

Republic of Seychelles
Project for Formulation of Master Plan
for Development of Micro Grid in
Remote Islands

Final Report

July, 2016

**Japan International
Cooperation Agency (JICA)**

Okinawa Enetech Co.,Inc.

IL
JR
16-056

Summary of Survey Results

1. Background and purpose

As with other island nations, the main power supply in the Republic of Seychelles is diesel power generation, and it is dependent on imports from abroad for almost all of its primary energy.

Therefore, power costs are more expensive and are affected by market prices making the country's energy security vulnerable.

Under these circumstances, in order to secure sources of power other than diesel power generation and to accommodate future power demand growth, the Seychelles Government is actively engaged in the deployment of renewable energy sources such as solar and wind power, and it has set its deployment goals at 5% by 2020 and 15% by 2030.

However, there are concerns that the power system will become unstable due to the integration of renewable energy, so the Government of Seychelles requested technology transfer and human resources development utilizing Japan's experience in microgrid operations in its island regions.

Based on the above background, toward the resolution of issues concerning achieving the Seychelles Government's renewable energy goals of 5% by 2020 and 15% by 2030, a survey was conducted to help develop a microgrid deployment plan for remote islands in Seychelles and an operating structure for grid stabilization technology based on Japan's experience in its island regions.

2. Survey content:

A study and technology transfer on the items shown in the following figure was conducted.

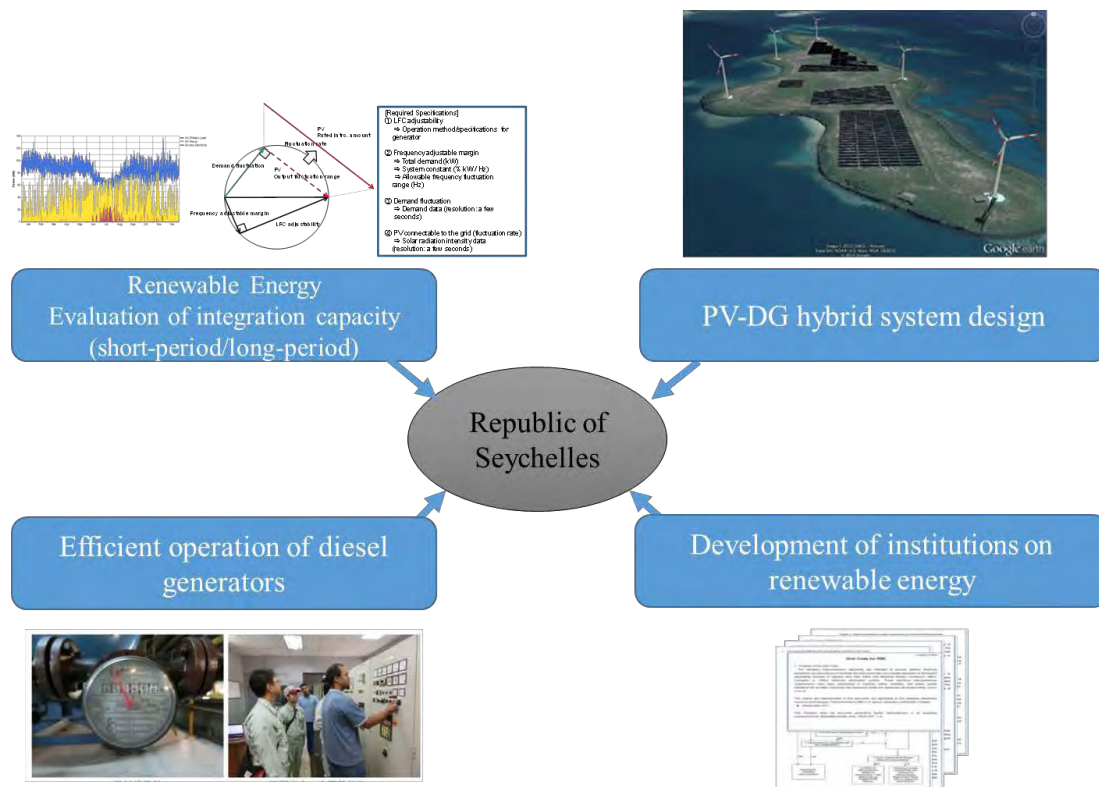


Figure 1 Study items for this survey

Evaluation to determine the RE integration capacity

The technology on the method to verify that the power system can absorb fluctuations and maintain a stable power supply when renewable energy is integrated considering their unstable output was transferred.

① Short-period constraints (Report Section 3.1)

The power system's capacity to maintain frequency (stable operation limit) for short-period (within 10 minutes) renewable energy output fluctuations.

② Long-period constraints (Report Section 3.3 and Chapter 4)

The power system's capacity to accept long-period (1 hour or more) renewable energy output fluctuations (occurrence of surplus power).

PV-DG hybrid system design

Simulation of PV deployment and layout plan (Report Section 3.3)

Diesel power generation operation efficiency

EDC (Economic load Dispatching Control), a method which reduces the overall fuel consumption of the power plant by properly dispatching load among diesel generators with differing fuel consumption characteristics, is being implemented in the remote islands of Okinawa Prefecture, and a study and technology transfer on a method for efficient diesel power plant operation leveraging this technology was conducted. (Report Section 3.2)

Development of institutions for renewable energy

The need for changes to the grid code and promotion scheme implemented in Seychelles was discussed by comparing them to those implemented in Japan. (Report Section 3.5)

3. Master plan for achieving RE deployment goals

Using the technology transferred in this survey, a study on what needs to be considered for a master plan to achieve the Seychelles Government's renewable energy deployment goals (5% by 2020, 15% by 2030) was conducted. (Report Section 4.2) In addition, a specific study process is summarized as shown in Figure 2 below.

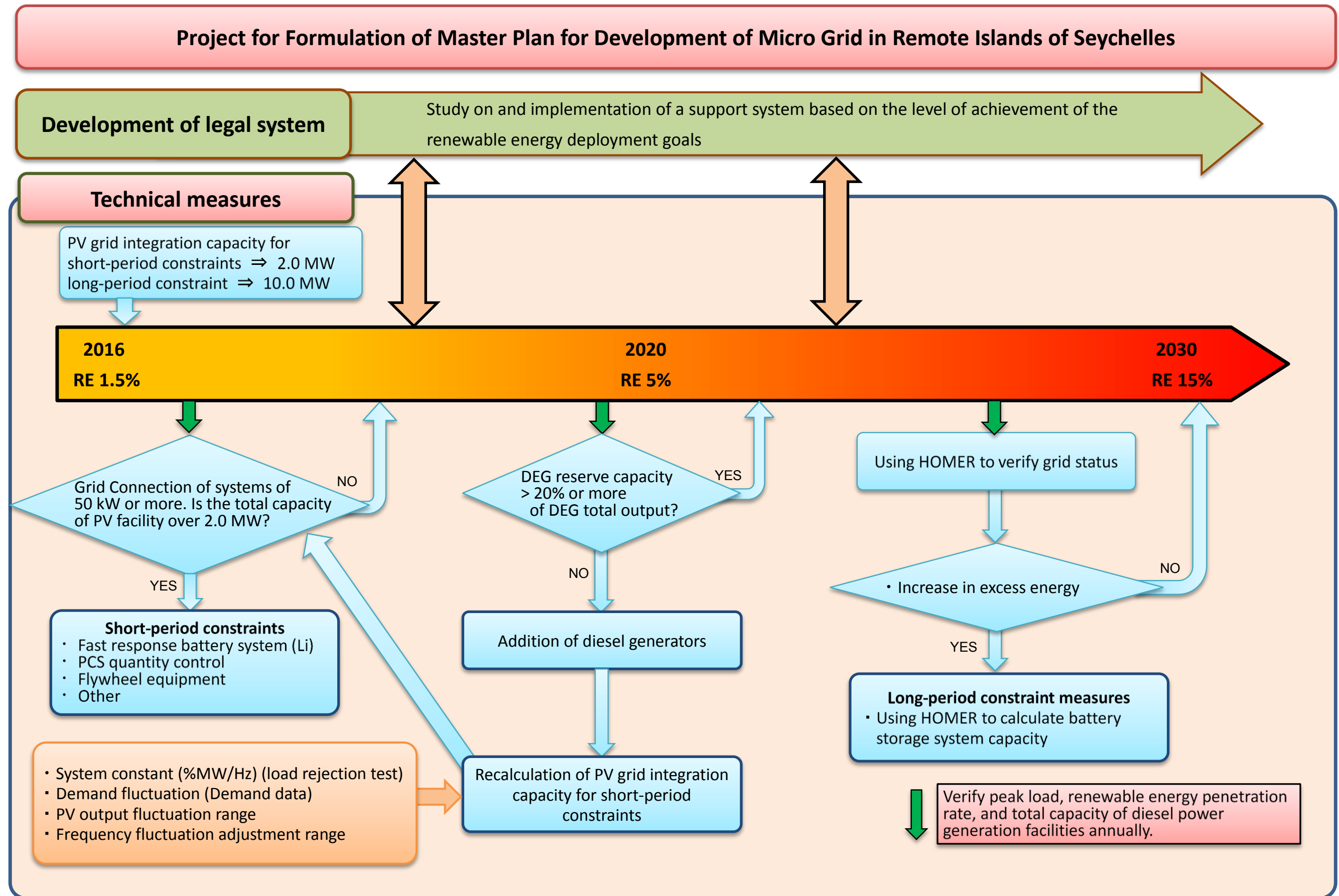


Figure 2 Study process for RE integration

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Attachments

Attachments (Lecture materials)

- 1) Algebraic Method
- 2) Economical Load Dispatch (EDC)
- 3) Facility Planning Method (Large-scale PV system)
- 4) Facility Planning Method (Exercise)
- 5) SketchUP software
- 6) Homer software
- 7) Feed in Tariff (FIT)
- 8) Grid Code
- 9) Seychelles Seminar presentation



¹ ... on the map are the target survey areas for this project (Mahe, Praslin, La Digue, Curieuse, Desroches)



Meeting with PUC



Measurement signal extraction survey
(Praslin Island)



Survey conditions
(Curieuse Island)



Interview at the Ministry of Community
(La Digue Island)



Power plant survey conditions
(Desroches Island)



Load measurement conditions
(Praslin Island)



Load measurement
(Mahe Island)



Measured fuel consumption rate
(Mahe Island)



Meeting before load rejection test
(Mahe Island)



Load rejection data analysis
(Mahe Island)



Installation of measuring instruments for load rejection
(Praslin Island)



Load rejection data analysis
(Praslin Island)



Explanation of load rejection test results
(Mahe Island)



Explanation of HOMER
(Mahe Island)



Explanation of related laws and regulations
(Mahe Island)



Tour of pump facility
(Mahe Island)

List of abbreviations

Abbreviation	Official name
AFC	Automatic Frequency Control
CDM	Clean Development Mechanism
CEO	Chief Executive Officer
C/P	Counterpart
DEG	Diesel Engine Generator
ENA	Energy Networks Association
EDC	Economic Dispatching Control
FFT	Fast Fourier Transform
FIT	Feed-in Tariff
GNI	Gross National Income
GDP	Gross Domestic Product
GEF	Global Environment Facility
GF	Governor Free
HFO	Heavy Fuel Oil
IDC	Island Development Company
ITC	Investment tax credit
IEEE	The Institute of Electrical and Electronics Engineers, Inc.
IPP	Independent Power Producer
IAEA	International Atomic Energy Agency
JET	Japan Electrical Safety & Environment Technology Laboratories
LFC	Load Frequency Control
LFO	Light Fuel Oil
MEA	Maldives Energy Authority
MEECC	Ministry of Environment, Energy And Climate Change
NPA	National Park Authority
NPV	Net Present Value
NEDO	New Energy and Industrial Technology Development Organization
PUC	Public Utilities Corporation
PTC	Production tax credit
PCS	Power Conditioner System
PV	Photovoltaic
ROE	Return On Equity
RPS	Renewable Portfolio Standard
RE	Renewable Energy
R&D	Record of Discussion
SEYPEC	Seychelles Petroleum Company
SEC	Seychelles Energy Commission
UNDP	United Nations Development Programme
WB	World Bank
WT	Wind turbine
WACC	Weighted Average Cost of Capital

Chapter 1 Survey Overview

1.1 Project background

Republic of Seychelles (hereafter, "Seychelles") is an island country consisting of 115 islands in the Indian Ocean with a population of 88,000 and a land area of approximately 460 square kilometers. In the economic field, its major industries are tourism and fisheries, and the per capita GNI is \$14,640 (World Bank, 2014). It is dependent on imports for most fuel and food, and imports (\$889,600,000) chronically exceed exports (\$493,300,000). Japan is the third destination country for its exports (15.2%) after France and the United Kingdom, and it mainly exports frozen fish. In addition, in relations with Japan, the Seychelles Government and Japan Oil, Gas and Metals National Corporation (JOGMEC) signed an agreement in August 2013 for a joint research on petroleum exploration in Seychelles waters, and assessments for oil development are currently ongoing.

Seychelles Energy Commission (SEC hereafter) is in charge of planning, regulation, and management of power supply. For the power generation, transmission, and distribution, Public Utilities Corporation (hereinafter PUC) is in charge of Mahe (main island), where over 90 percent of the population live, Praslin, La Digue, and their surrounding islands; Island Development Company (hereinafter IDC) is in charge of most of the other remote islands; and the National Park Authority (hereinafter NPA) is in charge some national park islands. In addition, the country's major power supply is diesel power generation, and it is dependent on imports from abroad for almost all of its primary energy. Therefore, power costs are more expensive and are affected by market prices making the country's energy security vulnerable.

Under these circumstances, in order to secure power supplies other than diesel power generation and to accommodate future power demand growth, the Seychelles Government is actively engaged in the deployment of renewable energy sources such as solar and wind power, and it has set its deployment goals at 5% by 2020 and 15% by 2030. In addition, based on the Seychelles Energy Act enacted in December 2012, it has established a Feed-in Tariff scheme (hereinafter FIT), Clean Development Mechanism (CDM), and other relevant institutions.

Renewable energies such as wind and solar power are already connected to the grid in Seychelles. However, since these integrations occurred without adequate adjustments among the concerned institutions and donors, there are concerns that the grid on Mahe, the main island, and others will become unstable in the near future, so the accumulation of knowledge pertaining to grid stabilization measures and human resource development is indispensable. Therefore, the Government of Seychelles requested the transfer of technology and human resources development using our experience in microgrid operations in the island regions of Japan. In July 2014, a detailed planning survey was conducted and in October 2014, and related institutions of Seychelles and JICA signed a Record of Discussion (hereinafter R/D) on the "Project for Formulation of Master Plan for Development of Micro Grid in Remote Islands" (hereinafter Project).

Moreover, the "Remote Island Microgrid" in this Project refers to a hybrid operation of diesel power generation and renewable energy.

1.2 Project objectives, assistance items, and results

Based on the above background, in order to resolve issues concerning achieving the Seychelles Government's renewable energy goals of 5% by 2020 and 15% by 2030, the objectives, aid items, and deliverables of this project are as follows.

The purpose of the project

The purpose is to help develop a microgrid deployment plan for remote islands in Seychelles and an operating structure for grid stabilization technology which leverages our experience in the island regions of Japan.

Support matters for the project

1. Aid with evaluation method to determine the RE integration capacity
2. Aid with technical and economic study on the efficient use of diesel generators
3. Aid with planning and designing PV-diesel hybrid power generation equipment
4. Proposal of a remote island microgrid deployment plan suitable to the characteristics of the power grid
5. Aid with development of institutions for stable remote island microgrid operation
6. Introduction to grid stabilization technology for island regions of Japan through our training program in Japan, etc.

Project outcome

1. A remote island microgrid master plan will be formulated.
2. Not only will the maximum allowable amount of RE that can be connected to the grid 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 Project implementation period

3/2015 - 8/2016

1.4 Agencies and organizations related to the project

- 1) Agency in charge: Ministry of Environment, Energy and Climate Change (MEECC)
- 2) Implementing agencies: Seychelles Energy Commission (SEC) and Public Utilities Corporation (PUC)

1.5 Survey area

<Survey area>

Mahe Island, Praslin Island, La Digue Island, Curiuse Island, and Desroches Island

1.6 Member make-up

Table 1.6-1 Member make-up

No.	Name	Field	Organization
1	Luis Kakefuku	Coordinator/Remote island microgrid	Okinawa Enetech Co., Ltd.
2	Masanori Shimabuku	Sub-coordinator/Remote island microgrid	Okinawa Enetech Co., Ltd.
3	Jun Hagihara	Grid planning	Private consultant (reinforcement)
4	Chihiro Tobaru	RE grid connection technology/A	Okinawa Enetech Co., Ltd.
5	Hideyasu Hokama	RE grid connection technology/B	Okinawa Enetech Co., Ltd.
6	Yuma Uezu	Diesel power generation operation efficiency/A	Okinawa Enetech Co., Ltd.
7	Hirotsune Gibo	Diesel power generation operation efficiency/B	Private consultant (reinforcement)
8	Yumoto Noboru	Economic and financial analysis/A	Energy & Environment Research Institute, Ltd. (reinforcement)
9	Yasumasa Tahara	Economic and financial analysis/B	Okinawa Enetech Co., Ltd.

1.7 Survey schedule

In this project, we conducted three field surveys (the 1st-5th Field Survey) and five analyses in Japan.

See Attachment 1 for details on the process and the field survey schedule.

■ Work Schedule

	Field Survey		Analysis in Japan
①	May 18, 2015 - May 28, 2015	①	May 29, 2015 - August 2, 2015
②	August 3, 2015 - August 13, 2015	②	August 14, 2015 - December 6, 2015
③	December 7, 2015 - December 20, 2015	③	December 21, 2015 – March10, 2016
④	March 12, 2016 - March 26, 2016	④	March 27, 2016 – June17, 2016
⑤	June 18, 2016 – June25, 2016	⑤	June27, 2016 – July15, 2016

Chapter 2 Overview of Power and Energy Sector in Seychelles

2.1 Overview of the socio-economic conditions

2.1.1 General conditions

Seychelles is an island country composed of 115 islands spanning an area of 460 km² with a population of approximately 90,000 people, and it is an upper middle income country with a per capita GNI of 14,100 USD. 95% of the population reside on the three main islands of Mahe Island, Praslin Island, and La Digue Island.



Figure 2.1.1-1 Seychelles location map

(1) General conditions

Area	: 460 km ²
Population	: 91,000 (2015)
Capital	: Victoria
Ethnic groups	: Creole (a mixed race of Europeans and Africans)
Language	: English, French, Creole
Religion	: Christianity
Climate	: Oceanic climate

It has a northwest monsoon season, which spans from December to March, a southwest monsoon season, which spans from May to October, and relatively short interim periods during November and April. In addition, temperatures range from 24 to 29°C throughout the year; the average humidity is 80%; although it is in a tropical zone, it lies outside of cyclone storm zones. There is little rain fall from May to October, when South-East trade winds blow, but the remaining period is the rainy season with an exceptionally large amount of rain fall from December to January.

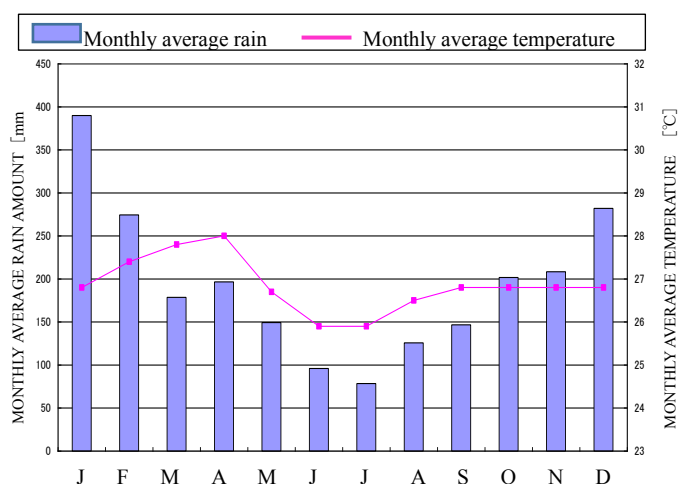


Figure 2.1.1-2 Rainfall and temperature in Seychelles

2.1.2 Political conditions

(1) Political system and internal affairs

Seychelles gained independence from the United Kingdom in 1976, and it was a dictatorship run by the Seychelles People's Progressive Front (SPPF) since it declared a one-party system in 1978, but it decided to implement a multi-party system in December 1991. In addition, in the first election after the implementation of a multi-party system, which took place in 1993, and President Rene was re-elected giving the ruling SPPF an overwhelming victory. President Rene was re-elected in the second and third presidential elections as well.

In 2004, Rene President resigned for health reasons in the middle of his term, and in accordance with the provisions of the Constitution, Vice President Michel became President. In the presidential election which took place in July 2006, President Michel won by a narrow margin obtaining 53.73% of the votes. Parliamentary elections were held in May 2007, but with no changes in the number of seats, the ruling party retained the 23 seats.

In June 2009, the name of the ruling party was changed from Seychelles People's Progressive Front (SPPF), to [People's Party (Parti Lepep)].

President Michel was re-elected in December 2015 as a result of the second ballot.

Government : Republic

Head of State : President James Alix Michel

Parliament : Unicameral (34 seats: of which 25 seats are elected in single-seat constituencies, and for the remaining 9 seats, an electoral system comprised of single-seat constituencies and proportionally represented multiple-seat constituencies is adopted where the seats are distributed to the parties who obtained at least 10% of the votes)

A brief history of Seychelles is shown in Table 2.1-1.

Table 2.1.2-1 Brief history of Seychelles

Month, Year	Brief history
1756	French colony
1814	English colony
1976	Gained independence (First President, Mancham)
1977	Coup d'état, Prime Minister Rene becomes President
1978	One-party system declaration (Seychelles People's Progress Front: SPPF)
1984	President Rene re-elected
1989	President Rene re-elected
1991	Converted to multi-party system
1993	1 st Presidential and National Assembly elections, President Rene re-elected (SPPF regime continues)
1998	2 nd Presidential and National Assembly elections, President Rene re-elected
2001	3 rd Presidential election, President Rene re-elected
2002	National Assembly election (SPPF regime continues)
2004	President René resigns, Michel becomes president
2006	4 th Presidential election, President Michel re-elected
2007	National Assembly election (SPPF regime continues)
May 2011	5 th Presidential election, President Michel re-elected
October 2011	Parliamentary elections (People's Party regime)
December 2015	6 th Presidential election, President Michel re-elected

Source: Ministry of Foreign Affairs website

(2) Economy

In 2014, Seychelles' gross national income (GNI) was 1,291,000,000 USD, and GNI per capita in 2014 was 14,100 USD which far surpasses other African countries. Seychelles' economy is dependent on tourism and fishery, its primary industries, and is very vulnerable since it is dependent on imports for the majority of its food and fuel. Moreover, its tourism and fishery industries have received serious blows in recent years from pirate incidents in the exclusive economic zone (EEZ). Economic growth in 2014 was 3.3%.

2014 exports value was 580 million USD, and the major export items are canned tuna, mineral fuels, fish, etc. Imports value was 1,182 million USD, and the major import items are machinery, mineral fuels, machinery products, etc. It has a trade deficit, so the Seychelles Government aims to improve the self-sufficiency of daily commodities and food in order to reduce imports.

Major industries	: Tourism, fishery
GNI (gross national income)	: 1,291,000,000 USD (2014: World Bank)
Per capita GNI	: 14,100 USD (2014: World Bank)
Economic growth rate	: 3.3% (2014: World Bank)
Inflation rate	: 3.1% (2014: World Bank)
Total trade value (2013)	: (1) Exports 580 million USD (2) Imports 1,010 million USD
Major trade items (2013)	: (1) Exports canned tuna, mineral fuels, fish, etc. (2) Imports machinery, mineral fuels, machinery products, etc.
Major trade partners (2013)	: (1) Exports France (27%), United Kingdom (19.1%), Italy (11.0%), Japan (9.1%) (2) Imports Saudi Arabia (35.4%), Spain (19.1%), France (12.1%), India (7.6%)
Currency	: Seychellois rupee (SCR) 1 USD = 13.1 SCR (October 2015) 1 SCR = 9.12 JPY (October 2015)

2.2 Energy sector overview

2.2.1 Trends in energy and electricity policy

The Ministry of Environment & Energy (MEECC) is responsible for energy policy, but the Seychelles Energy Commission (SEC), a regulatory agency which was established based on the Seychelles Energy Commission Act of 2010 (amended in energy law in 2012) to implement policies, assumes the role in practice. Article 3 of the Energy Act stipulates that MEECC create energy policies receiving advice from SEC, and that MEECC may give orders to SEC regarding policies or the like. On the other hand, Article 6 stipulates that SEC develop an energy plan and implement energy policies. In this way, SEC is not an independent regulatory body, but rather it has the role of both a regulatory agency and a policy developing agency under the MEECC. SEC is also responsible for promoting the development of renewable energy and energy conservation. SEC's organizational chart is shown in Figure 2.2.1-1.

