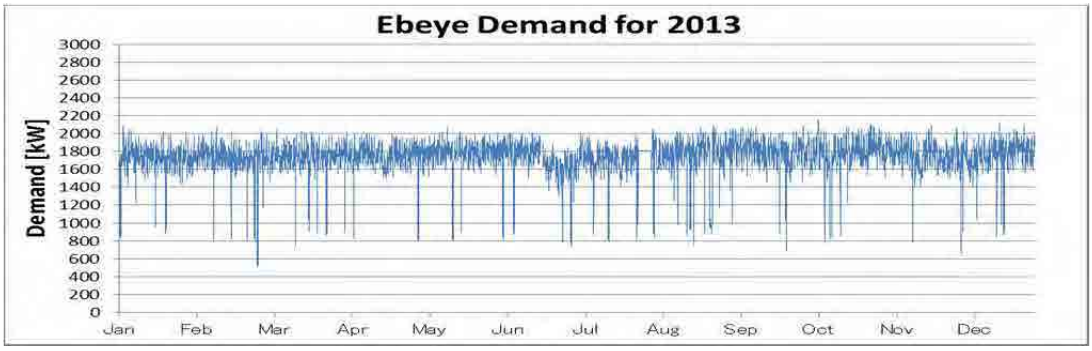


Figure 3.3.4-18 Corrected measured load change data for Ebeye (2013)

Step 3: If there is data for multiple years, average them to prepare a load change graph.

If data for multiple years is unavailable, get the average for 3 hours before and after to prepare a load change graph.

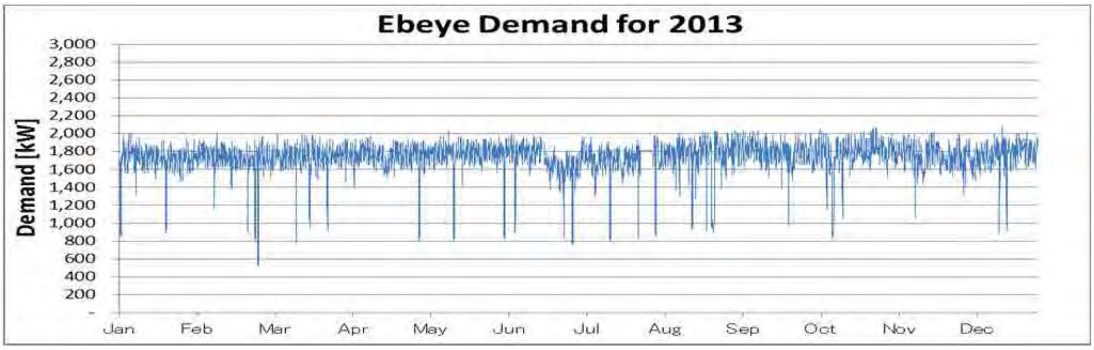


Figure 3.3.4-19 Average measured load change data for Ebeye (2013, 3 hour average)

(c) Solar radiation data

Solar radiation data to be used are saved in HOMER, etc.

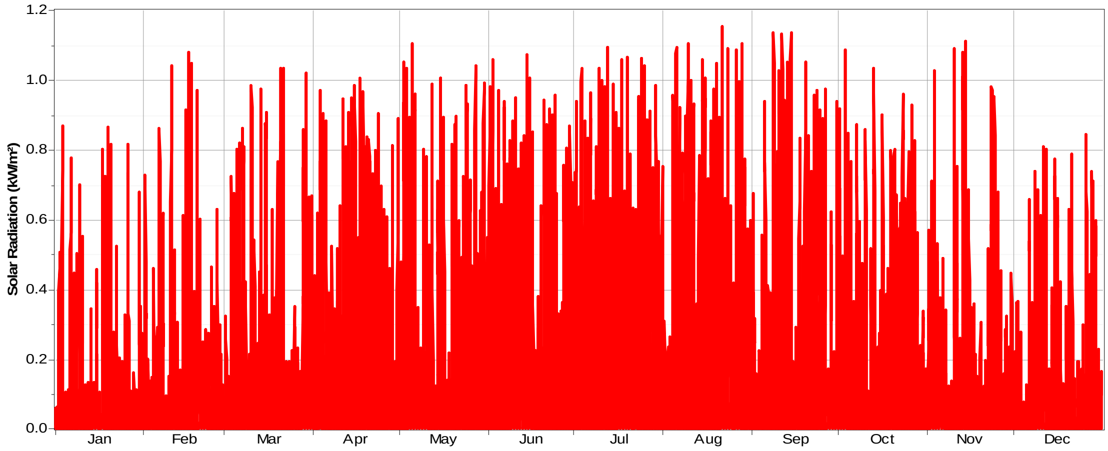


Figure 3.3.4-20 Solar radiation data for Ebeye

*For solar radiation data to perform the trial calculations for the amount PV generated power, 8,760 hours worth of data for hourly values is loaded in HOMER which will be introduced later.

* The approximate PV generated power is system output [kW] x 8,760h x 13%.

(d) Wind speed data

Because wind speed has regional characteristics, it is necessary to actually measure wind conditions. Wind speed data recorded from 9/20/2012 to 8/16/2013 in Wotje will be used.

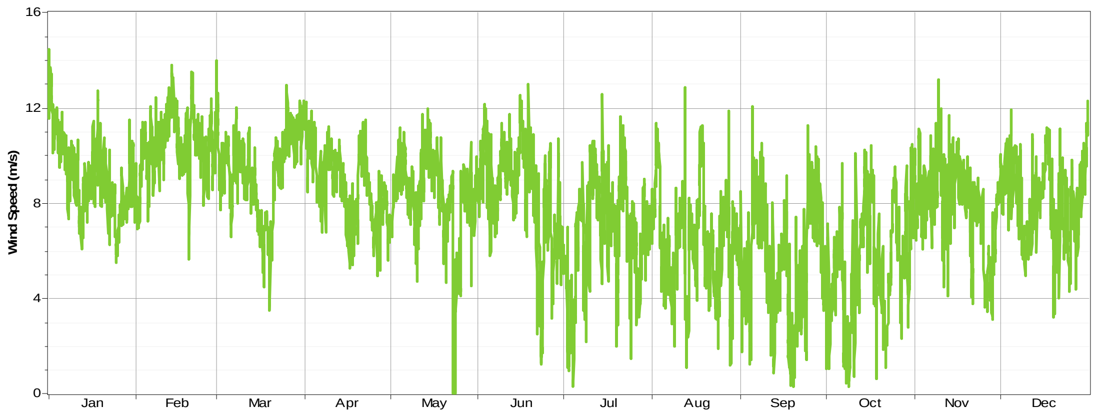


Figure 3.3.4-21 Wotje wind speed data

* Wind conditions in Jaluit were measured from 9/21/2012 to 4/12/2013, but since there is a lack of approx. 5 months of data, using this data is difficult.

* Wind speed varies depending on the height at which it is measured. The height of the observation point shall be reflected by adjusting the wind turbine hub height with the simulation software (HOMER).

3.3.5 Installation sites

(1) Wotje Atoll

(a) List of sites for PV installation

From the field survey results of the remote islands, possible PV installation sites were as follows.

Table 3.3.5-1 Possible PV installation sites (Wotje)

Target sites	Area available for installation	Max. PV capacity
a: Power plant premises	Approx. 600m^2	60kW
b: Power plant building roof	Approx. 280m^2	28kW
b: High school roof	Approx. 2,250m^2	225kW
Classroom building	(Approx. 1,700 m$^{2)}$	(170 kW)
Teachers' office building	(Approx. 220m$^{2)}$	(22kW)
Cafeteria	(Approx. 330m$^{2)}$	(33kW)

(b) Boundary of power plant premises

When installing the hybrid system, sites where control and operation can be performed easily such as power plant premises on remote islands is preferable. We would like to introduce a large amount of renewable energy, but it is assumed that the scale will be limited to the power plant premises for the time being. The figure below shows the boundary of the power plant premises derived from the land data shown in the next section.

Figure 3.3.5-1 Boundary of power plant premises

(c) Land data

The land information obtained is reflected as the area framed in red in the aerial photo on the previous page.

Republic of the Marshall Islands
Ministry of Internal Affairs
P.O. BOX 18
Majuro, Marshall Islands MH 96960
Tel: 625-8240 / 8225 / 8718 • Fax: 625-5353

LEGAL DESCRIPTION

For. WOTJE POWER PLANT
Portion of MONKIRIN ROK Weto, Wotje Island,
Wotje Atoll.

That portion of MONKIRIN ROK Weto, Wotje Island, Wotje Atoll being designated as Lease Area being depicted and properly described on Survey Map No. MI-039/02 filed with the Division of Lands and Surveys, Ministry of Internal Affairs, Republic of the Marshall Islands.

That portion described as follows.

Commencing from a point which is designated as "A" with assumed coordinates N40,000.00 and E50,000.00; Thence N37-00-00E 37.20 meters to "B", Thence N22-10-465 31.11 meters to a nail designated as "C-1", the point of beginning.

Thence N37-01-26E 81.74 meters to a nail designated as "C-2",

Thence N53-02-47W 71.75 meters to a nail designated as "WC-1",

Thence S40-05-18W 90.05 meters to a nail designated as "WC-2",

Thence S59-08-49E 77.01 meters to a nail designated as "C-1", the point of beginning.

That portion of MONKIRIN ROK Weto is consisting a total land area of 0.6355 Hectares or 0.1.5703 Acres.

Div. of Lands and Surveys
Ministry of Internal Affairs

08/13/02
Date

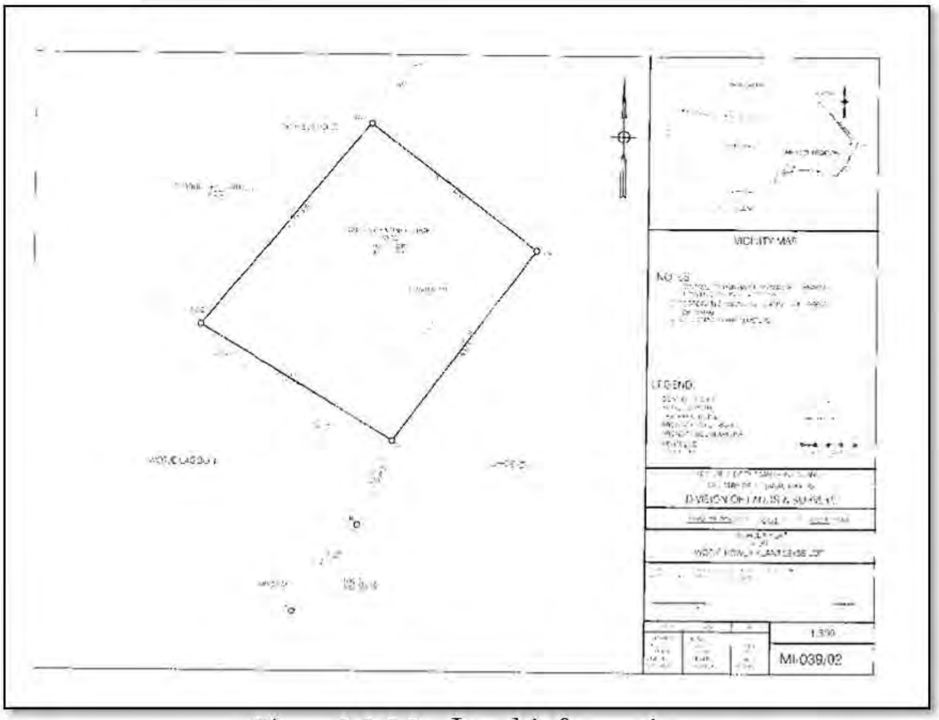


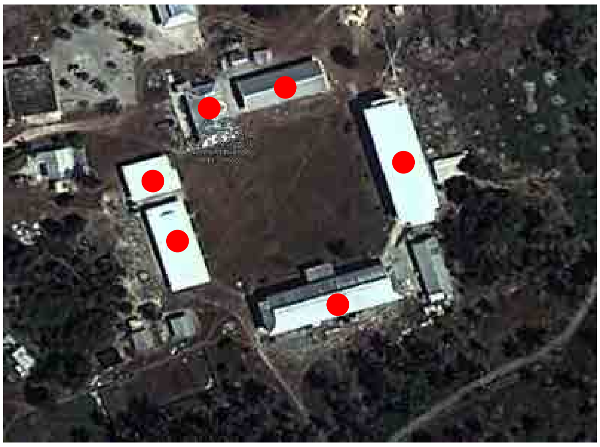
Figure 3.3.5-2 Land information

(d) Status of the possible installation sites

Power plant premises

power plant building

Complete view of high school



classroom building

Classroom building

classroom building

Figure 3.3.5-3 Status of the possible installation sites

(2) Jaluit Atoll

(a) List of sites for PV installation

From the field survey results of the remote islands, possible PV installation sites were as follows.

Table 3.3.5-2 Possible PV installation sites (Jaluit)

Target sites	Area available for installation	Max. PV capacity
a: Power plant premises	Approx. 600m^2	60kW
b: Fish base roof	Approx. 400m^2	40kW
c: Power plant building roof	Approx. 280m^2	30kW
d: High school	Approx. 3,000 m^2	300kW

(b) Boundary of power plant premises

When installing the hybrid system, sites where control and operation can be performed easily such as power plant premises on remote islands is preferable. We would like to introduce a large amount of renewable energy, but it is assumed that the scale will be limited to the power plant premises for the time being. The figure below shows the boundary of the power plant premises derived from the land data shown in the next section.

Figure 3.3.5-4 Boundary of power plant premises

(c) Land data

The land information obtained is reflected as the area framed in red in the aerial photo on the previous page.

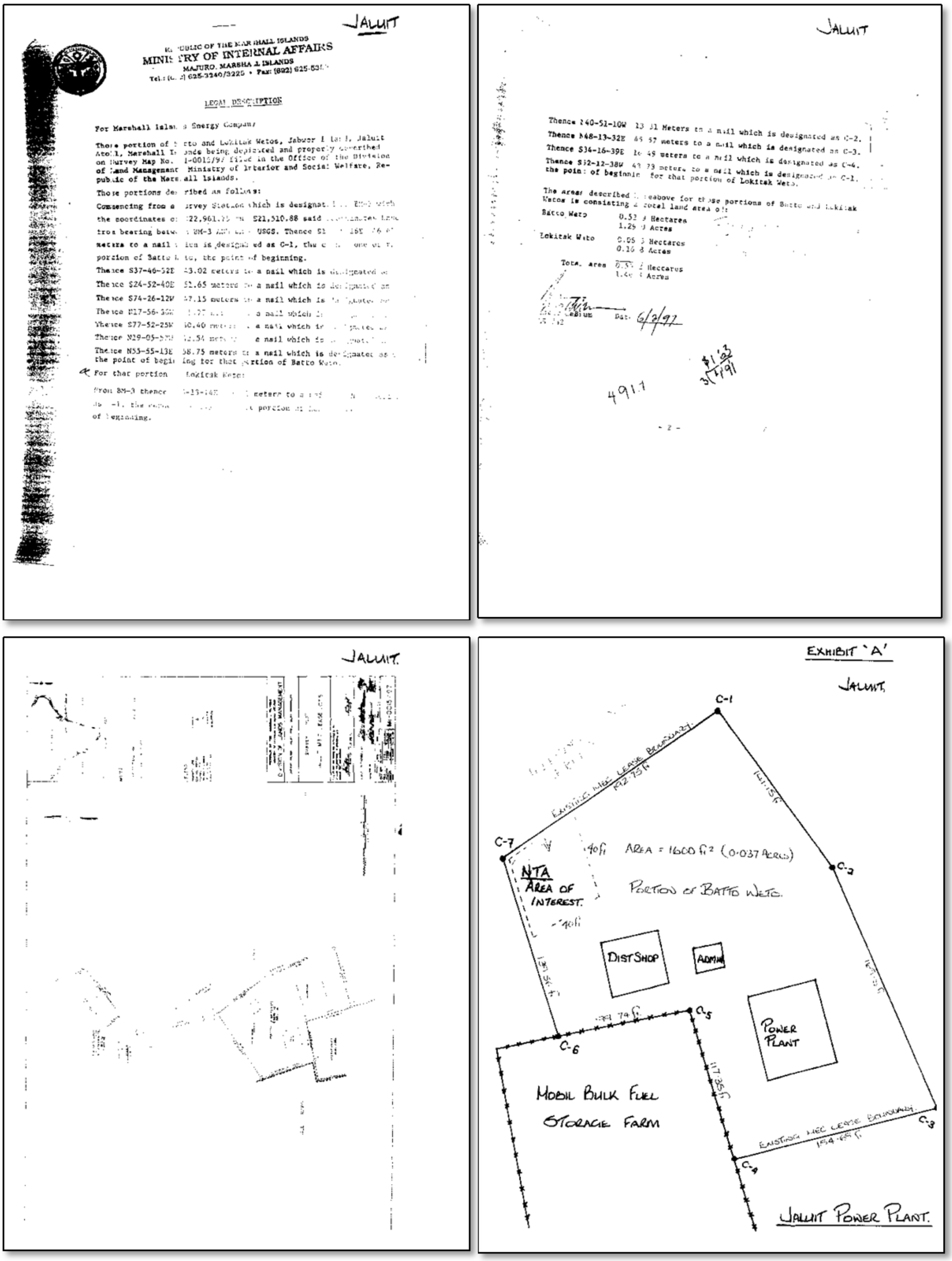
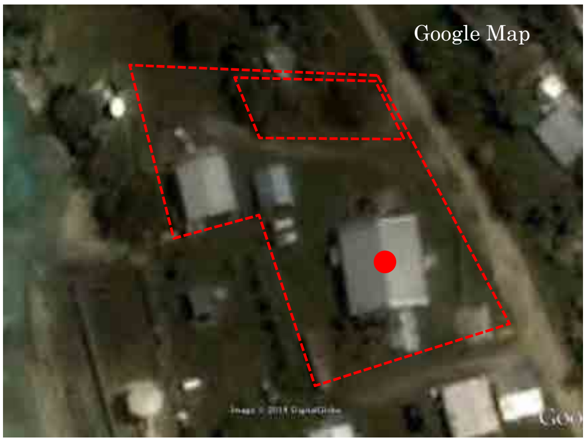


Figure 3.3.5-5 Land information

(d) Status of the possible installation sites

Power plant premises



power plant building

Complete view of fish base

fish base building

Complete view of high school

high school building

Figure 3.3.5-6 Status of the possible installation sites

(3) Ebeye Island

(a) List of sites for PV installation

From the field survey results of the remote islands, possible PV installation sites were as follows.

Table 3.3.5-3 Possible PV installation sites (Ebeye)

Target sites	Area available for installation	Max. PV capacity
a: Power plant premises	Approx. 7,000m^2	700kW
b: PAYLESS Super Market roof	Approx. 1,500m^2	150kW

(b) Boundary of power plant premises

When installing the hybrid system, sites where control and operation can be performed easily such as power plant premises on remote islands is preferable. We would like to introduce a large amount of renewable energy, but it is assumed that the scale will be limited to the power plant premises for the time being. The figure below shows the boundary of the power plant premises derived from the land data shown in the next section.

Figure 3.3.5-7 Boundary of power plant premises

(c) Land data

No land information was obtained. Information on ownership and the like must be verified eventually.

(d) Status of the possible installation sites

Power plant premises

PAYLESS Super Market

Figure 3.3.5-8 Status of the possible installation sites

3.3.6 Supply-demand balance simulation

3.3.6.1 Overview

It is recommended that a supply-demand balance simulation be conducted to assess how much renewable energy can be deployed to the existing power system. This simulation is a calculation for hourly load fluctuations, solar radiation, and wind speed, the so-called long-period fluctuation analysis. Since short period output changes, etc. within one hour, e.g. a few seconds or minutes, are not included, this point should be fully understood when considering the system. In addition, regarding whether or not such short-period fluctuations are acceptable to the power system, see "3.2 Evaluation on the maximum allowable amount of RE that can be connected to the distribution network."

HOMER, a simulation software used widely around the world, is recommended as a tool for evaluation. For instructions on using HOMER, see the attachment, "Getting Started Guide for Homer."

HOMER calculates the energy balance of each time zone for one year or 8,760 hours to simulate. HOMER compares the power demand for each hour with the amount of energy that the system can supply to calculate the energy flow from each component of the system. With a system which has storage batteries or a generator, how the generator should be operated or whether the batteries should be charged or discharged is determined for each time zone.

HOMER determines the possibility of each system configuration that the user is considering at the same time. It can determine whether or not power demand will be met under the conditions specified by the user as well as estimate the cost of installing and managing the system over the whole period of the project. When calculating the cost system, construction costs, replacement costs, maintenance costs, fuel costs, interest, and other expenses are considered.

Optimization: Once simulations of all possible system configurations have been completed, HOMER displays them as a list sorted in the order of life cycle cost so that each system design can be compared.

Sensitivity analysis: When sensitivity variable is defined as an input value, HOMER repeats the optimization process for each sensitivity variable specified. For example, if wind speed is defined as a sensitivity variable, HOMER simulates the system configuration for the wind speed range specified by the user.

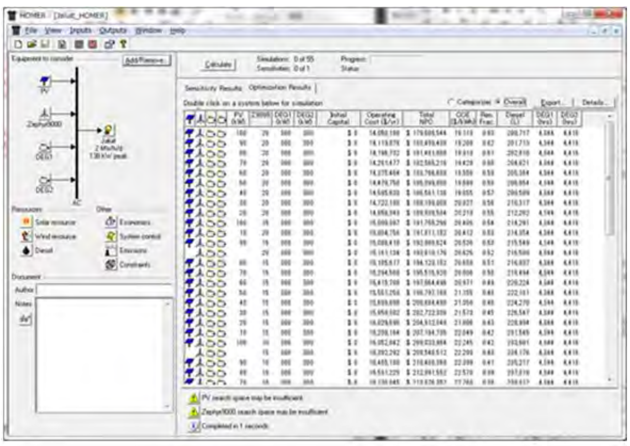


Figure 3.3.6-1 Screenshot of HOMER

3.3.6.2 Simulation results for each remote island

The supply and demand balance simulation results for each remote island using HOMER is shown below.

(1) Wotje Atoll

(a) Status of the power plant

Details of the plant are as follows.

Table 3.3.6-1 Generator specification (Wotje)

Engine #	1	2
MANUFACTURER	Wartsila	Wartsila
ENGINE MODEL	UD25	UD25
NAME PLATERATING（kW）	275	275
Maximum output (kW)	275	275
SPEED（RPM）	1200	1200
INSTALLATION YEAR	2003	2003
Governor Control	Isochronous	Isochronous
Synchronous capability	Unavailable	Unavailable

Operation range: with load, 5-20% output and up to 100 hours (after that, 70% or more output and 100 hours or more)

With no load, up to 10 minutes (when stopped after that)

Up to 6 hours (if a load will be carried after that)

Governor control: isochronous control

Switch operation: basically 1 unit is operated and switched at 300 hours

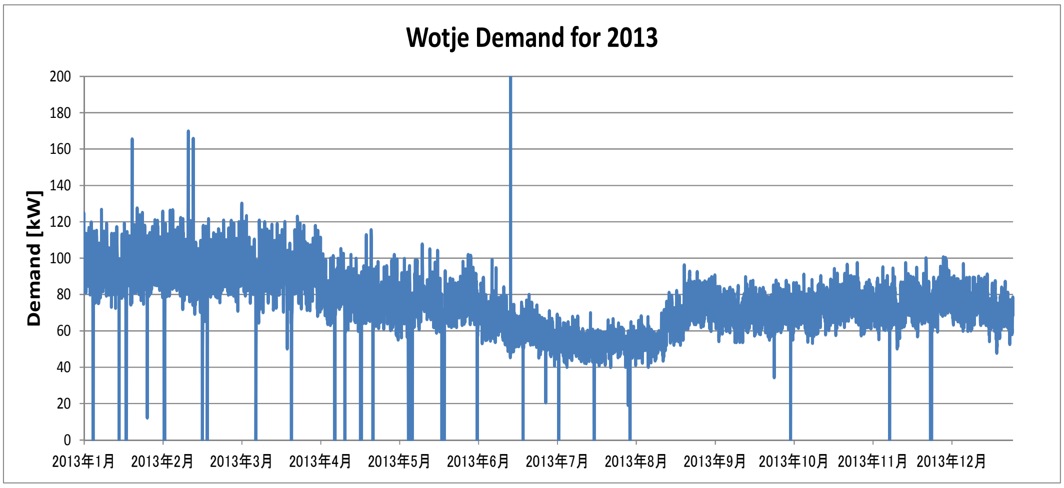


Figure 3.3.6-2 2013 Load trends

The maximum annual load is approx. 160 kW.