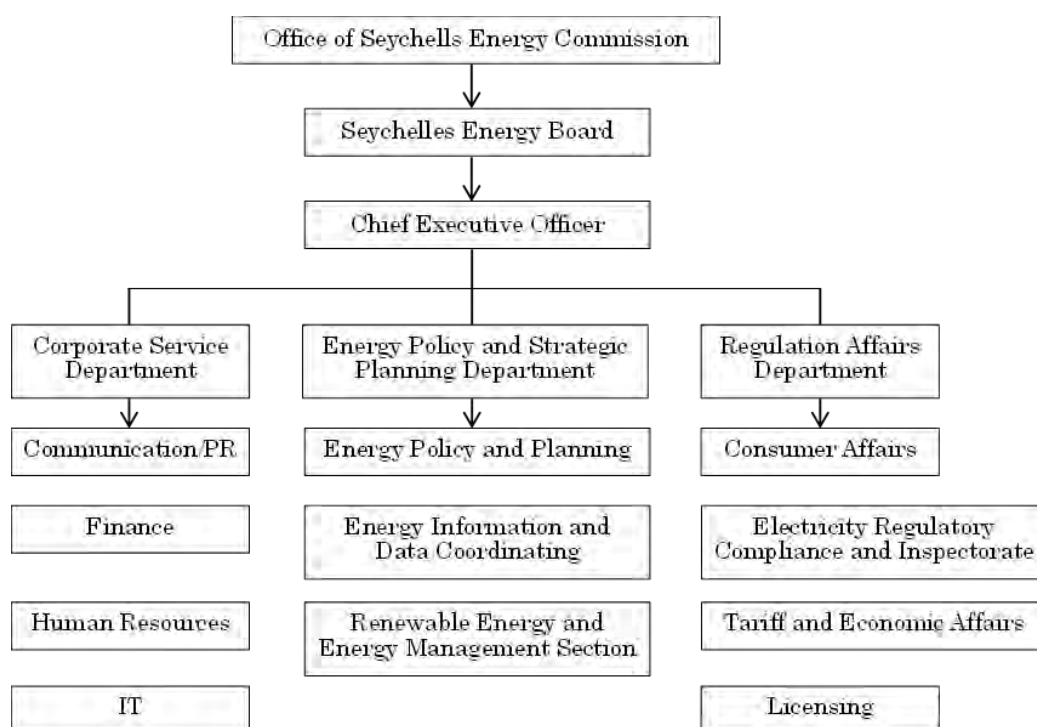


Figure 2.2.1-1 SEC Organization Chart

The basic energy policy in Seychelles is the “Energy Policy of the Republic of Seychelles, 2010-2030” which was established in 2010. The same policy aims to be converted to 100% renewable energy in the long term, and its immediate goals are to raise the RE penetration rate to 5% in 2020 and to 15% in 2030. The Energy Act was enacted in 2012 based on the same policy.

SEC is currently receiving technical assistance from IAEA in carrying out a 30-year study from 2014 to 2034 called "Integrated Energy Study." It plans to carry out the "Energy Demand Analysis" using IAEA's MAED (software) in Part 1 and prepare the "Power Supply Expansion plan" using the WASP in Part 2. PUC intends to create an "Electricity Sector Master Plan" on its own. (The Water Sector has already created a master plan.)

2.2.2 Primary energy supply

Seychelles relies almost 100% on imported oil for its primary energy supply. Oil is imported and sold exclusively by Seychelles Petroleum Company which is operated by the government. The company imports petroleum products to Victoria, the capital, from Fujairah of Dubai with 40,000-ton tankers, and it has an oil depot in Victoria. Oil is transported to the oil depot in Praslin (base is on adjacent island, Eve) from Victoria in 1,500-ton coastal tankers. There are no oil depots on La Digue Island, and there is only one gas station. As for the outer islands, IDC and a hotel purchase oil in Victoria from the same company, and have it transported in 15 kL tanks. Price of petroleum products in Seychelles are set in conjunction with the Arabian Gulf prices. Although the government imposes a tax of 8 rupees/L for domestic sales of petroleum products, PUC is exempted from this tax on its oil supply. The characteristic of the supply of petroleum products in Seychelles is that about two thirds of imported petroleum products (including the refueling of ocean-going vessels and aircraft) is reexported. Figure 2.2.2-1 shows oil import trends in Seychelles by product.

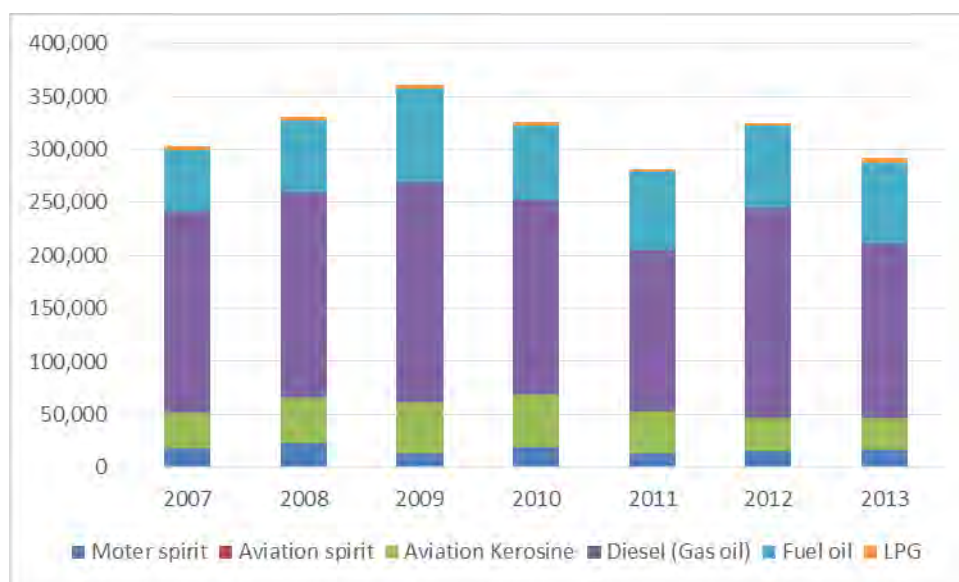


Figure 2.2.2-1 Oil imports trends in Seychelles by product.³

Due to the rapid rise in oil prices, the ratio of petroleum products as a percentage of the country's total imports has risen sharply as shown in Figure 2.2.2-2, and the net value of petroleum product imports as a percentage of net value of imports (domestic consumption) reached approx. 14% in 2012 and 9% in 2013. For this reason, RE development has become a pressing need to improve trade balance.

³ Created based on "Seychelles in Figures"

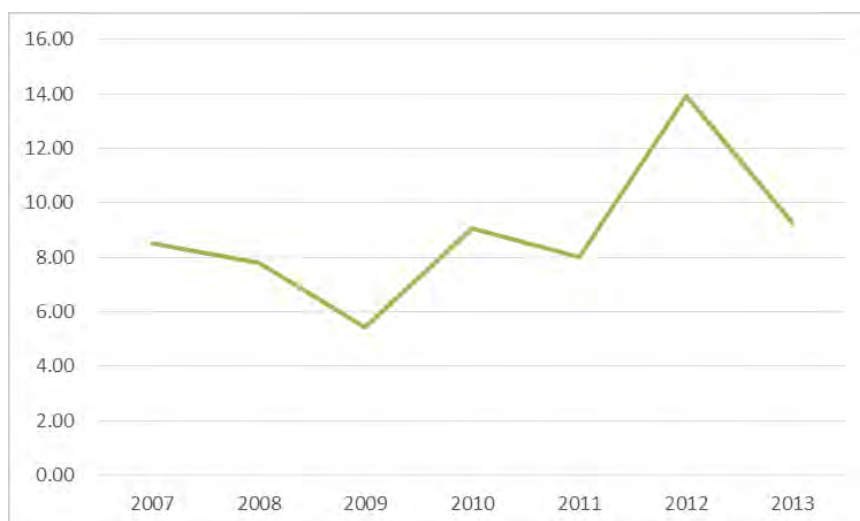


Figure 2.2.2-2 Trends in the net value of petroleum product imports as a percentage of net value of imports⁴

Heavy oil (HFO) and diesel oil (LFO) for PUC along with Mahe Island and Praslin Island is supplied from SEYPEC's oil depot through a pipeline. The price of the oil supplied by SEYPEC to PUC is free of commodity tax (8 SCR/L). Figure 2.2.2-3 shows the trend in PUC's purchase price for Victoria C Power Plant from SEYPEC. PUC's oil purchase price (SCR/L) peaked in April 2012 (LFO at 15.3 SCR/L). Since April 2013, LFO prices have been stable at 12-13 SCR/L influenced in part by the rise in the value of the rupee (compared to 2012, in 2013, the value of the rupee increased by 13.6% against the US dollar). Due to the plummeting of global oil prices after the fall of 2014, PUC oil purchase prices had plunged, and in mid-March 2016, LFO prices were at around 8.5 SCR/L. The price difference between HFO and LFO remained at around 3.50-4.00 SCR/L since 2012, and was at around 4.3 SCR/L as of mid-March 2016. In addition, concerning diesel oil price, if you compare SEYPEC's retail price and PUC's purchase price, the retail price as of July 2016 was 14-15 SCR/L while PUC's purchase price was approx. 8.5 SCR/L. This is mainly the effect of tax exemption (8 SCR/L) making it significantly cheaper than the retail price.

⁴ Created based on "Seychelles in Figures"

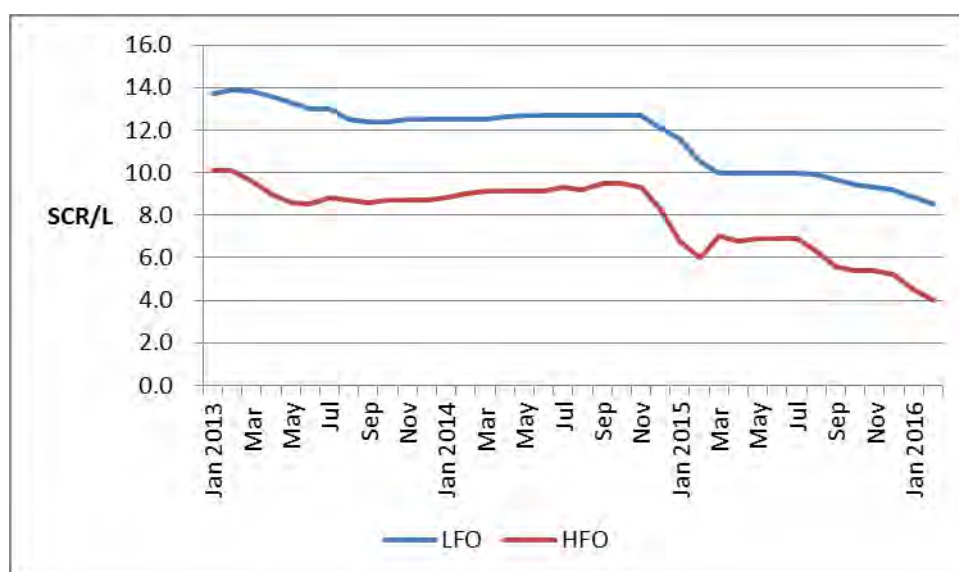


Figure 2.2.2-3 Trend in PUC's purchase price from SEYPEC (Victoria C Power Plant).

2.3 Status of the power sector

2.3.1 Overview of the power supply

The Seychelles Energy Commission (hereinafter SEC) is in charge of planning, regulation, and management of power supply. For the power generation, transmission, and distribution, Public Utilities Corporation (hereinafter PUC) is in charge of Mahe (main island), where over 90 percent of the population live, Praslin, La Digue, and their surrounding islands; Island Development Company (hereinafter IDC) is in charge of most of the other remote islands; and the National Park Authority (hereinafter NPA) is in charge some national park islands. In addition, the country's major power supply is diesel power generation, and it is dependent on imports from abroad for almost all of its primary energy. Therefore, power costs are more expensive and are affected by market prices making the country's energy security vulnerable.

There are two power plants (VICTORIA B, VICTORIA C) on Mahe Island, the main island of the Seychelles, where all power is supplied by diesel generators. Moreover, the power generation capacities of VICTORIA B and VICTORIA C are 16,700 kW and 74,000kW respectively, bringing the total to 90,700kW. Since the peak load for Mahe Island is about 50 MW, there is sufficient supply capacity. In addition, a 6 MW (750 kW × 8 units) Abu Dhabi-funded wind turbine facility has been deployed separately. In addition, two additional 8 MW diesel power generators were installed at the VICTORIA C plant in October 2015 with PUC's own funds. As a result, the total supply capacity of VICTORIA B and VICTORIA C as of January 2016 was greatly enhanced at 90,700 kW.

On Praslin Island, the next biggest island after Mahe, there is one power plant, and all power is supplied by diesel generators. Moreover, the power generation capacity is 11,050 kW and peak load is approximately 8 MW. In addition, La Digue Island, located next to Praslin Island, is supplied by Praslin Island via submarine cable. La Digue Island's system load is approximately

700 kW. Furthermore, similar to Mahe Island, the one additional 2.5MW diesel generator was installed in October 2015. As a result, the power supply capacity on Praslin Island as of January 2016 was 13,550 kW.

On the other hand, PUC's power demand is increasing each year, and the maximum power demand for Mahe Island was 53 MW, while Praslin Island and La Digue Island combined was 7.7 MW in 2015. For the amount of power demand, Mahe Island was 287 GWh/year; Praslin Island was 27 GWh/year; and La Digue Island was 9.8 GWh/year.

Table 2.3.1-1 Overview of PUC's power supply and demand

Year		2011	2012	2013	2014	2015
Mahe						
Peak Demand	kW	44,800	46,500	49,900	50,900	53,200
Production	MWh	286,431	296,748	307,728	321,166	331,679
Energy Sales	MWh	248,324	256,982	273,039	278,863	287,251
Losses (Tech.+ Non Tech)	%	10.23	10.58	8.31	10.22	10.45
Praslin						
Peak Demand	kW	7,200	6,930	7,250	8,060	7,700
Production	MWh	37,404	39,745	39,546	40,806	44,411
Energy Sales-Praslin	MWh	23,296	24,021	24,436	24,603	27,142
Energy Sales-La Digue	MWh	8,162	8,709	9,345	9,135	9,828
Total Energy Sales	MWh	31,458	32,730	33,781	33,738	36,970
Losses (Tech.+ Non Tech)	%	13.87	15.83	12.52	15.39	13.86
PUC- Overall						
Energy Production	MWh	323,835	336,493	347,274	361,972	376,090
Energy Sales	MWh	279,782	289,712	306,820	312,601	324,221

2.3.2 PUC's implementation structure

PUC's organizational chart is shown in Figure 2.3.2-1. The PUC is led by the Chief Executive Officer and composed of 6 departments: Project Management Unit, Operations Department, Customer Service Department, Finance Department, Information and Communication Department, and Human Resources Department.

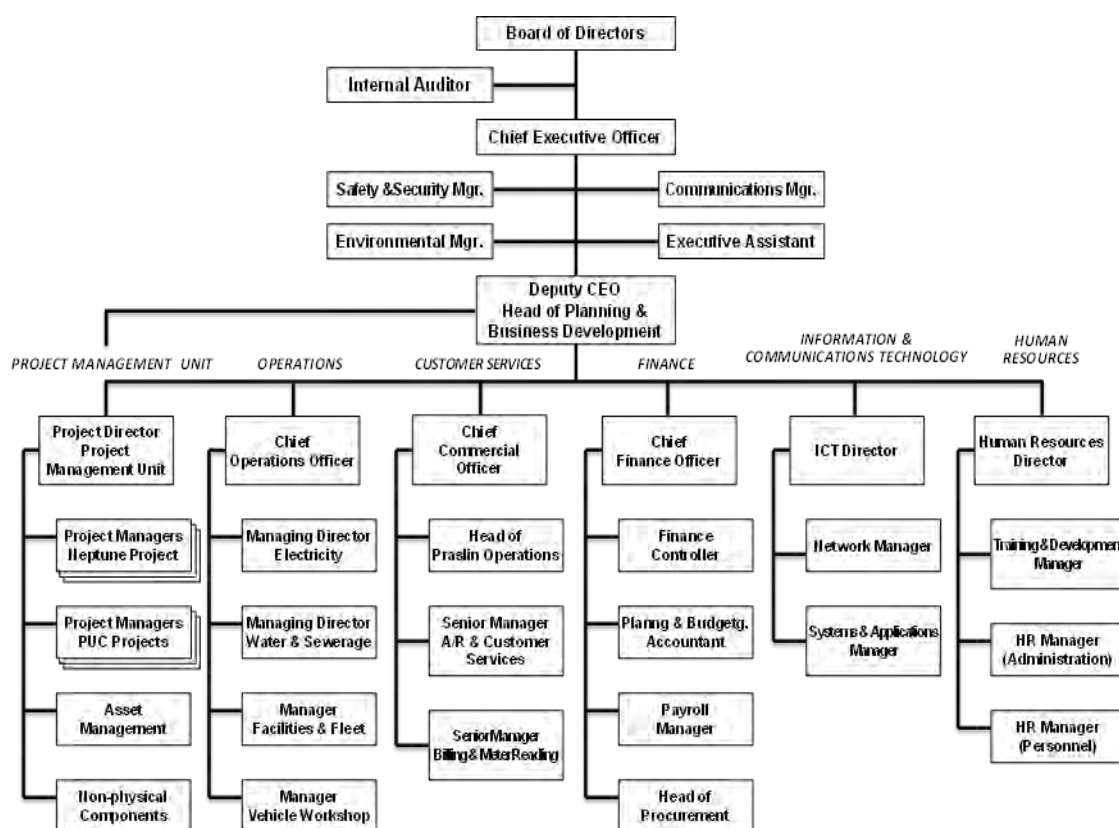


Figure 2.3.2-1 PUC Organizational Chart

2.3.3 Electricity rate system

Seychelles Government decided to revise the pricing for electricity, water, and sewage utilities in October 2013 based on the Tariff Study conducted with funds from the World Bank. The basic direction of rate revision is to reduce the financial support from the electric sector to water and sewerage sectors as well as to reduce internal subsidies for small residential electricity rates within the electricity sector. More specifically, the goal is to raise electricity rates for residential customers, which are significantly below cost, to rates that can recoup fuel costs and to significantly increase rates for water and sewer sectors which are in great deficit. The plan to raise residential electricity rates is shown in Figure 2.3.3-1. As a measure for raising electricity rates for low-income customers, the government has established a Social Tariff using the government budget. In addition, to avoid a sharp expense increase to the consumer, a gradual revision of the entire rate structure it planned to take place over ten years from 2013 to 2022.

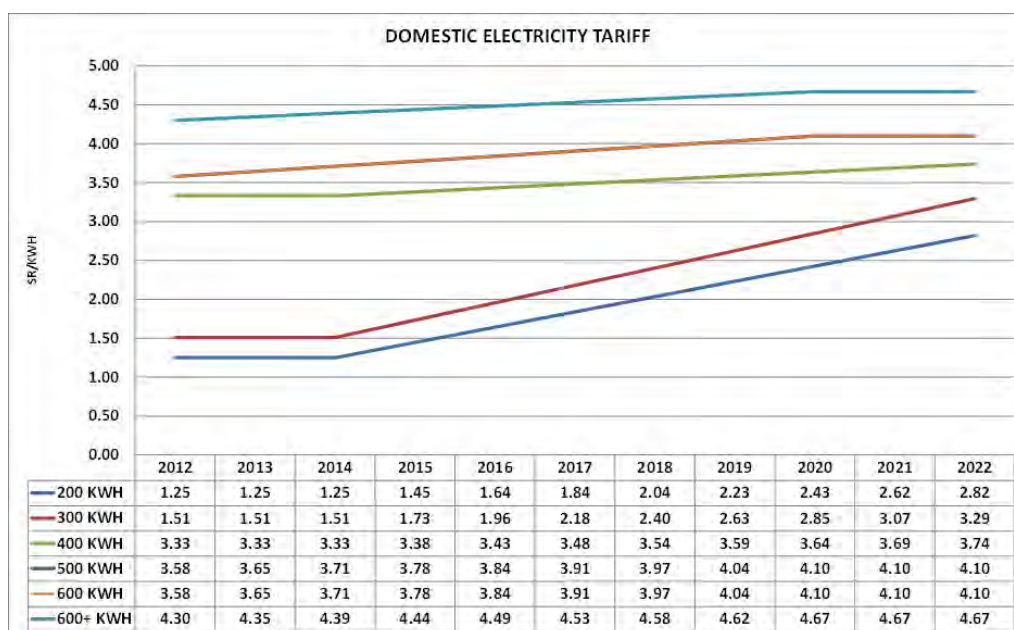


Figure 2.3.3-1 Plan to raise residential electricity rates

As the first step of the rate revision, electricity rates were revised in November 2011. Moreover, beginning July 2013, an automatic fuel adjustment clause was introduced for electricity rates, where electricity rates (energy charge) are revised quarterly according to fluctuations in fuel costs. Due to the sharp decrease in crude oil prices since the fall of 2014, PUC electricity rates (energy charge) have dropped significantly since April 2015. In particular, electricity rates of small residential customers (200 kWh/month or less) have dropped to 50% or less of the soaring crude oil prices in the summer of 2014. However, a review of the electricity rate system in accordance with the Cabinet decision (to raise residential electricity rates to recoup fuel costs) has yet to be conducted. Figure 2.3.3-2 shows adjustments in electricity rates (energy charge) since the implementation of the Automatic Fuel Cost Adjustment clause. Table 2.3.3-1 show electricity rates for October-December 2015.

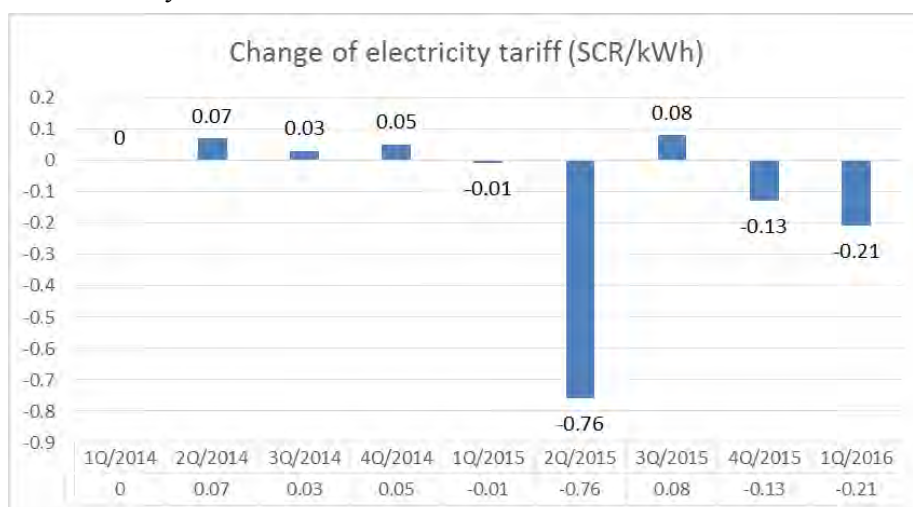


Figure 2.3.3-2 Trends in automatic fuel cost adjustments to PUC electricity rates (energy charge)

Table 5.5.5-1 PUC Electricity rates (January-March 2016)

		Power demand charge (SCR/kVA)	Energy Charge (SCR/kWh)	
Domestic	0-2.4 kVA	0.00	0-200 kWh 201-300 kWh 301-400 kWh 401-600 kWh	0.37 0.63 2.45 2.83
	2.4-9.6 kVA	4.90	Exceeding 600 kWh	3.51
	9.6 KVA or more	9.85		
Commercial	Single phase 0-200 kWh	9.60	2.86	
	Single phase Exceeding 200 kWh	16.65	0-500 kWh	2.86
			501-1000 kWh	3.22
			Exceeding 1000 kWh	3.79
	Three Phase 0-200 kWh	9.39	2.86	
	Three Phase Exceeding 200 kWh	16.65	0-50 kWh	2.86
			501-1000 kWh	3.22
Exceeding 1000 kWh			3.79	
Government	Single Phase	28.85	4.14	
	Three Phase	28.85	4.14	
Bulk consumers with power demand over 150 kVA		85.25	0-25,000 kWh	3.50
			Exceeding 25,000 kWh	3.79

2.3.4 PUC's financial situation and grants

PUC holds the electricity, waterworks, and sewerage sectors, but electricity sales accounted for 84% (2014) of the combined revenues of these sectors, so the main sector is the electricity sector. Figure 2.3.4-1 shows recent trends in PUC sales by sector.

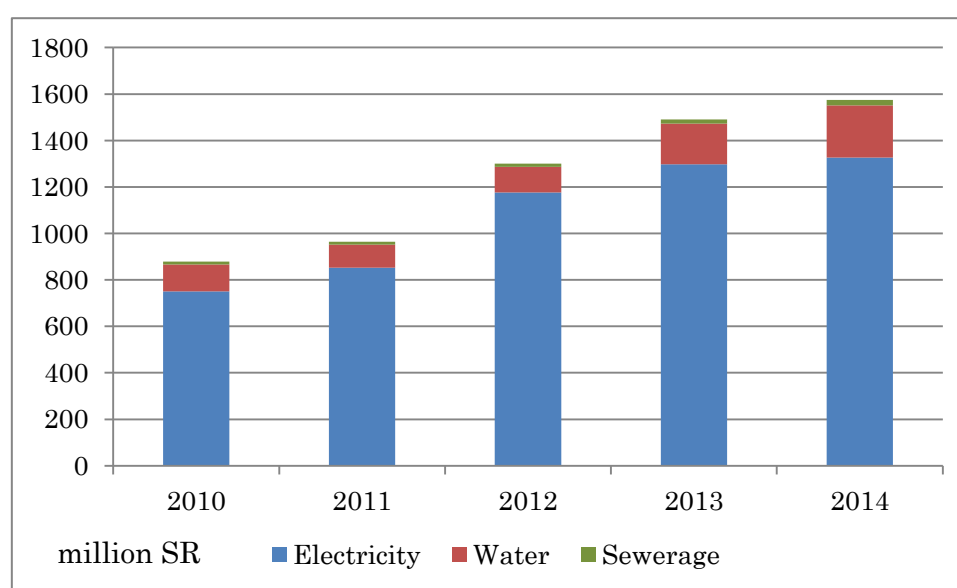


Figure 2.3.4-1 Recent trends in PUC sales by sector

Figure 2.3.4-2 shows the revenue trends for each sector. PUC is in deficit for its waterworks and sewerage sectors, but are profiting in its electricity sector since 2012.

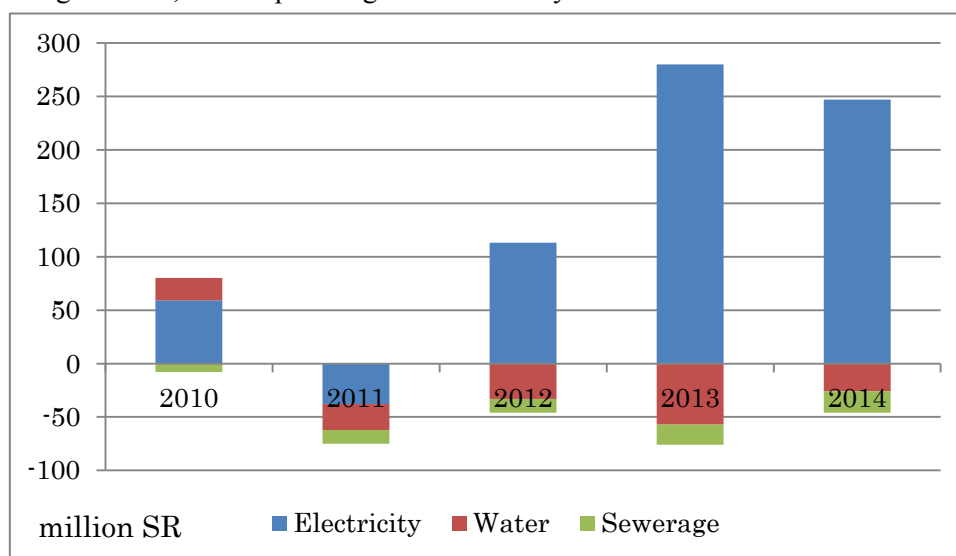


Figure 2.3.4-2 PUC revenue trends for each sector

Table 2.3.4-1 shows 2014 PUC revenue and expenses for each sector. Fuel accounted for 76% of costs for the electricity sector. Therefore, it is urgent to speed up the integration of renewable energy in order to reduce and stabilize the cost of supplying power.

Table 2.3.4-1 2014 PUC revenue and expenses for each sector (Thousand SCR)

	Electricity	Water	Sewerage	Total Segments	Adjustments and eliminations	Consolidated
<u>Income</u>						
Revenue from operations	1,288,918	181,511	21,933	1,492,362	-	1,492,362
Other income	36,806	43,742	1,598	82,146	7,085	89,231
Total	1,325,724	225,253	23,531	1,574,508	7,085	1,581,593
<u>Expenditure</u>						
Consumables and spares	843,865	33,253	5,084	882,202	-	882,202
Employee benefit expenses	78,554	73,766	10,289	162,609	-	162,609
Finance expense	-	-	-	-	9,089	9,089
Depreciation and amortisation	38,886	55,276	9,088	103,250	-	103,250
Other operating overheads	117,403	88,863	19,227	225,493	627	226,120
Total	1,078,708	251,158	43,688	1,373,554	9,716	1,383,270
<u>Profit/(Loss) from operations</u>	247,016	(25,905)	(20,157)	200,954	(2,631)	198,323

Table 2.3.4-3 shows PUC's balance sheet. PUC's balance sheet reflects the improvement in revenues for one fiscal year, which has led to an improved financial situation and equity ratio. Government subsidies for capital investment for the electricity, waterworks, and sewerage sectors continue, but the amount has decreased.

Table 2.3.4-2 PUC balance sheet (2014 Financial Report)

	Notes	2014 SR	As restated 2013 SR	As restated 2012 SR
ASSETS				
Non Current assets:				
Property, plant and equipment	6	1,443,004,889	1,435,874,264	947,073,071
Intangible assets	7	1,670,929	2,144,622	481,070
Capital work in progress	8	416,417,404	229,529,944	499,810,109
Trade and other receivables	9	1,908,143	-	-
		<u>1,863,001,365</u>	<u>1,667,548,830</u>	<u>1,447,364,250</u>
Current assets:				
Inventories	10	319,341,893	220,007,682	159,424,974
Trade and other receivables	9	245,458,483	198,814,288	161,744,944
Cash and cash equivalents	11	294,637,104	353,103,382	98,119,491
		<u>859,437,480</u>	<u>771,925,352</u>	<u>419,289,409</u>
Total Assets		<u>2,722,438,845</u>	<u>2,439,474,182</u>	<u>1,866,653,659</u>
EQUITY, DEFERRED GRANT AND LIABILITIES				
Equity				
Assigned capital	12	1,439,743,591	1,439,743,591	1,439,743,591
Revenue deficit		(122,772,249)	(321,095,820)	(525,270,221)
Total Equity		<u>1,316,971,342</u>	<u>1,118,647,771</u>	<u>914,473,370</u>
Deferred Grants				
Non Current	13	66,495,606	64,393,399	759,274,672
Current	13	986,869,031	979,336,872	27,846,094
		<u>1,053,364,637</u>	<u>1,043,730,271</u>	<u>787,120,766</u>
Non Current liabilities:				
Borrowings	14	142,665,867	118,330,371	-
Trade and other payables	15	30,194,424	29,085,018	25,844,449
Employee benefit liabilities	16	52,795,716	41,401,042	39,006,880
		<u>225,656,007</u>	<u>188,816,431</u>	<u>64,851,329</u>
Current liabilities:				
Borrowings	14	41,189,794	-	-
Trade and other payables	15	82,566,932	82,160,391	96,002,584
Employee benefit liabilities	16	2,690,133	6,119,318	4,205,610
		<u>126,446,859</u>	<u>88,279,709</u>	<u>100,208,194</u>
Total Liabilities		<u>352,102,866</u>	<u>277,096,140</u>	<u>165,059,523</u>
Total Equity, Deferred Grants and Liabilities		<u>2,722,438,845</u>	<u>2,439,474,182</u>	<u>1,866,653,659</u>

2.3.5 Policies and institutions

The Energy Act was established in 2012 to achieve the objectives of the energy policy, and it permits IPPs to enter the power generation business using renewable energy. As shown below, the promotion policy for the integration of renewable energy (mostly PV) is being implemented, and since the latter half of 2013, the integration of grid-connected PV generation systems is progressing rapidly.

(1) Establishing a PUC rooftop PV net metering system

PUC has permitted the connection of PV generation systems to the grid since September 2013, and it has implemented the net metering system where power meters are installed to measure the electricity sold to PUC, and this amount is subtracted from the amount of power purchased from PUC. The customer is then billed for the amount due. There are no restrictions for residential customers on PV installation capacity, but PV installations for commercial customers are limited to a maximum of 50% of the power they purchase. If the power supplied to PUC exceeds the power consumed, PUC will purchase it at a rate equivalent to 88% of fuel costs. Since the introduction of this system, PV integration has progressed rapidly mostly for major power consumers such commercial customers and the Government.

(2) Creating a low-interest loan scheme for residential PV installations

With the aid of the World Bank ["Seychelles Energy Efficiency and Renewable Energy Program" (SEEREP)], a low-interest loan scheme with a maximum amount of 100,000 rupees was established through commercial banks to help cover energy efficient and renewable energy equipment installation costs. The interest rate is 5%, and the repayment period is 1-5 years. When obtaining a loan, one is required to pay 2.5% of the loan amount with personal funds. SEEREP guarantees commercial banks up to 50% of each loan.

(3) The creation of a subsidy program for residential and commercial PV installations

With the aid of UNDP/GEF, subsidies to help cover residential PV installation costs was established in the spring of 2014. It covers 3 kW or less rooftop PV equipment and originally subsidized 35% of the cost, has been reduced to 25% beginning in April 2015. Subsidies are paid after installation is completed. Subsidies to help cover commercial PV installation costs was established in July 2014. It covers 15kW or less rooftop PV equipment and will subsidize 15% of the cost. The maximum on subsidies is 100,000 USD. Both systems will apply to equipment installed up to one year before the launch of the system. The unit price for installation, which will be the foundation for calculating the subsidy amount, will be calculated based on market prices, and they are currently 2.8 USD/W for residential and 3.2 USD/W for commercial.

(4) Establishing a feed-in tariff and renewable energy IPP

SEC plans to consider establishing a Feed-in tariff system for renewable energy based on the results of the study conducted by Energynautics in a cabinet meeting at the end of August. Feed-in tariff will cover up to 100 kW (or 500 kW). Requiring any renewable energy facility greater than this to negotiate conditions for selling power individually as an IPP is under consideration. The Feed-in tariff will apply to all renewable energy (with the exception of ocean energy), and the plan is to set purchase prices separately for each type of renewable energy.

2.3.6 Status of assistance from other donors

The World Bank (WB) and UNDP play a central role in providing aid to the electric power sector and renewable energy deployment in Seychelles. World Bank aims to improve management of PUC (secure management sustainability including capital investment) by aiding the study on electricity rates (Tariff Study) and correcting internal subsidization of electricity rates and cross-subsidization among PUC's electricity, waterworks, and sewerage sectors. Based on the results of the electricity rates study, the Government of Seychelles plans to revise the electricity rates system by rebalancing the rates for each sector of PUC over 8 years. It revised electricity rates in November 2013. In addition, the World Bank (WB) aids the dissemination of energy conservation and renewable energy, and it provides financial aid to the "Seychelles Energy Efficiency and Renewable Energy Program" (SEEREP). This aid program provides low-interest loans through commercial banks in Seychelles, and guarantees banks up to 50% on low-interest loans.

The UNDP uses GEF funds to aid subsidy programs for residential (3 kW or less) and commercial (15 kW or less) PV system installation costs.

Aid for the energy sector from aid organizations other than the World Bank and UNDP are as follows.

- EU aids the energy sector through the IOC (Indian Ocean Commission), which includes Seychelles, Madagascar, Mauritius, Comoros, and Reunion (territory of France). The content of the aid centers mainly on establishing a legal system and energy conservation.
- China has provided aid for solar powered street lights and solar water heaters.
- Korea plans to conduct a pilot project on La Digue Island for a small PV-diesel-battery hybrid system (to supply 30 homes). They are currently considering an implementation plan.
- India is promoting projects which aid the deployment of small PV systems for low-income households with grant funds. Currently, they are considering how to aid the deployment of PV systems for low-income households (high rate subsidies, etc.). In addition, they plan to conduct a biomass energy project on La Digue Island.
- Mitsubishi Motors is proposing to deploy electric cars on La Digue Island. They propose using a PV-DG hybrid system as a power source. They are counting on other aid funds for to finance the project.
- Sri Lanka is planning a pilot project for a small commercial PV-wind-diesel hybrid system on Praslin Island. Sri Lanka plans to make the capital investment and recover it through electricity bills.
- The Abu Dhabi Fund for Development aids the deployment of diesel generators for PUC (grant).

2.4 Mahe Island and Praslin Island power supply facilities

2.4.1 Mahe Island

(1) Diesel power generation facilities

PUC owns two power plants on Mahe Island: Victoria B (Output capacity: 16,700 kW), Victoria C (Output capacity: 74,000kW). Victoria B Power Plant has many decrepit generators, and their output is limited, so the actual total output capacity is 16,700 kW as opposed to the rated capacity of 22,848 kW.

On the other hand, since Victoria C Power Plant is newer than Victoria B Power Plant, it is operated as the main power supply for Mahe Island. A list of generators for each power plant is shown in Table 2.4.1-1. In addition, the load curve for Mahe Island on April 09, 2014 is shown in Figure 2.4.1-1 for reference. In Figure 2.4.1-1, the peak load for Mahe Island is approximately 50 MW.

Table 2.4.1-1 List of diesel generators in Mahe Island

POWER PLANT: VICTORIA B (NEW PORT) MAHE ISLAND							
GENSET	MAKE/TYPE	RATED OUTPUT(Kw)	Derated Capacity (kw)	SPEED	MANUFACTURER	YEAR INSTALLED	FUEL USED
SET 1B	K8 MAJOR	2,500	1,000	500	MIRRELES BLACKSTONE (UK)	1971	LFO (Diesel)
SET 3B	K8 MAJOR	2,500	1,200	500	MIRRELES BLACKSTONE (UK)	1971	LFO (Diesel)
SET 4B	K8 MAJOR	2,500	1,500	500	MIRRELES BLACKSTONE (UK)	1978	LFO (Diesel)
SET 5B	KV12 MAJOR	5,000	3,500	600	MIRRELES BLACKSTONE (UK)	1981	LFO (Diesel)
SET 6B	8ZAL 40	5,000	0	600	SULZER (Switzerland)	1986	HFO (Heavy fuel oil, 180 cSt@50°C)
SET 7B	8ZAL 40 S	5,000	3,500	500	SULZER (Switzerland)	1990	HFO (Heavy fuel oil, 180 cSt@50°C)
SET 8B	18V 32 LN	6,348	6,000	750	WARTSILA FINLAND	1998	HFO (Heavy fuel oil, 180 cSt@50°C)
Total		28,848	16,700				
POWER PLANT: VICTORIA C (ROCHE CAIMAN) MAHE ISLAND							
GENSET	MAKE/TYPE	RATED OUTPUT (kw)	Derated Capacity (kw)	SPEED	MANUFACTURER	YEAR INSTALLED	FUEL USED
SET A11	18V 32 LN	6,348	6,000	750	WARTSILA FINLAND	2000	HFO (Heavy fuel oil, 180 cSt@50°C)
SET A21	18V 32 LN	6,348	6,000	750	WARTSILA FINLAND	2000	HFO (Heavy fuel oil, 180 cSt@50°C)
SET A31	18V 32 LN	6,348	6,000	750	WARTSILA FINLAND	2000	HFO (Heavy fuel oil, 180 cSt@50°C)
SET A41	18V 32 LN	6,348	6,000	750	WARTSILA FINLAND	2000	HFO (Heavy fuel oil, 180 cSt@50°C)
SET A51	W18V 32	8,000	8,000	750	WARTSILA FINLAND	2015	HFO (Heavy fuel oil, 180 cSt@50°C)
SET A61	W18V 32	8,000	8,000	750	WARTSILA FINLAND	2015	HFO (Heavy fuel oil, 180 cSt@50°C)
SET B11	18V 32 LN	6,348	6,000	750	WARTSILA FINLAND	2000	HFO (Heavy fuel oil, 180 cSt@50°C)
SET B21	18V 32 LN	6,348	6,000	750	WARTSILA FINLAND	2000	HFO (Heavy fuel oil, 180 cSt@50°C)
SET B31	18V 32 LN	6,348	6,000	750	WARTSILA FINLAND	2000	HFO (Heavy fuel oil, 180 cSt@50°C)
SET B41	W18V 32	8,000	8,000	750	WARTSILA FINLAND	2011	HFO (Heavy fuel oil, 180 cSt@50°C)
SET B51	W18V 32	8,000	8,000	750	WARTSILA FINLAND	2011	HFO (Heavy fuel oil, 180 cSt@50°C)
Total		76,436	74,000				

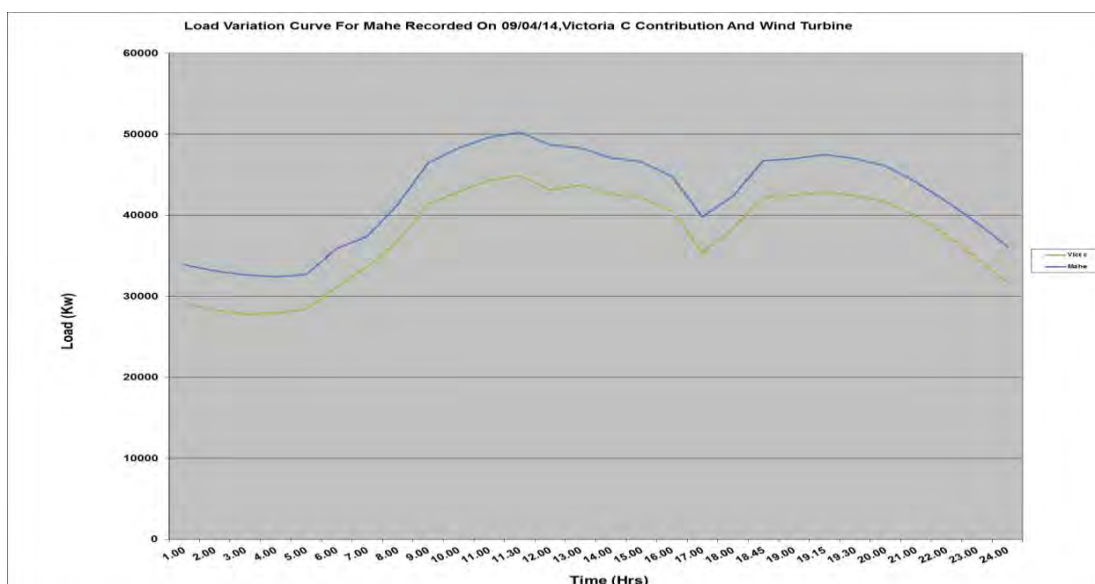


Figure 2.4.1-1 Mahe Island load curve (April 9, 2014)

	
Complete view of PUC Victoria C Power Plant	PUC Victoria C Power Plant generator
	
PUC Victoria C Power Plant central control room	PUC Victoria C Power Plant electric room
	
PUC Victoria B Power Plant central control room	PUC Victoria B Power Plant premises generator

(2) Wind power facility

A 6 MW (750 kW × 8 units) Abu Dhabi-funded wind turbine facility manufactured by Unison of Korea has been deployed on Mahe Island. A list of generators is shown in Table 2.4.1-2. In addition, annual and monthly average wind speeds for each unit are shown in Figure 2.4.1-2 and Figure 2.4.1-3.

Table 2.4.1-2 List of wind turbines in Mahe Island

WIND FARM						
WINDTURBINE	MAKE/TYPE	RATED OUTPUT (kw)	Derated Capacity (kw)	SPEED	MANUFACTURER	YEAR INSTALLED
1	U57-30	750	750		UNISON CO LTD	2012
2	U57-31	750	750		UNISON CO LTD	2012
3	U57-32	750	750		UNISON CO LTD	2012
4	U57-33	750	750		UNISON CO LTD	2012
5	U57-34	750	750		UNISON CO LTD	2012
6	U57-35	750	750		UNISON CO LTD	2012
7	U57-36	750	750		UNISON CO LTD	2012
8	U57-37	750	750		UNISON CO LTD	2012
Total		6,000	6,000			

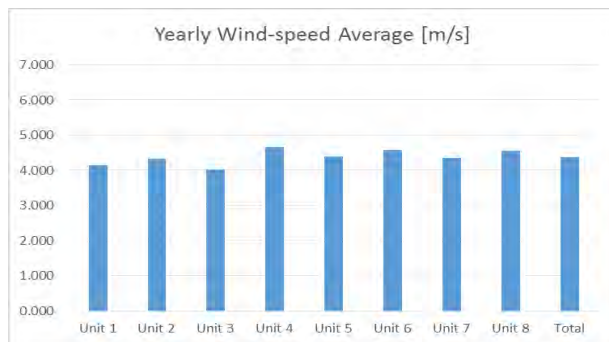


Figure 2.4.1-2

Annual average wind speed for each unit

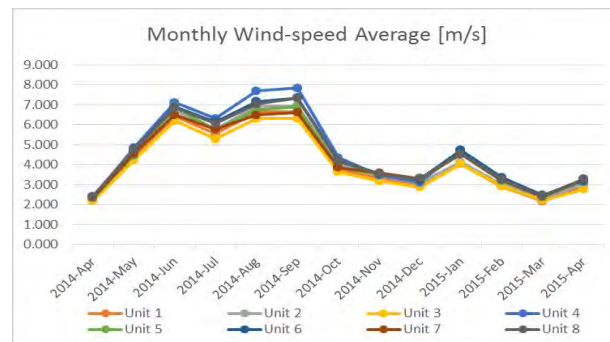


Figure 2.4.1-3

Monthly average wind speed



Figure 2.4.1-4 Status of wind power facility

(3) PV facilities

1) Deployment status

According to data collected in the 1st survey, there are 135 PV installations in the Seychelles mainly concentrated in the capital of Mahe Island, with a total of 1,151 kW. The largest PV installation is at Central Bank on Mahe Island with 139 kW. Table 2.4.1-3 shows a list of relatively large installations of 10 kW or more.

Table 2.4.1-3 List of PV installations

ID	Applicant	Address	island	Installer	Total kW	Commissioned
1	Amalgamated Tobacco	Point Larue	Mahe	Sea & Sun Technology	39.8	20/09/2013
2	Central Bank of Seychelles	Victoria	Mahe	Pace Seychelles	139.3	16/12/2013
3	L'Archipel Hotel	Praslin	Praslin	Pace Seychelles	74.4	01/09/2014
4	L'Aurier Eco Hotel & Restaurant	Cote D'Or (Praslin)	Praslin island	Pace Seychelles	39.2	02/07/2014
5	Amalgamated Tobacco	Point Larue	Mahe	Sea & Sun Technology	39.8	26/02/2014
6	Radley Weber	Glacis	Mahe	MEJ Electrical	10.9	24/02/2014
7	France Bonte	La Misere	Mahe	Jim Lesperance	15.0	20/08/2014
8	Abhaje Valabhji Pty Ltd	Providence	Providence Atoll	Sea & Sun Technology	45.1	01/08/2014
9	Sahajanand Builders	Providence	Providence Atoll	MEJ Electrical	17.0	04/11/2014
10	Hunt Deltel	Ile Du Port	Mahe	MEJ Electrical	102.0	03/06/2014
11	Ravi Raghvani	Capucins	Mahe	MEJ Electrical	10.0	28/07/2014
12	Nandu Raghvani	Capucins	Mahe	MEJ Electrical	10.0	12/09/2014
13	Guy Adam	Ma Constance	Mahe	Sea & Sun Technology	10.2	17/06/2014
14	Seychelles Pension Fund	Victoria	Mahe	MEJ Electrical	76.0	19/12/2014
15	Independence School	Ile Du Port	Mahe	MEJ Electrical	30.0	09/01/2015
16	Civil Construction Co. Ltd	Providence	Providence Atoll	MEJ Electrical	40.0	09/02/2015
17	Heliconia Grove Beach Bangalow	Cote D'Or (Praslin)	Praslin island	MEJ Electrical	10.0	09/01/2015
18	Nigel Michel	Glacis	Mahe	MEJ Electrical	10.0	09/12/2014
19	Charles Pool	Cote D'Or (Praslin)	Praslin island	MEJ Electrical	10.0	27/03/2015
20	Allied Builders (Seychelles) limit	Le Rocher	Mahe	Sea & Sun Technology	15.0	19/12/2014
21	Allied Builders #2	Le Rocher	Mahe	Sea & Sun Technology	15.0	19/12/2014
22	Castello Beach Hotel	Praslin	Praslin island	Sea & Sun Technology	32.3	17/03/2015
23	Lederic Chetty	Mont Simpson	Mahe	Seysolar Green Energy LTD	17.0	31/03/2015
24	Penlac Seychelles	Le Rocher	Mahe	Sea & Sun Technology	10.8	06/03/2015
25	Vijay Construction PTY LTD	Providence	Providence Atoll	Vijay Construction PTY Ltd.	32.2	29/12/2014
26	Seychelles Civil Aviation Authorit	Point Larue	Mahe	MEJ Electrical	30.0	22/01/2015
27	James Laporte	English River	Mahe	MEJ Electrical	15.0	27/04/2015

	
Amalgamated Tobacco Company 80 kW	Seychelles Central Bank in Victoria City 140 kW

2) Deployment examples

A total of approx. 1.2 MW of residential and commercial PV equipment has been installed in Seychelles. A Tobacco factory near the airport with an 80 kW system and a 140 kW system at the Central Bank are shown as examples below.

Example PV system (AMALGAMATED TOBACCO COMPANY)
[Equipment Overview] ● Equipment capacity: 80kW ● Panel: LG (polycrystalline), power conditioner (PCS): 6 × 15 kW SMA (Sunny tripower) ● Capital investment: 2,900,000 USD (22,600,000 yen) years required to recover initial investment: 3.5 years ● Warranty: 10 years ● Factory maximum load: 60 kW   Figure 2.4.1-5 PV deployment photos (tobacco factory)

Example PV system
(Central Bank of Seychelles)

[Equipment Overview]

- Equipment capacity: 140 kW (Dec. 2013)
- Panel: LG (mono-crystalline), power conditioner (PCS): 9 × 17 kW SMA (Sunny tripower) PV panel, a black panel which suppress reflection is used. (The bank's policy on visual consideration)
- Capital investment: 500,000 USD (52,000,000 yen) years required to recover initial investment: 4-5 years



Figure 2.4.1-6 PV deployment photos (Central Bank)

(4) Power transmission and distribution equipment

The power system in Mahe Island transmits power through high voltage 33 kV, medium voltage 11 kV, and low voltage 400 V/230 V overhead and underground lines. According to the interviews conducted in the 1st Survey, there are plans to reinforce (loop) the weak 33 kV power transmission capacity in the southern region over two years using funds from Saudi Arabia.