It shifted between 70 and 110kW throughout the year.

There is a tendency for the load to fall to 40 - 60 kW from June to August.

The load is approximately half as compared with the load 10 years ago.

Number of power outages (time): 24 times/year, 118 hours/year (2013)

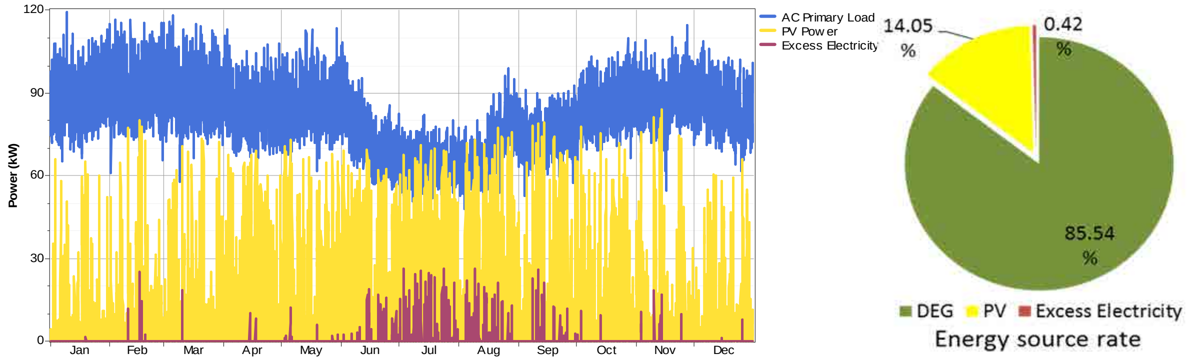
(b) The approximate amount of PV to be introduced

We performed a simulation of when 50 - 100 kW of PV are introduced as an approximation of the amount of PV to introduce.

【PV 100 kW】

Resulted in a 0.42% surplus of power in terms of annual energy source.

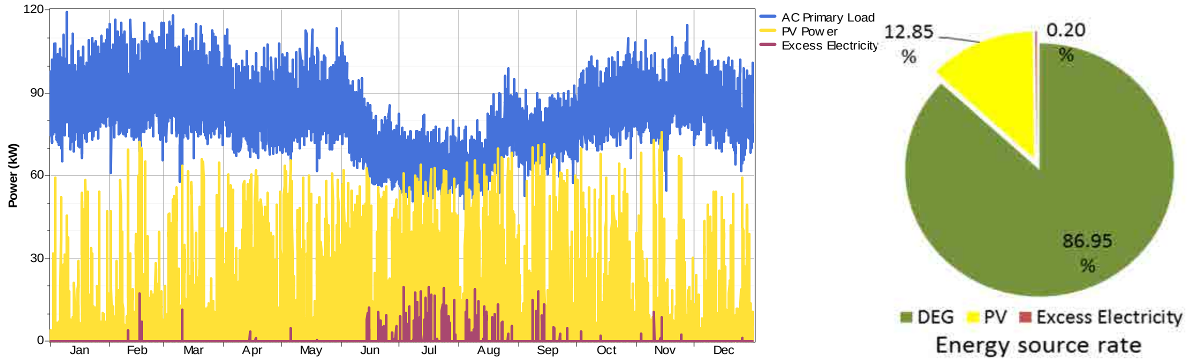
The PV supply ratio is 14.05%.



【PV 90 kW】

Resulted in a 0.20% surplus of power in terms of annual energy source.

The PV supply ratio is 12.85%.



【PV 80 kW】

Resulted in a 0.07% surplus of power in terms of annual energy source.

The PV supply ratio is 11.54%.

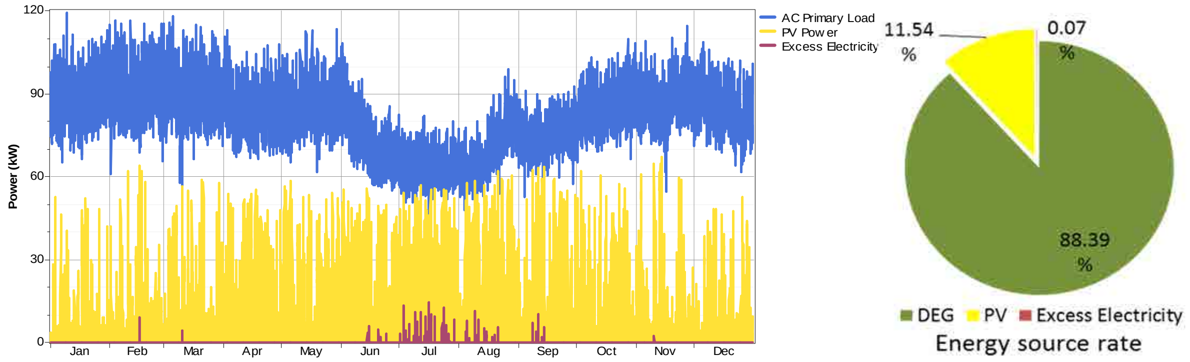
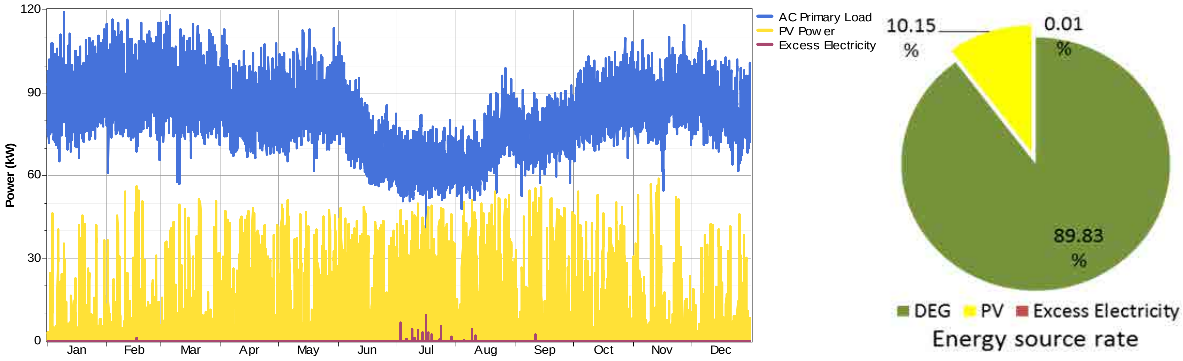


Figure 3.3.6-3 PV deployment simulation (100~80kW)

【PV 70 kW】

Resulted in a 0.01% surplus of power in terms of annual energy source.

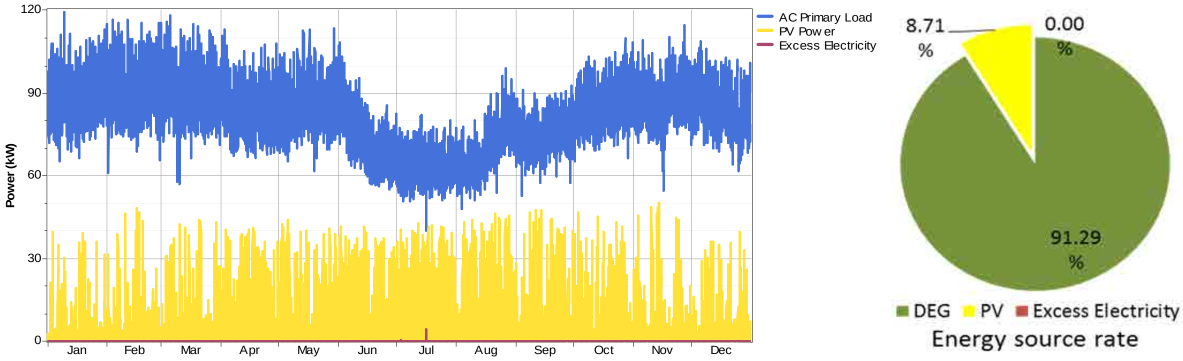
The PV supply ratio is 10.15%.



【PV 60 kW】

Resulted in a 0.00% (trace amount) surplus of power in terms of annual energy source.

The PV supply ratio is 8.71%.



【PV 50 kW】

Resulted in no surplus of power in terms of annual energy source.

The PV supply ratio is 7.26%.

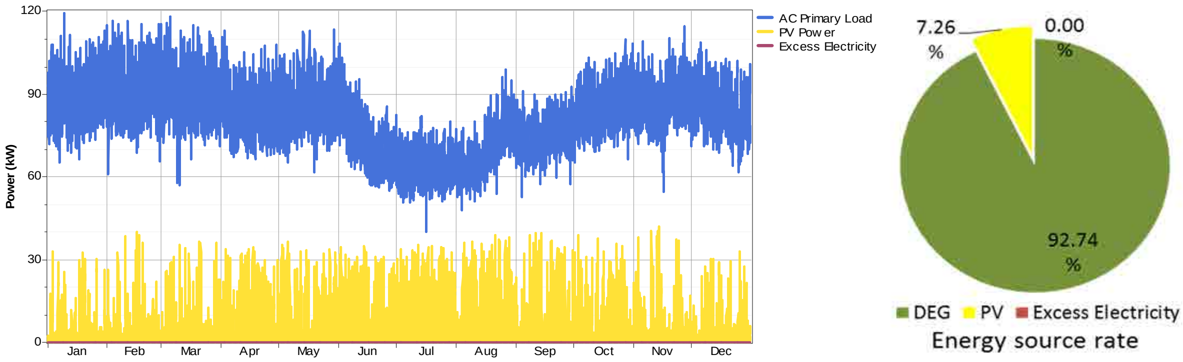
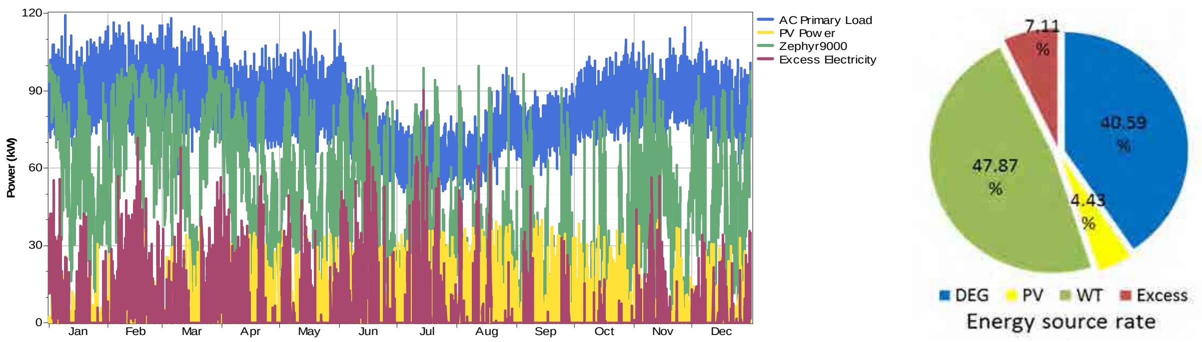


Figure 3.3.6-4 PV deployment simulation (70~50kW)

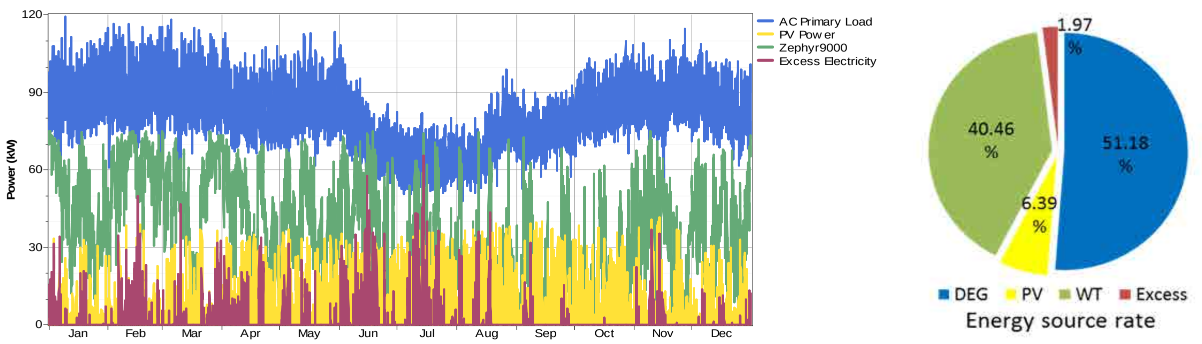
(c) DEG-PV-WT hybrid system

The next page shows a hybrid system where a wind turbine is added.

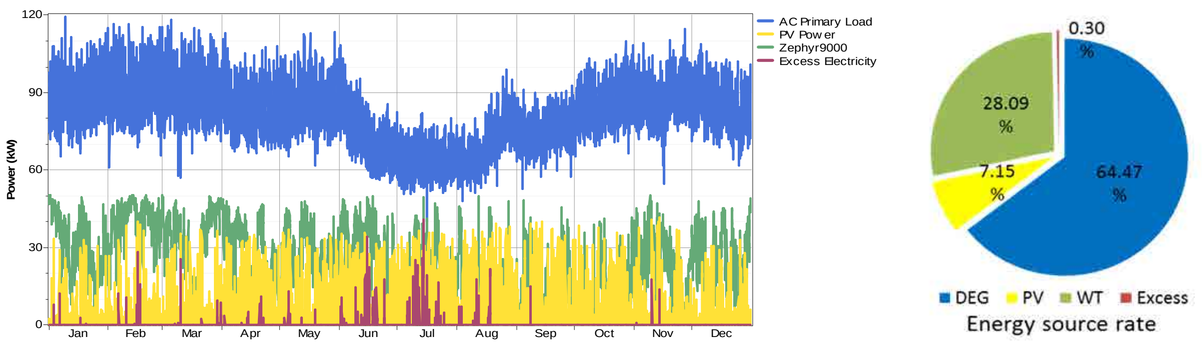
【PV 50 kW + WT 100 kW】



【PV 50 kW + WT 75 kW】



【PV 50 kW + WT 50 kW】



【PV 50 kW + WT 25 kW】

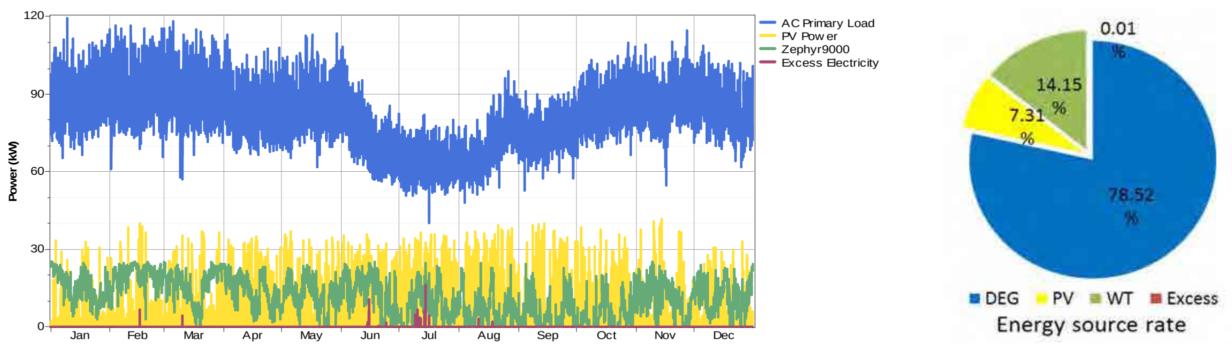


Figure 3.3.6-5 DEG-PV-WT hybrid system simulation

(d) Conclusion

We conducted a supply and demand balance simulation when when 50kW to 100kW of PV is deployed.

With 100kW of PV, there is a large amount of surplus power, and even when multiple PCS systems are considered it is highly likely that it will be disadvantageous in terms of controllability and economy (because of the downturn in equipment utilization due to output limitation through quantity control).

The amount of surplus power decreases with the decrease in PV deployment, and at 50kW to 70kW of PV, almost no surplus power is expected.

Considering economic efficiency, we shall adopt a system where the equipment utilization rate is maximized.

With this condition, 50kW of PV is recommended.

The ratio of PV supplied power to power supply (renewable energy supply ratio) with 50kW of PV is 7.26%.

In addition, as another method to increase the renewable energy supply ratio, the deployment of wind turbines (WT) is recommended. The Marshall Islands have very favorable wind conditions as the annual average wind speed is approximately 7.5 m/s or more at 25 m or more above ground.

We also conducted a supply and demand balance simulation when when 25kW to 100kW of WT is deployed in addition to 50kW of PV. When the amount of surplus power is considered as with PV, 25kW of WT is recommended.

The renewable energy supply ratio with 50kW PV and 25kW WTis21.46% (= PV 7.31％ + WT 14.15％).

＜Notes＞

- When installing the hybrid system, sites where control and operation can be performed easily such as power plant premises on remote islands is preferable. We would like to introduce a large amount of renewable energy, but it is assumed that the scale will be limited to the power plant premises for the time being.
- If surplus energy is generated, in the case of an advanced system, output limiting operation would be implemented in real time using the output limiting function. It can externally signal the PCS for PV to control output per second. In the case of wind turbine, output can be limited through pitch control, but it takes about one minute.
  In order to realize a simple system, we will basically use quantity control by operating multiple units.

Considering the above notes, each system configuration is as shown below.

Table 3.3.6-2 Proposed system configurations (Wotje)

Hybrid system	Deployment size	System configuration
DEG+PV	PV 50 kW	PV-PCS 10 kW x 5 units
DEG+PV+WT	PV50kW WT25kW	PV-PCS 10 kW x 5 units WT5kW×5 turbines

(2) Jaluit Atoll

(a) Status of the power plant

Details of the plant are as follows.

Table 3.3.6-3 Generator specification (Jaluit)

Engine #	1	2
ENGINE MAKE	Wartsila	Wartsila
ENGINE MODEL	UD25	UD25
NAME PLATERATING (kW)	300	300
Maximum output (kW)	300	300
SPEED (RPM)	1200	1200
YEAR INSTALLED	1993	1993
Governor Control	Droop	Droop
Synchronous capability	Unavailable	Unavailable

Operation range: with load, 5-20% output and up to 100 hours (after that, 70% or more output and 100 hours or more)

With no load, up to 10 minutes (when stopped after that)

Up to 6 hours (if a load will be carried after that)

Governor control: isochronous control

Switch operation: basically 1 unit is operated and switched at 300 hours

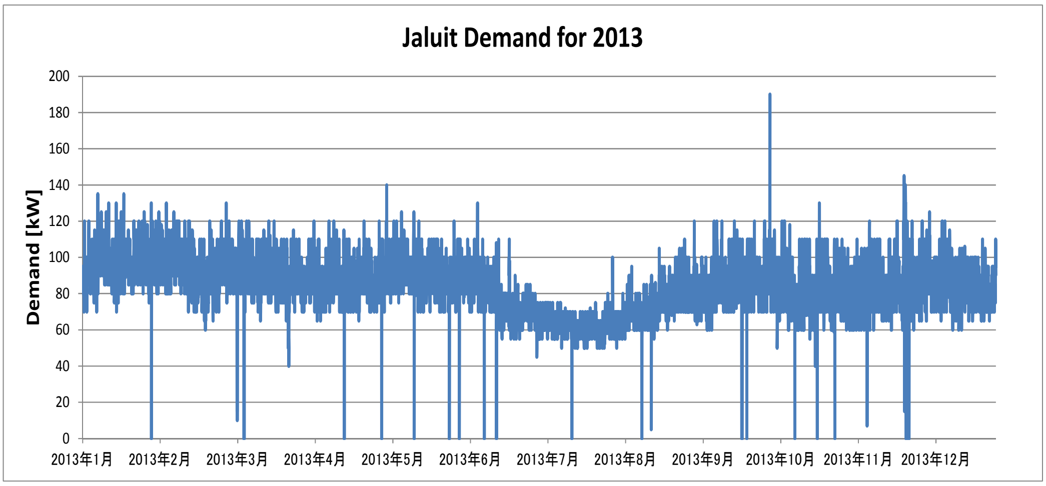


Figure 3.3.6-6 2013 Load trends

The maximum annual load is approx. 180kW.

It shifted between 80 and 100kW throughout the year.

There is a tendency for the load to fall to 40 - 60kW from June to August.

The load is approximately half as compared with 10 years ago.

Number of power outages (time): 18 times/year, 45 hours/year (2013)

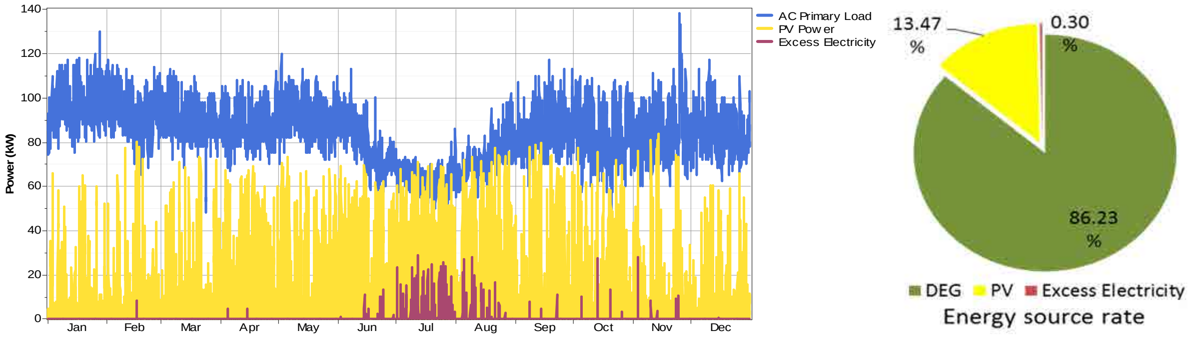
(b) The approximate amount of PV to be introduced

We performed a simulation of when 50 - 100 kW of PV are introduced as an approximation of the amount of PV to introduce.

【PV 100 kW】

Resulted in a 0.30% surplus of power in terms of annual energy source.

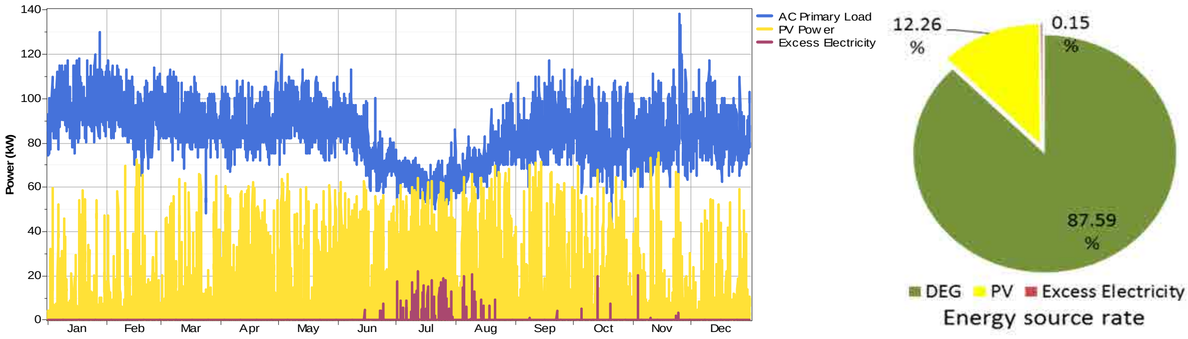
The PV supply ratio is 13.47%.