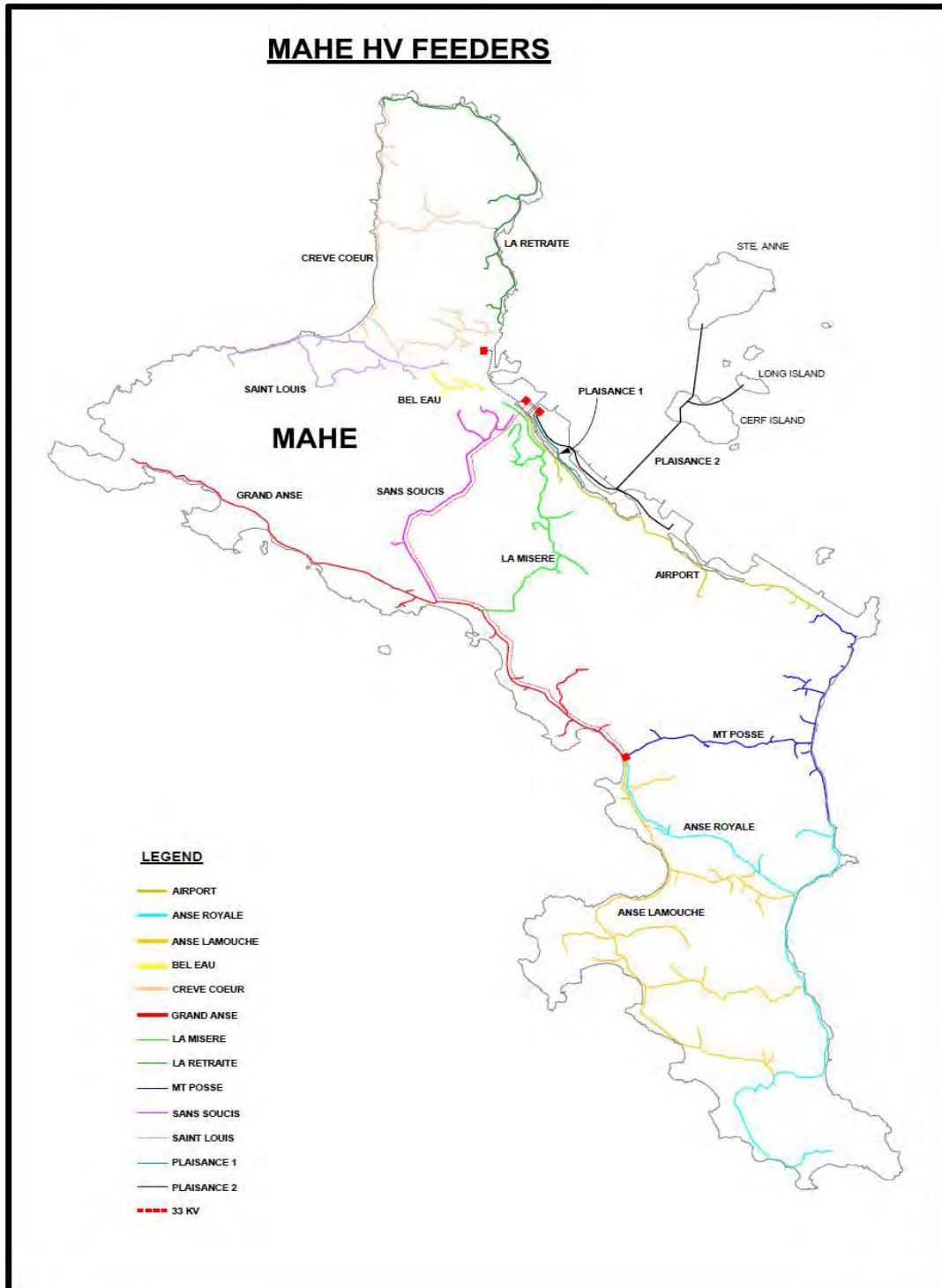


Figure 2.4.1-7 Mahe Island power transmission and distribution system diagram

2.4.2 Praslin Island

(1) Diesel power generation facilities

PUC owns the power plant on Praslin Island with an output capacity of 13,550kW. A list of generators is shown in Table 2.4.2-1. In addition, the load curve for Praslin Island on April 23, 2015 is shown in Figure 2.4.2-1 for reference. In addition, a graph of the peak load and minimum load for 2014 is shown in Figure 2.4.2-2. In Figure 2.4.2-2, the peak load for Praslin Island is approximately 8,000 kW.

Table 2.4.2-1 List of diesel generators in Praslin Island

POWER PLANT: PRASLIN ISLAND								
GENSET	MAKE/TYPE	RATED OUTPUT (kw)	Derated Capacity (kw)	SPEED	MANUFACTURER	YEAR INSTALLED	FUEL USED	TOTAL RUNNING HOURS
SET 1P	ESL 8	670	450	750	BLACKSTONE (UK)	1981	LFO (Diesel)	114131
SET 2P	ESL 8	670	450	750	BLACKSTONE (UK)	1981	LFO (Diesel)	128908
SET 3P	ESL 8	670	450	750	BLACKSTONE (UK)	1981	LFO (Diesel)	132098
SET 4P	ESL 8	670	0	750	BLACKSTONE (UK)	1990	LFO (Diesel)	127793
SET M4	3516	1,400	1,200	1500	CATERPILLAR (US)	1999	LFO (Diesel)	57898
SET M5	3516	1,200	1,100	1500	CATERPILLAR (US)	2000	LFO (Diesel)	33654
SET M6	KTA 50 G3	1,000	1,000	1500	CUMMINS	2013	LFO (Diesel)	171
SET 5P	W6L32	2,500	2,500	750	WARTSILA FINLAND	2015	LFO (Diesel)	3052
SET 6P	6 SW 280	1,500	1,400	750	STORK WARTSILA (Holland)	1996	LFO (Diesel)	107608
SET 7P	12 SW 280	3,000	2,500	750	STORK WARTSILA (Holland)	2003	LFO (Diesel)	76586
SET 8P	12 SW 280	3,000	2,500	750	STORK WARTSILA (Holland)	2003	LFO (Diesel)	78285
Total		16,280	13,550					

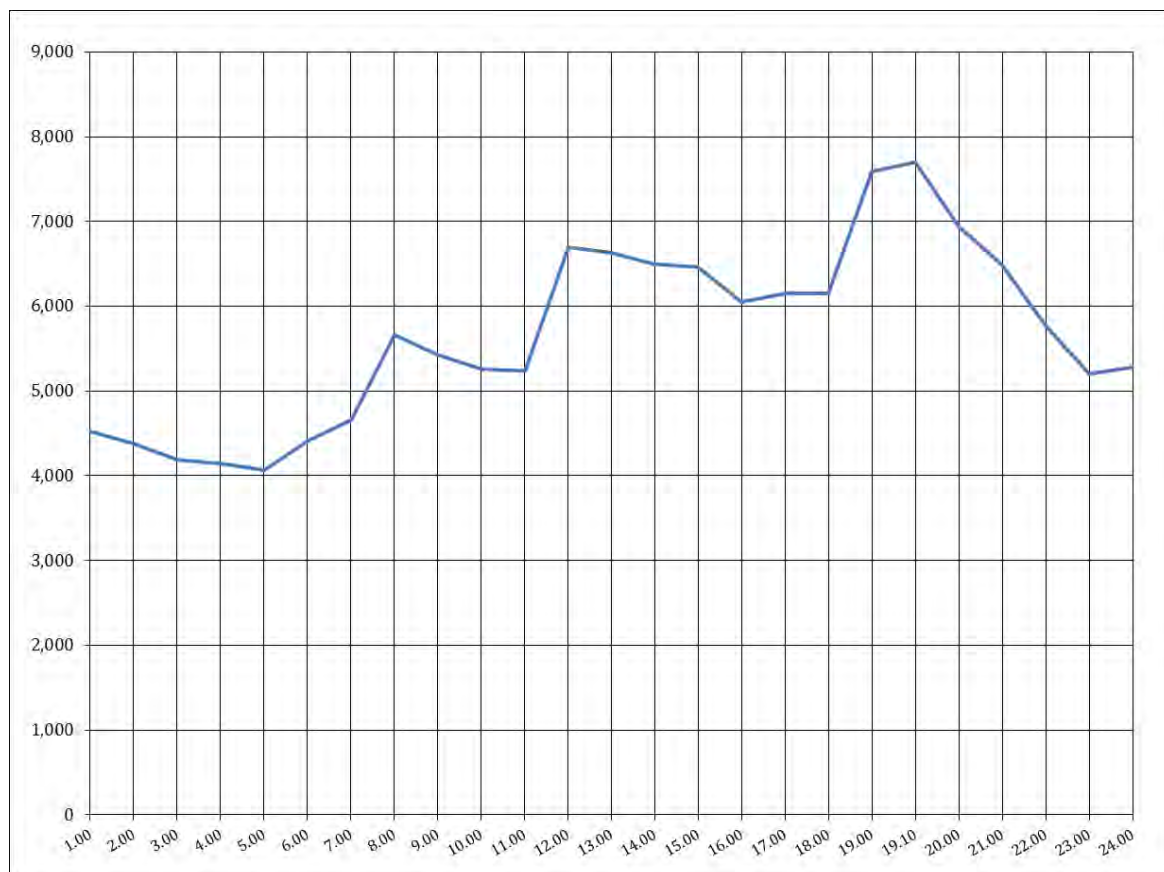


Figure 2.4.2-1 Praslin Island load curve (April 23, 2015)

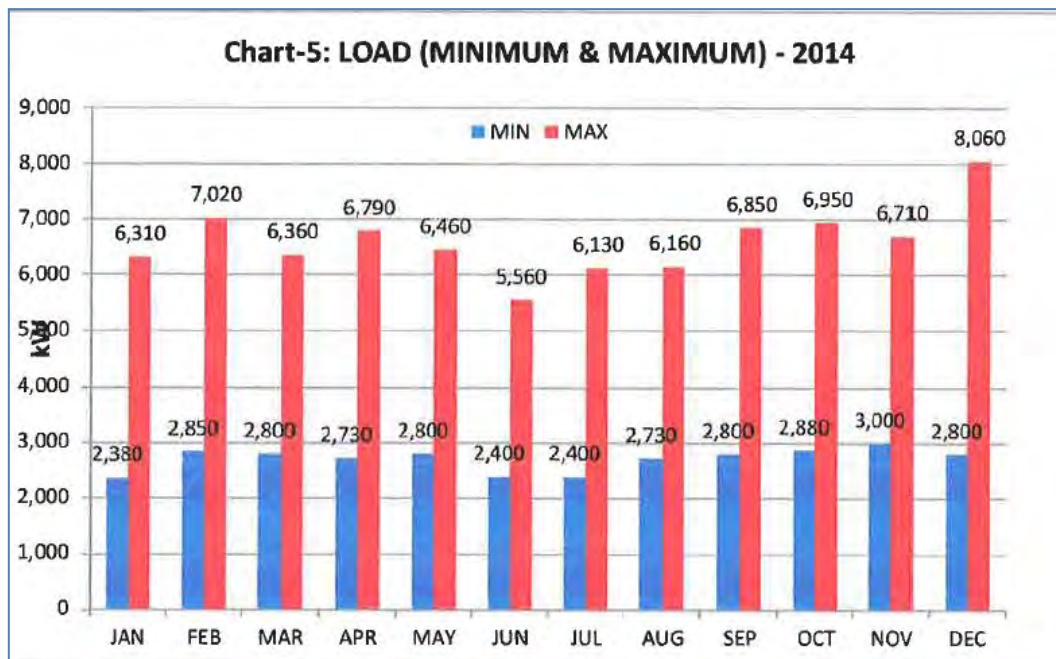


Figure 2.4.2-2 Praslin Island peak load and minimum load (2014)

	
PUC Praslin Power Plant DEG power plant	PUC Praslin Power Plant DEG
	
PUC Praslin Power Plant central control room	PUC Praslin Power Plant container type DEG

(2) PV facilities

According to data collected in the 1st survey, there are 7 PV installations in Praslin Island, mainly concentrated at hotels, with a total of 180 kW. The largest PV installation is at L'Archipel Hotel with 74.4 kW. A list of PV installations is shown in Table 2.4.2-2.

Table 2.4.2-2 List of PV installations

ID	Applicant	Address	island	Installer	Total kW	Commissioned
1	L'Archipel Hotel	Praslin	Praslin island	Pace Seychelles	74.4	01/09/2014
2	L'Aurier Eco Hotel & Restaurant	Cote D'Or (Praslin)	Praslin island	Pace Seychelles	39.2	02/07/2014
3	Vijay International School	Praslin	Praslin island	Pace Seychelles	6.5	25/10/2013
4	Island Motors Co. Ltd	Bois De Rose (New)	Praslin island	MEJ Electrical	5.0	12/12/2013
5	Heliconia Grove Beach Bangalow	Cote D'Or (Praslin)	Praslin island	MEJ Electrical	10.0	09/01/2015
6	Charles Pool	Cote D'Or (Praslin)	Praslin island	MEJ Electrical	10.0	27/03/2015
7	Castello Beach Hotel	Praslin	Praslin island	Sea & Sun Technology	32.3	17/03/2015

(3) Power transmission equipment

The power system in Praslin Island transmits power through high voltage 33 kV, medium voltage 11 kV, and low voltage 400V/230V lines. On the other hand, La Digue Island, located next to Praslin Island, is supplied from Praslin power station via two submarine cables. Figure 2.4.2-3 shows the power transmission diagram for Praslin Island.

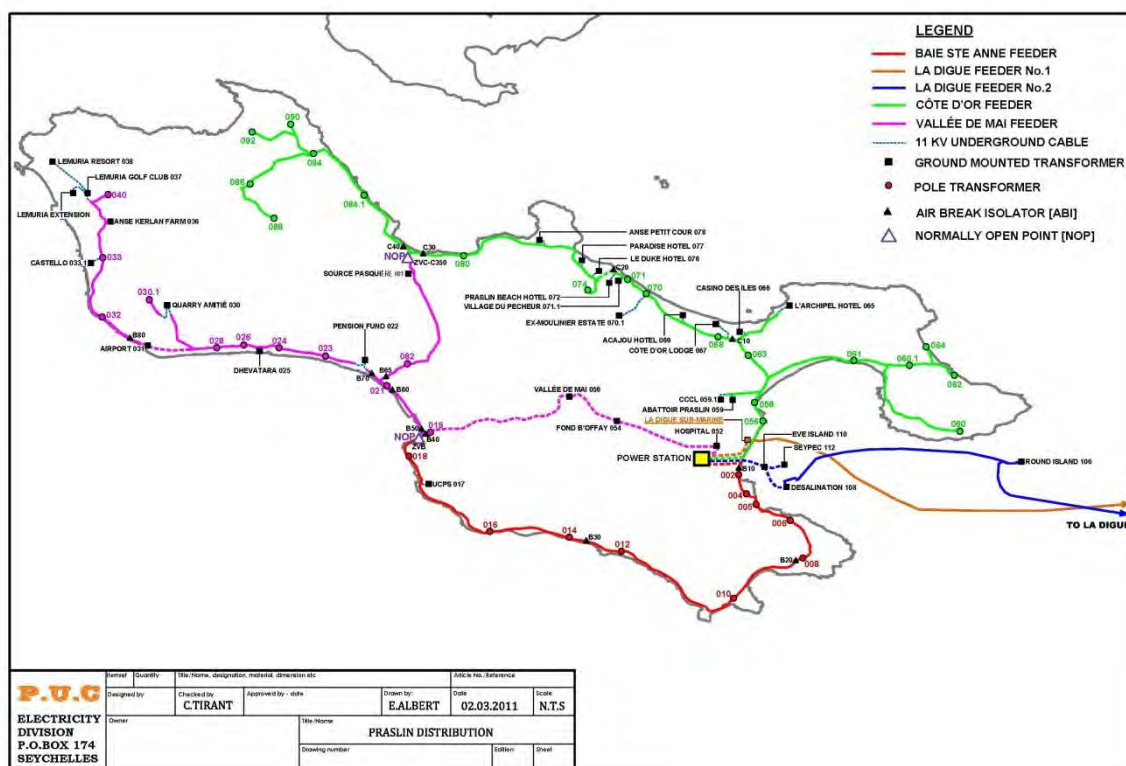


Figure 2.4.2-3 11 kV power transmission system diagram

2.5 Remote island survey overview

2.5.1 La Digue Island

LA Digue Island is a small island with a population of approximately 3,000, and tourism is the main industry. According to the "Carrying Capacity Study of La Digue Island," total bed count for 2012 was approximately 1,000, and most facilities are self-catering facilities and small guest houses.

The main public facilities include La Digue District Administration, Logan Hospital, La Digue School (elementary school), L' Union State Park (with a pig farm) the PUC water purification plant, and one gas station. Construction of a fish market planned to start in July 2015. In addition, there are approximately 40 vehicles on the island.



Figure 2.5.1-1 La Digue Island survey points

(1) Main lodging facilities

■ **Le Domaine De L'orangeraine**

55 villas (8 villas are currently under construction). Load 300~350 kW. Equipped with emergency power generation (500 kW).

	
La Digue District Administration	Logan Hospital
	
Le Domaine De L'orangeraine	Interview

■ **La Digue Island Lodge**

73 rooms. No emergency power generation. Load 350kW

	
La Digue Island Lodge	Interview

(2) La Digue Island power supply

Power is supplied through two submarine cables. One cable runs from Baie St. Anne Power Plant on Praslin Island to La Passe. The other cable runs from the power plant to La Passe via Eva Island, a sea water desalination plant, and Round Island. Currently, there is a plan for the third submarine cable. In addition, there are 40 PV-powered streetlights installed through aid from China.

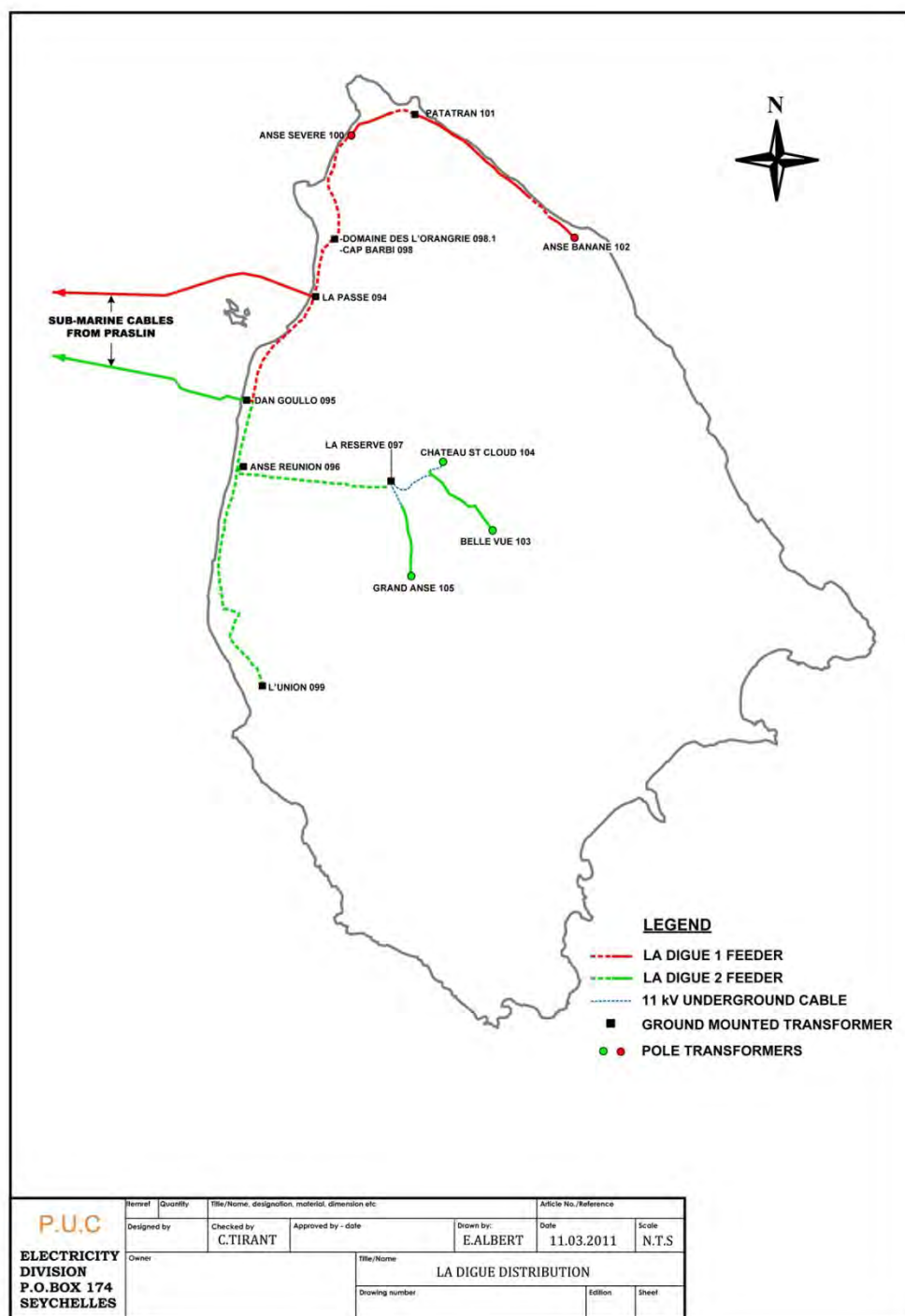


Figure 2.5.1-2 La Digue Island power distribution line system diagram

(3) La Digue Island water supply

PUC supplies water to the entire island. (Current water purification capacity is 850 m³/day)
The water supply breakdown is as follows.

■ **Surface water**

600 – 800 m³/day (wet season)

0 m³/day (dry season)

■ **Groundwater**

800 – 900 m³/day (wet season)

200 – 300 m³/day (dry season)

■ **Desalination**

Maximum 900 m³/day

(Since 08/2012; previously 300 m³/day)

■ **Supply pump**

- There are 6 pumps. Two are (2.2 kW) groundwater pumps (only one is being used). The amount of water supplied on May 5, 2015 was 1,345 m³/day.



Figure 2.5.1-3 PUC owned groundwater filtration facility

2.5.2 Curieuse Island

Curieuse Island is one of the remote islands of the Seychelles Islands. It is located to the northwest of Praslin Island and has an area of 2.86 km² making it the second largest remote island in the Seychelles.



Figure 2.5.2-1 Map of the location of the main facilities on Curieuse Island

(1) Power supply-demand status

- Generation equipment: 5.5 kVA diesel generator and 5 kVA gasoline generator (Elemax SH7600 made by Sawafuji Electric with a Honda GX390 engine)

*The diesel generator was out of order during our visit in 2014 as well as during this visit and are currently being repaired on Praslin Island.

- During our visit in 2014, there was also a 2 kW generator which was used to supply daytime power, but it was not confirmed on our latest visit.
- Normal feeding time: 17:00-6:00
- Distribution voltage: single phase 240 V
- Peak demand: approximately 5 kW
- Generator fuel consumption: 20 L/day (approximately 40L/day at times)
 - *3.5 L/h at engine rated output
- Gasoline price: SR22/L



Figure 2.5.2-2 Diesel generator

(2) Power demand of main facilities

Main equipment accounting for demand is as follows.

■ Administration building:

Refrigerator, washing machine, LCD TV, water pumps, lighting, PC

■ Administrator residence:

Refrigerator, TV, lighting, PC, etc.

■ Water supply relocation:

Water pump (1.3kW)

■ Guest quarters (used only when external researchers visit):

Lighting

■ Guest researchers stay from a couple of days to several weeks.

Power is supplied 24 hours/day during guest researchers' stay.

Maximum power during guest researchers' stay is 7-8 kW (large research equipment is powered by rented generator).

Administration
building appliances



Figure 2.5.2-3 Equipment inside the administration building



Figure 2.5.2-4 Administration building



Figure 2.5.2-5 Water supply facility

2.5.3 Desroches Island

Desroches Island is located 230 km to the southwest of Mahe Island (approximately 40 minutes by plane).

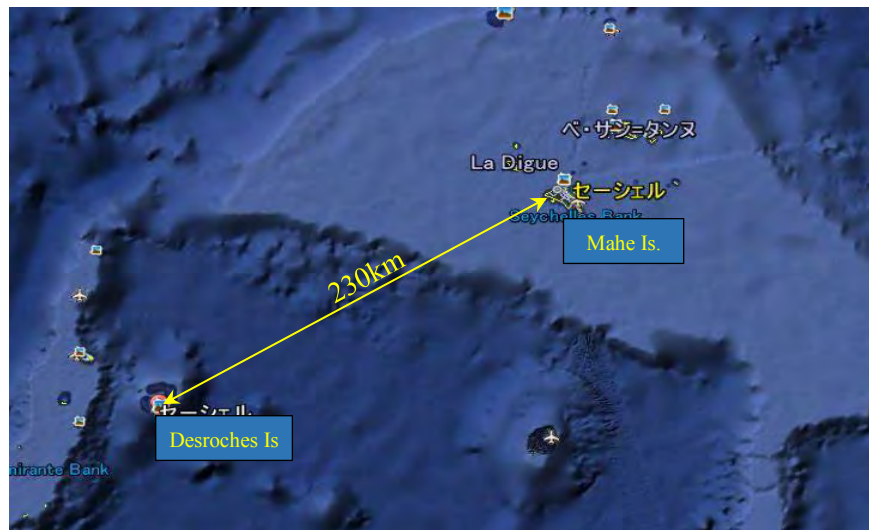


Figure 2.5.3-1 Map of Desroches Island location



Figure 2.5.3-2 Map of Desroches Island facilities location

(1) Diesel power generation facility and potential installation site for PV facility

The diesel power plant is located to the west of a road which crosses the central part of the airport runway. The IDC staff gave us a tour of the potential installation site for the PV facility. It is located approximately 400 m east of the diesel power plant.



Figure 2.5.3-3 Diesel power generation facility and potential installation site for PV facility

(2) Generation equipment configuration

Three diesel generators are installed in the diesel power plant, and power is normally supplied by one unit. Model and other specifications of the equipment are as follows.