【PV 90 kW】

Resulted in a 0.15% surplus of power in terms of annual energy source.

The PV supply ratio is 12.26%.



【PV 80 kW】

Resulted in a 0.06% surplus of power in terms of annual energy source.

The PV supply ratio is 10.98%.

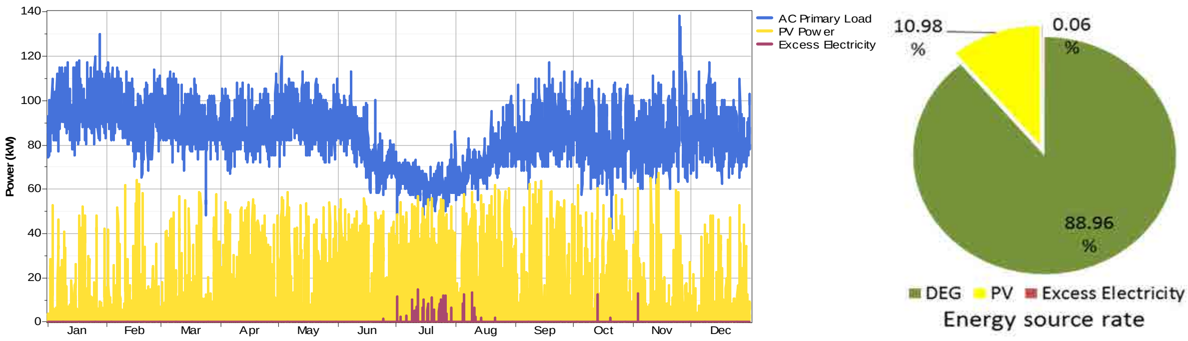
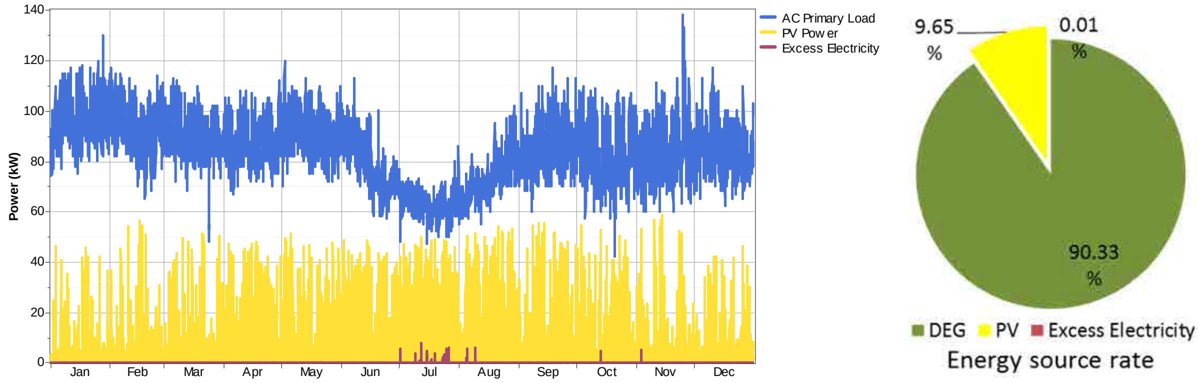


Figure 3.3.6-7 PV deployment simulation (100-80kW)

【PV 70 kW】

Resulted in a 0.01% surplus of power in terms of annual energy source.

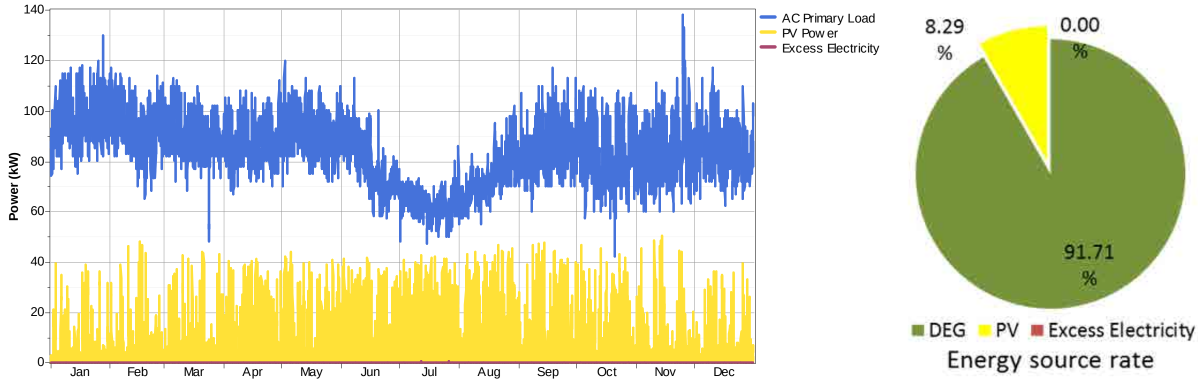
The PV supply ratio is 9.65%.



【PV 60 kW】

Resulted in no surplus of power in terms of annual energy source.

The PV supply ratio is 8.29%.



【PV 50 kW】

Resulted in no surplus of power in terms of annual energy source.

The PV supply ratio is 6.91%.

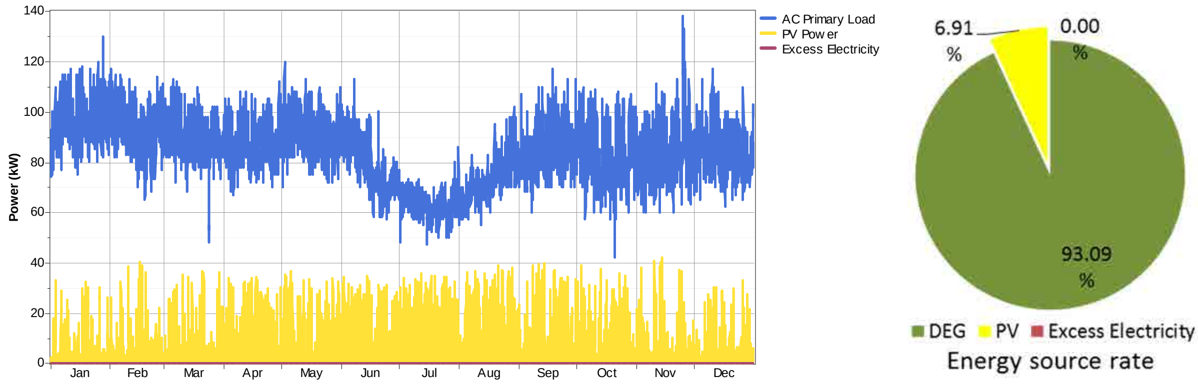
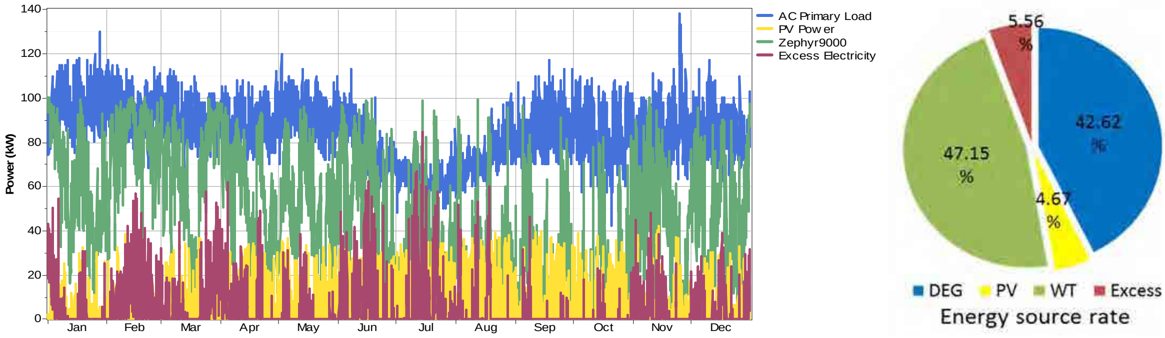


Figure 3.3.6-8 PV deployment simulation (70-50kW)

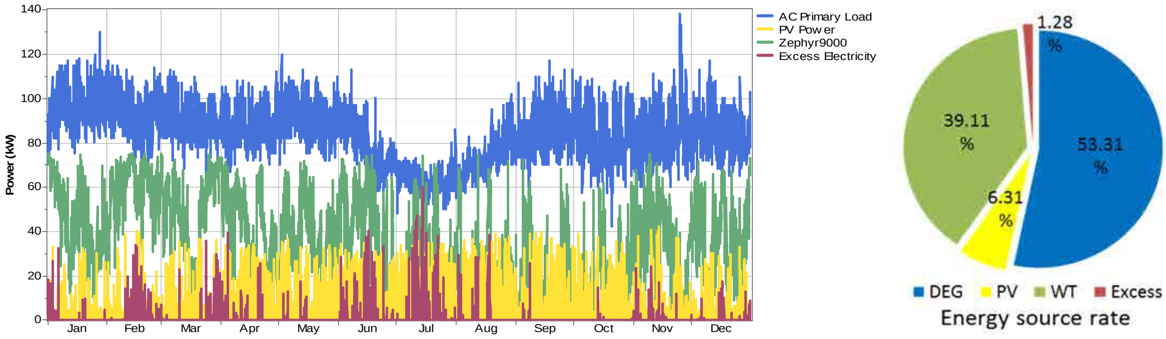
(c) DEG-PV-WT hybrid system

The next page shows a hybrid system where a wind turbine is added.

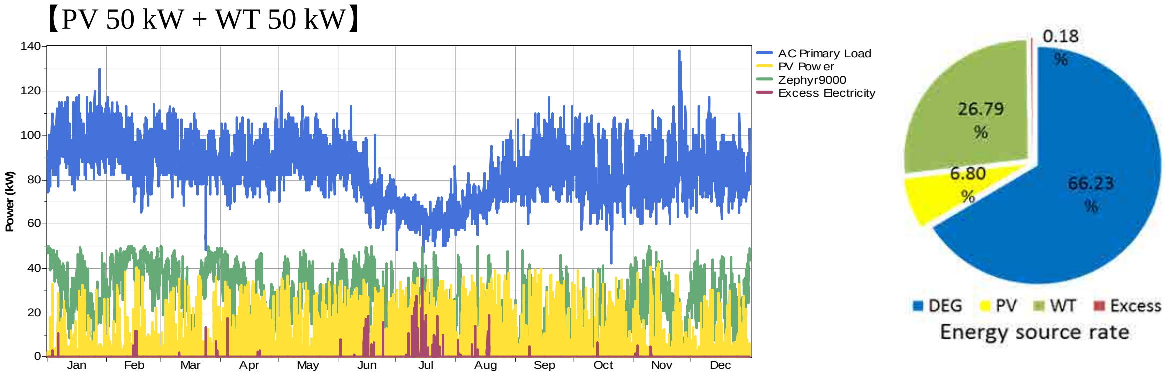
【PV 50 kW + WT 100 kW】



【PV 50 kW + WT 75 kW】



【PV 50 kW + WT 50 kW】



【PV 50 kW + WT 25 kW】

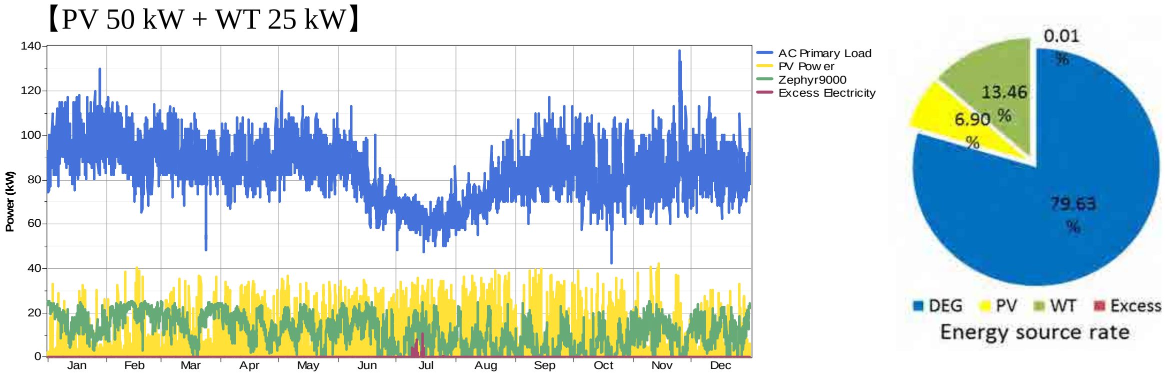


Figure 3.3.6-9 DEG-PV-WT hybrid system simulation

(d) Conclusion

We conducted a supply and demand balance simulation when when 50kW to 100kW of PV is deployed.

With 100kW of PV, there is a large amount of surplus power, and even when multiple PCS systems are considered it is highly likely that it will be disadvantageous in terms of controllability and economy (because of the downturn in equipment utilization due to output limitation through quantity control).

The amount of surplus power decreases with the decrease in PV deployment, and at 50kW to 70kW of PV, almost no surplus power is expected.

Considering economic efficiency, we shall adopt a system where the equipment utilization rate is maximized.

With this condition, 50kW of PV is recommended.

The ratio of PV supplied power to power supply (renewable energy supply ratio) with 50kW of PV is 6.91%.

In addition, as another method to increase the renewable energy supply ratio, the deployment of wind turbines (WT) is recommended. The Marshall Islands have very favorable wind conditions as the annual average wind speed is approximately 7.5 m/s or more at 25 m or more above ground.

We also conducted a supply and demand balance simulation when when 25kW to 100kW of WT is deployed in addition to 50kW of PV. When the amount of surplus power is considered as with PV, 25kW of WT is recommended.

The renewable energy supply ratio with 50kW PV and 25kW WTis20.36% (= PV 6.90% + WT 13.46%).

＜Notes＞

- When installing the hybrid system, sites where control and operation can be performed easily such as power plant premises on remote islands is preferable. We would like to introduce a large amount of renewable energy, but it is assumed that the scale will be limited to the power plant premises for the time being.
- If surplus energy is generated, in the case of an advanced system, output limiting operation would be implemented in real time using the output limiting function. It can externally signal the PCS for PV to control output per second. In the case of wind turbine, output can be limited through pitch control, but it takes about one minute.

  In order to realize a simple system, we will basically use quantity control by operating multiple units.

Considering the above notes, each system configuration is as shown below.

Table 3.3.6-4 Proposed system configurations (Jaluit)

Hybrid system	Deployment size	System configuration
DEG+PV	PV 50 kW	PV-PCS 10 kW × 5 units
DEG+PV+WT	PV 50 kW WT25kW	PV-PCS 10 kW × 5 units WT5kW × 5 turbines

(3) Ebeye Island

(a) Status of the power plant

Details of the plant are as follows.

Table 3.3.6-5 Generator specification (Ebeye)

Engine #	2	3	4
ENGINE MAKE	Cummins		
ENGINE MODEL	—	—	—
NAME PLATERATING（kW）	1,286	1,286	1,286
Maximum output (kW)	1,286	1,286	1,286
SPEED（RPM）	1,800	1,800	1,800
YEAR INSTALLED	—	—	—
Governor Control	Isochronous		
Synchronous capability	Available		

Operating range: Unknown However, estimated at 35% or more based on past (2013) operating data for each unit.

35% output
450 kW

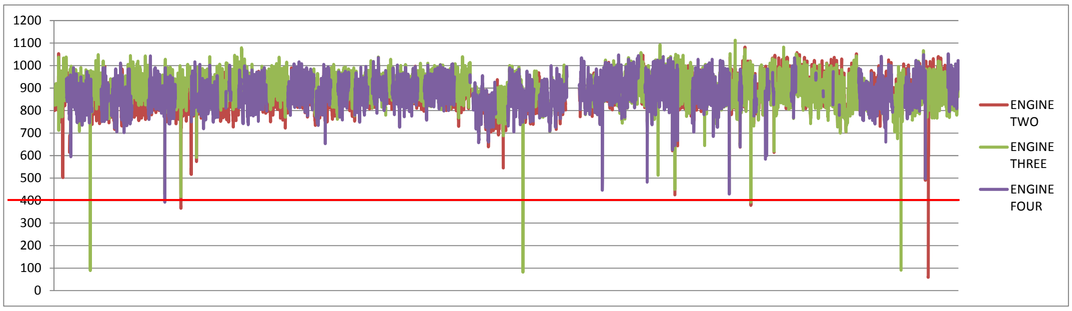


Figure 3.3.6-10 Operation data for each unit

Governor control: isochronous control ＋ load sharing control

Switch operation: basically 2 units are operated

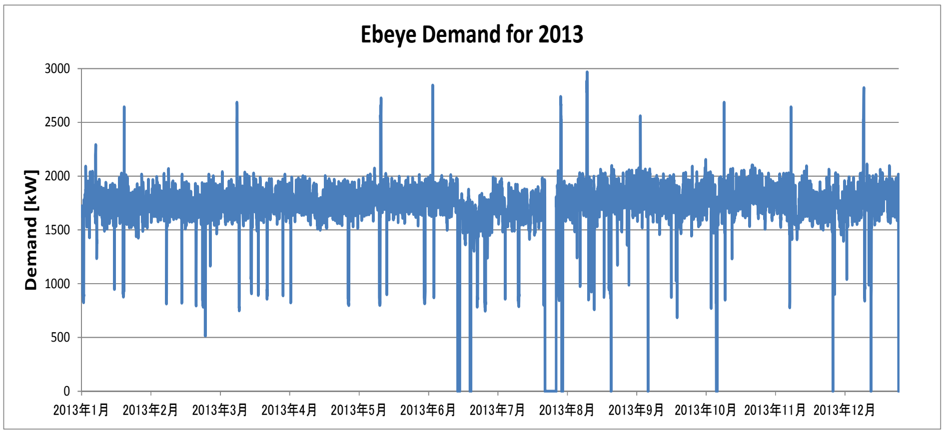


Figure 3.3.6-11 2013 Load trends

The maximum annual load is approx. 180 kW.

It shifted between 1600 and 1900 kW throughout the year.

Number of power outages (time): 10 times/year, 185 hours/year

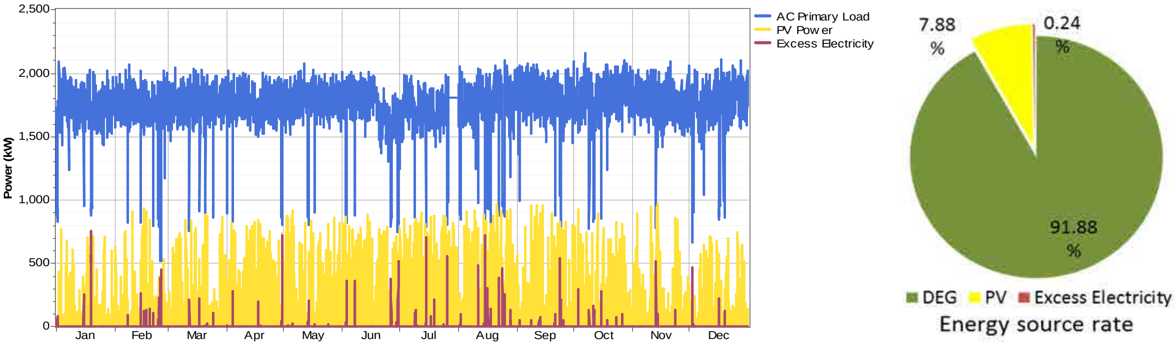
(b) The approximate amount of PV to be introduced

We performed a simulation of when 200 - 1200kW of PV are introduced as an approximation of the amount of PV to introduce.

【PV 1200 kW】

Resulted in a 0.24% surplus of power in terms of annual energy source.

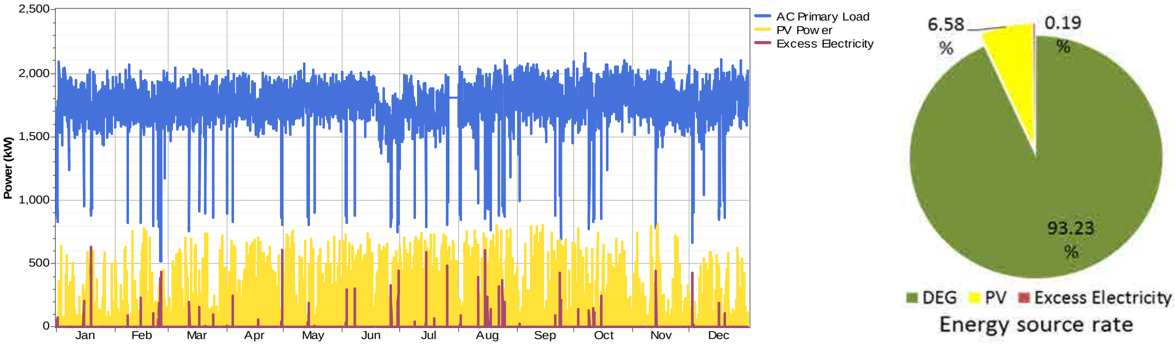
The PV supply ratio is 7.88%.



【PV 1000 kW】

Resulted in a 0.19% surplus of power in terms of annual energy source.

The PV supply ratio is 6.58%.



【PV 800 kW】

Resulted in a 0.16% surplus of power in terms of annual energy source.

The PV supply ratio is 5.26%.

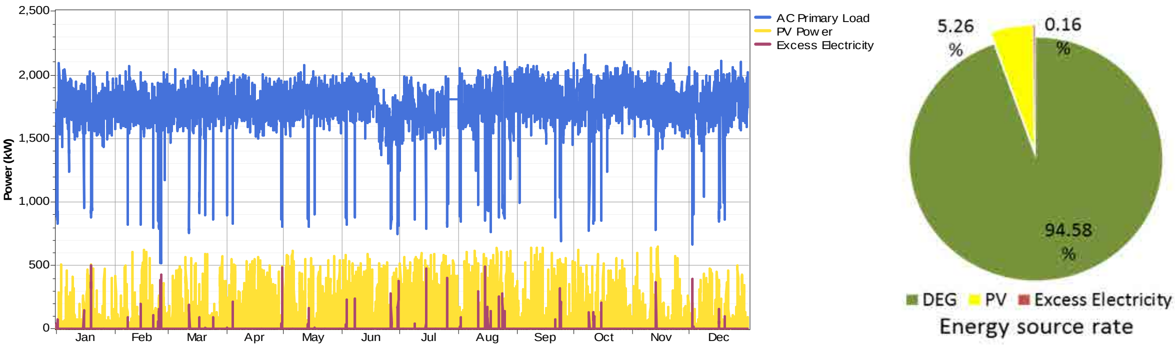
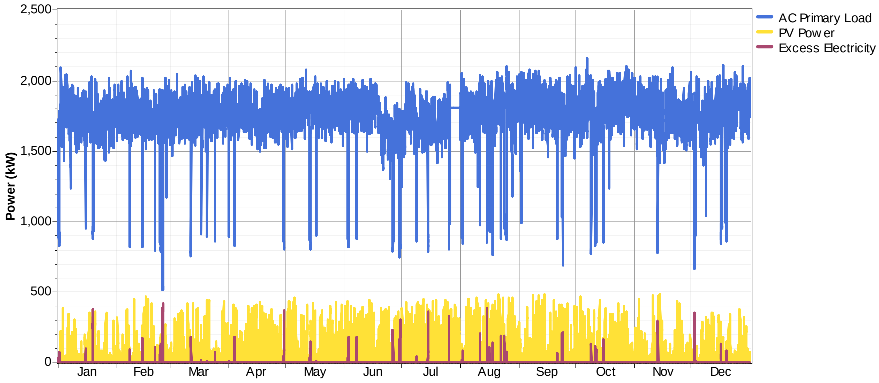


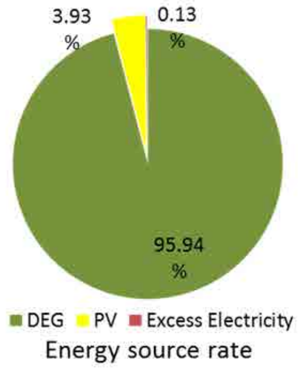
Figure 3.3.6-12 PV deployment simulation (1200-800kW)

【PV 600 kW】

Resulted in a 0.13% surplus of power in terms of annual energy source.