- CAT 800F 725KVA ($\cos\phi 0.8$) 580 kW $\times$ 3 units
- N:1,500 rpm, 400/230 V. 50 Hz
- Total output 1.74 MW
- Control method: isochronous, load sharing



Figure 2.5.3-4 Diesel generation facility

(3) Load curve

The annual load curve for Desroches Island is shown in Figure 2.5.3-5. The peak load is approximately 570 kW (April), the average load is roughly 300 kW - 400 kW. In addition, according to information from IDC, due to a change in ownership of the hotel, the system load is expected to increase by approximately 1.5 times.

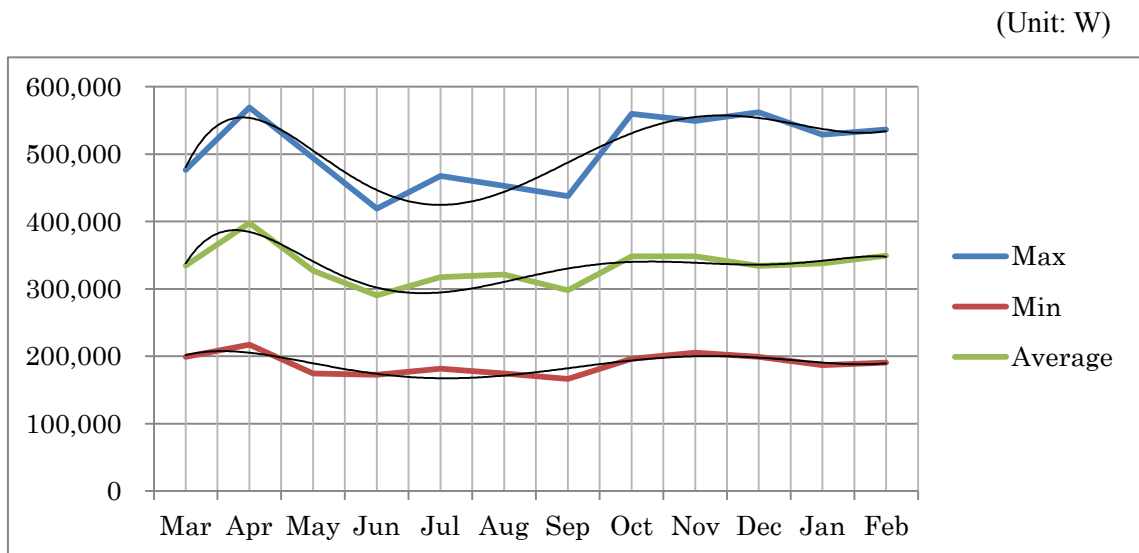


Figure 2.5.3-5 Annual load curve

Chapter 3 Survey Results

3.1 Aid with evaluation method to determine the RE integration capacity

(Study on short period constraints)

3.1.1 Evaluation method to determine the RE integration capacity

Since renewable energy such as solar and wind power are variable power sources that are dependent on natural forces, they are difficult to control in the way diesel generators are controlled. Therefore, there are 4 major challenges to expanding RE integration.¹

① Frequency fluctuation (short-period fluctuations)

In order supply power stably, demand and generation must always be matched by controlling the output of each power plant for the constantly fluctuating demand. This in turn maintains frequency at a constant value. If this balance is not maintained, frequency will fluctuate, and may not only affect the operation of the electrical equipment on the customers' side, but if frequency fluctuates over a certain value, protection mechanisms of the generators are triggered forcing them to trip (disconnect from the power grid) one after another and may cause a blackout.

② Excess electricity measures (long-period fluctuations)

The power utility operates power supply by controlling the output of each power plant according to the ever changing power demand such that demand and supply are equal at all times. Such operation is due to the physical characteristics of electricity and is indispensable for the stable supply of power. However, if the amount of renewable energy power where output is difficult to control increases, a gap between supply and demand may occur during periods of low load due to RE power output conflicting with the output lower limit of existing firm generation.

③ Rise in distribution system voltage

If the amount of renewable energy sources interconnected to the distribution system (distribution lines), such as PV systems installed on homes in particular increases, voltage at the interconnection point may deviate from the proper value (in Japan 101 ± 6 V) due to reverse power flow in the distribution system. Maintaining voltage at the proper value is necessary from the perspective of impact to the life and normal use of electrical equipment on the customer side, and protection of equipment on the grid side, so measures such as stopping PV generation such that voltage does not exceed proper values and curtailing output are needed.

④ RE islanding and unnecessary disconnection

Although item 3 above is a matter of concern during normal operations, RE islanding and unnecessary disconnections are examples of events that may occur during system faults including emergency shutdown faults.

1) Islanding: Islanding refers to a condition where distributed energy sources including RE continue to operate while connected to grids where power supply should normally be stopped and voltage is not present due to system faults caused by lightning, etc. or for construction.

¹ NEDO Renewable Energy Technology White Paper

Since there is a possibility that people or workers may be shocked, equipment damaged, fire-fighting activities impaired, etc., these power sources must be disconnected from the grid.

2) Unnecessary disconnections: Unnecessary disconnection refers to a condition where RE sources disconnect unnecessarily when grid frequency and voltage fluctuations occur, although they normally should not disconnect, because 1. anti-islanding device is unnecessarily triggered, 2. impact of transient undervoltage or other disturbances. If many renewable energy power sources over a wide area disconnect at once, it leads to a significant drop in supply and causes an imbalance in supply and demand and may disrupt the supply of power. As an example in Japan, when system frequency dropped by Hz 0.9 due to stopping the operation of Tokyo Electric Power Company's Kashiwazaki Kariwa Nuclear Power Station as a result of the Chuetsu-Oki Earthquake in 2007, some brands of the 550 solar panels NEDO had deployed in Ota City, Gunma Prefecture disconnected at once. If this event occurs over a vast area, a large amount of power would be lost, and may result in system failure.

Towards the high penetration of renewable energy in island regions, since short-period fluctuations tend to manifest first, **the algebraic method, a simple method to calculate RE integration capacity, was used in this study to evaluate system frequency stability (short-period constraint)**. PV, which is included in short-period constraints, of 50 kW or more were target of the study, and PV of under 50 kW were excluded from the study as they have a very high smoothing effect due to their distributed installation and have little impact on frequency fluctuations. However, these small scales PV are included in long-period constraints.

<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, which operate based on the frequency of the electricity that they 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.

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

3.1.2.1 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 renewable energy output fluctuations as parameters, the integration capacity 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 Seychelles by using the algebraic method.

The algebraic method uses allowable adjustable margin, the frequency response range of the generator, demand fluctuation rate, and RE fluctuation rate as parameters. A schematic diagram of the algebraic method is shown in Figure 3.1.2-1.

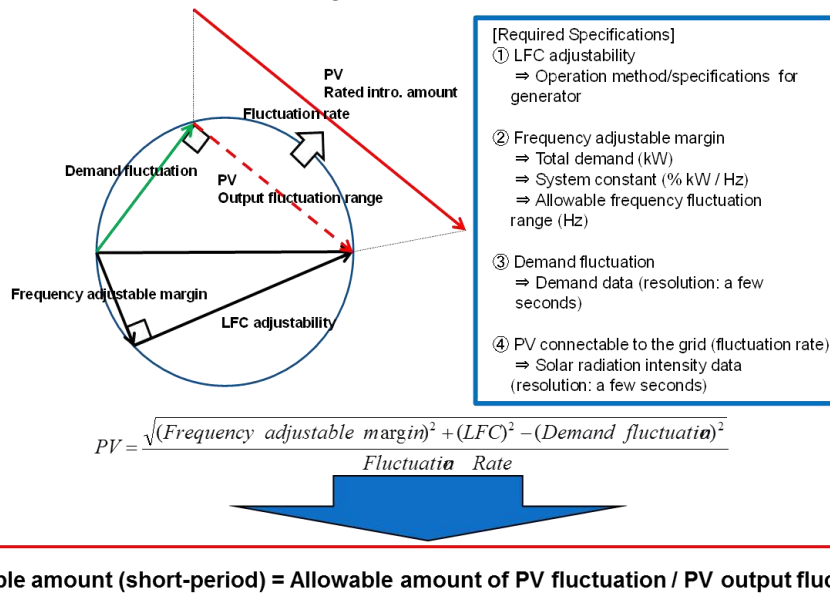


Figure 3.1-11 A schematic of the algebraic method

With this method, the maximum allowable amount of PV can be calculated using the following formula.

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

<Reference: Detailed generator simulation>

By simulating the responsiveness of the generator in detail, frequency fluctuations due to output fluctuations of renewable energy can be quantitatively calculated. Data for modeling and a dedicated simulation tool is 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, are capable of dynamic analysis of the grid and 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.

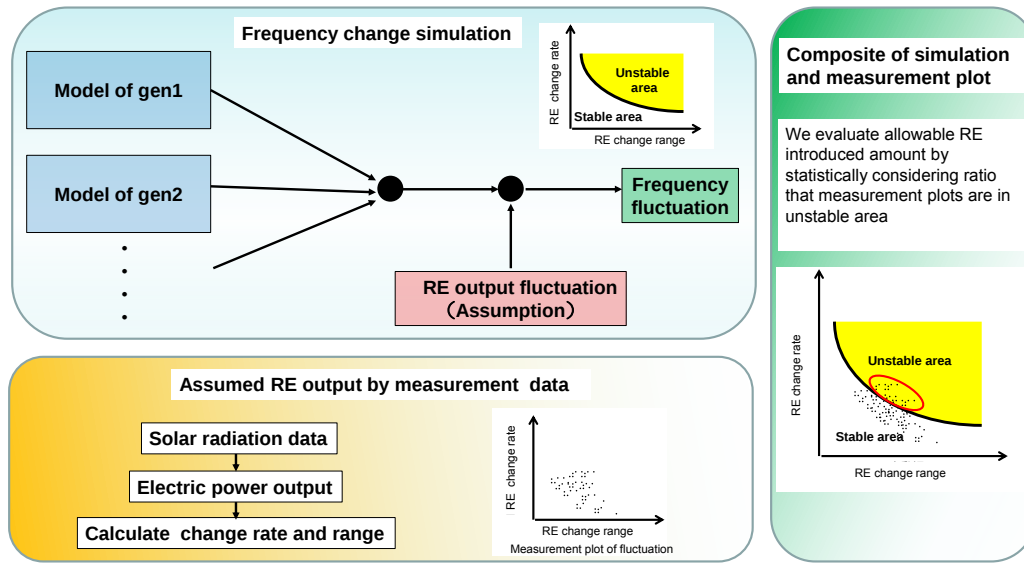


Figure 3.1.2-2 Detailed schematic diagram of a generator simulation

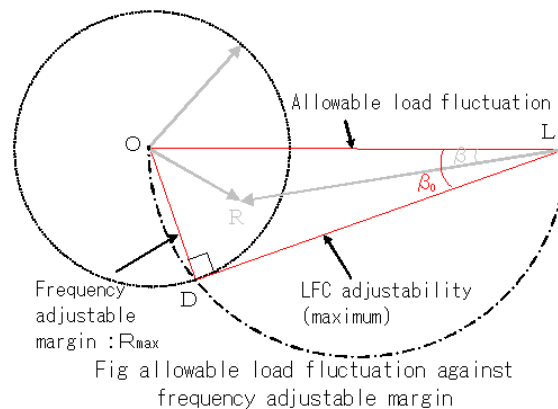
[Glossary]

- Allowable adjustable margin

Allowable adjustable margin is the range which the power supplying side should maintain in order to maintain power quality. For the grid in Okinawa, the adjustment range is within $60 \pm 0.3\text{Hz}$. This frequency range greatly affects the value of the maximum allowable amount. A schematic diagram of the allowable adjustable margin is shown in Figure 3.1.2-3. In addition, the allowable adjustable margin is calculated using Formula (1).

Formula for calculating allowable adjustable margin

Allowable adjustable margin $R_{\max} = \text{system constant (\%MW/Hz)} \times \text{frequency range (0.3 Hz)}$
 $\times \text{total demand (MW)} \dots (1)$



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

Figure 3.1.2-3 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.

3.1.2.2 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 Seychelles, which is a similar island. 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 Figure 3.1.2-4.

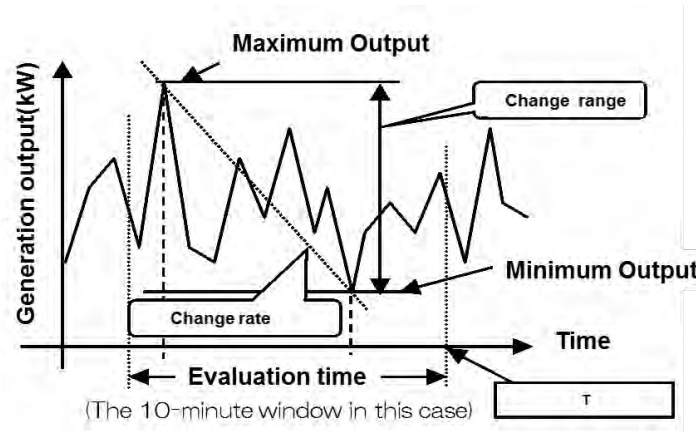


Figure 3.1.2-3 Definition of evaluation time window and output fluctuation range

3.1.2.3 Overview of the probabilistic method

If output fluctuation range is used as defined above, rare fluctuations will be considered, so RE output fluctuation rate (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) are often used. 3σ means that there is a 99.7% probability that a frequency deviation will not occur. How risks will be taken will be determined after consultation with the local CP as the needs of Seychelles are important.

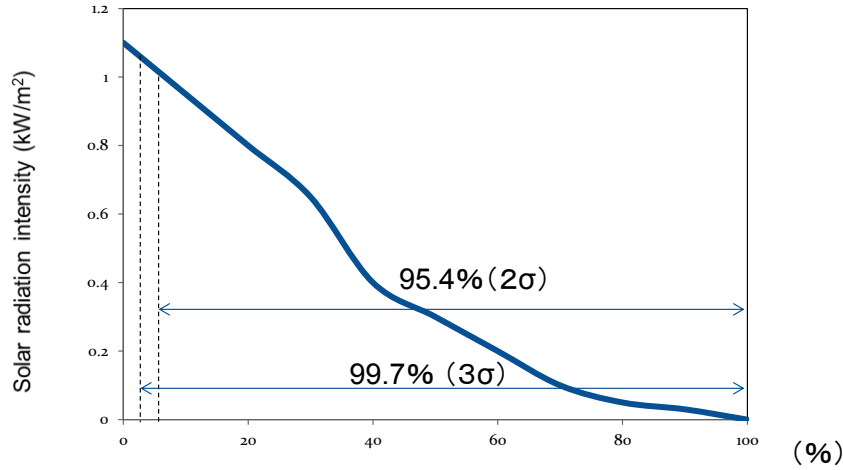


Figure 3.1.2-4 Representation of the probabilistic calculation (2σ , 3σ)

3.1.3 Short period renewable energy constraints for Mahe and Praslin

The RE integration capacity considering short period constraints for the 2 target islands for survey in this project (Mahe and Praslin) was calculated using the algebraic method. The parameters required for the algebraic method (system constant, demand fluctuation rate, total demand, solar radiation intensity fluctuation rate, and wind speed fluctuation rate) were analyzed using the measurement data or values near the measurement data.

3.1.3.1 Calculating system constant (frequency fluctuation test)

Since the RE anticipated to be deployed (solar power, wind power, etc.) is an unstable power source, controlling it in accordance with 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 following 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 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.

$$(\Delta P (\%MW) = \Delta P (MW) / \text{total rated output of parallel input generators})$$

$$\Delta P / \Delta F = K (\text{constant value: \%MW/Hz}) \dots (1)$$

In a load rejection test, one of the multiple generators which are connected to the grid is disconnected causing a load imbalance. By doing so, the load following 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 carried it out with the consent of the local power plant officials.

① Load rejection test in Mahe

The load rejection test was conducted twice; 2 MW was rejected the first time; and 4 MW was rejected the second time. Since frequency fell to 49.2 Hz on the second time, it was assumed that a rejection of 4 MW or more would result in a frequency of 49 Hz or less, which means it would enter a range that would trigger under frequency relays on the feeder (49 Hz), so further testing was terminated. With this test, system constant was calculated at 6.83% MW/Hz with a 2 MW rejection and 7.99% MW/Hz with a 4 MW rejection. In the algebraic method, the value with the larger rejection of 4 MW (7.99% MW/Hz) will be used. Detailed testing conditions and the results are described in the following pages.

When comparing the responsiveness of each generator with a 4 MW rejection, it can be seen that there is little difference in the responses of 6 MW rated generators. However, there is a difference in the 8 WM rated generators where the new units, A51 and A61 were found to be faster than the old units, B41 and B51. In order to improve the responsiveness of these generators, the governor function of the old units should be considered and collaboration with manufacturers is needed.

It can be said that compared to typical constants of diesel generators, the system constant calculated in this survey is smaller, and responsiveness is poor. Future validation of the responsiveness of these generators is needed, and data such as when generators trip should be accumulated to improve accuracy.

(1) 2 MW rejection

Using the following test conditions, a load rejection of approximately 2 MW was conducted on generator A21 to measure the output response and frequency response of a sound generator in 20 ms.

Test conditions

Time of test	16/03/2016 9:26			
	Unit	rated output	Run	Trip
Rated Output (MW)	SET 8B	6.00	○	
	SET A21	6.00		○
	SET A31	6.00	○	
	SET A41	6.00		
	SET A51	8.00	○	
	SET A61	8.00	○	
	SET B11	6.00	○	
	SET B21	6.00	○	
	SET B31	6.00	○	
	SET B41	8.00	○	
	SET B51	8.00	○	
Generator Output (MW)	SET 8B	4.05		
	SET A21	2.06		
	SET A31	4.31		
	SET A41			
	SET A51	6.49		
	SET A61	6.59		
	SET B11	4.47		
	SET B21	4.53		
	SET B31	4.05		
	SET B41	6.72		
	SET B51	7.26		
Demand (MW)	50.98			

Result of test

Original frequency(Hz)	50.05
Bottom frequency(Hz)	49.21
Frequency deviation(Hz)	0.84
Dropout generator output(MW)	4.14
Time of bottom frequency(s)	1.32
End frequency(Hz)	49.87

System constant

System constant(%MW/Hz)	7.99
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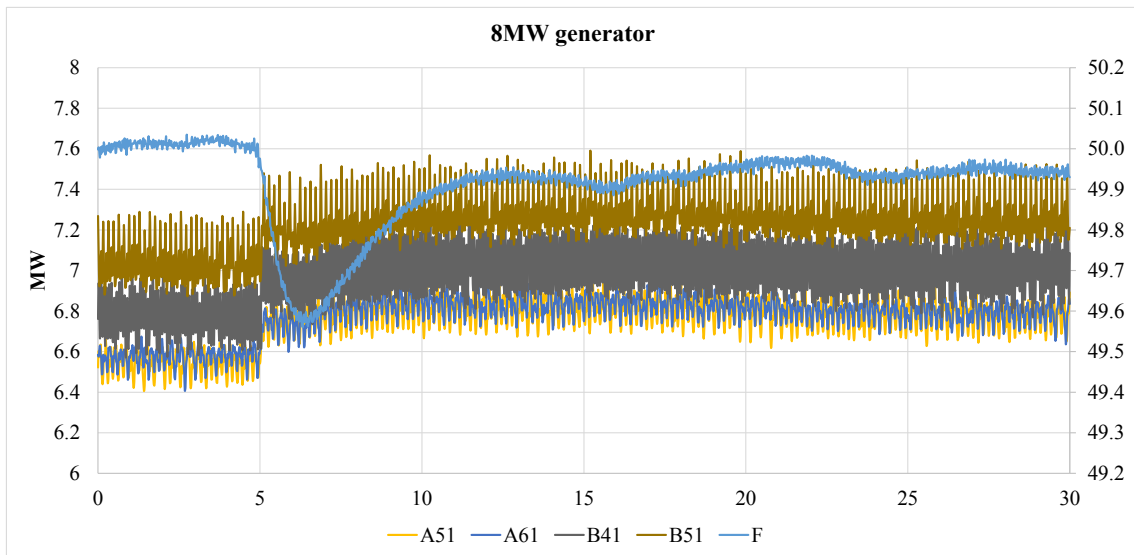
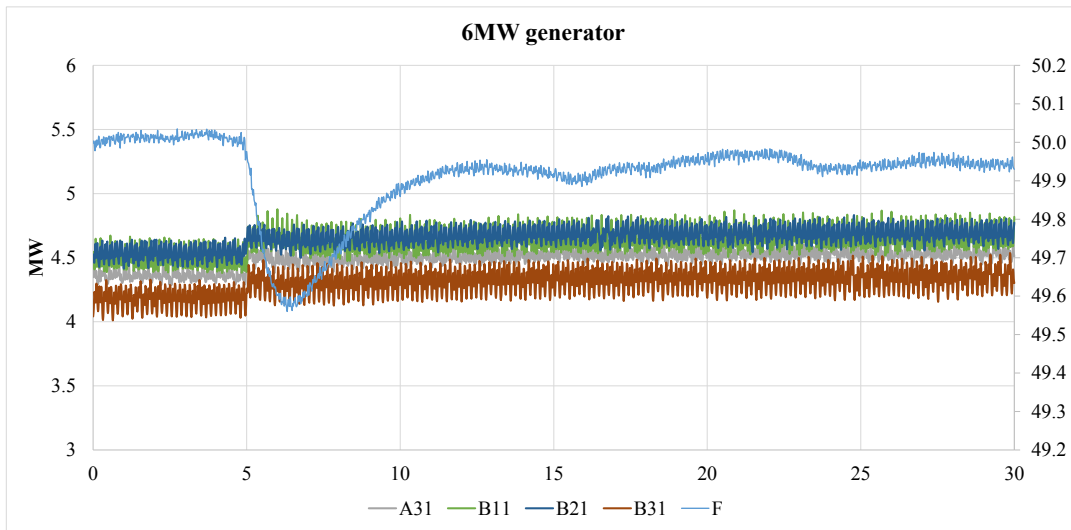
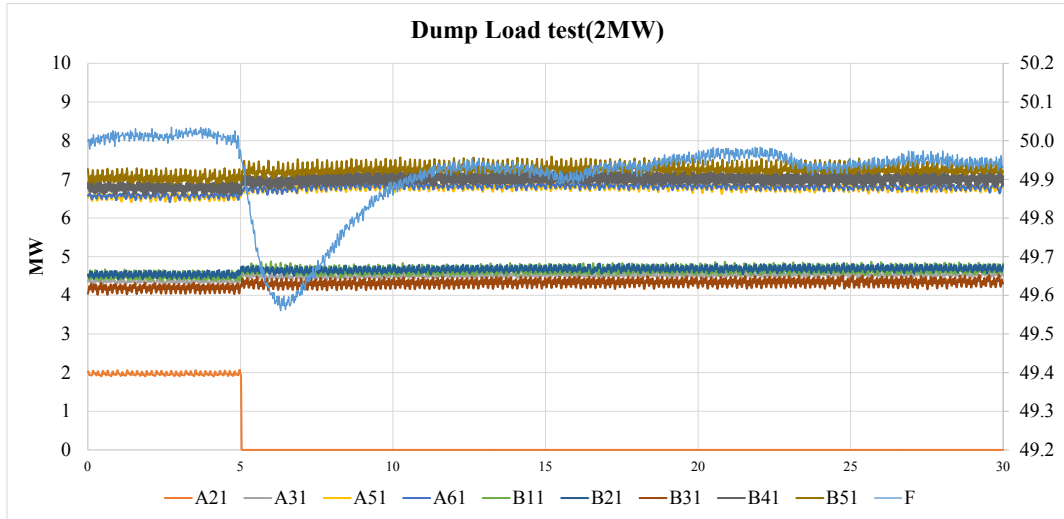


Figure 3.1.3-1 2 MW load rejection test results (Mahe)

(2) 4 MW rejection

Using nearly the same condition as the 2 MW rejection, a 4 MW rejection was conducted on A21 to measure the output response and frequency response of a sound generator.