The PV supply ratio is 3.93%.

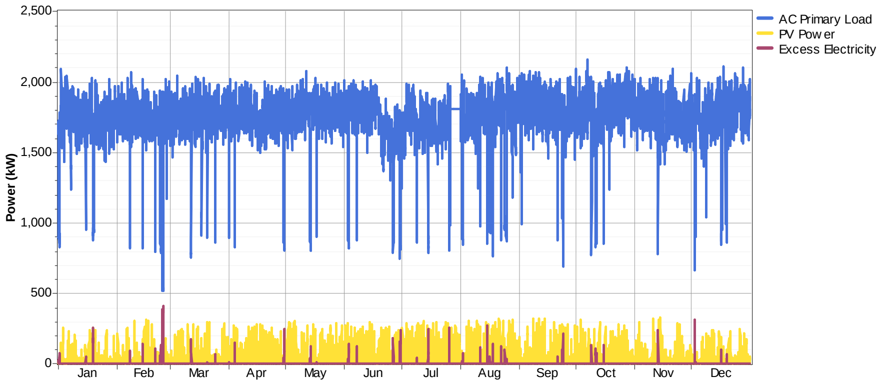


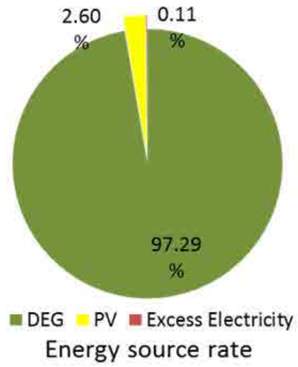


【PV 400 kW】

Resulted in a 0.11% surplus of power in terms of annual energy source.

The PV supply ratio is 2.60%.

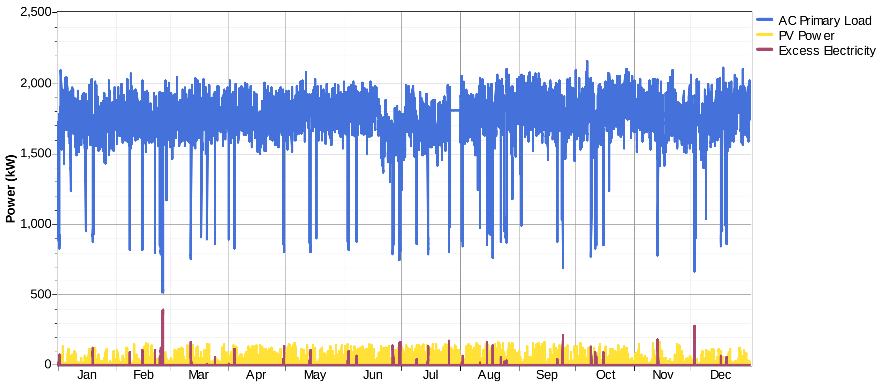




【PV 200 kW】

Resulted in a 0.09% surplus of power in terms of annual energy source.

The PV supply ratio is 1.27%.



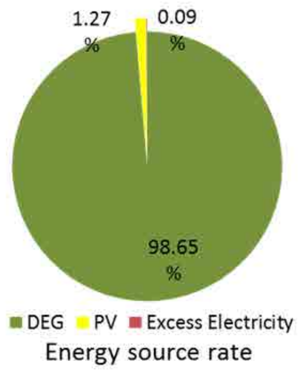
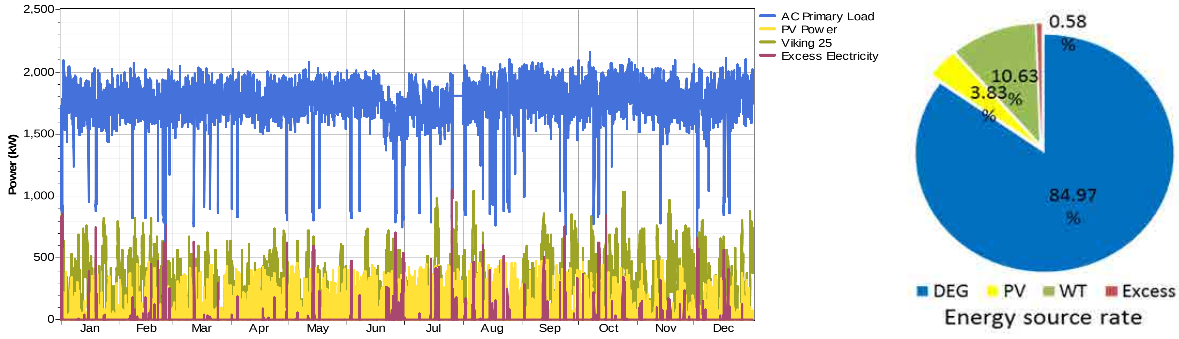


Figure 3.3.6-13 PV deployment simulation (600-200kW)

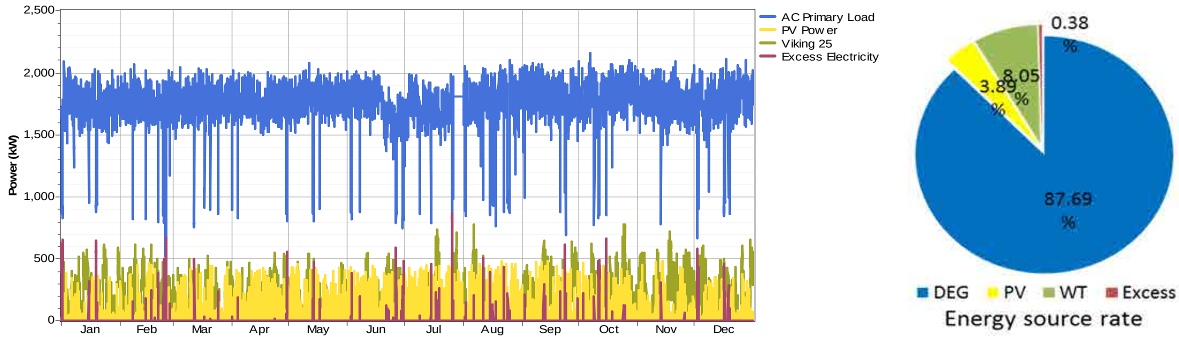
(c) DEG-PV-WT hybrid system

The next page shows a hybrid system where a wind turbine is added.

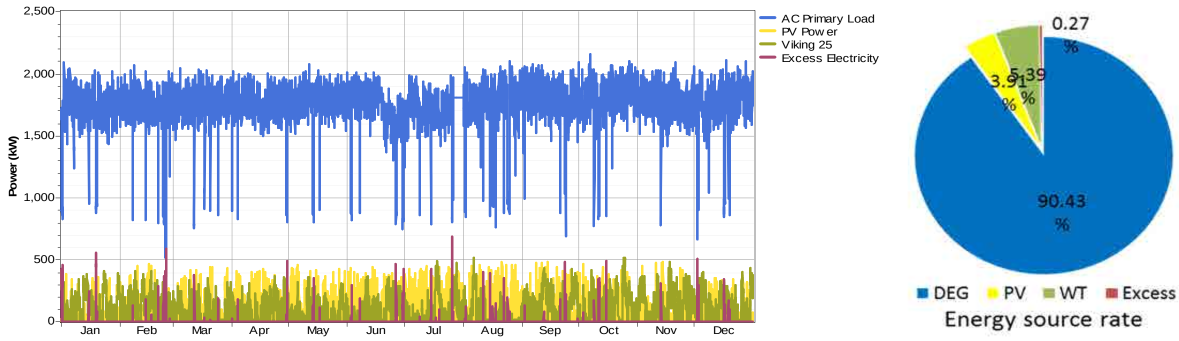
【PV 600 kW + WT 1000 kW】



【PV 600 kW + WT 750 kW】



【PV 600 kW + WT 500 kW】



【PV 600 kW + WT 250 kW】

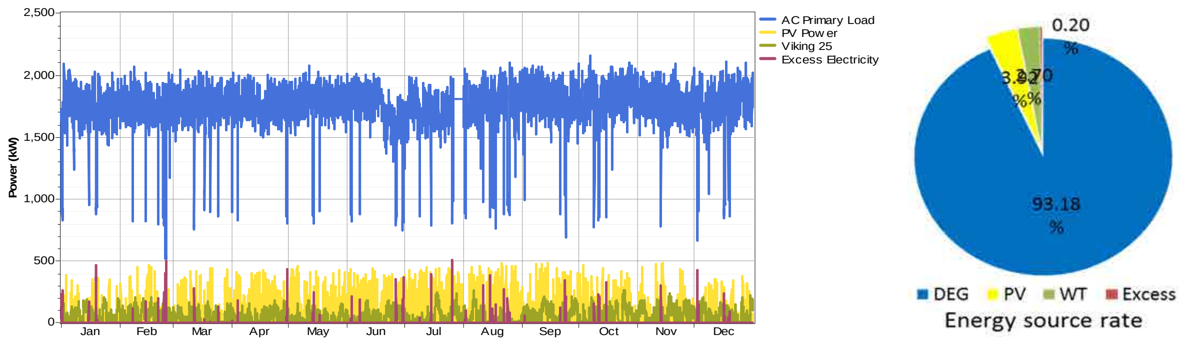


Figure 3.3.6-14 DEG-PV-WT hybrid system simulation

(d) Conclusion

We conducted a supply and demand balance simulation when when 200kW-1200kW of PV is deployed.

With 1200kW of PV, there is a large amount of surplus power, and even when multiple PCS systems are considered it is highly likely that it will be disadvantageous in terms of controllability and economy (because of the downturn in equipment utilization due to output limitation through quantity control).

The amount of surplus power decreases with the decrease in PV deployment, and at 200kW to 600kW of PV, almost no surplus power is expected (surplus power only occurs during power outage).

Considering economic efficiency, we shall adopt a system where the equipment utilization rate is maximized.

With this condition, 600kW of PV is recommended.

The ratio of PV supplied power to power supply (renewable energy supply ratio) with 600kW of PV is 3.93%.

In addition, as another method to increase the renewable energy supply ratio, the deployment of wind turbines (WT) is recommended. The Marshall Islands have very favorable wind conditions as the annual average wind speed is approximately 7.5 m/s or more at 25 m or more above ground.

We also conducted a supply and demand balance simulation when when 250kW to 100kW of WT is deployed in addition to 600kW of PV. When the amount of surplus power is considered as with PV, 500kW of WT is recommended.

The renewable energy supply ratio with 600kW PV and 500kW WT is 9.3% (= PV 3.91% + WT 5.39%).

＜Notes＞

- When installing the hybrid system, sites where control and operation can be performed easily such as power plant premises on remote islands is preferable. We would like to introduce a large amount of renewable energy, but it is assumed that the scale will be limited to the power plant premises for the time being.
- If surplus energy is generated, in the case of an advanced system, output limiting operation would be implemented in real time using the output limiting function. It can externally signal the PCS for PV to control output per second. In the case of wind turbine, output can be limited through pitch control, but it takes about one minute.

  In order to realize a simple system, we will basically use quantity control by operating multiple units.

Considering the above notes, each system configuration is as shown below.

Table 3.3.6-6 Proposed system configurations (Ebeye)

Hybrid system	Deployment size	System configuration
DEG+PV	PV 600 kW	PV-PCS 10 kW × 60 units
DEG+PV+WT	PV 600 kW WT500kW	PV-PCS 10 kW × 60 units WT 250 kW × 2 turbines

3.3.7 System design exercise

3.3.7.1 System design method

Regarding how to design of large-scale solar power generation facilities, selecting a tilt angle and orientation of the solar modules, selecting panels and power conditioners, conducting a study on the number of solar cell modules to connect in series and array configuration and layout, and a method to estimate the amount of power generated annually will be explained in Section 3.3.7.2.

In addition, calculation examples for Okinawa 1000 kW, Majuro 50kW, and Ebeye 200kW are shown for reference in Sections 3.3.7.3, 3.3.7.4, and 3.3.7.5.

As shown in the figure below, the optimum tilt angle in all regions of the Marshall Islands including Majuro is 0°, but a 5° tilt is recommended in the hope that rain will provide self-cleaning.

Moreover, when the tilt angle is 30° or less, azimuth is orientation-independent as shown in the figure below. In other words, it is thought that the amount of power generated annually will be the same regardless of orientation.

The projected amount of solar energy to be generated in Majuro

Using HOMER, we analyzed the the relationship between the tilt angle and azimuth angle of the 10 kW PV system in Majuro.
As a result, we found that the best angle of inclination is 0°, but the best angle of inclination providing for a natural cleaning effect is 5°.
An angle of inclination of 5°has almost no effect on azimuth angle.

The estimated amount of power to be generated by a 10kW PV system based on angle of inclination and azimuth angle. (kWh/year/PV10kW)

Azimuth	the tilt angle (Degree)																		
	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
0° Due south	12,574	12,535	12,420	12,233	11,976	11,657	11,277	10,844	10,360	9,826	9,248	8,634	7,992	7,326	6,654	6,001	5,437	4,928	4,460
±30°	12,574	12,525	12,397	12,196	11,947	11,641	11,271	10,853	10,397	9,897	9,367	8,813	8,237	7,653	7,064	6,481	5,917	5,375	4,862
±60°	12,574	12,518	12,384	12,200	11,971	11,673	11,341	10,972	10,549	10,110	9,648	9,156	8,664	8,156	7,643	7,131	6,616	6,116	5,618
±90°	12,574	12,518	12,386	12,210	11,984	11,696	11,379	11,015	10,603	10,189	9,745	9,267	8,807	8,326	7,820	7,343	6,853	6,346	5,880
±180°	12,574	12,540	12,435	12,261	12,018	11,710	11,340	10,912	10,430	9,899	9,327	8,722	8,106	7,496	6,890	6,283	5,678	5,089	4,521

Comparison of the amount of power generated at the inclined plane solar radiation angle to the optimum angle of inclination

Azimuth	the tilt angle (Degree)																		
	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
0° Due south	1.000	0.997	0.988	0.973	0.952	0.927	0.897	0.862	0.824	0.781	0.736	0.687	0.636	0.583	0.529	0.477	0.432	0.392	0.355
±30°	1.000	0.996	0.986	0.970	0.950	0.926	0.896	0.863	0.827	0.787	0.745	0.701	0.655	0.609	0.562	0.515	0.471	0.427	0.387
±60°	1.000	0.996	0.985	0.970	0.952	0.928	0.902	0.873	0.839	0.804	0.767	0.728	0.689	0.649	0.608	0.567	0.526	0.486	0.447
±90°	1.000	0.996	0.985	0.971	0.953	0.930	0.905	0.876	0.843	0.810	0.775	0.737	0.700	0.662	0.622	0.584	0.545	0.505	0.468
±180°	1.000	0.997	0.989	0.975	0.956	0.931	0.902	0.868	0.830	0.787	0.742	0.694	0.645	0.596	0.548	0.500	0.452	0.405	0.360

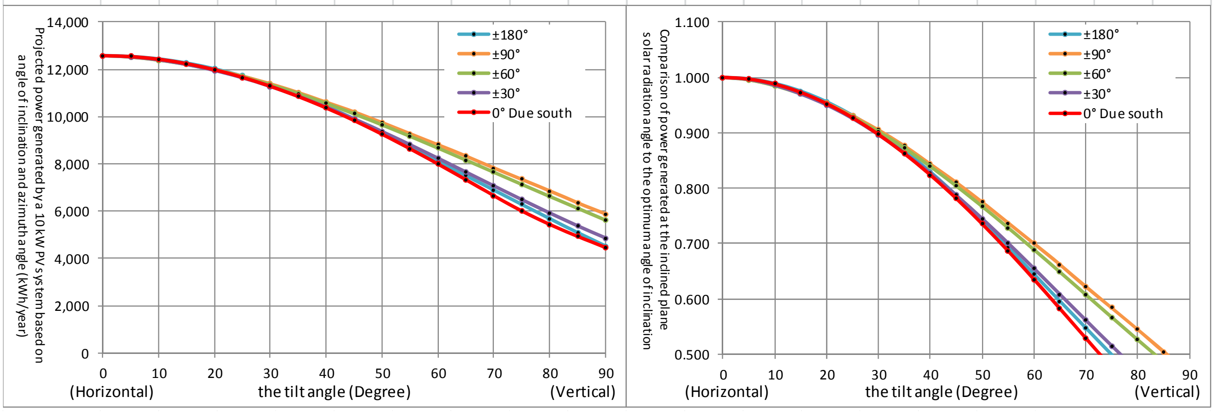


Figure 3.3.7-1 Relationship between tilt angle and azimuth in Majuro

3.3.7.2 System planning for mega-solar [Exercise]

(1) Procedures of a mega-solar system planning in the exercise

In this exercise, the system planning for a mega-solar at 1MW is implemented. In the implementation of the mega-solar system planning, the data in your country shall be used for the natural conditions such as solar radiation and temperature. Also, environmental conditions such as snow in your country shall be considered.

Figure 3.3.7-2 shows procedures of PV system planning in this exercise. In the exercise, the system planning of mega-solar at 1MW (AC terminal of PCS) is implemented, and calculate annual energy production. Study of the PV array rack and foundation are not included. Also, study of system configuration for connecting to the electric power system is performed.

In the real system planning, it is necessary to calculate the approximate cost after determination of system configuration, and perform an economical evaluation. However, we perform up to system configuration study in this exercise.

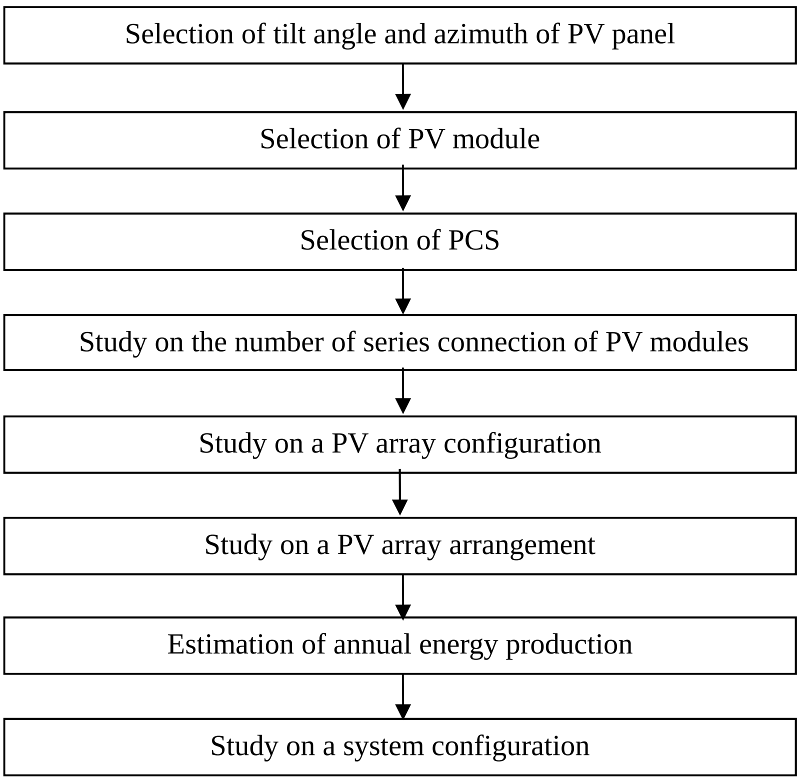


Figure 3.3.7-2 Procedure of system planning for mega-solar

(2) System planning for mega-solar

(a) Selection of tilt angle and azimuth of PV panel

The optimal tilt angle and azimuth of PV panel in each country is determined using HOMER (https://users.homerenergy.com/) or RETScreen (http://www.retscreen.net/) . The solar radiation of the daily average in each month at selected optimal tilt angle and azimuth is recorded. Also, the average temperature in each month is recorded.

(b) Selection of PV module

Select PV module from the table 3.3.7-1 “PV module list”.

Table 3.3.7-1 PV module list

	PV module A	PV module B	PV module C	PV module D
Type	Monocrystalline silicon (HIT Power 240S)	Polycrystalline silicon (KD250GX-LFB2)	Multi-junction Hybrid (F-NJ150)	CIS (SF160-S)
Nominal Max. Output (P_{max})	240W	240W	150W	160W
PV module conversion efficiency	19.0	14.6	9.60	12.6
Nominal Max. Output Working Voltage (V_{pm})	43.7V	29.8V	125.8V	84.0V
Nominal Max. Output Working Current (I_{pm})	5.51A	8.06A	1.20A	1.91A
Nominal Open Circuit Voltage (V_{oc})	52.4V	36.9V	158.1V	110V
Nominal Short Circuit Current (I_{sc})	5.85A	8.59A	1.45A	2.2A
External Dimensions (mm) W×L×D	1,580 × 798 × 35	1,662 × 990 × 46	1,500 × 1,100 × 50	1,257 × 977 × 35
Temperature coefficient of short circuit current(I_{sc})	+0.03%/K	+0.060%/K	+0.055%/K	+0.01%/K
Temperature coefficient of open circuit voltage(V_{oc})	−0.24%/K	−0.36%/K	−0.39%/K	−0.30%/K
Temperature coefficient of Max. output(P_{max})	−0.30%/K	−0.46%/K	−0.35%/K	−0.31%/K

* The temperature coefficient of output working voltage shall be the same as the temperature coefficient of open circuit voltage.

(c) Selection of Power Conditioning System

Selecting Power Conditioning System from the table 3.3.7-2 “Power Conditioning System list”.

Table 3.3.7-2 Power Conditioning System list

		PCS-A	PCS-B	PCS-C	PCS-D
Output capacity		10kW	100kW	250kW	500kW
DC input	Rated voltage	400V	345V	350	350
	DC voltage range	0～600V	0～650V	0～600V	0～600V
	Range of MPPT	200～550V	315～600V	320～550V	320～550V
	Number of phase	Three-phase three-wire	Three-phase three-wire	Three-phase three-wire	Three-phase three-wire
AC input	Rated voltage	202V	202V	415V	210V
	Rated frequency	50 or 60Hz	50 or 60Hz	50 or 60Hz	50 or 60Hz
	Power conversion efficiency	94.5%	95.3%	95.7%	96.8%

* You can confirm specifications for each solar module and power conditioner at the following site to assist you in making your selection. (http://www.enfsolar.com/)

(d) Study on the number of series connection of PV modules

The number of series connection of PV modules is considered from the specification of the selected PV module and a Power Conditioning System. The number of series connection of PV modules is: 110% of rated voltage (on DC side) of a selected PCS is divided by the maximum working voltage of the PV module, as a reference value. Also, the number of series connection of PV modules is determined in consideration of following points eventually.

- Is the variation by the temperature characteristics of a PV string's open circuit voltage within the DC voltage range (below the upper limit of the DC voltage range) of a power conditioning system?
- Is the variation by the temperature characteristics of a PV string's output working voltage within MPPT (maximum power point tracking) range of a power conditioning system?
- The highest and the lowest PV module temperatures are calculated by the following formulas:

  The highest PV module temperature=Annual highest temperature in each country + weighted average PV module temperature rise⊿T

  The lowest PV module temperature=Annual lowest temperature in each country + weighted average PV module temperature rise⊿T

  * Installation type is a back open type (rack-mount type), the weighted average PV module temperature rise ⊿T is at 18.4 (℃). (JIS C 8907)

(e) Study of the PV array configuration

In consideration of the PV array configuration, the number of parallel connections of the PV strings in the PV array is determined, and then the number of lines and rows of PV modules is determined. If the size of the PV array is specified, it is necessary to consider the PV array to fit its size as specified. The PV array consists of the number of PV modules of the integral multiple of the determined PV modules connected in series.