Test conditions

Time of test	16/03/2016 9:26			
	Unit	rated output	Run	Trip
Rated Output (MW)	SET 8B	6.00	○	
	SET A21	6.00		○
	SET A31	6.00	○	
	SET A41	6.00		
	SET A51	8.00	○	
	SET A61	8.00	○	
	SET B11	6.00	○	
	SET B21	6.00	○	
	SET B31	6.00	○	
	SET B41	8.00	○	
	SET B51	8.00	○	
Generetator Output (MW)	SET 8B	4.50		
	SET A21	4.14		
	SET A31	4.37		
	SET A41			
	SET A51	6.52		
	SET A61	6.58		
	SET B11	4.49		
	SET B21	4.44		
	SET B31	4.01		
	SET B41	6.40		
	SET B51	6.50		
Demand (MW)	51.94			

Result of test

Original frequency(Hz)	50.05
Bottom frequency(Hz)	49.21
Frequency deviation(Hz)	0.84
Dropout generator output(MW)	4.14
Time of bottom frequency(s)	1.24
End frequency(Hz)	49.87

System constant

System constant(%MW/Hz)	7.99
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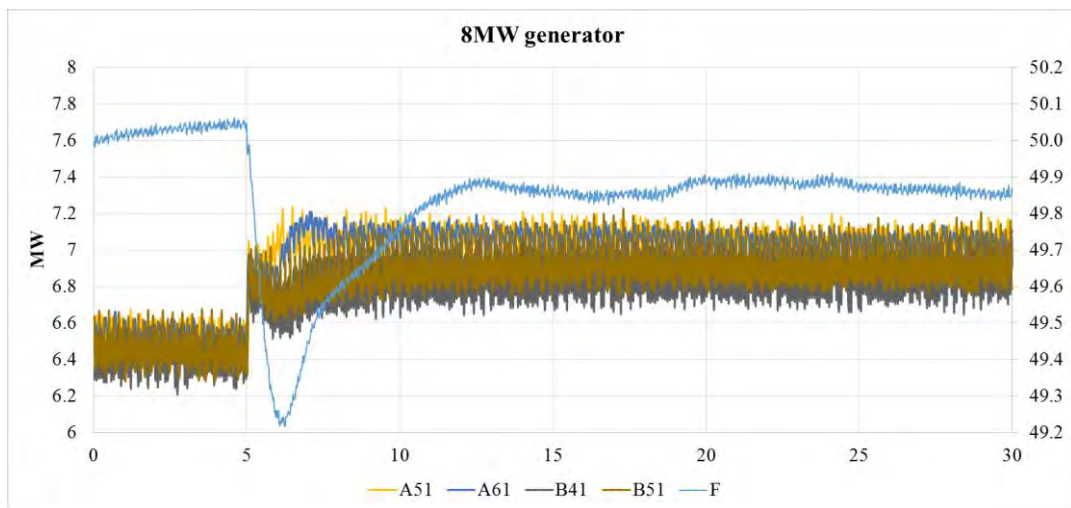
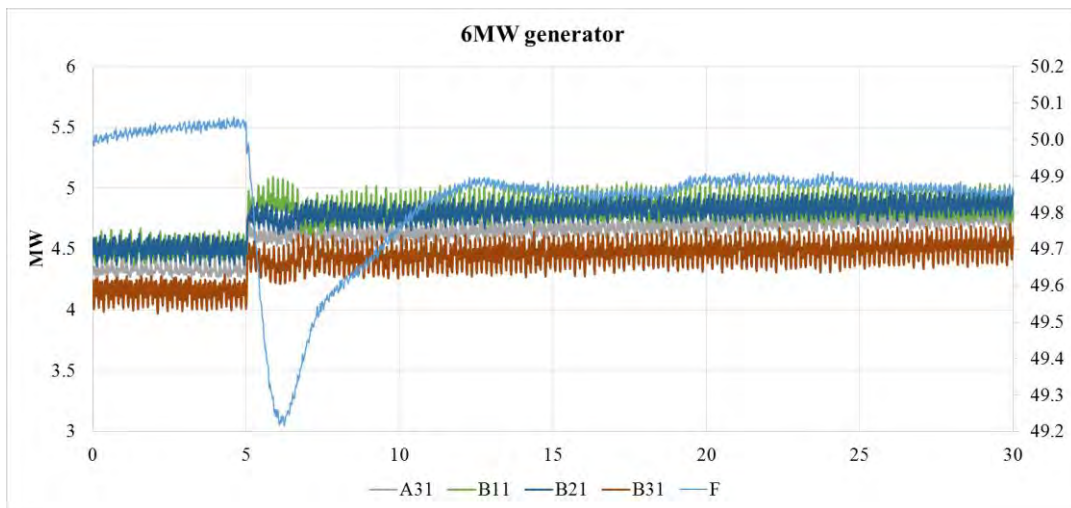
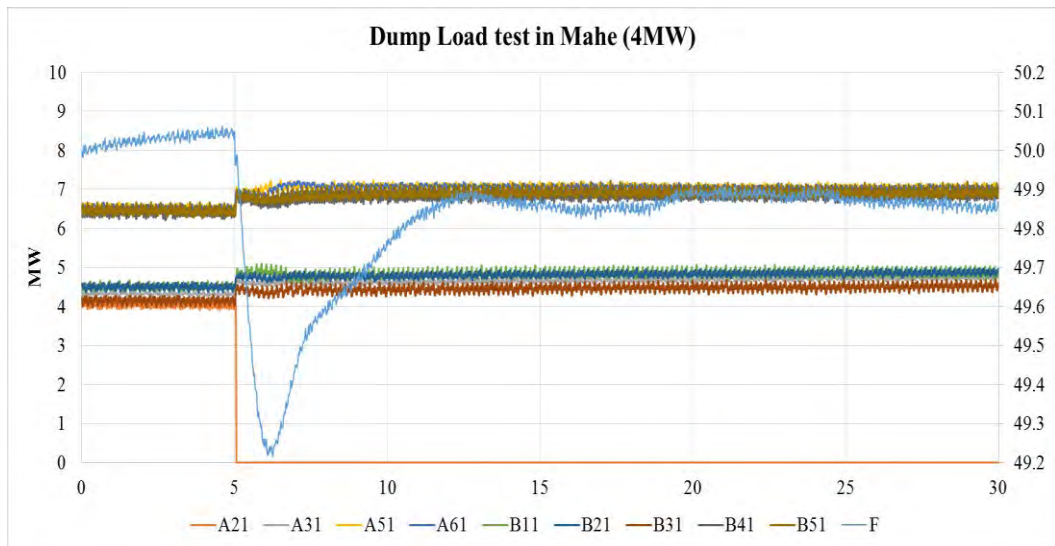


Figure 3.1.3-2 4 MW load rejection test results (Mahe)

The system constant calculated based on the results of the simulation conducted by Energy nautics is introduced below for reference. A system constant of 27.5% MW/Hz is significantly different from the actual measured value (8.54% MW/Hz) in this survey.

- Amount of PV disconnected: 5 MW
- Total rated output of generators: 26 MW
- Frequency deviation: 0.7 Hz
- System constant: 27.5% MW/Hz

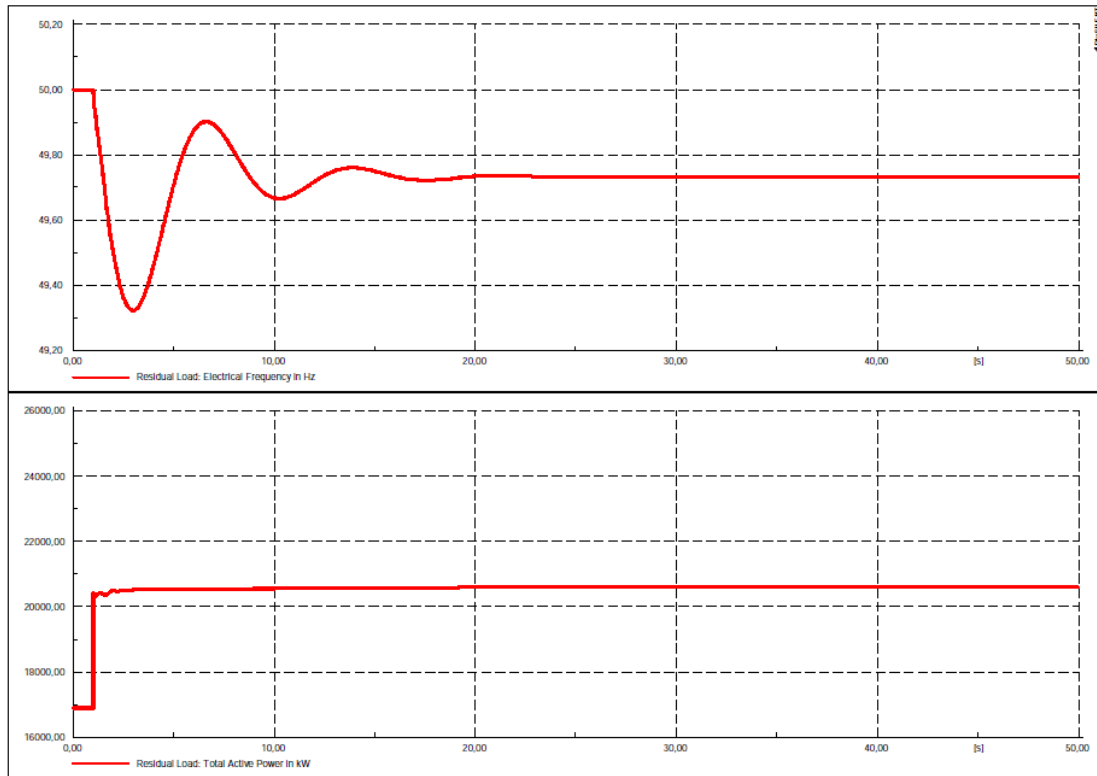


Figure 22: Frequency behaviour (top graph) during sudden loss of 5 MW PV plant (residual load is shown in lower graph) on Mahé in 2015. (Source: Energynautics)

Figure 3.1.3-3 Energynautics simulation

② Load rejection test in Praslin

The load rejection test was conducted twice; 400 kW was rejected the first time; and 600 kW was rejected the second time. Since frequency fell to 49.48Hz on the second time (a drop of 0.64 Hz), it was assumed that a rejection of 600kW or more would result in a frequency of 49 Hz or less, which means it would enter a range that would trigger under frequency relays on the feeder (49 Hz), so further testing was terminated. With this test, system constant was calculated at 9.5% MW/Hz with a 400 kW rejection and 9.79% MW/Hz with a 600 kW rejection. In the algebraic method, the value with the larger rejection of 600 kW (9.79% MW/Hz) will be used. Detailed testing conditions and the results are described in the following pages.

(1) 400kW rejection

Using the following test conditions, a load rejection of approximately 400 kW was conducted on generator M5 to measure the output response and frequency response of a sound generator in 20 ms.

Test conditions

Time of test	16/03/2016 9:26			
	Unit	rated output	Run	Trip
Rated Output (MW)	SET 1P	0.67		
	SET 2P	0.67		
	SET 3P	0.67		
	SET 4P	0.67		
	SET M4	1.40		
	SET M5	1.20		○
	SET M6	1.00		
	SET 5P	3.00	○	
	SET 6P	1.50	○	
	SET 7P	3.00	○	
	SET 8P	3.00	○	
Generator Output (MW)	SET 1P			
	SET 2P			
	SET 3P			
	SET 4P			
	SET M4			
	SET M5	0.45		
	SET M6			
	SET 5P	1.72		
	SET 6P	0.93		
	SET 7P	1.59		
	SET 8P	1.73		
Demand (MW)	6.42			

Result of test

Original frequency(Hz)	50.12
Bottom frequency(Hz)	49.6
Frequency deviation (Hz)	0.45
Dropout generator output(MW)	0.45
Time of bottom frequency(s)	1.18
End frequency(Hz)	49.97

System constant

System constant(%MW/Hz)	9.5
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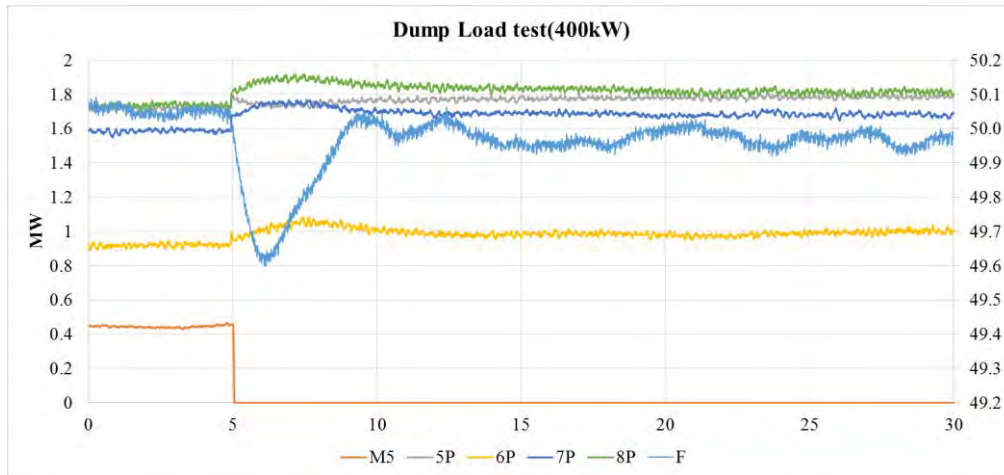


Figure 3.1.3-4 400 kW load rejection test results (Praslin)

(2) 600 kW rejection

Using the same test conditions described above, a load rejection of approximately 600 kW was conducted on generator M5 to measure the output response and frequency response of a sound generator in 20 ms.

Test situation

Time of test	23/03/2016 9:34		Run	Trip
Rated Output (MW)	SET 1P	0.67		
	SET 2P	0.67		
	SET 3P	0.67		
	SET 4P	0.67		
	SET M4	1.40		
	SET M5	1.20		○
	SET M6	1.00		
	SET 5P	3.00	○	
	SET 6P	1.50	○	
	SET 7P	3.00	○	
Generator Output (MW)	SET 8P	3.00	○	
	SET 1P			
	SET 2P			
	SET 3P			
	SET 4P			
	SET M4			
	SET M5	0.65		
	SET M6			
	SET 5P	1.71		
	SET 6P	0.92		
Demand (MW)	SET 7P	1.59		
	SET 8P	1.70		
		6.58		

Result of test

Original frequency(Hz)	50.12
Bottom frequency(Hz)	49.48
Frequency deviation(Hz)	0.64
Dropout generator output(MW)	0.65
Time of bottom frequency(s)	1.08
End frequency(Hz)	49.98

System constant

System constant(%MW/Hz)	9.79
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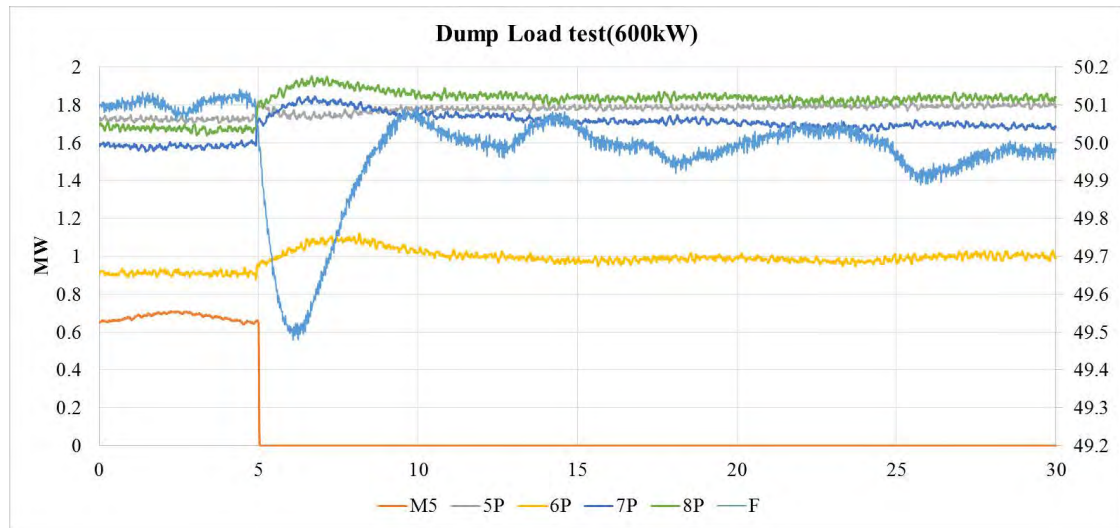


Figure 3.1.3-5 600 kW load rejection test results (Praslin)

3.1.3.2 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 Figure 3.1.3-6. Assuming the fluctuation range is the difference between the 10 min moving average value (5 minutes before and after) and the actual value, the values for 2σ and 3σ were determined from the standard deviation (σ value), and the daytime and 24-hour analysis results are shown for PV and wind power analysis. The daily load curve and frequency trend from measurements are shown for reference.

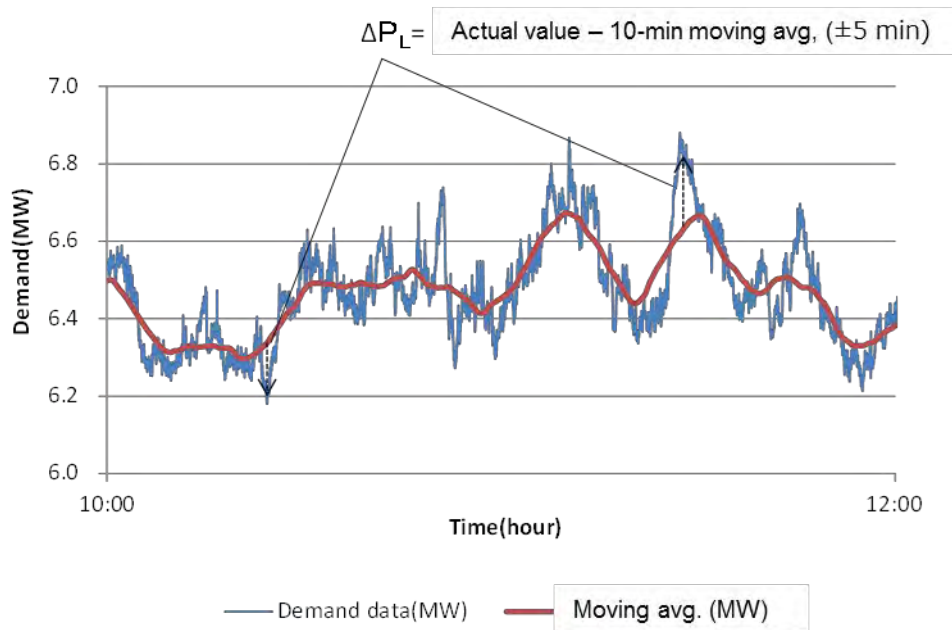


Figure 3.1.3-6 Example of demand fluctuation data processing method

① Mahe

(1) Measurement period: August 10-13, 2015 (Mon-Thur)

(2) Feeders measured: 6 feeders connected to Victoria C

- ① Transformer_TA1
- ② Transformer_TB1
- ③ Victoria_C NO1
- ④ Victoria_C No2
- ⑤ Victoria_B No1
- ⑥ Victoria_B No2

* Since we could not measure the amount supplied from Victoria B, we lack data for the total demand of Mahe. However, on the night of August 10, power was supplied only by Victoria C, so the power supplied during this period can be considered as total demand.

(3) Feeder power measurement results:

Power trends of the continuously measured feeders are shown in Figure 3.1.3-7 - Figure 3.1.3-9. From around 21:30 8/10 - 8:00 8/11 is the period supplied only by Victoria C. The other hours are supplied by Victoria B, so the power supplied during those hours is not total demand. According to the data obtained during this survey, demand for one day peaks in the evening due to lighting, reaches the minimum during the middle of the night, and ranges around 20-40 MW during the daytime.

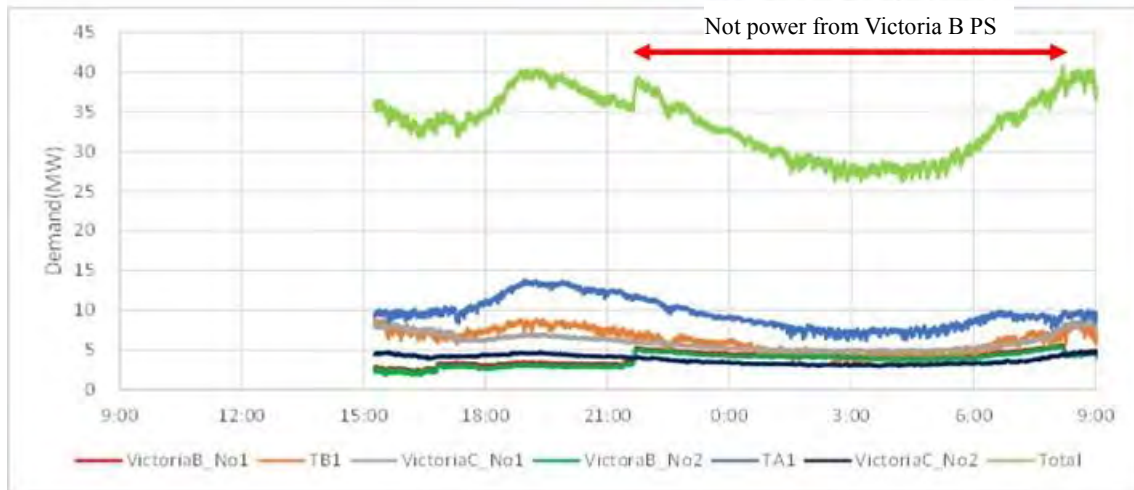


Figure 3.1.3-7 Feeder power (15:00 8/10 - 9:00 8/11)

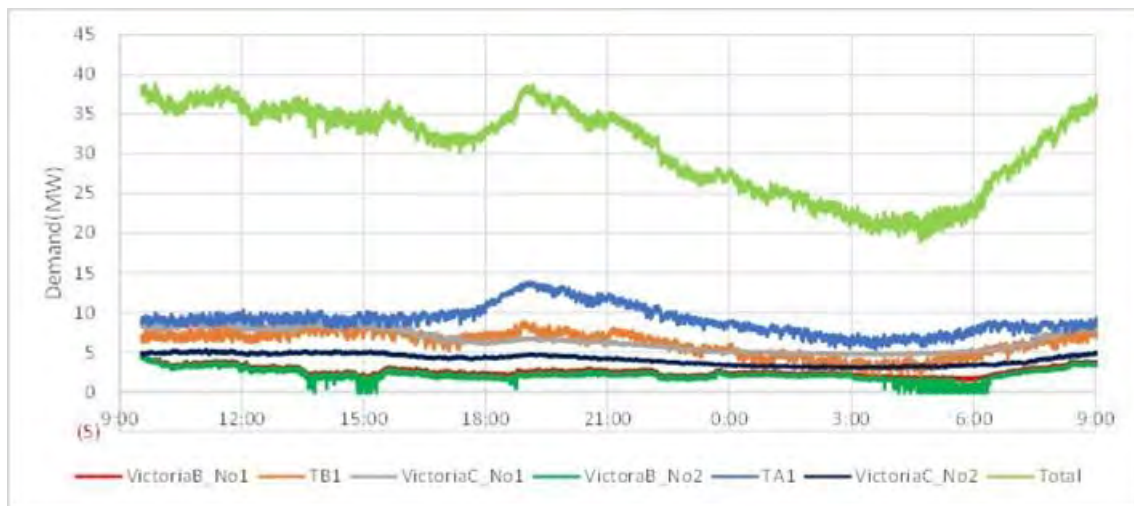


Figure 3.1.3-8 Feeder power (9:00 8/11 - 9:00 8/12)



Figure 3.1.3-9 Feeder power (10:00 8/12 - 9:00 8/13)

(4) Calculating demand fluctuation rate:

Demand fluctuation rate was calculated based on measurement data. The results are shown in Figure 3.1.3-10 - Figure 3.1.3-12 and Table 3.1.3-1 - Table 3.1.3-3. Since we could not measure total demand with feeder measurements as described above, we tentatively calculated the demand fluctuation rate from the power supplied by Victoria C. As a result, σ value was approximately 0.6-0.9%, 2σ value was approximately 1.1-1.8%, and 3σ value was approximately 1.6-2.7%. This fluctuation takes into account fluctuations of existing wind turbines (6 MW), but normally they must be excluded for the calculation. We conducted an analysis considering the fluctuation of wind turbines in the next section as a reference.