[Conditions of PV array arrangement]

Condition 1: The width of a PV array shall be 25m and below.
(Consideration given for efficiency during inspection)

Condition 2: Maximum height of a PV array is 2.0m and below from GL.(Consideration given for reach)
The bottom of a PV panel shall be 0.5m from GL.
(To minimize the impact of insects, small animals, and grass). Please refer to figure 3.3.7-3.

Condition 3: The spaces between PV modules and the edge of PV modules shall be kept at 50mm. (Space is created with mounting brackets. In cases where the mounting brackets are specified, 10 mm brackets are sometimes used.)

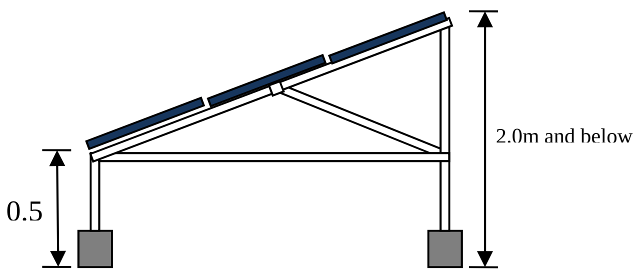


Figure 3.3.7-3 Conditions of PV array arrangement 2

(f) Study of the PV array arrangement

The number of the PV array is determined to be set at 1MW (AC terminal of PCS) and work out the PV array arrangement. The conversion efficiency of PCS and DC loss (2%) should consider when determining the number of the PV array. It assumes that the site for the PV array arrangement is a flat land, and the arrangement should be formed as a square shape as much as possible.

[Conditions of PV array arrangement]

Condition 1: The space at 10m x 10m for installing a collecting box, PCS, a transformer board, and an interconnection board is secured.

Condition 2: The distance of PV arrays facing to the north-south is set in consideration of shade impact by a front PV array. Please refer to figure 3.3.7-4.

Condition 3: The distance of PV arrays facing to the east-west should be more than 1.5m. Please refer to figure 3.3.7-5.

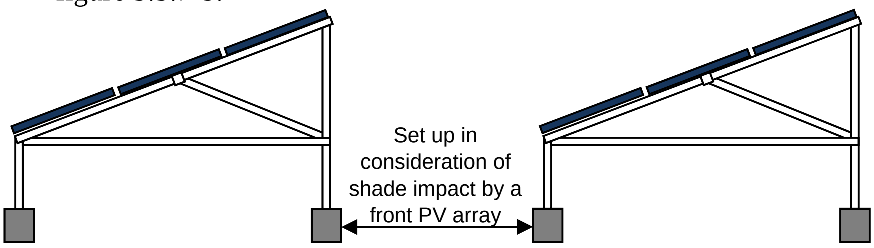


Figure 3.3.7-4 Conditions of PV array arrangement 2

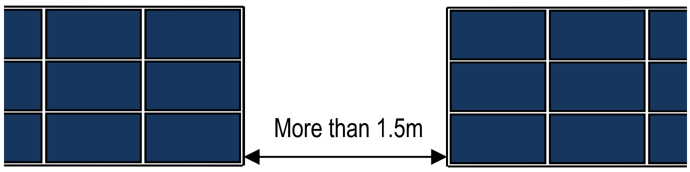


Figure 3.3.7-5 Conditions of PV array arrangement 3

(g) Estimation of annual energy production

Annual energy production is calculated from the capacity of the PV array

Expected annual energy Ep can be represented by the following equation:

$Ep = \Sigma H_A / Gs \times K \times P_{AS}$

・ Ep = Expected annual energy (kWh/year)

・ H_A = Average daily irradiation on a monthly basis (kWh/m^2/day)

・ Gs = Irradiance under standard condition = 1 (kW/m^2)

・ K = Total design factor (= Kd × Kt × η_{INV})

* DC correction factor Kd:

Corrects change in solar irradiance due to stains on the PV cell surface and characteristic difference in PV cell. Kd is about 0.9.

* Temperature correction factor Kt: Corrects temperature rise of PV cell and change in conversion efficiency due to sunlight.

$Kt = 1 + \alpha (Tm - 25) / 100$

α: Temperature coefficient at max. output (%／℃)

Tm: Module temperature (℃) = Tav + ΔT

Tav: Monthly mean temperature (℃)

ΔT: Module's temperature rise (℃) = 18.4 (℃)

* PCS efficiency η_{INV}: AC/DC conversion efficiency of the inverter.

・ P_{AS} = PV array output under standard condition (kW)

AM = 1.5*; Irradiance = 1 kW/m^2; PC cell temperature = 25ºC

(h) Study of the PV system configuration

As shown in the figure below, solar power generation reaches 90% or more only a few % of the hours per year. Therefore, the PCS rated output or more power cannot be generated, but to effectively increase the annual power generation output, extra PV modules should be installed such that their output total is approximately 10% of PCS rated output.

＜Example＞

PCS output = PV module output DC9.88kW × DC loss 98% (-2%)
×PCS conversion efficiency 95% ＝ AC9.20kW

PCS output ＝ PV module output DC11.4kW × DC loss 98％（-2%）
×PCS conversion efficiency 95% ＝ AC10.61kW
→PCS rated output, but actually AC10kW

DC9.88kW-AC10kW	DC11.4kW-AC10kW
11,251kWh/year (9.88kW*8760h*0.13)	12,852kWh/ year (11.4kW*8760h*0.13*0.99)

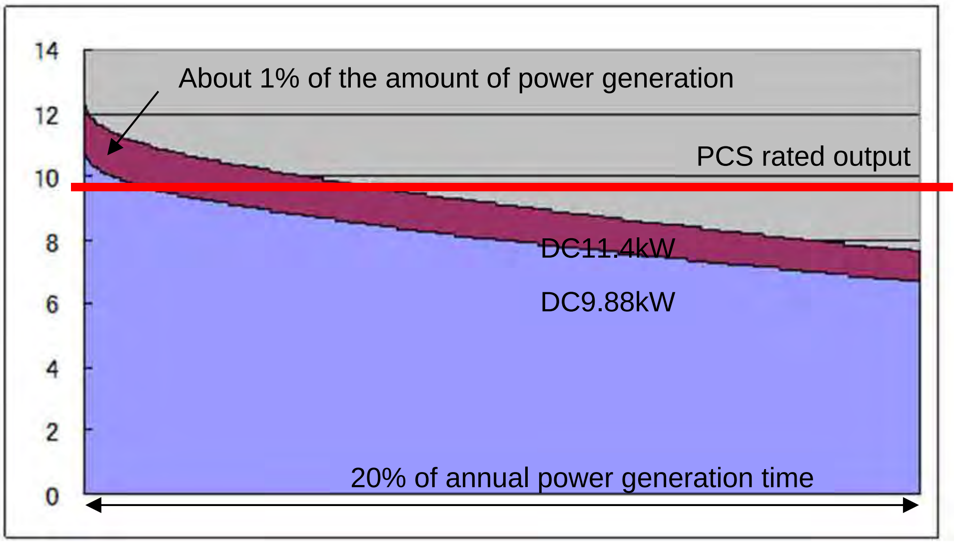


Figure 3.3.7-6 Dilation curve of solar power output（1 second measurement）

Others. In the consideration of the PV system configuration, the specification of each equipment except PV array and PCS is worked out. Also, the number of circuits and the necessary number of units of the junction box and the collection box are worked out. A junction box is selected from four, eight, ten, twelve or sixteen circuits, and calculates the required number of units. A collection box is set per PCS, and calculates required number of circuits. In addition, it is necessary to configure the PV system for connecting to the electric power system in each country. (Installation of the step-up transformer to the system voltage, etc.)

3.3.7.3 Suggested answer [Okinawa]

Mega solar planned installation site: [Country] Japan [Area] Okinawa Naha

(a) Tilt angle of PV panel 18 °

Azimuth South

Solar irradiation in the above-mentioned tilt angle and azimuth

Table 3.3.7-3 Annual solar radiation

Month	Solar irradiation per day (kWh/m^2/day)	Ambient Temperature (℃)
January	2.89	17.4
February	3.13	17.4
March	3.79	19.1
April	4.54	21.7
May	4.99	24.3
June	5.46	26.9
July	6.57	29.1
August	6.22	28.9
September	5.66	27.8
October	4.79	25.5
November	3.70	22.6
December	3.11	19.2
Annual	**4.58**	**17.4**

(b) Specification of selected PV module

Table 3.3.7-4 Solar cell module specifications

	PV module B
Type	Polycrystalline Silicon
Nominal Max. Output(P_{max})	240W
PV module conversion efficiency	14.6
Nominal Max. Output Working Voltage (V_{pm})	29.8V
Nominal Max. Output Working Current (I_{pm})	8.06A
Nominal Open Circuit Voltage (V_{oc})	36.9V
Nominal Short Circuit Current (I_{sc})	8.59A
External Dimensions (mm) W×L×D	1,662 × 990 × 46
Temperature coefficient of short circuit current	+0.060%/K
Temperature coefficient of open circuit voltage	－0.36%/K
Temperature coefficient of Max. output	－0.46%/K

(c) **Specification of selected power conditioning system**

Table 3.3.7-5 Power conditioner specifications

		PCS-A
Output capacity		10kW
DC input	Rated voltage	400V
	DC voltage range	0～600V
	Range of MPPT	200～550V
	Number of phase	Three-phase three-wire
AC output	Rated voltage	202V
	Rated frequency	50 or 60Hz
	Power conversion efficiency	94.5%

(d) Number of series connection of PV modules ___16 in series___

PV string open circuit voltage (PV module temperature 25℃) : ___590.4 V___

(Max. PV module temperature 54.0℃): ___427.25 V___

(Min. PV module temperature 25.0℃): ___475.52 V___

PV string output working voltage (PV module temperature 25℃): ___468.8 V___

(Max. PV module temperature 54.0℃): ___349.34 V___

(Min. PV module temperature 25.0℃): ___388.80 V___

(Calculation)

1) Calculation of the number of series connection of the PV module from the rated voltage of a power conditioning system and the nominal maximum output voltage of a PV module.

Rated voltage of power conditioning system: 400V, Nominal max. output voltage of PV module: 29.3V

400V× 1.1 = 440V 440V / 29.3V≒15.02≒16 in series

2) Calculation of maximum and minimum PV module temperature

Maximum temperature in Naha: 35.6℃, Minimum temperature in Naha: 6.6℃

Max. PV module temperature = 35.6 + 18.4 = 54.0℃

Min. PV module temperature = 6.6 + 18.4 = 25.0℃

3) Calculation of the PV string open circuit voltage at the highest and the lowest PV module temperature

Temperature coefficient of the PV module open circuit voltage: -0.36% / ℃

PV string open circuit voltage at PV module temperature of 25℃ 36.9V × 16 = 590.4V

PV string open circuit voltage at the maximum PV module temperature (54.0℃)

590.4V × {1 - 0.0036× (54.0 - 25)} ≒ 528.76V

PV string open circuit voltage at the minimum PV module temperature (25.0℃)

590.4V× {1 - 0.0036× (25.0 - 25)} = 590.40V

4) Calculation of PV string output working voltage at the maximum and the minimum PV module temperature

Temperature coefficient of PV module output working voltage: -0.36% / ℃ (Same as the temperature coefficient of open circuit voltage)

PV string output working voltage at PV module temperature of 25℃ 29.3V × 16 = 468.8V

PV string output working voltage at the maximum PV module temperature (54.0℃)

468.8V× {1 - 0.0036 × (54.0 - 25)} = 349.336 ≒ 419.86V

PV string output working voltage at the minimum PV module temperature (25.0℃)

468.8V × {1 - 0.0036 × (25.0 - 25)} = 468.80V

(Check on DC voltage range and MPPT range)

DC voltage range: The PV string open circuit voltage operates in the range of 528.76 to 590.40V to the DC voltage range of a power conditioning system at 0 to 600V. Hence, there is no problem.

MPPT range : The PV string output working voltage operates in the range of 419.86V to 468.80V to the maximum power point tracking range of a power conditioning system in 200V to 550V. Hence, there is no problem.

(e) PV array configuration 4 lines 12 rows (PV modules: 48 pieces)

16 in series 3 in parallel

PV array output 11.52 kW

PV array size (W) 20.594 m × (L) 4.004 m (projection of horizontal surface)

The maximum height of PV array 1.801 m

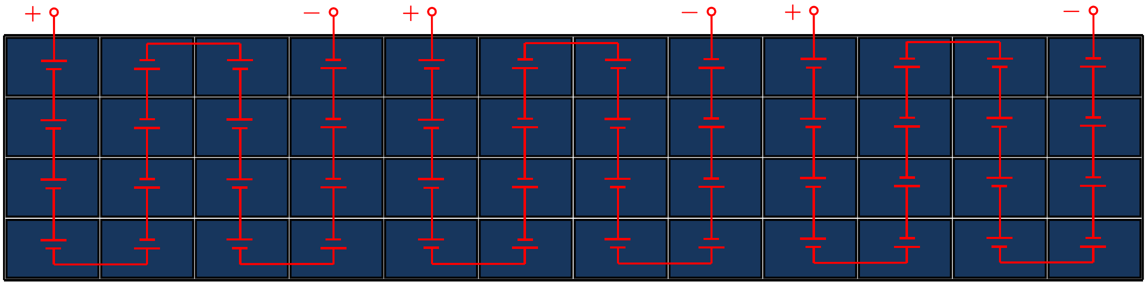


Figure 3.3.7-7 Wiring diagram of the PV array

(Calculation)

1) Calculation of the maximum number of lines and rows of the PV array

The maximum number of lines of the PV array: a

The maximum height of PV array: 2.0m and below from GL (The bottom of the PV panel is 0.5m from GL), Tilt angle of the PV panel: 18°

Depth of PV module: 990mm. (2.0m - 0.5m) = 1.5m

$1.5m \geqq X \times \sin 18° \Rightarrow 4.854m \geqq X$ ($\sin 18° = 18 \times \pi / 180$) $4.854 / 0.99 ≒ 4.9$ a = 4 lines

The maximum number of rows of the PV array: b

The maximum width of PV array: 25m and below, width of the PV module: 1,662mm

$25 / 1.662 ≒ 15.1$ b = 15 rows

The maximum number of the PV module piece only on the conditions of PV array arrangement is 4 lines, 15 rows and 60 pieces.

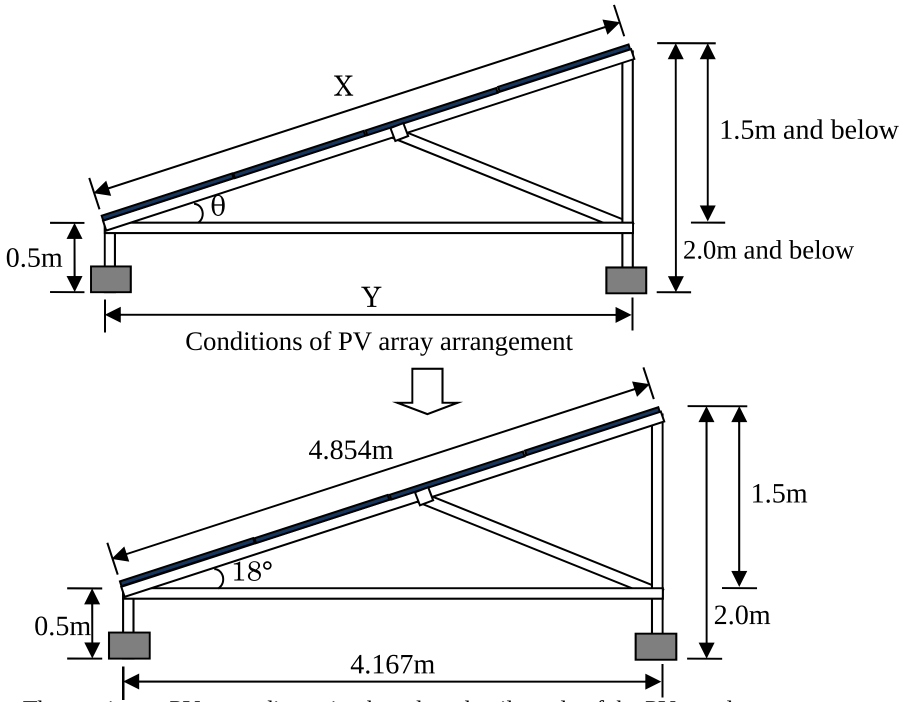


Figure 3.3.7-8 PV array size

2) Calculation of the maximum number of parallel connection and the number of the PV module pieces from the number of series connection of the PV module

The maximum number of PV module piece only on the conditions of PV array arrangement: 60 pieces

The number of series connection of the PV module: 16 in series

60 / 16≒3.75 3 in parallel

16 in series × 3 in parallel = 48 pieces

3) Calculation of the PV array output from the number of PV module pieces

Nominal maximum output of the PV module: 240W

240W × 48 = 11,520W ⇒ 11.52kW

4) Calculation of the number of PV array rows from the number of PV module pieces

The number of PV module piece: 48 pieces, the maximum number of lines of PV array a: 4 lines

48 / 4 = 12 12 rows

5) Calculation of the PV array size from the number of lines and rows of the PV array

Dimension of the PV panel: (0.99 × 4) + {0.05 × (4 + 1)} = 4.21m

Depth of the PV module: 990mm, The space between PV modules and the edge of the PV modules: 50mm

The maximum height of the PV array: (4.21m × sin18°) + 0.5m = 1.801m

Tilt angle of the PV panel: 18°Height of the bottom of the PV panel: 0.5m from GL

Length of the PV array L (projection of horizontal surface): 4.21m × cos18°= 4.004m

Width of the PV array W: (1,662× 12) + {0.05 × (12 + 1)} = 20.594m

Width of the PV module: 1,662mm

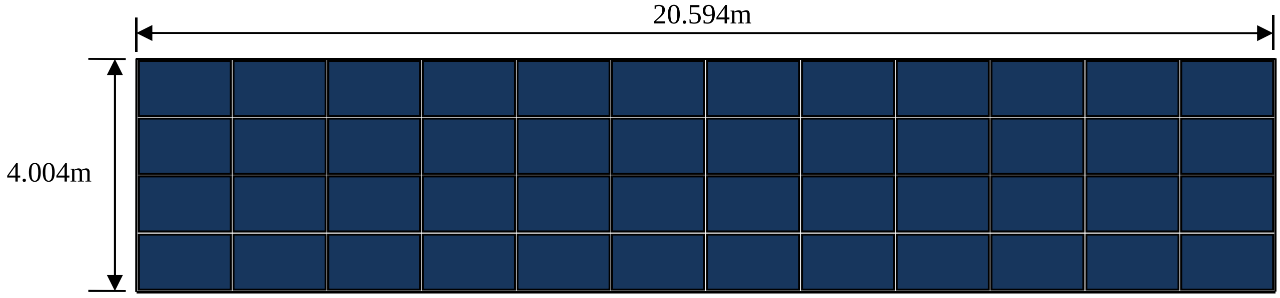


Figure 3.3.7-9 PV array size (projection of horizontal surface)

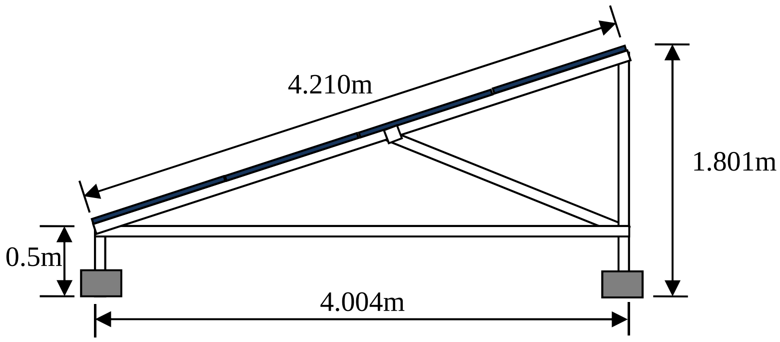


Figure 3.3.7-10 PV array size

(f) PV array arrangement

Number of PV array 100 units

Total output of PV array 1,152 kW

(Calculation)

1) Calculation of the total output of the PV arrays

11.52kW × 100 = 1,152kW

2) Calculation of the shadow scale factor of north and south direction

The latitude and the longitude in Naha: North latitude 26.1312, East longitude 127.4048

Solar altitude h: 19.35° Azimuth: 50.11°

*The data is at 9am on the winter solstice (21st of December 2012), the azimuth is directly south at 0°

Scale factor of the shadow $R = L_S / L = \coth \times \cos \alpha = \cot (19.35°) \times \cos (50.11°) = 1.826$

(The length "Ls" of the shadow of north and south direction cast by the object of height "L".)

3) Calculation of the distance of PV arrays facing to the north-south

The maximum height of PV array: 1.801m

$(1.801 - 0.5) \times 1.826 \fallingdotseq 2.375$ m

4) PV array arrangement and total area

Install according to the location. Consider with SketchUp.

(g) Annual Energy Production

Table 3.3.7-6 Annual Energy Production

Month	Generated energy (kWh)
January	80,025
February	78,283
March	104,033
April	118,981
May	133,295
June	139,198
July	171,031
August	162,096
September	143,598
October	127,138
November	96,510
December	85,323
Annual	**1,439,509**

*Annual energy production is the sum total of monthly expected energy production.

Annual power generation projections can be made using HOMER (https://users.homerenergy.com/) or RETScreen (http://www.retscreen.net/).

The calculation method is as shown below.

(Calculation)

1) Calculation of expected monthly energy production [January](kWh / Month)

Average daily irradiation on monthly basis H_A: 2.89kWh/m^2/day, Irradiance under standard condition Gs: 1kW/m^2

PCS conversion efficiency η_{INV}: 94.5%, DC correction factor Kd: 0.9, Temperature coefficient at max. outputα: -0.46 % / K

Monthly mean temperature Tav: 17.4℃, Weighted average PV module temperature rise⊿T: 18.4℃

Module temperature Tm = Tav + ⊿T = 17.4 + 18.4 = 35.8℃

Temperature correction factor Kt = 1 + α (Tm-25) / 100 = 1 - 0.46 (35.8－25) / 100 = 0.95032

Total design factor K = Kd × Kt × η_{INV} = 0.9 × 0.95032 × 0.945 = 0.808247

Expected monthly energy production Ep = ΣH_A / Gs × K × P_{AS}

= 31 × 2.89 / 1 × 0.808247 × 1,152 ≒ 83,417kWh

(h) System configuration

- Generation scale 1,000 kW（AC）
- Number of arrays 100
- Array output 1,152 kW（DC）
- Number of PCS 100
- System voltage 6.6 kV
- Step-up transformer 1,000 kVA

Primary voltage / Secondary voltage 6.6 kV/ 415 V

- Power transformer for substation 50 kVA

Primary voltage / Secondary voltage 6.6 kV/ 200 V

3.3.7.4 Suggested answer [Majuro]

Mega solar planned installation site: [Country] Marshall Islands [Area] Majuro

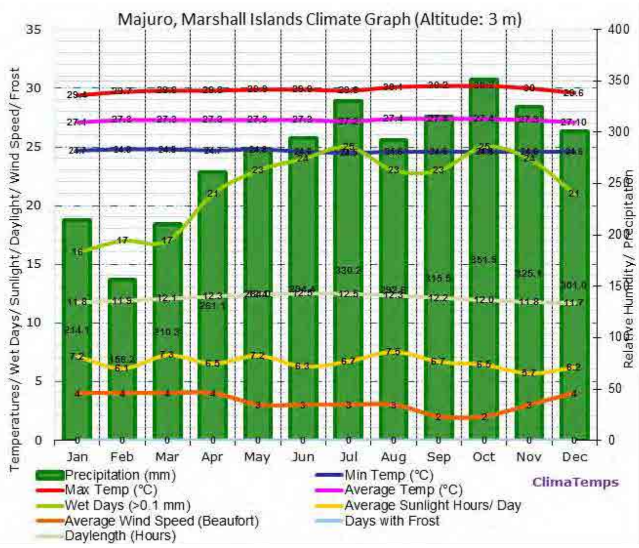
(a) Tilt angle of PV panel 5 °

Azimuth South

Solar irradiation in the above-mentioned tilt angle and azimuth

Table 3.3.7-7 Annual solar radiation

Month	Solar irradiation per day ($kWh/m^2/day$)	Ambient Temperature (℃)
January	2.372	27.4
February	2.880	27.3
March	3.464	27.3
April	4.527	27.3
May	4.735	27.3
June	5.306	27.3
July	5.850	27.2
August	5.431	27.4
September	4.675	27.4
October	3.909	27.4
November	2.976	27.3
December	2.554	27.1
Annual	**4.603**	**27.3**



(b) Specification of selected PV module

Table 3.3.7-8 Solar cell module specifications

	PV module B
Type	Polycrystalline Silicon
Nominal Max. Output(P_{max})	240W
PV module conversion efficiency	14.6
Nominal Max. Output Working Voltage (V_{pm})	29.8V
Nominal Max. Output Working Current (I_{pm})	8.06A
Nominal Open Circuit Voltage (V_{oc})	36.9V
Nominal Short Circuit Current (I_{sc})	8.59A
External Dimensions (mm) W×L×D	1,662 × 990 × 46
Temperature coefficient of short circuit current	+0.060%/K
Temperature coefficient of open circuit voltage	−0.36%/K
Temperature coefficient of Max. output	−0.46%/K

(c) Specification of selected power conditioning system

Table 3.3.7-9 Power conditioner specifications

		PCS-A
Output capacity		10kW
DC input	Rated voltage	400V
	DC voltage range	0～600V
	Range of MPPT	200～550V
	Number of phase	Three-phase three-wire
AC output	Rated voltage	202V
	Rated frequency	50 or 60Hz
	Power conversion efficiency	94.5%

(d) Number of series connection of PV modules 16 in series

PV string open circuit voltage (PV module temperature 25℃) : 590.4 V

(Max. PV module temperature 48.6℃): 540.24 V

(Min. PV module temperature 43.0℃): 552.14 V

PV string output working voltage (PV module temperature 25℃): 468.8 V

(Max. PV module temperature 48.6℃): 428.97 V

(Min. PV module temperature 43.0℃): 438.42 V

（Calculation）

1) Calculation of the number of series connection of the PV module from the rated voltage of a power conditioning system and the nominal maximum output voltage of a PV module.

Rated voltage of power conditioning system: 400V, Nominal max. output voltage of PV module: 29.3V

400V× 1.1 = 440V 440V / 29.3V≒15.02≒16 in series

2) Calculation of maximum and minimum PV module temperature

Maximum temperature in Naha: 30.2℃, Minimum temperature in Naha: 24.6℃

Max. PV module temperature = 30.2 + 18.4 = 48.6℃

Min. PV module temperature = 24.6 + 18.4 = 43.0℃

3) Calculation of the PV string open circuit voltage at the highest and the lowest PV module temperature

Temperature coefficient of the PV module open circuit voltage: -0.36% / ℃

PV string open circuit voltage at PV module temperature of 25℃ 36.9V × 16 = 590.4V

PV string open circuit voltage at the maximum PV module temperature (48.6℃)

590.4V × {1 - 0.0036× (48.6 - 25)} ≒ 540.24V

PV string open circuit voltage at the minimum PV module temperature (43.0℃)

590.4V× {1 - 0.0036× (43.0 - 25)} = 552.14V

4) Calculation of PV string output working voltage at the maximum and the minimum PV module temperature

Temperature coefficient of PV module output working voltage: -0.36% / ℃ (Same as the temperature coefficient of open circuit voltage)

PV string output working voltage at PV module temperature of 25℃ 29.3V × 16 = 468.8V

PV string output working voltage at the maximum PV module temperature (48.6℃)

468.8V× {1 - 0.0036 × (48.6 - 25)} = 349.336 ≒ 428.97V

PV string output working voltage at the minimum PV module temperature (43.0℃)

468.8V × {1 - 0.0036 × (43.0 - 25)} = 438.42V

(Check on DC voltage range and MPPT range)

DC voltage range: The PV string open circuit voltage operates in the range of 540.24V to 552.14V to the DC voltage range of a power conditioning system at 0 to 600V. Hence, there is no problem.

MPPT range : The PV string output working voltage operates in the range of 428.97V to 438.42V to the maximum power point tracking range of a power conditioning system in 200V to 550V. Hence, there is no problem.

(e) PV array configuration 4 lines 12 rows (PV modules: 48 pieces)

16 in series 3 in parallel

PV array output 11.52 kW

PV array size (W) 20.594 m × (L) 4.194 m (projection of horizontal surface)

The maximum height of PV array 0.867 m

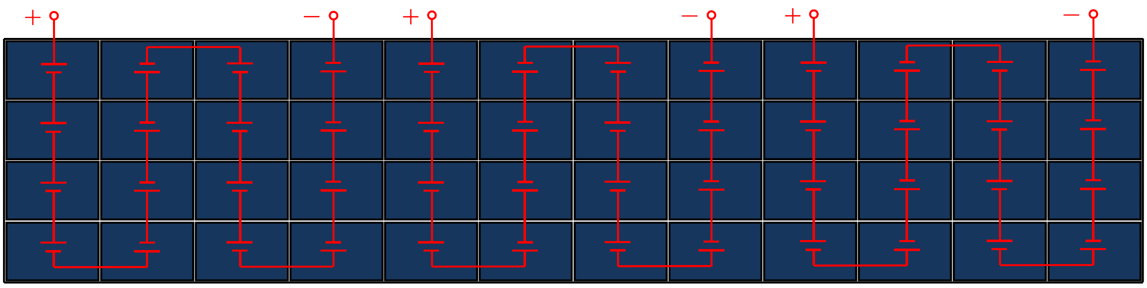


Figure 3.3.7-11 Wiring diagram of the PV array

(Calculation)

1) Calculation of the maximum number of lines and rows of the PV array

The maximum number of lines of the PV array: a

The maximum height of PV array: 2.0m and below from GL (The bottom of the PV panel is 0.5m from GL), Tilt angle of the PV panel: 5°

Depth of PV module: 990mm. (2.0m - 0.5m) = 1.5m

1.5m≧X× sin5° ⇒ 17.21m≧X (sin 5° = 5×π/180) 17.21/0.99≒17.273 a = 17 lines → 4 lines

The maximum number of rows of the PV array: b

The maximum width of PV array: 25m and below, width of the PV module: 1,662mm

25 / 1.662 ≒ 15.1 b = 15 rows

The maximum number of the PV module piece only on the conditions of PV array arrangement is 4 lines, 15 rows and 60 pieces.

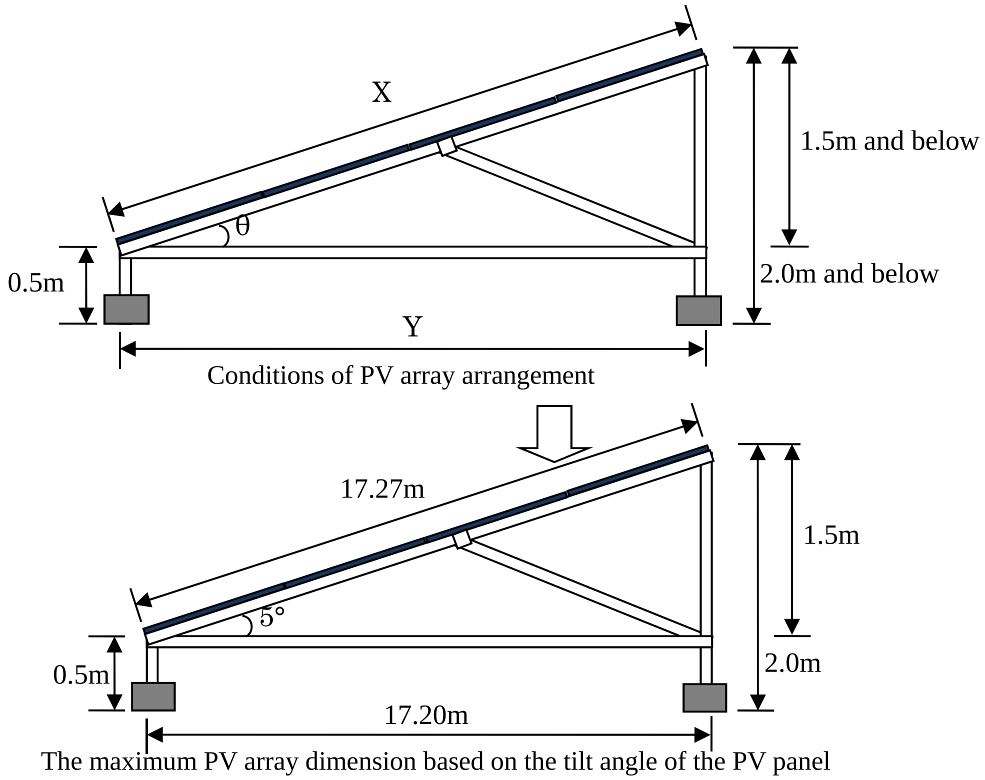


Figure 3.3.7-12 PV array size

2) Calculation of the maximum number of parallel connection and the number of the PV module pieces from the number of series connection of the PV module

The maximum number of PV module piece only on the conditions of PV array arrangement: 60 pieces

The number of series connection of the PV module: 16 in series

60 / 16≒3.75 <u>3 in parallel</u>

16 in series × 3 in parallel = <u>48 pieces</u>

3) Calculation of the PV array output from the number of PV module pieces

Nominal maximum output of the PV module: 240W

240W × 48 = 11,520W ⇒ <u>11.52kW</u>

4) Calculation of the number of PV array rows from the number of PV module pieces

The number of PV module piece: 48 pieces, the maximum number of lines of PV array a: 4 lines

48 / 4 = 12 <u>12 rows</u>

5) Calculation of the PV array size from the number of lines and rows of the PV array

Dimension of the PV panel: (0.99 × 4) + {0.05 × (4 + 1)} = 4.21m

Depth of the PV module: 990mm, The space between PV modules and the edge of the PV modules: 50mm

The maximum height of the PV array: (4.21m × sin5°) + 0.5m = <u>0.867m</u>

Tilt angle of the PV panel: 5°Height of the bottom of the PV panel: 0.5m from GL

Length of the PV array L (projection of horizontal surface): 4.21m × cos5°= 4.194m

Width of the PV array W: (1,662× 12) + {0.05 × (12 + 1)} = 20.594m

Width of the PV module: 1,662mm

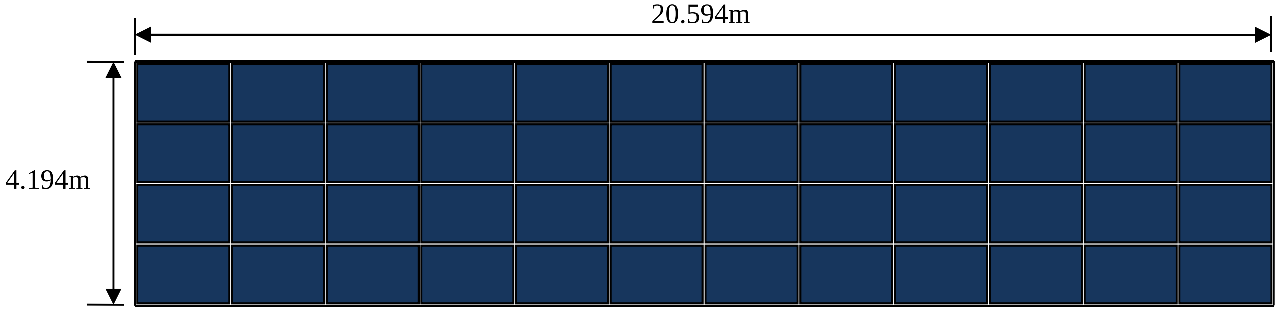


Figure 3.3.7-13 PV array size (projection of horizontal surface)

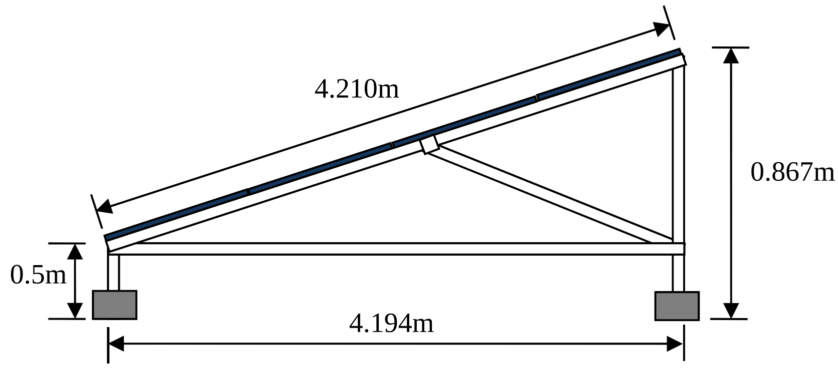


Figure 3.3.7-14 PV array size

(f) PV array arrangement

Number of PV array 5 units

Total output of PV array 57.6 kW

(Calculation)

1) Calculation of the total output of the PV arrays

11.52kW × 5 = 57.6 kW

2) Calculation of the shadow scale factor of north and south direction

Install according to the location. Consider with SketchUp.

The calculation method is as shown below.

The latitude and the longitude in Majuro: North latitude 7.0846 East longitude 171.3675

Solar altitude h: 30.01° Azimuth: 57.71°

*The data is at 9am on the winter solstice (21st of December 2012), the azimuth is directly south at 0°

Scale factor of the shadow R = L_S / L = coth × cos α = cot (30.01°) × cos (57.71°) = 0.925

(The length "Ls" of the shadow of north and south direction cast by the object of height "L".)

3) Calculation of the distance of PV arrays facing to the north-south

The maximum height of PV array: 0.867m

(0.867- 0.5) ×0.925 ≒ 0.340 m

4) PV array arrangement and total area

Install according to the location. Consider with SketchUp.

(g) Annual Energy Production

Table 3.3.7-10 Annual Energy Production

Month	Generated energy (kWh)
January	2,828
February	3,103
March	4,132
April	5,225
May	5,648
June	6,125
July	6,981
August	6,475
September	5,393
October	4,660
November	3,435
December	3,049
Annual	**57,053**

*Annual energy production is the sum total of monthly expected energy production.

Annual power generation projections can be made using HOMER (https://users.homerenergy.com/) or RETScreen (http://www.retscreen.net/).

The calculation method is as shown below.

(Calculation)

1) Calculation of expected monthly energy production [January](kWh / Month)

Average daily irradiation on monthly basis H_A: 2.372kWh/m^2/day, Irradiance under standard condition Gs: 1kW/m^2

PCS conversion efficiency η_{INV}: 94.5%, DC correction factor Kd: 0.9, Temperature coefficient at max. outputα: -0.46 % / K

Monthly mean temperature Tav: 27.4℃, Weighted average PV module temperature rise ⊿T: 18.4℃

Module temperature Tm = Tav + ⊿T = 27.4 + 18.4 = 45.8℃

Temperature correction factor Kt = 1 + α (Tm-25) / 100 = 1 - 0.46 (45.8－25) / 100 = 0.90432

Total design factor K = Kd × Kt × η_{INV} = 0.9 × 0.90432 × 0.945 = 0.769124

Expected monthly energy production Ep = ΣH_A / Gs × K × P_{AS}

= 31 × 2.372 / 1 × 0.769124 × 50 ≒ 2,828 kWh

(h) **System configuration**

- Generation scale 50 kW (AC)
- Number of arrays 5
- Array output 57.6 kW (DC)
- Number of PCS 5
- System voltage 6.6 kV

- Step-up transformer 100 kVA

  Primary voltage / Secondary voltage 6.6 kV/ 415 V

- Power transformer for substation ______ kVA

  Primary voltage / Secondary voltage 6.6 kV/ 200 V

3.3.7.5 Suggested answer [Ebeye]

Mega solar planned installation site: [Country] Marshall Islands [Area] Ebeye

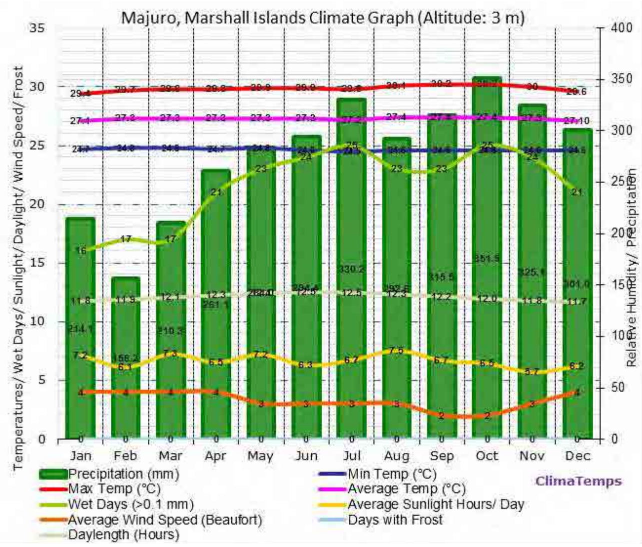
(a) Tilt angle of PV panel 5 °

Azimuth South

Solar irradiation in the above-mentioned tilt angle and azimuth

Table 3.3.7-11 Annual solar radiation

Month	Solar irradiation per day ($kWh/m^2/day$)	Ambient Temperature (℃)
January	2.372	27.4
February	2.880	27.3
March	3.464	27.3
April	4.527	27.3
May	4.735	27.3
June	5.306	27.3
July	5.850	27.2
August	5.431	27.4
September	4.675	27.4
October	3.909	27.4
November	2.976	27.3
December	2.554	27.1
Annual	**4.603**	**27.3**



(b) Specification of selected PV module

Table 3.3.7-12 Solar cell module specifications

	PV module B
Type	Polycrystalline Silicon
Nominal Max. Output(P_{max})	240W
PV module conversion efficiency	14.6
Nominal Max. Output Working Voltage (V_{pm})	29.8V
Nominal Max. Output Working Current (I_{pm})	8.06A
Nominal Open Circuit Voltage (V_{oc})	36.9V
Nominal Short Circuit Current (I_{sc})	8.59A
External Dimensions (mm) W×L×D	1,662 × 990 × 46
Temperature coefficient of short circuit current	+0.060%/K
Temperature coefficient of open circuit voltage	−0.36%/K
Temperature coefficient of Max. output	−0.46%/K

(c) Specification of selected power conditioning system

Table 3.3.7-13 Power conditioner specifications

		PCS-A
Output capacity		10kW
DC input	Rated voltage	400V
	DC voltage range	0～600V
	Range of MPPT	200～550V
	Number of phase	Three-phase three-wire
AC output	Rated voltage	202V
	Rated frequency	50 or 60Hz
	Power conversion efficiency	94.5%

(d) Number of series connection of PV modules 16 in series

PV string open circuit voltage (PV module temperature 25℃) : 590.4 V

(Max. PV module temperature 48.6℃): 540.24 V

(Min. PV module temperature 43.0℃): 552.14 V

PV string output working voltage (PV module temperature 25℃): 468.8 V

(Max. PV module temperature 48.6℃): 428.97 V

(Min. PV module temperature 43.0℃): 438.42 V

(Calculation)

1) Calculation of the number of series connection of the PV module from the rated voltage of a power conditioning system and the nominal maximum output voltage of a PV module.

Rated voltage of power conditioning system: 400V, Nominal max. output voltage of PV module: 29.3V

400V× 1.1 = 440V 440V / 29.3V≒15.02≒16 in series

2) Calculation of maximum and minimum PV module temperature

Maximum temperature in Naha: 30.2℃, Minimum temperature in Naha: 24.6℃

Max. PV module temperature = 30.2 + 18.4 = 48.6℃

Min. PV module temperature = 24.6 + 18.4 = 43.0℃

3) Calculation of the PV string open circuit voltage at the highest and the lowest PV module temperature

Temperature coefficient of the PV module open circuit voltage: -0.36% / ℃

PV string open circuit voltage at PV module temperature of 25℃ 36.9V × 16 = 590.4V

PV string open circuit voltage at the maximum PV module temperature (48.6℃)

590.4V × {1 - 0.0036× (48.6 - 25)} ≒ 540.24V

PV string open circuit voltage at the minimum PV module temperature (43.0℃)

590.4V× {1 - 0.0036× (43.0 - 25)} = 552.14V

4) Calculation of PV string output working voltage at the maximum and the minimum PV module temperature

Temperature coefficient of PV module output working voltage: -0.36% / ℃ (Same as the temperature coefficient of open circuit voltage)

PV string output working voltage at PV module temperature of 25℃ 29.3V × 16 = 468.8V

PV string output working voltage at the maximum PV module temperature (48.6℃)

468.8V× {1 - 0.0036 × (48.6 - 25)} = 349.336 ≒ 428.97V

PV string output working voltage at the minimum PV module temperature (43.0℃)

468.8V × {1 - 0.0036 × (43.0 - 25)} = 438.42V

(Check on DC voltage range and MPPT range)

DC voltage range: The PV string open circuit voltage operates in the range of 540.24V to 552.14V to the DC voltage range of a power conditioning system at 0 to 600V. Hence, there is no problem.

MPPT range : The PV string output working voltage operates in the range of 428.97V to 438.42V to the maximum power point tracking range of a power conditioning system in 200V to 550V. Hence, there is no problem.

(e) PV array configuration 4 lines 12 rows (PV modules: 48 pieces)

16 in series 3 in parallel

PV array output 11.52 kW

PV array size (W) 20.594 m × (L) 4.194 m (projection of horizontal surface)

The maximum height of PV array 0.867 m

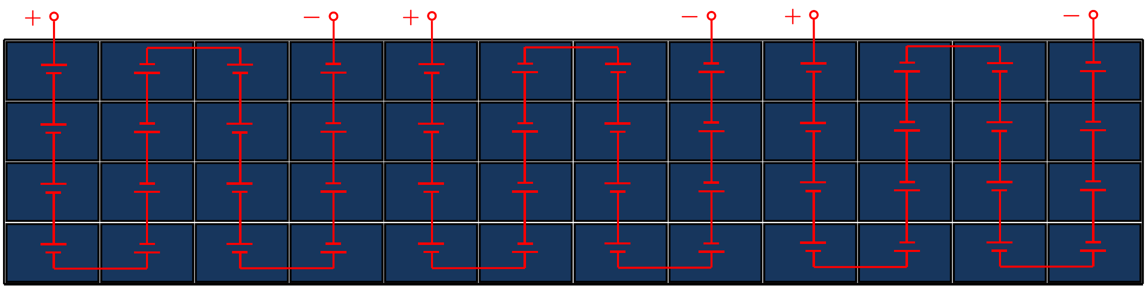


Figure 3.3.7-15 Wiring diagram of the PV array

(Calculation)

1) Calculation of the maximum number of lines and rows of the PV array

The maximum number of lines of the PV array: a

The maximum height of PV array: 2.0m and below from GL (The bottom of the PV panel is 0.5m from GL), Tilt angle of the PV panel: 5°

Depth of PV module: 990mm. (2.0m - 0.5m) = 1.5m X ≦1.5m/sin5°

1.5m≧X×sin5° ⇒ 17.21m≧X (sin5°= 5×π/180) 17.21/0.99≒17.273 a = 17 lines → 4 lines

The maximum number of rows of the PV array: b

The maximum width of PV array: 25m and below, width of the PV module: 1,662mm

25 / 1.662 ≒ 15.1 b = 15 rows

The maximum number of the PV module piece only on the conditions of PV array arrangement is 4 lines, 15 rows and 60 pieces.