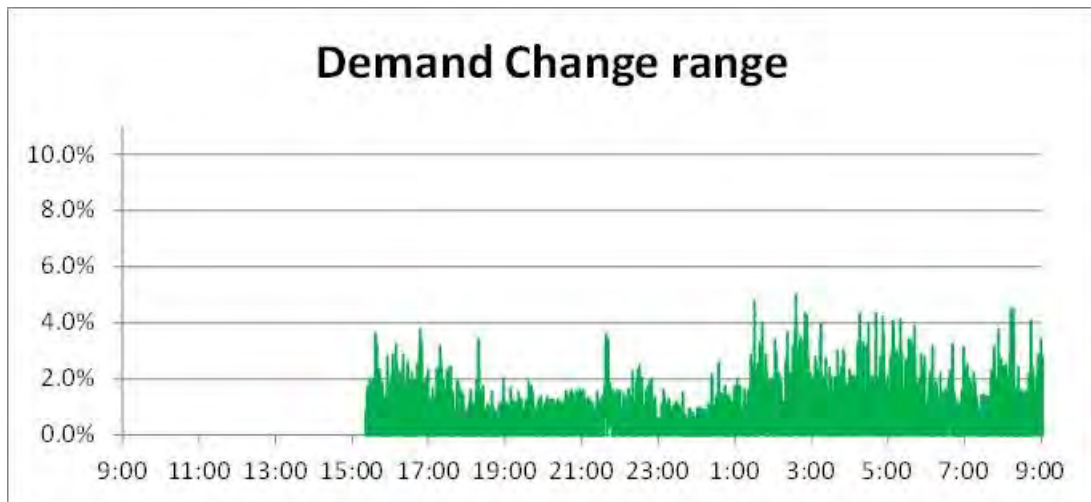


Figure 3.1.3-10 Demand fluctuation rate time trend (August 10, 2015)

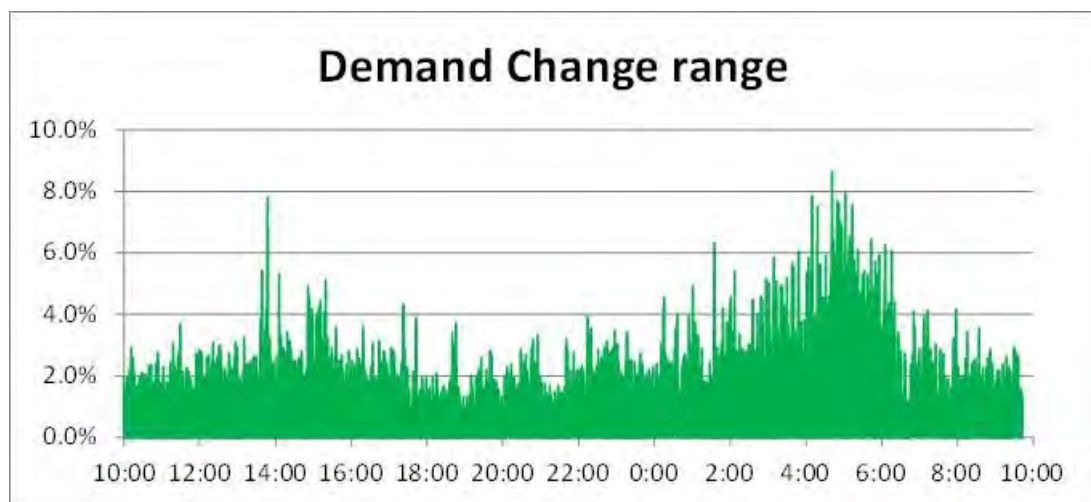


Figure 3.1.3-51 Demand fluctuation rate time trend (August 11, 2015)

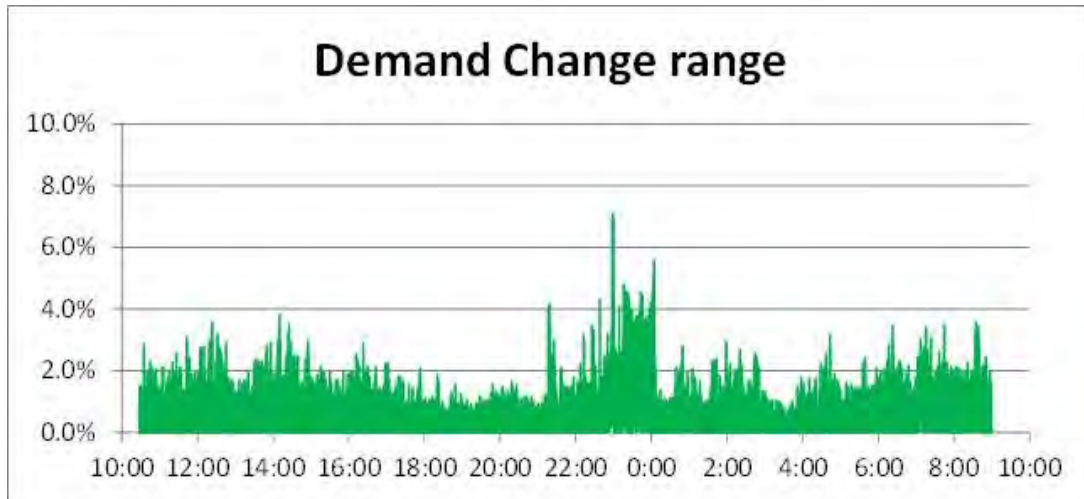


Figure 3.1.3-62 Demand fluctuation rate time trend (August 12, 2015)

Table 3.1.3-1 Probability distribution for fluctuation rate (August 10, 2015)

Probability	Demand change range	
	Daytime	All time
Max(100%)	5.00%	3.73%
3 σ (99.7%)	2.02%	1.56%
2 σ (95.4%)	1.35%	1.24%
σ (68.3%)	0.67%	0.62%

Table 3.1.3-2 Probability distribution for fluctuation rate (August 11, 2015)

Probability	Demand change range	
	Daytime	All time
Max(100%)	8.64%	7.74%
3 σ (99.7%)	2.68%	2.09%
2 σ (95.4%)	1.79%	1.39%
σ (68.3%)	0.89%	0.70%

Table 3.1.3-3 Probability distribution for fluctuation rate (August 12, 2015)

Probability	Demand change range	
	Daytime	All time
Max(100%)	7.07%	3.78%
3 σ (99.7%)	1.75%	1.64%
2 σ (95.4%)	1.17%	1.09%
σ (68.3%)	0.58%	0.55%

[Reference]

Since total demand can be derived from the period when Victoria B is not in operation (22:00 August 10 - 8:00 August 11), pure demand fluctuation was calculated by combining wind turbine data. However, since wind turbine data and our measurement data are out of time sync, we tentatively combined them.

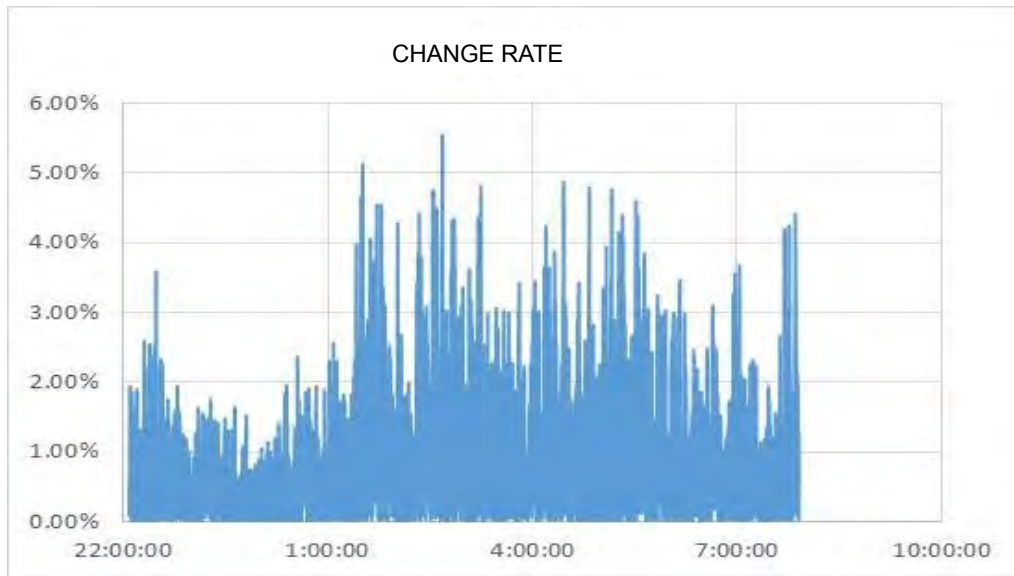


Figure 3.1.3-73 [Reference] Demand fluctuation rate time trend (August 10, 2015)

Table 3.1.3-4 [Reference] Probability distribution for fluctuation rate (August 10, 2015)
considering WT and Victoria B

Probability	Demand change range		
	Total Demand	Daytime	All time
Max(100%)	5.54%	76.74%	4.78%
3 σ (99.7%)	2.58%	29.65%	2.18%
2 σ (95.4%)	1.72%	19.77%	1.45%
σ (68.3%)	0.86%	9.88%	0.73%

(5) Frequency measurement results:

The measurement results and probability distribution are shown in Figure 3.1.3-14 - Figure 3.1.3-16 and Table 3.1.3-16. The 3 σ values are within 0.3 Hz, so it can be said that they are relatively stable. Frequencies change considerably in Figure 3.1.3-16 at 13:50 on August 12, but this was caused by a generator tripping. This measurement was for 1-sec period measurements, so we were not able to conduct a detailed analysis on frequency deviation, etc.

Table 3.1.3-5 Frequency deviation probability distribution (Mahe)

Propability	ΔF (Hz)		
	8/10	8/11	8/12
MAX	0.32	0.42	0.68
3 σ	0.22	0.28	0.17
2 σ	0.16	0.20	0.13
σ	0.09	0.11	0.07

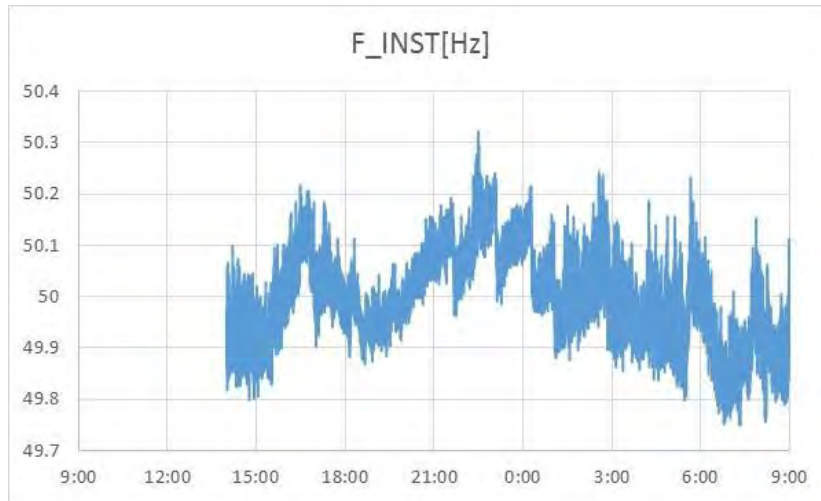


Figure 3.1.3-84 Frequency time trend (August 10, 2015)

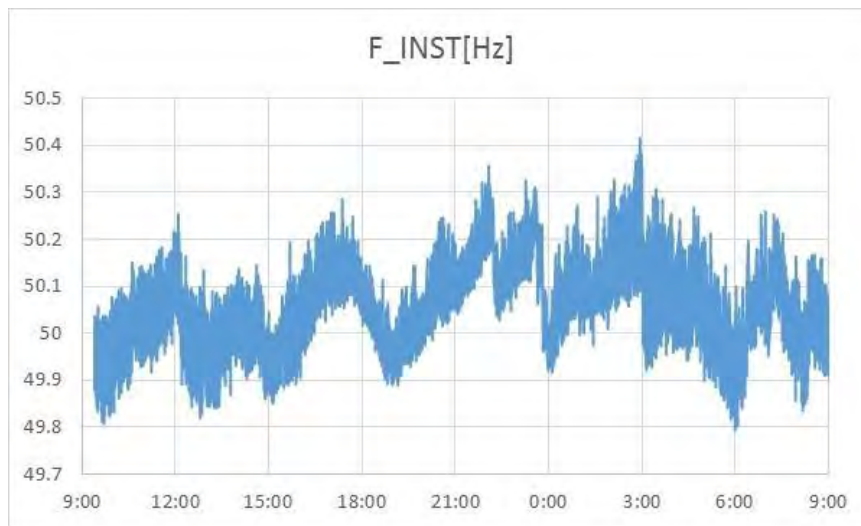


Figure 3.1.3-95 Frequency time trend (August 11, 2015)

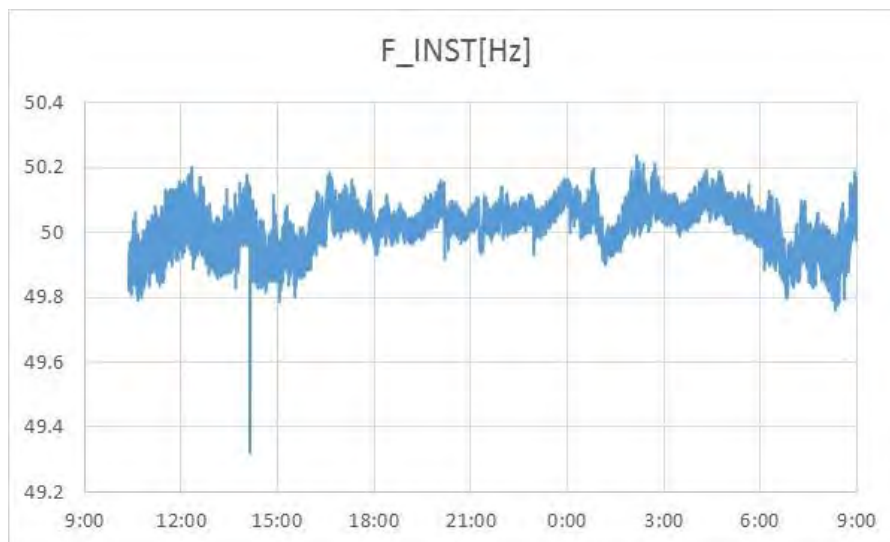


Figure 3.1.3-106 Frequency time trend (August 12, 2015)

②Praslin

Power supplied to 5 feeders by the power plant on Praslin Island was measured in 1-sec intervals. The results are shown below.

(1) Measurement period: August 5-7, 2015 (Wed-Fri)

12/12/2015 (Sat) - 12/14/2015 (Mon)

2) Feeders measured:

- ① Baite Ste Anne feeder
- ② Cote Dor feeder
- ③ Valle de Mai feeder
- ④ La Digue No1 feeder
- ⑤ La Digue No2 feeder (including sea water desalination plant)

(3) Feeder power measurement results:

Power trends of the feeders continuously measured during the periods mentioned above are shown in Figure 3.1.3-17 - Figure 3.1.3-20. Figure 3.1.3-11 shows power peaks in the evening 18:00-20:00, and total demand is approximately 4-6 MW. Out of the 5 feeders, the Cote Dor feeder has the largest demand with a demand of 1.3-2 MW.

In Figure 17 and Figure 18, it appears the demand in the middle of the night dropped, but this is because the Cote Dor feeder power data is missing (Cote Dor feeder was disconnected due to generator trip. The feeder was later restored, but the power plant personnel decided to remove the power measuring instrument during the night.).

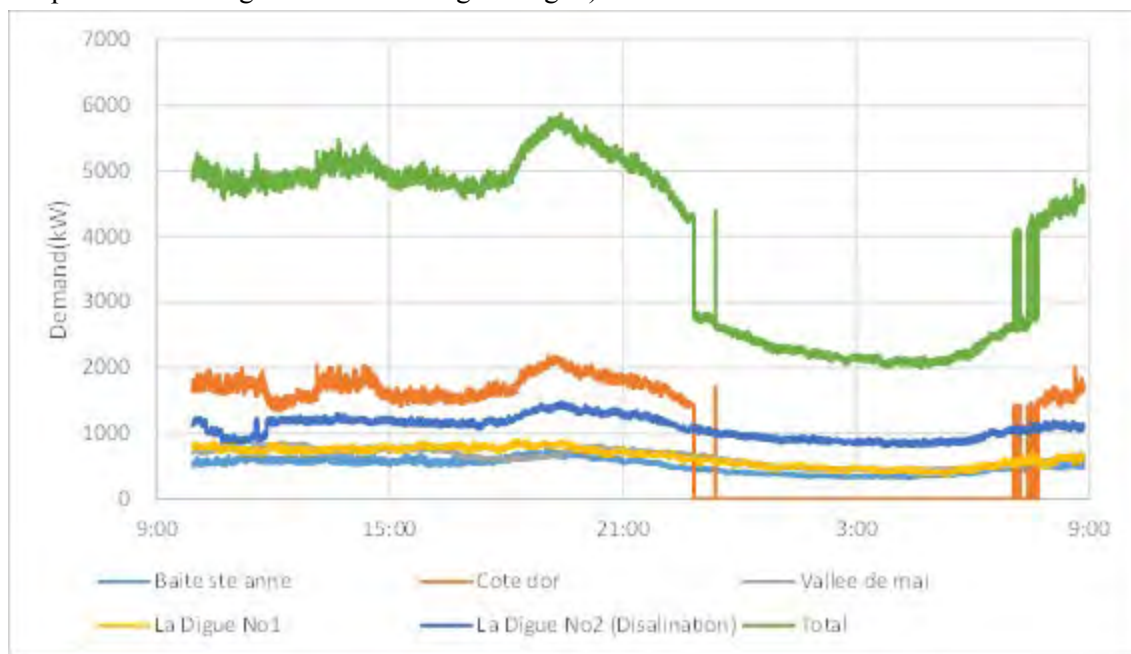


Figure 3.1.3-117 Feeder power (9:00 8/5 - 9:00 8/6)

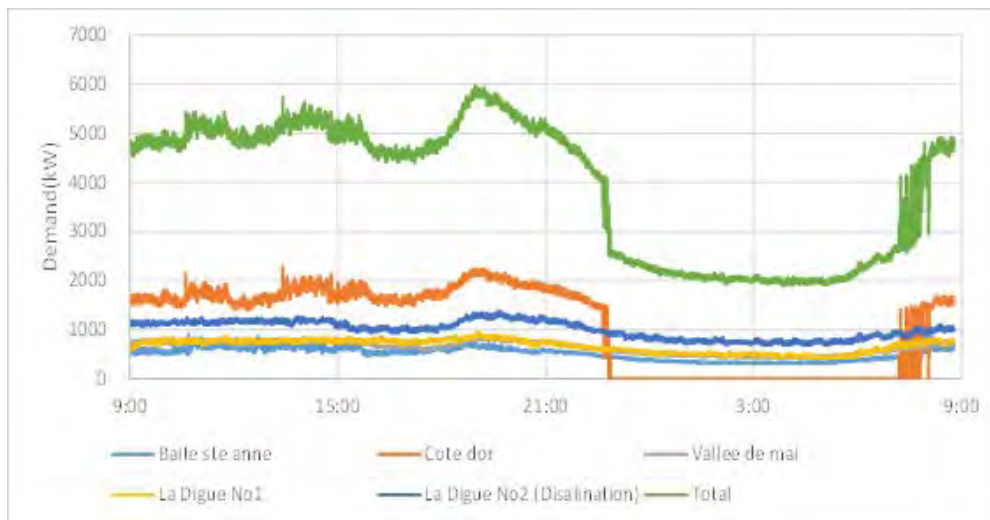


Figure 3.1.3-128 Feeder power (9:00 8/6 - 9:00 8/7)

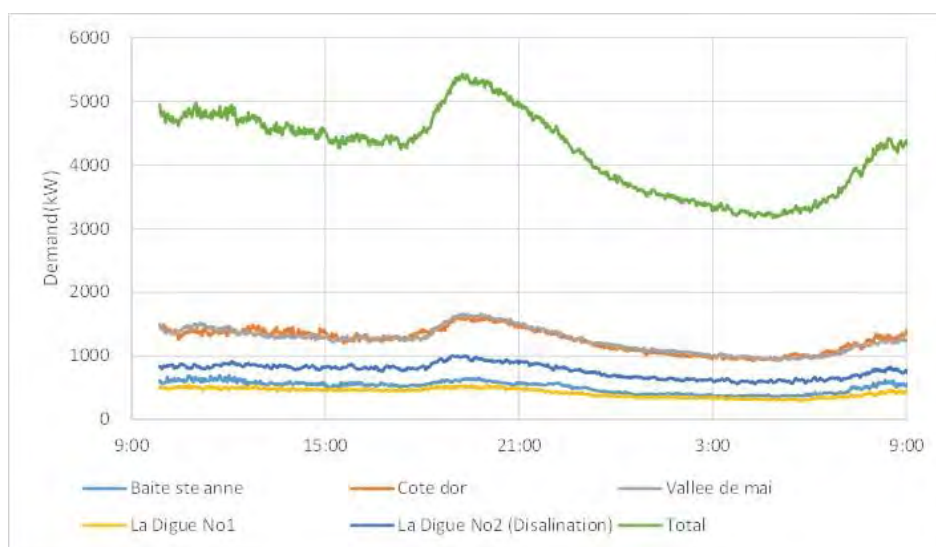


Figure 3.1.3-19 Feeder power (9:00 12/12 - 9:00 12/13)

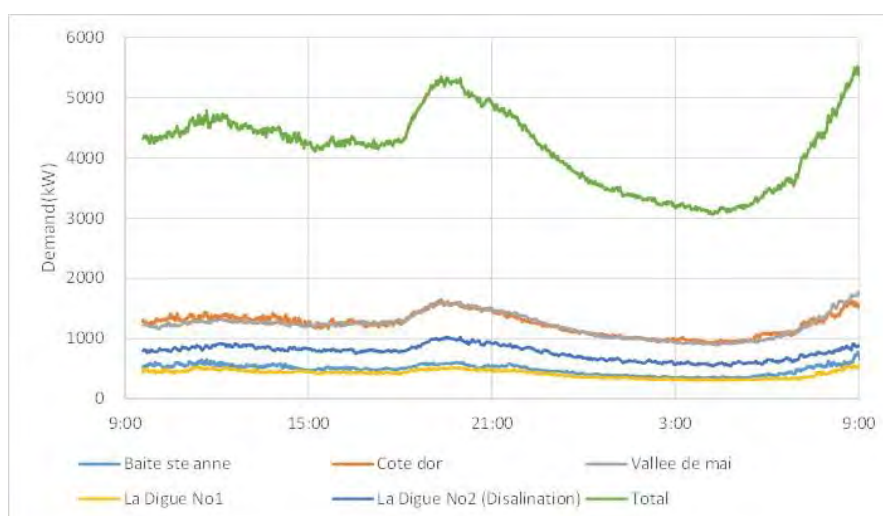


Figure 3.1.3-20 Feeder power (9:00 12/13 - 9:00 12/14)

(4) Calculating demand fluctuation rate:

Demand fluctuation rate was calculated based on measurement data. The results are shown in Figure 3.1.3-21 - Figure 3.1.3-24 and Table 3.1.3-6 - Table 3.1.3-9. You can see from the data for 4 days that a load fluctuation of up to 10% occurs. This deviation occurs because when demand for the Cote Dor feeder fluctuates approximately 200 kW, it is placed on top of the other fluctuations. However, according to the probability distribution, this rarely occurs.

Looking at the daytime only and whole day fluctuation rates, with a σ value of approximately 0.5-0.8%, 2σ value of 1.0-1.7%, and 3σ value of 1.6-2.5%, the differences were not large. In addition, we learned that since there are no facilities with a large load, the load fluctuation trend is similar to the remote islands of Okinawa.

In the future, we will use these results to evaluate the impact of demand fluctuations on the grid.

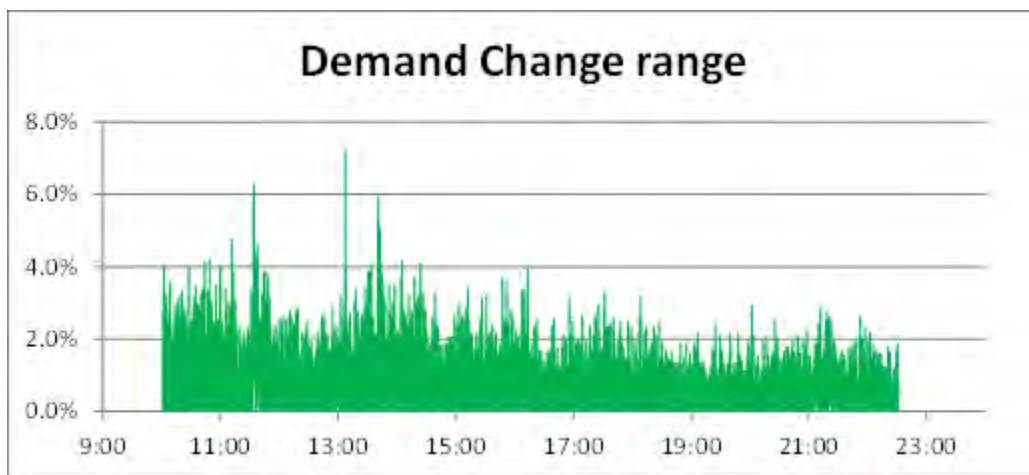


Figure 3.1.3-131 Demand fluctuation rate time trend (August 5, 2015)

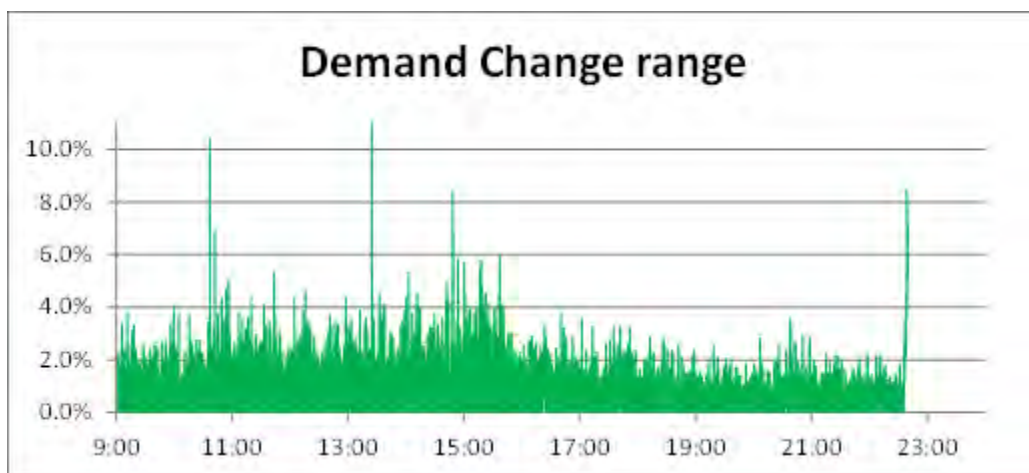


Figure 3.1.3-142 Demand fluctuation rate time trend (August 6, 2015)

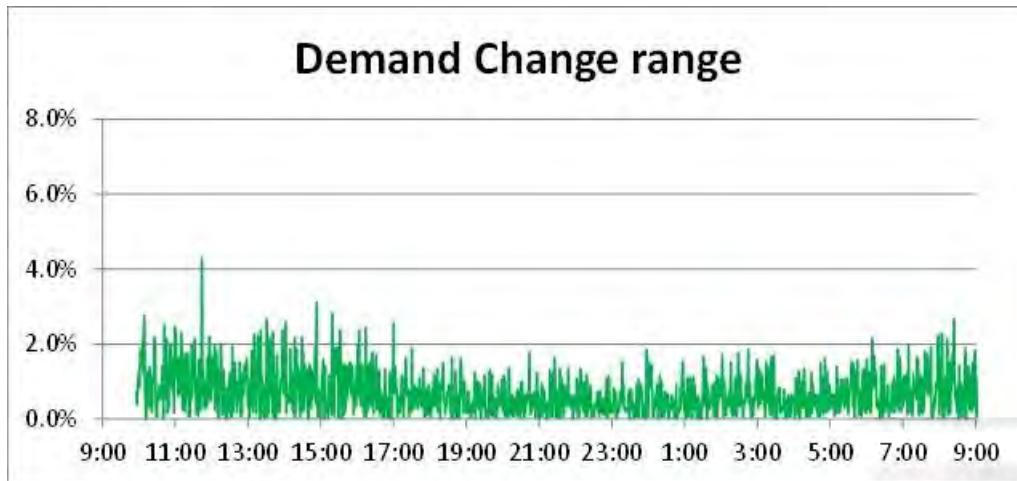


Figure 3.1.3-153 Demand fluctuation rate time trend (December 12, 2015)

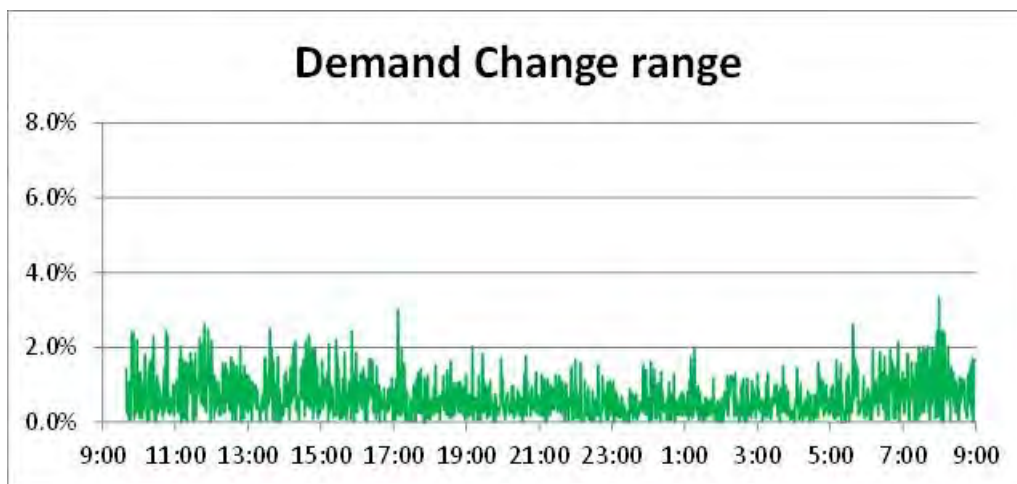


Figure 3.1.3-164 Demand fluctuation rate time trend (December 13, 2015)

Table 3.1.3-6 Probability distribution for fluctuation rate (August 5, 2015)

Probability	Demand change range	
	Daytime	All time
Max(100%)	7.08%	7.08%
3 σ (99.7%)	2.01%	2.29%
2 σ (95.4%)	1.34%	1.53%
σ (68.3%)	0.67%	0.76%

Table 3.1.3-7 Probability distribution for fluctuation rate (August 6, 2015)

Probability	Demand change range	
	Daytime	All time
Max(100%)	10.87%	10.87%
3 σ (99.7%)	2.34%	2.55%
2 σ (95.4%)	1.56%	1.70%
σ (68.3%)	0.78%	0.85%

Table 3.1.3-8 Probability distribution for fluctuation rate (December 12, 2015)

Probability	Demand change range	
	Daytime	All time
Max(100%)	4.28%	4.28%
3 σ (99.7%)	1.66%	2.03%
2 σ (95.4%)	1.11%	1.35%
σ (68.3%)	0.55%	0.68%

Table 3.1.3-9 Probability distribution for fluctuation rate (December 13, 2015)

Probability	Demand change range	
	Daytime	All time
Max(100%)	3.34%	2.62%
3 σ (99.7%)	1.59%	1.74%
2 σ (95.4%)	1.06%	1.16%
σ (68.3%)	0.53%	0.58%

(5) Frequency measurement results:

The measurement results and probability distribution are shown in Figure 3.1.3-25 - Figure 3.1.3-28 and Table 3.1.3-10. Around 23:00 on August 5, frequency fluctuates significantly. This significant drop in frequency is due an operator error which caused a generator to trip. For normal times without faults, the usual fluctuations are as shown on 8/6, 12/12, and 12/13, so the grid is operated in the range of 49.7-50.6 Hz. The generator operation rooms are distributed and awareness of frequency maintenance is low, so there is room for improvement in the future.