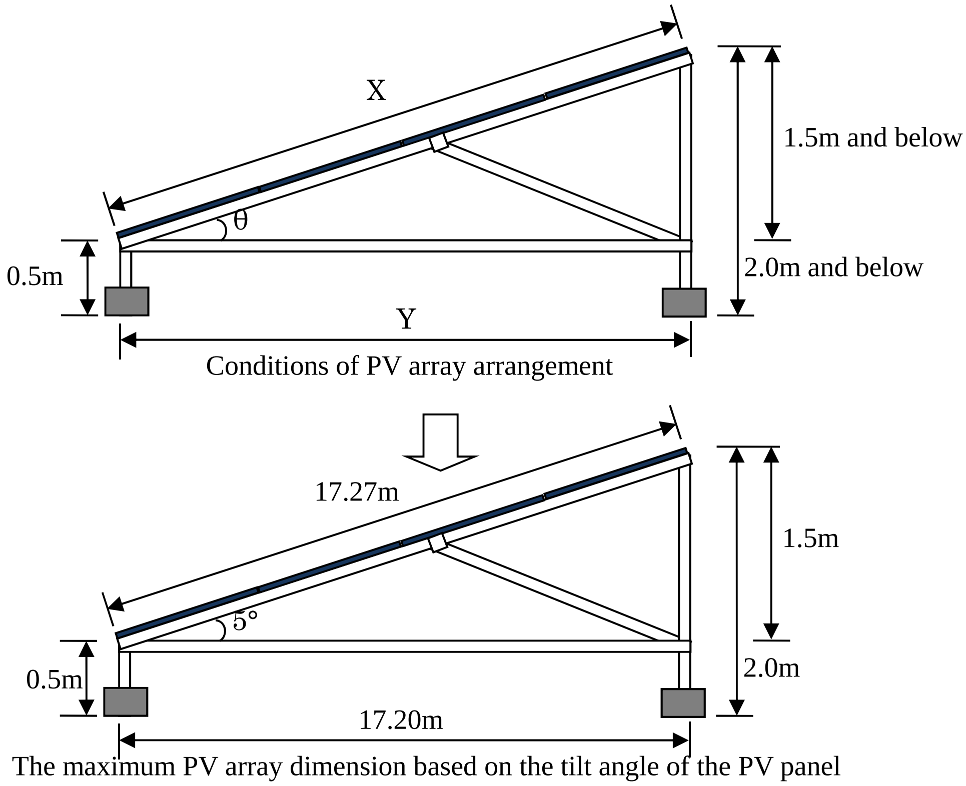


Figure 3.3.7-16 PV array size

2) Calculation of the maximum number of parallel connection and the number of the PV module pieces from the number of series connection of the PV module

The maximum number of PV module piece only on the conditions of PV array arrangement: 60 pieces

The number of series connection of the PV module: 16 in series

60 / 16≒3.75 3 in parallel

16 in series × 3 in parallel = 48 pieces

3) Calculation of the PV array output from the number of PV module pieces

Nominal maximum output of the PV module: 240W

240W × 48 = 11,520W ⇒ 11.52kW

4) Calculation of the number of PV array rows from the number of PV module pieces

The number of PV module piece: 48 pieces, the maximum number of lines of PV array a: 4 lines

48 / 4 = 12 12 rows

5) Calculation of the PV array size from the number of lines and rows of the PV array

Dimension of the PV panel: (0.99 × 4) + {0.05 × (4 + 1)} = 4.21m

Depth of the PV module: 990mm, The space between PV modules and the edge of the PV modules: 50mm

The maximum height of the PV array: (4.21m × sin5°) + 0.5m = 0.867m

Tilt angle of the PV panel: 5°Height of the bottom of the PV panel: 0.5m from GL

Length of the PV array L (projection of horizontal surface): 4.21m × cos5°= 4.194m

Width of the PV array W: (1,662× 12) + {0.05 × (12 + 1)} = 20.594m

Width of the PV module: 1,662mm

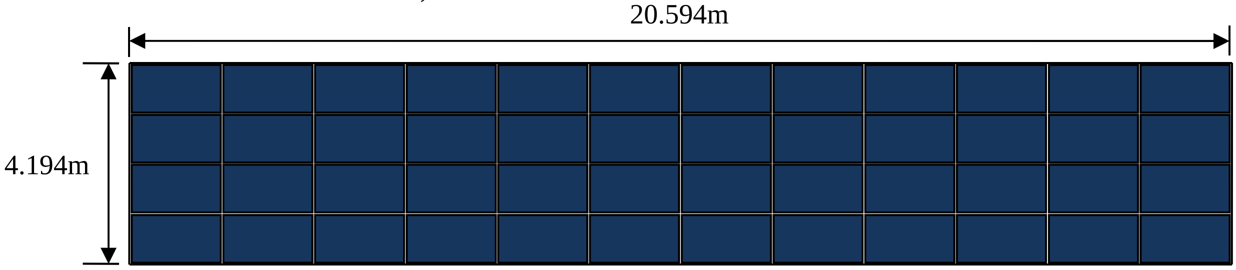


Figure 3.3.7-17 PV array size (projection of horizontal surface)

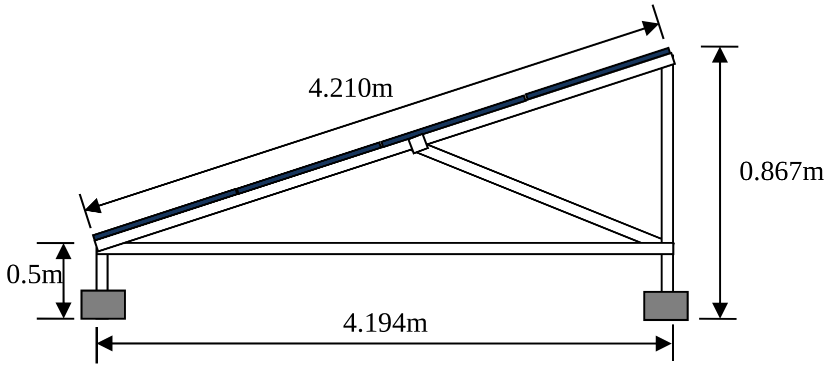


Figure 3.3.7-18 PV array size

(f) PV array arrangement

Number of PV array 20 units

Total output of PV array 230.4 kW

(Calculation)

1) Calculation of the total output of the PV arrays

11.52kW × 20 = 230.4 kW

2) Calculation of the shadow scale factor of north and south direction

Install according to the location. Consider with SketchUp.

The calculation method is as shown below.

The latitude and the longitude in Ebye: North latitude 8.4626 East longitude 167.4420

Solar altitude h: 25.95° Azimuth: 58.51°

*The data is at 9am on the winter solstice (21st of December 2012), the azimuth is directly south at 0° (http://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html)

Scale factor of the shadow R = L_S / L = coth × cos α = cot (25.95°) × cos (58.51°)

= cot (25.95°/180°×π) × cos (58.51°/180°×π) = 1.073

(The length "Ls" of the shadow of north and south direction cast by the object of height "L".)

3) Calculation of the distance of PV arrays facing to the north-south

The maximum height of PV array: 0.867m

(0.867- 0.5) ×0.925 ≒ 0.340 m

4) PV array arrangement and total area

Install according to the location. Consider with SketchUp.

(g) Annual Energy Production

Table 3.3.7-14 Annual Energy Production

Month	Generated energy(kWh)
January	11,312
February	12,412
March	16,528
April	20,900
May	22,592
June	24,500
July	27,924
August	25,900
September	21,572
October	18,640
November	13,740
December	12,196
Annual	228,212

*Annual energy production is the sum total of monthly expected energy production.

Annual power generation projections can be made using HOMER (https://users.homerenergy.com/) or RETScreen (http://www.retscreen.net/).

The calculation method is as shown below.

(Calculation)

1) Calculation of expected monthly energy production [January](kWh / Month)

Average daily irradiation on monthly basis H_A: 2.372kWh/m^2/day, Irradiance under standard condition Gs: 1kW/m^2

PCS conversion efficiency η_{INV}: 94.5%, DC correction factor Kd: 0.9, Temperature coefficient at max. outputα: -0.46 % / K

Monthly mean temperature Tav: 27.4℃, Weighted average PV module temperature rise⊿T: 18.4℃

Module temperature Tm = Tav + ⊿T = 27.4 + 18.4 = 45.8℃

Temperature correction factor Kt = 1 + α (Tm-25) / 100 = 1 - 0.46 (45.8－25) / 100 = 0.90432

Total design factor K = Kd × Kt × η_{INV} = 0.9 × 0.90432 × 0.945 = 0.769124

Expected monthly energy production $Ep = \Sigma H_A / Gs \times K \times P_{AS}$

= 31 × 2.372 / 1 × 0.769124 × 200 ≒ 11,312 kWh

(h) System configuration

- Generation scale 200 kW（AC）
- Number of arrays 20
- Array output 230.4 kW（DC）
- Number of PCS 20

- System voltage 6.6 kV
- Step-up transformer 250 kVA

  Primary voltage / Secondary voltage 6.6 kV/ 415 V
- Power transformer for substation ______ kVA

  Primary voltage / Secondary voltage 6.6 kV/ 200 V

3.3.7.6 Automatic calculation software

(a) Software overview

We provided an automatic calculation software that was created by setting a function in excel to the C/P.

This file contains a sheet similar to the one below, and by inputting the required information in the yellow cells, selection of tilt angle and orientation of the solar modules, selection of panels and power conditioners, conducting a study on the number of solar cell modules to connect in series and array configuration and layout can be calculated automatically.

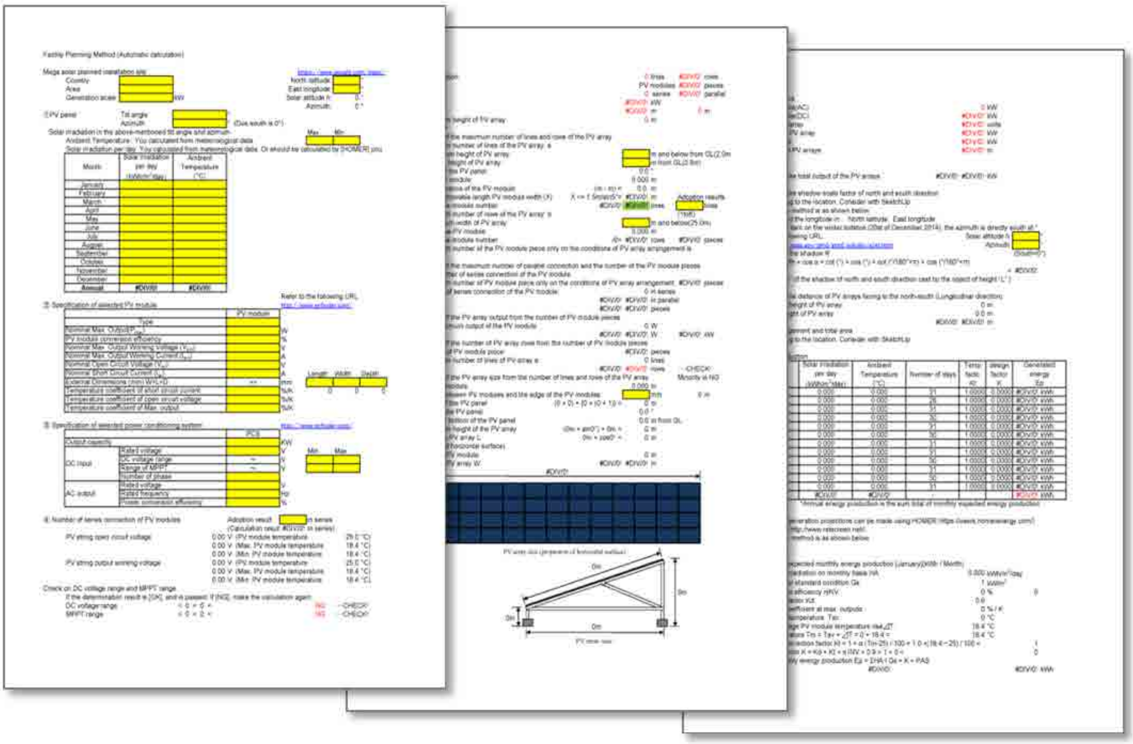


Figure 3.3.7-19 Illustration of automatic calculation software

(b) Calculation results

The results of the calculations for Majuro 200kW in the exercises we conducted there are shown on the following pages.

In addition, an illustration of the 200kW PV system for the exercise is shown below.

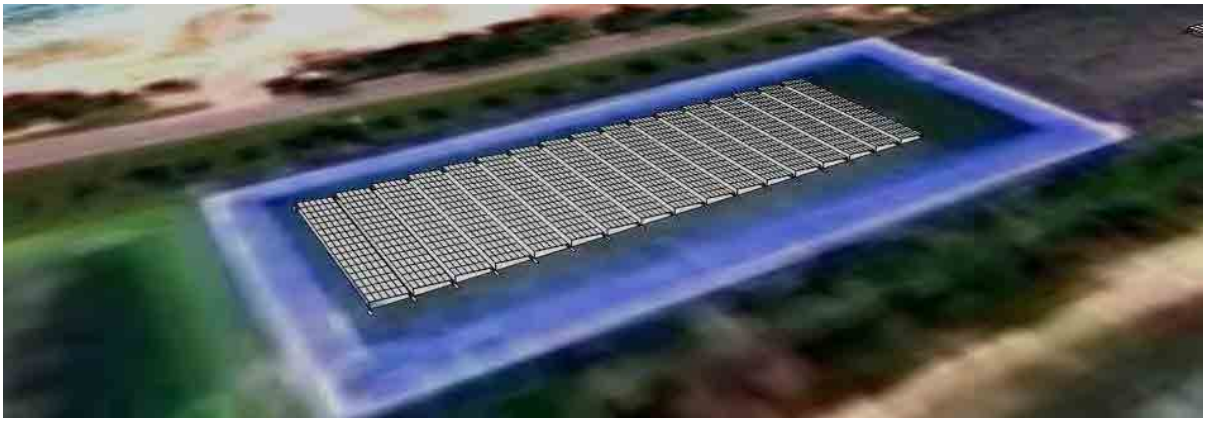


Figure 3.3.7-20　A 3D-CAD drawing prepared in the exercise

Facility Planning Method (Automatic calculation)

Mega solar planned installation site: https://www.google.com/maps/

Country	Marshall Islands		North latitude:	7.0504	°
Area	Majuro		East longitude:	171.216	°
Generation scale	200	kW	Solar altitude h:	29.89	°
			Azimuth:	57.77	°

①PV panel

Tilt angle	5.0	°
Azimuth	0.0	° (Due south is 0°)

Solar irradiation in the above-mentioned tilt angle and azimuth

Ambient Temperature: You calculated from meteorological data. Max 37.7 Min 12.4

Solar irradiation per day: You calculated from meteorological data. Or should be calculated by [HOMER] you.

Month	Solar irradiation per day ($kWh/m^2/day$)	Ambient Temperature (°C)
January	0.990	12.4
February	1.240	16.2
March	1.490	20.7
April	1.740	24.7
May	1.990	29.2
June	2.240	33.2
July	2.490	37.7
August	2.190	33.7
September	1.890	30.7
October	1.590	26.7
November	1.290	20.2
December	1.040	14.1
Annual	**1.682**	**25.0**

Refer to the following URL.

② Specification of selected PV module http://www.enfsolar.com/

	PV module				
Type	Polycrystalline Silicon				
Nominal Max. Output(P_{max})	140	W			
PV module conversion efficiency	14	%			
Nominal Max. Output Working Voltage (V_{pm})	17.7	V			
Nominal Max. Output Working Current (I_{pm})	1.91	A			
Nominal Open Circuit Voltage (V_{oc})	20.2	V			
Nominal Short Circuit Current (I_{sc})	1.03	A	Length	Width	Depth
External Dimensions (mm) W×L×D	1500×668×46	mm	1,500	668	46
Temperature coefficient of short circuit current	-0.46	%/K	1.5	0.668	0.046
Temperature coefficient of open circuit voltage	-0.36	%/K			
Temperature coefficient of Max. output	-0.06	%/K			

③ Specification of selected power conditioning system http://www.enfsolar.com/

		PCS		Min	Max
Output capacity		200	KW		
DC input	Rated voltage	345	V		
	DC voltage range	0～500	V	0	500
	Range of MPPT	125～280	V	125	280
	Number of phase	3phase 3wire			
AC output	Rated voltage	300	V		
	Rated frequency	60	Hz		
	Power conversion efficiency	95.5	%		

④ Number of series connection of PV modules — Adoption result 16 in series (Calculation result 21.4 in series)

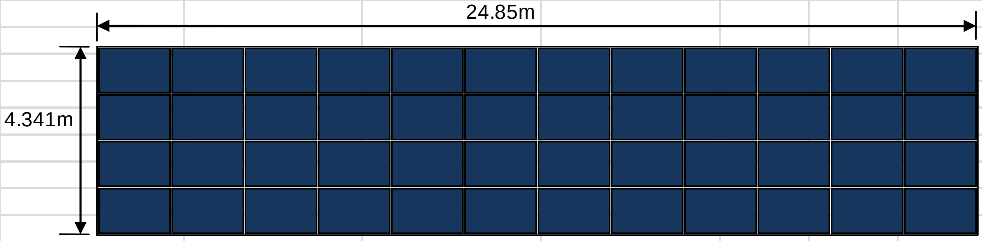
PV string open circuit voltage	323.20	V (PV module temperature	25.0	°C)
	287.01	V (Max. PV module temperature	56.1	°C)
	316.45	V (Min. PV module temperature	30.8	°C)
PV string output working voltage	283.20	V (PV module temperature	25.0	°C)
	251.49	V (Max. PV module temperature	56.1	°C)
	277.29	V (Min. PV module temperature	30.8	°C)

Check on DC voltage range and MPPT range

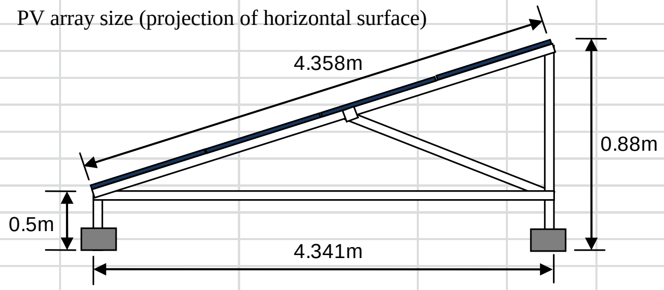
If the determination result is [OK], and is passed. If [NG], make the calculation again.

DC voltage range	0 < 287.014528 < 316.451584 < 500	OK	･･･CHECK!
MPPT range	125 < 251.492928 < 277.286784 < 280	OK	･･･CHECK!

⑤PV array configuration			6	lines	16	rows
	6 lines 16 rows (PV modules: 96 pieces)		PV modules		96	pieces
	16 in series 6 in parallel		16	series	6	parallel
	PV array output 13.44 kW		13.44	kW		
	PV array size (W)24.85m×(L)4.341m (projection of horizontal surface)		24.85	m	4.341	m
	The maximum height of PV array		0.88	m		
	(Calculation)					
1)	Calculation of the maximum number of lines and rows of the PV array					
	The maximum number of lines of the PV array: a					
	The maximum height of PV array:		2.0	m and below from GL(2.0m)		
	The bottom height of PV array:		0.5	m from GL(0.5m)		
	Tilt angle of the PV panel:		5.0	°		
	Width of PV module:		0.668	m		
	Height difference of the PV module	(2m - 0.5m) =	1.5	m		
	Maximum allowable length PV module width (X)	X <= 1.5m/sin5°=	17.21	m	Adoption results	
	Configurable module number	17.21/0.668=	25	lines	6	lines
	The maximum number of rows of the PV array: b				(1to6)	
	The maximum width of PV array:		25.0	m and below(25.0m)		
	Length of the PV module:		1.500	m		
	Configurable module number	25/1.5=	16	rows	96	pieces
	The maximum number of the PV module piece only on the conditions of PV array arrangement is					
	6 lines, 16 rows and 96 pieces					
2)	Calculation of the maximum number of parallel connection and the number of the PV module pieces					
	from the number of series connection of the PV module					
	The maximum number of PV module piece only on the conditions of PV array arrangement:				96	pieces
	The number of series connection of the PV module:		16	in series		
		96/16=	6	in parallel		
		16 in series × 6 in parallel =	96	pieces		
3)	Calculation of the PV array output from the number of PV module pieces					
	Nominal maximum output of the PV module:		140	W		
		140W × 96 =	13,440	W	13.44	kW
4)	Calculation of the number of PV array rows from the number of PV module pieces					
	The number of PV module piece:		96	pieces		
	The maximum number of lines of PV array a:		6	lines		
		96/6=	16	rows	···CHECK!	
5)	Calculation of the PV array size from the number of lines and rows of the PV array				Minority is NG	
	Width of PV module:		0.668	m		
	The space between PV modules and the edge of the PV modules:		50	mm	0.05	m
	Dimension of the PV panel	(0.668 × 6) + {0.05 × (6 + 1)} =	4.358	m		
	Tilt angle of the PV panel:		5.0	°		
	Height of the bottom of the PV panel:		0.5	m from GL		
	The maximum height of the PV array	(4.358m × sin5°) + 0.5m =	0.88	m		
	Length of the PV array L	4.358m × cos5° =	4.341	m		
	(projection of horizontal surface)					
	Width of the PV module:		1.5	m		
	Width of the PV array W	(1.5 × 16) + {0.05 × (16 + 1)} =	24.85	m		



PV array size (projection of horizontal surface)



PV array size

⑥PV array arrangement

Generation scale(AC)	200	kW
Generation scale(DC)	228.48	kW
Number of PV array	17	units
Total output of PV array	228.48	kW
PV array output	13.44	kW
The distance of PV arrays	0.353	m

(Calculation)

1) Calculation of the total output of the PV arrays 13.44kW ×17 = 228.48 kW

2) Calculation of the shadow scale factor of north and south direction

Install according to the location. Consider with SketchUp.

The calculation method is as shown below.

The latitude and the longitude in Majuro : North latitude:7.0504 East longitude:171.2156

*The data is at 9am on the winter solstice (20st of December 2014), the azimuth is directly south at 0°

Refer to the following URL. Solar altitude h: 29.89 °

http://www.esrl.noaa.gov/gmd/grad/solcalc/azel.html Azimuth: 57.77 °

Scale factor of the shadow R (South=0°)

R = LS / L = coth × cos α = cot (29.89°) × cos (57.77°) = cot (29.89°/180°×π) × cos (57.77°/180°×π)

= 0.928

(The length "Ls" of the shadow of north and south direction cast by the object of height "L".)

3) Calculation of the distance of PV arrays facing to the north-south (Longitudinal direction)

The maximum height of PV array: 0.88 m

The bottom height of PV array: 0.5 m

(0.88-0.5) ×0.928 = 0.353 m

4) PV array arrangement and total area

Install according to the location. Consider with SketchUp

⑦ Annual Energy Production

Month	Solar irradiation per day (kWh/m²/day)	Ambient Temperature (°C)	Number of days	Temp facto Kt	design factor K	Generated energy Ep	
January	0.990	12.400	31	0.9965	0.8564	6,005	kWh
February	1.240	16.200	28	0.9942	0.8545	6,778	kWh
March	1.490	20.700	31	0.9915	0.8521	8,992	kWh
April	1.740	24.700	30	0.9891	0.8501	10,138	kWh
May	1.990	29.200	31	0.9864	0.8478	11,949	kWh
June	2.240	33.200	30	0.9840	0.8457	12,984	kWh
July	2.490	37.700	31	0.9813	0.8434	14,874	kWh
August	2.190	33.700	31	0.9837	0.8454	13,113	kWh
September	1.890	30.700	30	0.9855	0.8470	10,972	kWh
October	1.590	26.700	31	0.9879	0.8491	9,562	kWh
November	1.290	20.200	30	0.9918	0.8524	7,537	kWh
December	1.040	14.100	31	0.9955	0.8556	6,302	kWh
Annual	1.682	24.958	–			119,206	kWh

*Annual energy production is the sum total of monthly expected energy production.

Annual power generation projections can be made using HOMER (https://users.homerenergy.com/)
or RETScreen (http://www.retscreen.net/)
The calculation method is as shown below.

(Calculation)

Calculation of expected monthly energy production [January](kWh / Month)

Average daily irradiation on monthly basis HA:	0.990	kWh/m²/day	
Irradiance under standard condition Gs:	1	kW/m²	
PCS conversion efficiency ηINV:	95.5	%	0.955
DC correction factor Kd:	0.9		
Temperature coefficient at max. outputα:	-0.06	% / K	
Monthly mean temperature Tav:	12.4	°C	
Weighted average PV module temperature rise ⊿T:	18.4	°C	
Module temperature Tm = Tav + ⊿T = 12.4 + 18.4 =	30.8	°C	

Temperature correction factor Kt = 1 + α (Tm-25) / 100 = 1 -0.06 ×(30.8－25) / 100 = 0.9965

Total design factor K = Kd × Kt × η INV = 0.9 × 0.9965 × 0.955 = 0.8564

Expected monthly energy production Ep = ΣHA / Gs × K × PAS

= 31 × 0.99 / 1 × 0.8564 × 228.48 = 6,005 kWh

3.3.8 Layout design method

3.3.8.1 SketchUP

As a layout design method for PV arrays, we recommend Google SketchUp, a free software used around the world.

For instructions on how to use Google SketchUp, see the attachment, Facility Planning Method [SketchUp].

With Google SketchUp, 3D (three-dimensional) designs to the millimeter are possible, and by matching reduced scale, these images can be placed anywhere on Google Earth.

In addition, when laying out several PV arrays, shadows cast by the PV array in front must be considered. The impact can be confirmed by rendering the shadows of any date and time you specify. Moreover, when designing systems that combine wind turbines, the spacing between wind turbines and the impact of shadows cast onto the PV arrays can be confirmed.

We will perform this layout design, assuming that the DEG+PV+WT system results calculated in Section 3.3.6 are adopted. For the PV array in this case, using the size of the results of Section 3.3.7, we set the tilt angle to 5°, and for azimuth, the topography of the land was considered to ensure the layout is efficient.

Table 3.3.6-2 Proposed system configuration (Wotje) *reshown

Hybrid system	Deployment size	System configuration
DEG+PV	PV 50 kW	PV-PCS 10 kW x 5 units
DEG+PV+WT	PV 50 kW WT25kW	PV-PCS 10 kW x 5 units WT5kW×5 turbines

Table 3.3.6-4 Proposed system configuration (Jaluit) *reshown

Hybrid system	Deployment size	System configuration
DEG+PV	PV 50 kW	PV-PCS 10 kW x 5 units
DEG+PV+WT	PV 50 kW WT25kW	PV-PCS 10 kW x 5 units WT5kW×5 turbines

Table 3.3.6-6 Proposed system configuration (Ebeye) *reshown

Hybrid system	Deployment size	System configuration
DEG+PV	PV 600 kW	PV-PCS 10 kW x 60 units
DEG+PV+WT	PV 600 kW WT500kW	PV-PCS 10 kW x 60 units WT 250 kW × 2 turbines

3.3.8.2 Proposed plan for each remote island

(1) Wotje Atoll

PV50kW (five 10 kW PV arrays) and WT25kW (five 5 kW wind turbines) can be sufficiently arranged.

This 3D design data produced with Google SketchUp can be downloaded from the following URL.

http://o-enetech.jp/marshall-data/Wotje_PV50kW_WT25kW.skp

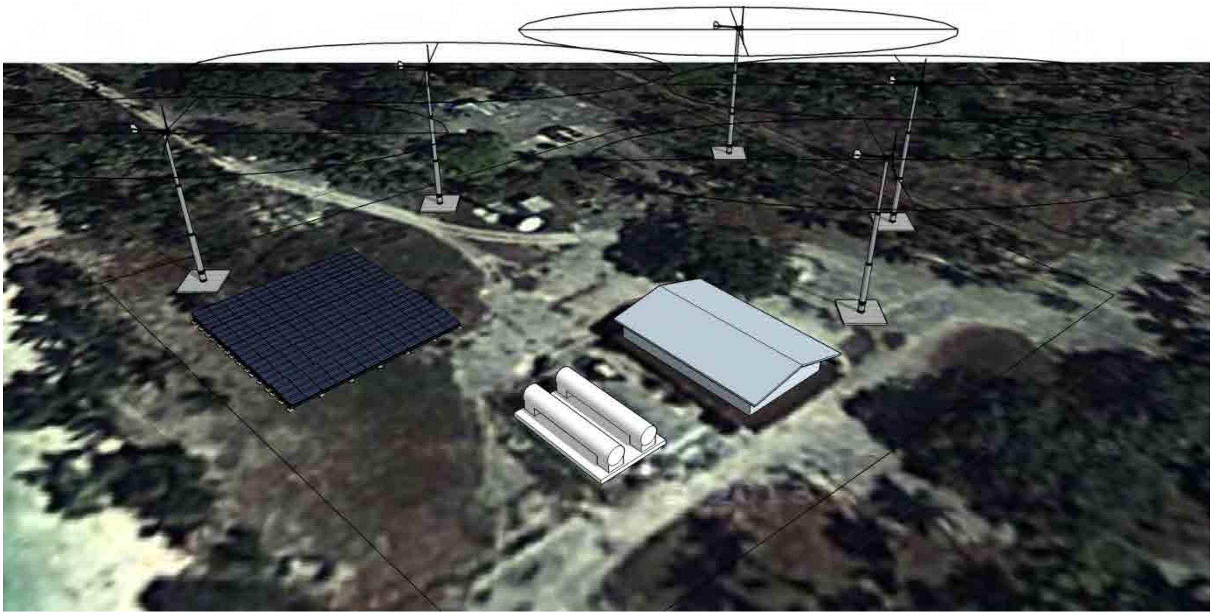


Figure 3.3.8-1 PV array layout diagram a

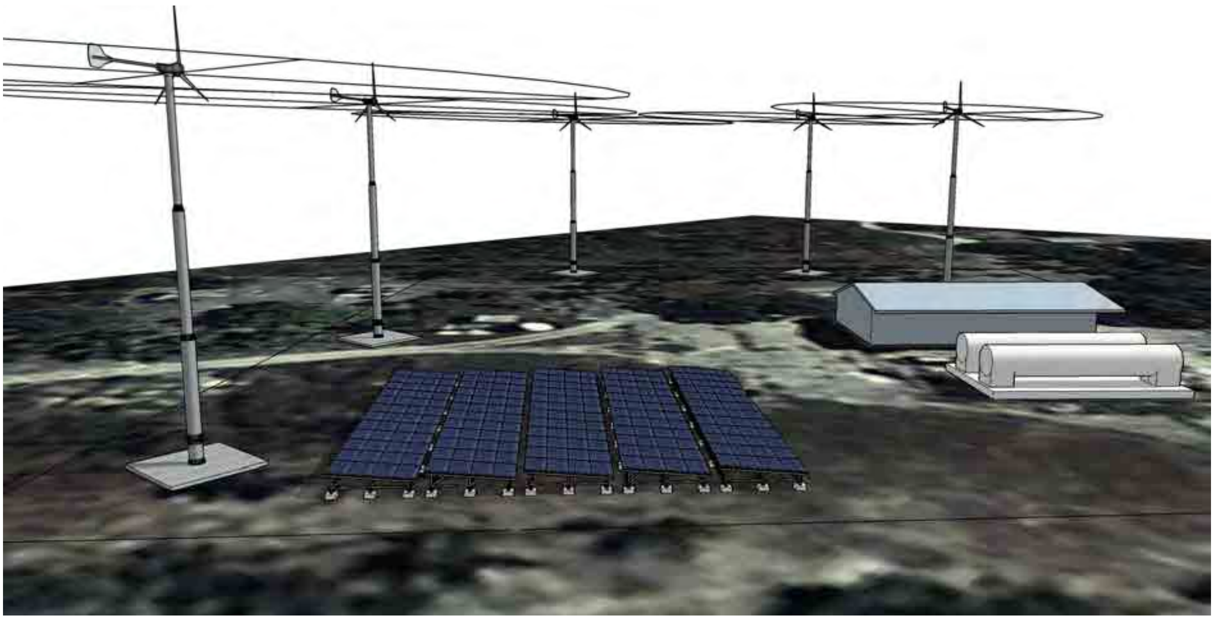


Figure 3.3.8-2 PV array layout diagram b

(2) Jaluit Atoll

PV50kW (five 10 kW PV arrays) and WT25kW (five 5 kW wind turbines) can be sufficiently arranged. This 3D design data produced with Google SketchUp can be downloaded from the following URL.

http://o-enetech.jp/marshall-data/Jaluit_PV50kW_WT25kW.skp

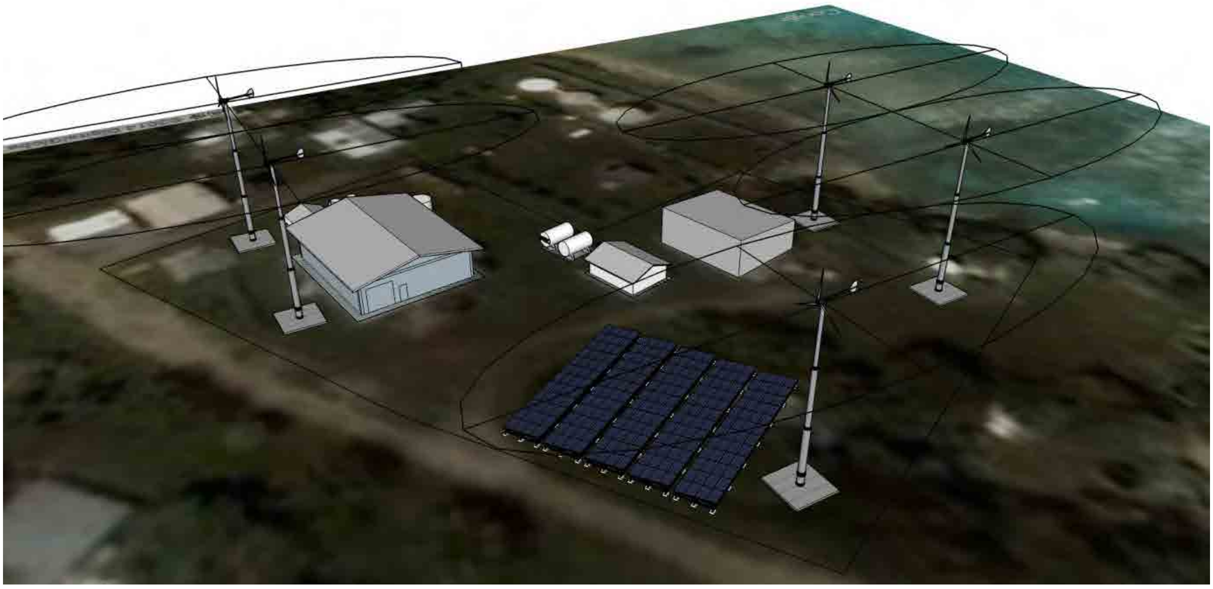


Figure 3.3.8-3 PV array layout diagram a

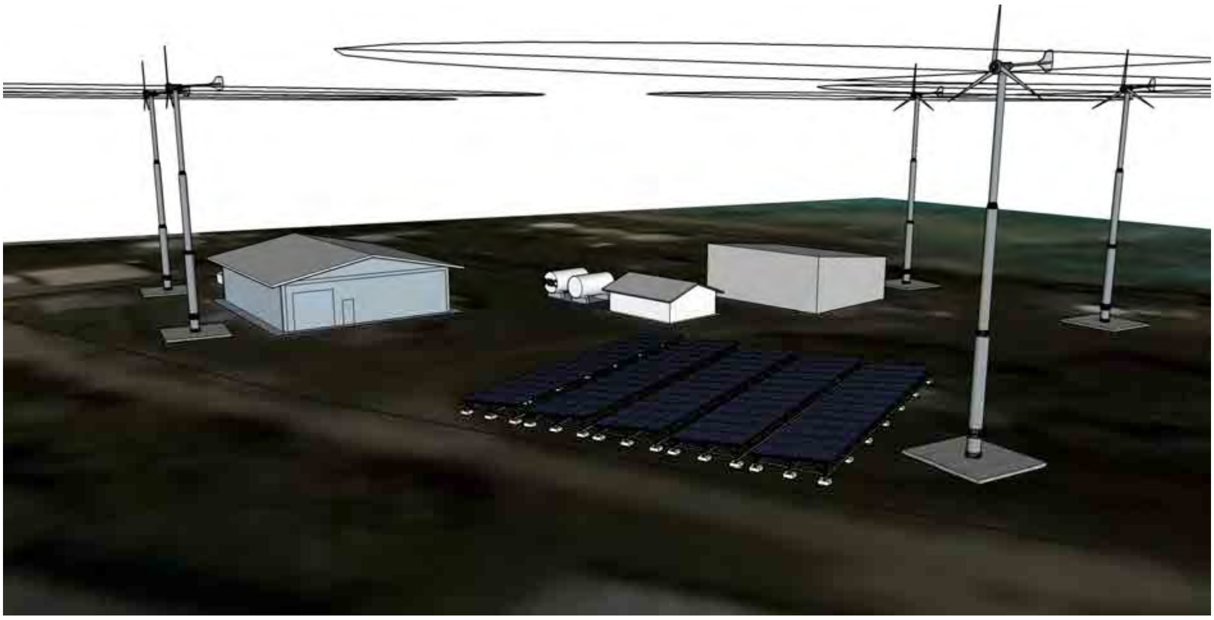


Figure 3.3.8-4 PV array layout diagram b

(3) Ebeye Island

PV600kW (sixty 10 kW PV arrays) and WT25kW (two 275kW retractable wind turbines) were arranged. The PV600kW can be sufficiently arranged, but considering the noise impact of WTs as they are near homes, only the WT on the reef side is feasible.

This 3D design data produced with Google SketchUp can be downloaded from the following URL.

http://o-enetech.jp/marshall-data/Ebeye_PV600kW_WT275kWx2.skp

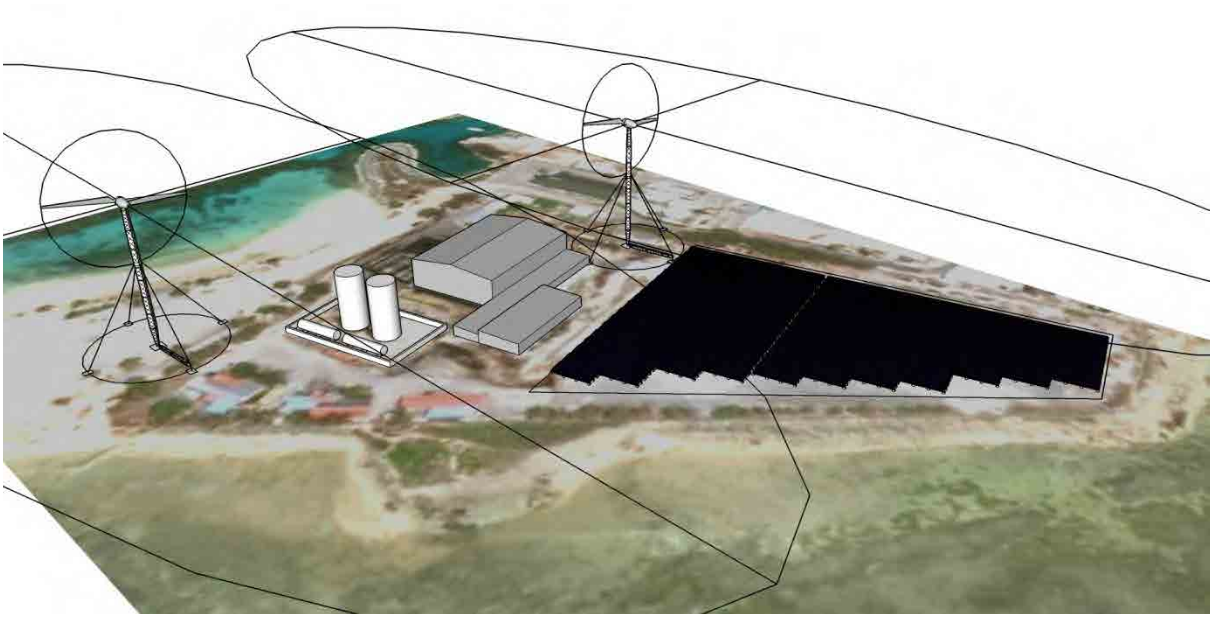


Figure 3.3.8-5 PV array layout diagram a

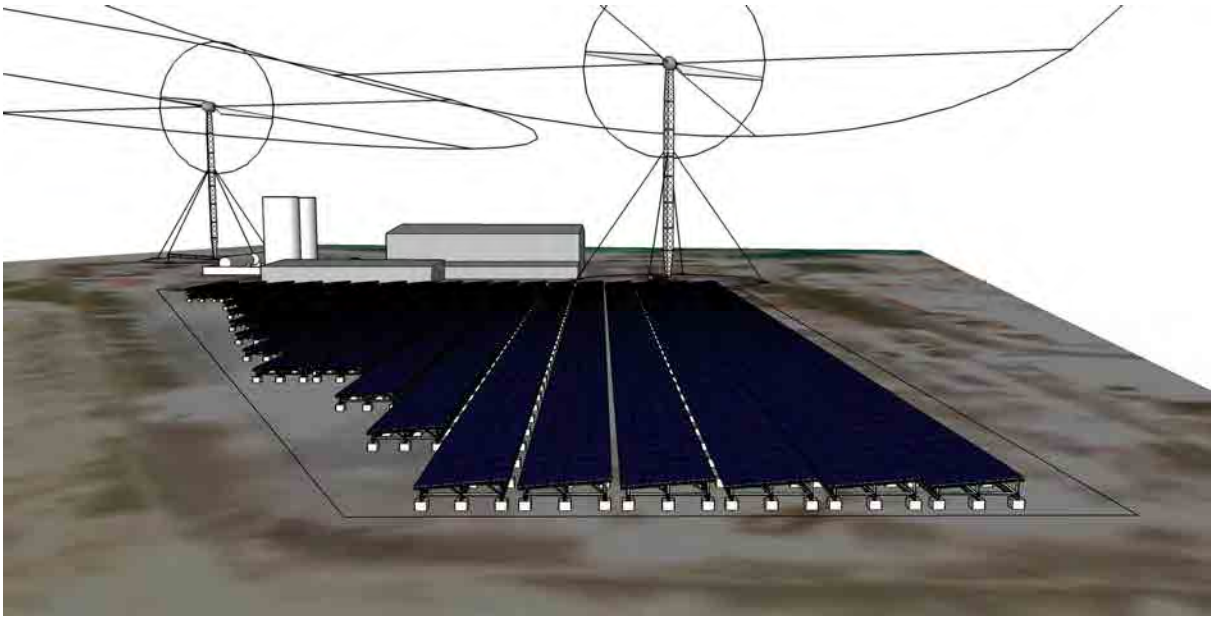


Figure 3.3.8-6 PV array layout diagram b

3.3.9 Summary

3.3.9.1 Study results

(1) Hybrid system

We will present the following 3 basic system configurations.

- PV-DEG hybrid system

We propose a system that does not incorporate stabilization devices such as storage batteries. This is a system that enhances frequency stability through quantity control of power conditioners (PCS) that come with the PV system and a system that takes into account measures for low output operation of DEGs through quantity control of power conditioners (PCS) that come with the PV system. Specific advantages of this system are as follows.

As each PCS can be switched on and off individually, limiting output can be done in a stepwise fashion.

Mitigate the risk of total shutdown of the PV system due to PCS failure

Using PCSs with low capacity (compact and lightweight) improves workability.

- PV-WT-DEG hybrid system

This system is basically similar to the PV/diesel power generation hybrid system. The basics of the WT is that it is small with a capacity of 5-25 kW and is capable of connecting to an inverter.

- PV-Battery-DEG hybrid system

It is possible to increase the RE supply rate to a high percentage by using a battery to absorb PV fluctuations and surplus power. A WT can also be included. However, storage battery equipment is very expensive.

(2) PV power generation system

The optimum tilt angle for all regions of the Marshall Islands including Majuro is 0°, but a 5° tilt is recommended in the hope that rain will provide self-cleaning. Moreover, when the tilt angle is 30° or less, azimuth is orientation-independent. In other words, it is thought that the amount of power generated annually will be the same regardless of orientation.

(3) Wind power generation system

Since the annual average wind speed is approximately 7.5 m/s or more at 25 m or more above ground for all regions of RMI including Majuro, if daily inspections and simple repairs can be performed, the deployment of wind turbines would be effective. To ensure ease of performing daily inspections and simple repairs on small remote islands, it is desirable that the tower of the wind turbine is retractable. Retractable wind turbines ranging from 1 kW to 275 kW are offered by wind turbine manufacturers around the world.

(4) Supply-demand balance simulation

The results of the supply and demand balance simulation using HOMER (considering long period fluctuations) are shown in the following section. However, we did not perform estimations that take economic viability into consideration as cost information could not be obtained.Since HOMER can be used to perform estimations that take economic viability into consideration, it is recommended to do so when possible.

3.3.9.2 Study results for each remote island

(1) Wotje and Jaluit

Recommendations for each hybrid system are shown in the table below. If frequency fluctuations occur even operating a PV system with multiple PCSs, the incorporation of small capacity batteries is required as a short period measure. In this case, it is desirable to have storage capacity equivalent to 30 minutes of the rated output if possible so that it can be used for backup power in case a DEG drops out. To secure charging and discharging rate, high rate batteries such as lithium-ion batteries are preferable.

On the other hand, existing DEGs are currently forced to operate at low output, so for this supply-demand balance simulation, the operation range is set to 5-100%, but the conditions provided by the generator manufacturer are "5-20% output for up to 100 hours (70% or more for 100 hours or more thereafter)."

Since the deployment of PV, etc. would require operation at lower output and make operating conditions harsher, storage batteries for long period measures are required depending on the state of the DEGs. Storage batteries for long period measures with a 6-hour capacity capable of absorbing almost all the power generated by the PV system are preferable. Since DEGs are currently forced to operate at 25-40% output, sometimes switching to smaller generators is recommended. In this case, depending on the conditions, storage batteries for long period measures may not be required.

Table 3.3.9-1 Proposed system configuration (Wotje and Jaluit)

Hybrid system	Deployment size	System configuration
DEG+PV	PV 50 kW	PV-PCS 10 kW x 5 units
DEG+PV+WT	PV 50 kW WT25kW	PV-PCS 10 kW x 5 units WT5kW×5 turbines
DEG+PV+Battery (Only short period measures)	PV 50 kW 50kW*25kWh	PV-PCS 10 kW x 5 units INV50kW * 25kWh (lithium-ion)
DEG+PV+Battery (Including long-period measures)	PV 50 kW 50kW*300kWh	PV-PCS 10 kW x 5 units INV50kW * 300 kWh (lead)

(2) Ebeye

Recommendations for each hybrid system are shown in the table below. If frequency fluctuations occur even operating a PV system with multiple PCSs, the incorporation of small capacity batteries is required as a short period measure. In this case, it is desirable to have storage capacity equivalent to 30 minutes of the rated output if possible so that it can be used for backup power in case a DEG drops out. To secure charging and discharging rate, high rate batteries such as lithium-ion batteries are preferable.

Table 3.3.9-2 Proposed system configuration (Ebeye)

Hybrid system	Deployment size	System configuration
DEG+PV	PV 600 kW	PV-PCS 10 kW x 60 units
DEG+PV+WT	PV 600 kW WT500kW	PV-PCS 10 kW x 60 units WT 250 kW × 2 turbines
DEG+PV+Battery (Only short period measures)	PV 600 kW 600 kW * 300 kWh	PV-PCS 10 kW x 5 units INV50kW * 25kWh (lithium-ion)