Table 3.1.3-10 Frequency deviation probability distribution (Praslin)

Propability	ΔF (Hz)			
	8/5	8/6	12/12	12/13
MAX	4.65	0.55	0.63	0.41
3 σ	0.71	0.43	0.37	0.34
2 σ	0.36	0.37	0.26	0.25
σ	0.28	0.28	0.19	0.19

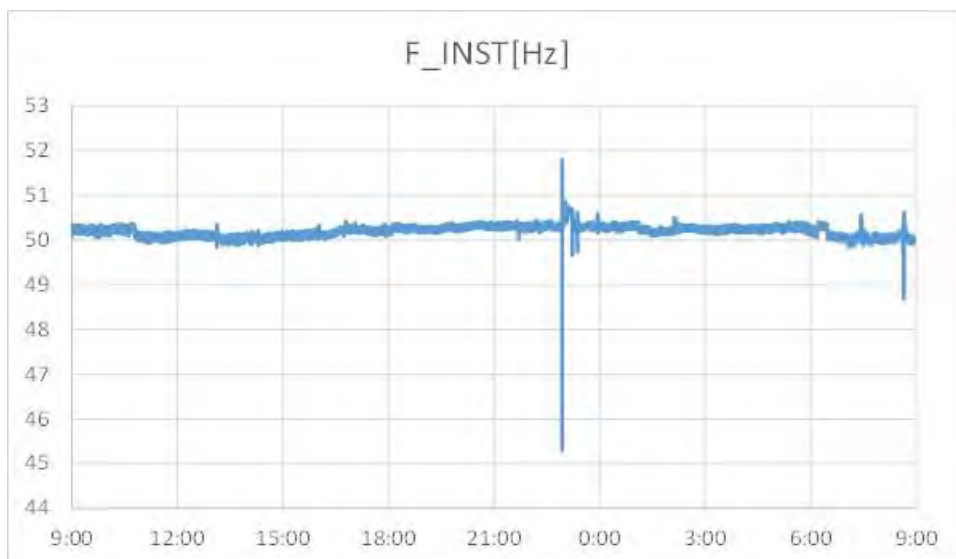


Figure 3.1.3-175 Frequency time trend (August 5, 2015)

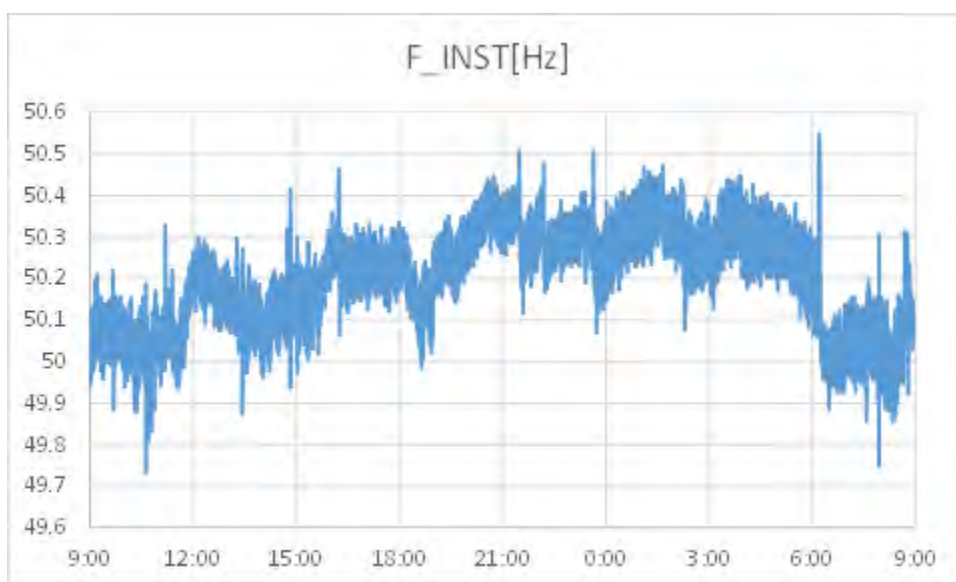


Figure 3.1.3-186 Frequency time trend (August 6, 2015)

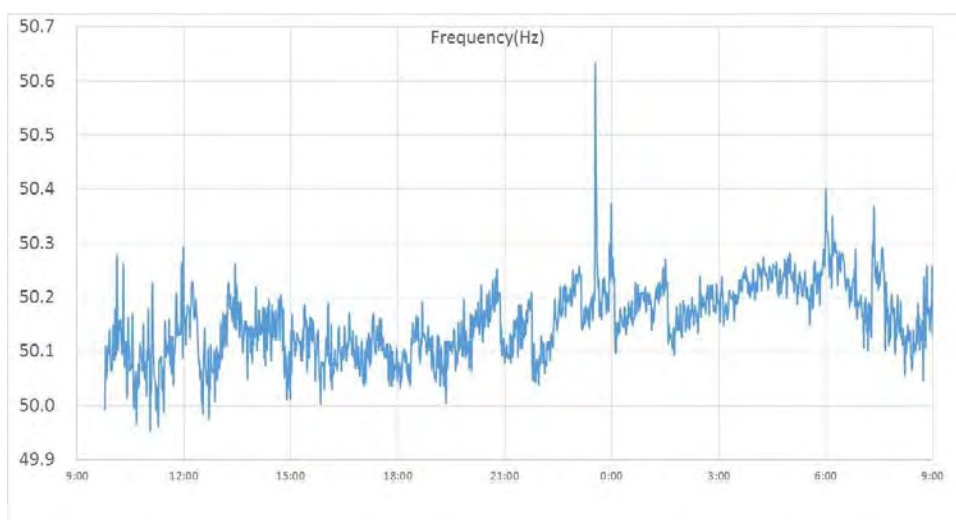


Figure 3.1.3-197 Frequency time trend (December 12, 2015)

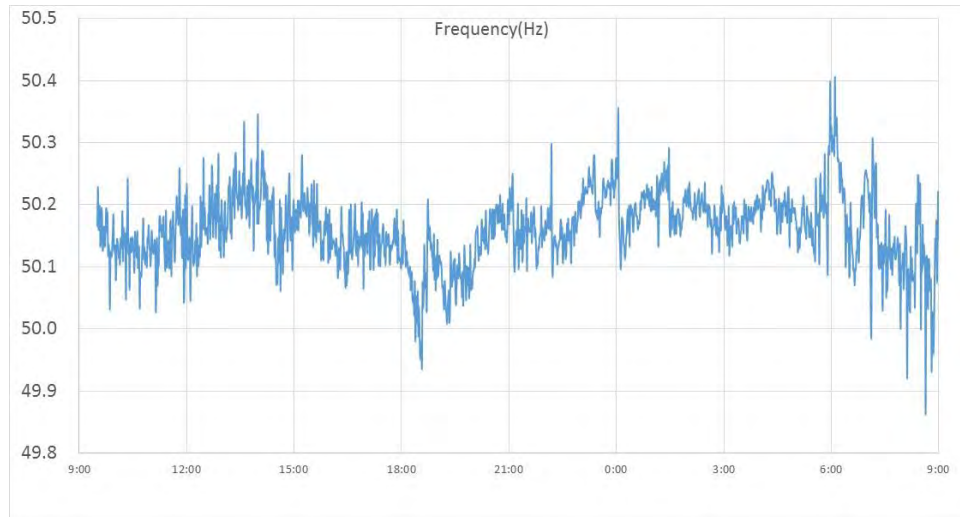


Figure 3.1.3-208 Frequency time trend (December 13, 2015)

3.1.3.3 Demand analysis (determining the expected load)

Analyze the demand distribution from the annual demand data to calculate cumulative distribution (3σ , 2σ , σ). Each power plant on each island keeps a daily operation report with demand data for every hour. The expected demand is determined from this data.

Cumulative distribution was estimated from a section with high demand. Allowable adjustment 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

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

(1) When demand is 1MW... allowable adjustable margin: 0.1MW (= 1 MW $\times$ 10% MW/Hz $\times$ 1 Hz)

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

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 demand distribution when demand data for daytime hours (9:00 to 15:00) and demand data for a whole day (24 hours) is extracted from the annual demand data.

① Mahe

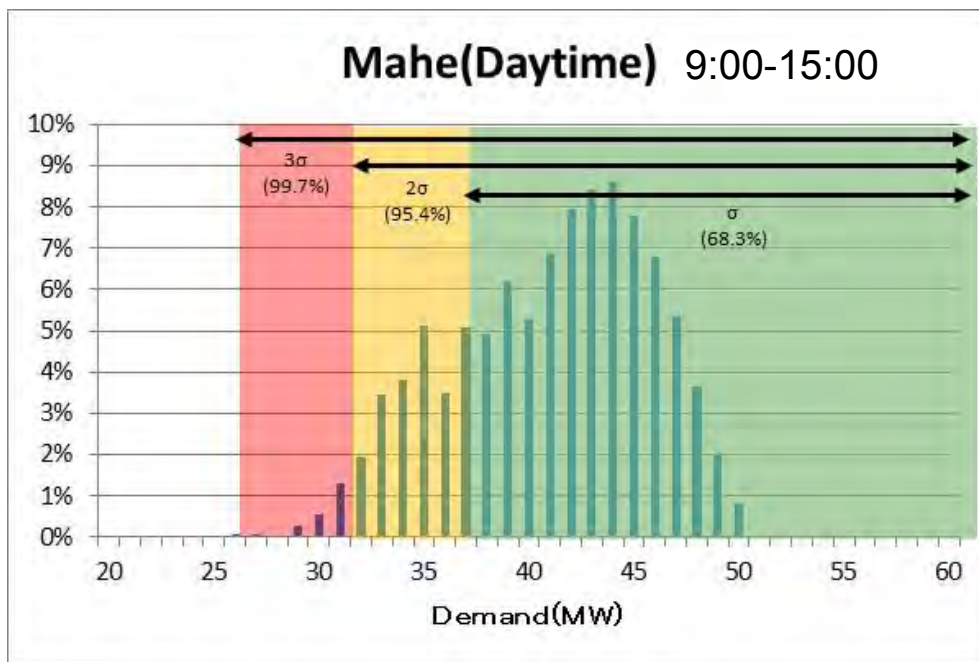


Figure 3.1.3-219 Daytime demand distribution (Mahe)

Table 3.1.3-11 Daytime demand considering probability distribution (Mahe)

Min (100%)	20.2MW
3σ (99.7%)	28.1MW
2σ (95.4%)	32.1MW
σ (68.3%)	38.3MW
Average	40.5MW

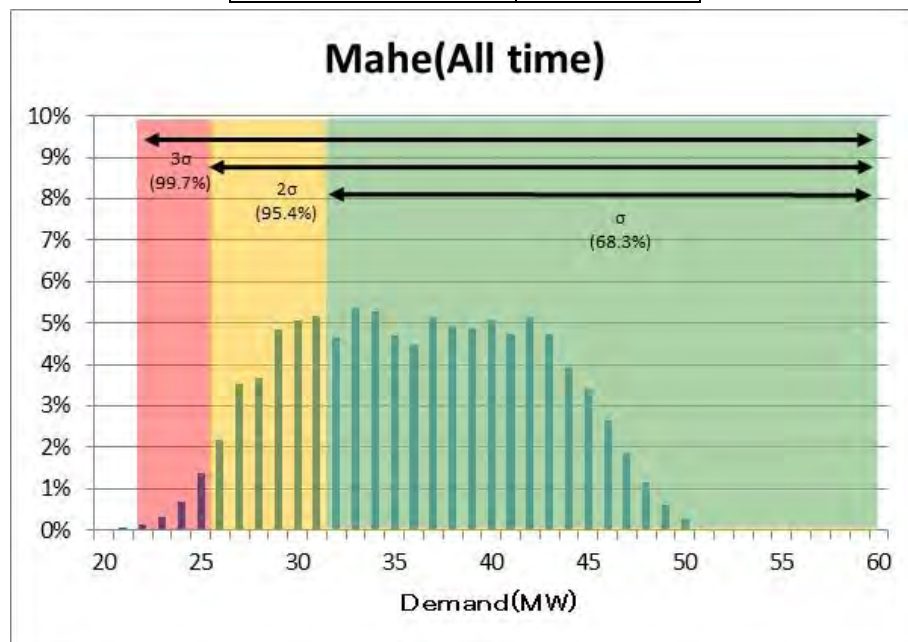


Figure 3.1.3-30 24-hour demand distribution (Mahe)

Table 3.1.3-12 24-hour demand considering probability distribution (Mahe)

Min (100%)	20.2MW
3σ (99.7%)	22.3MW
2σ (95.4%)	26.0MW
σ (68.3%)	32.1MW
Average	35.8MW

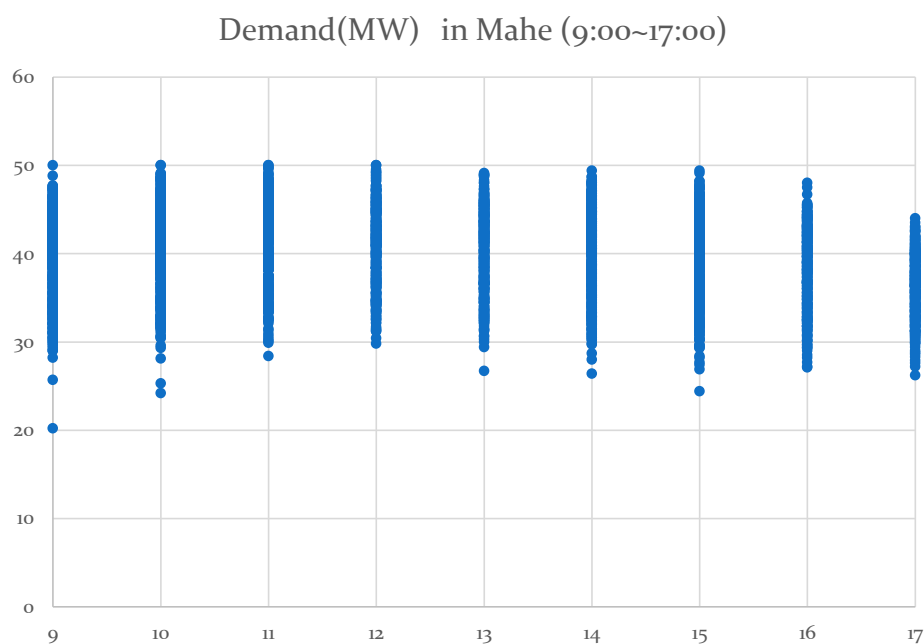


Figure 3.1.3-31 Hourly demand in Mahe

② Praslin

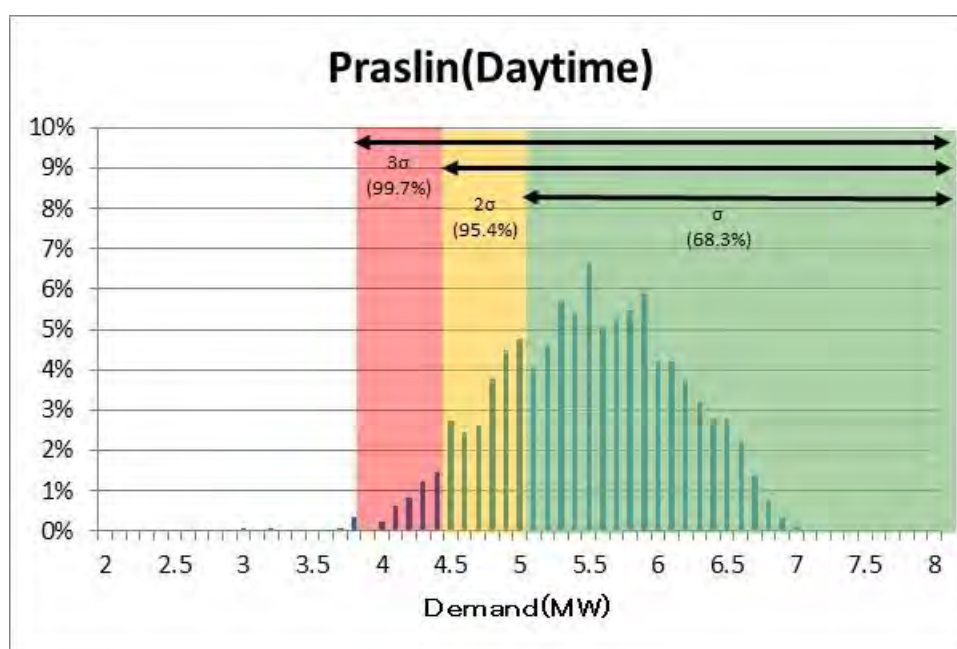


Figure 3.1.3-32 Daytime demand distribution (Praslin)

Table 3.1.3-13 Daytime demand considering probability distribution (Praslin)

Min (100%)	2.28MW
3σ (99.7%)	3.68MW
2σ (95.4%)	4.40MW
σ (68.3%)	5.15MW
Average	5.50MW

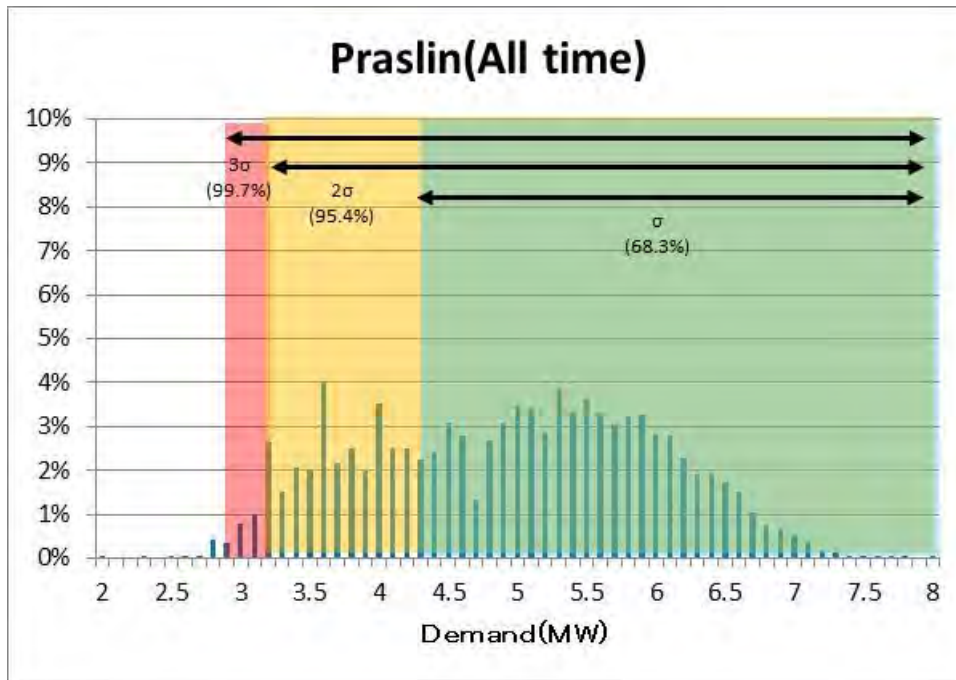


Figure 3.1.3-33 24-hour demand distribution (Praslin)

Table 3.1.3-14 24-hour demand considering probability distribution (Praslin)

Min (100%)	2.00MW
3σ (99.7%)	2.80MW
2σ (95.4%)	3.20MW
σ (68.3%)	4.30MW
Average	4.91MW

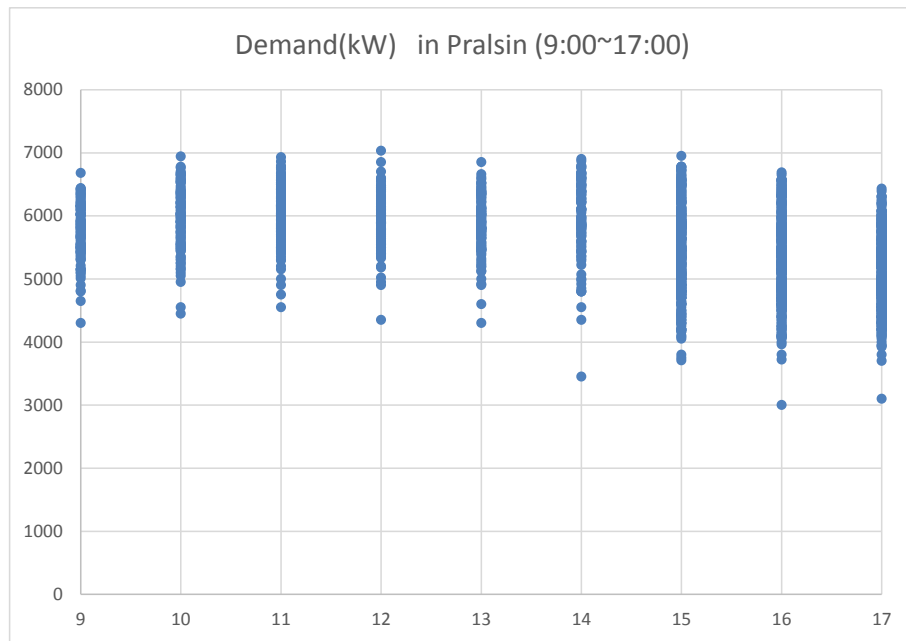


Figure 3.1.3-34 Hourly demand in Praslin

3.1.3.4 Fluctuation rate of solar radiation intensity and wind conditions

There are $750 \text{ kW} \times 8$ units (total capacity of 6 MW) of wind turbines deployed on Mahe Island, this data (2-sec period) was used to analyze the short-period fluctuation characteristics. For the analysis, the evaluation time window was set at 10 minutes, and the fluctuation rate was calculated considering probability distribution from the maximum and minimum values in this time. Figure 3.1.3-35 shows the definition of evaluation time window and output fluctuation range. Since fluctuations in renewable energy are irregular, stability is evaluated by defining fluctuation range as the difference between the maximum and minimum in the evaluation time and considering the sharp fluctuations.

Probability distribution, as with demand fluctuation rate, is derived by calculating the fluctuation of PV and wind power at maximum, 3σ (99.7%), 2σ (95.4%), σ (68.3%) (output fluctuation range in terms of renewable energy rated output).

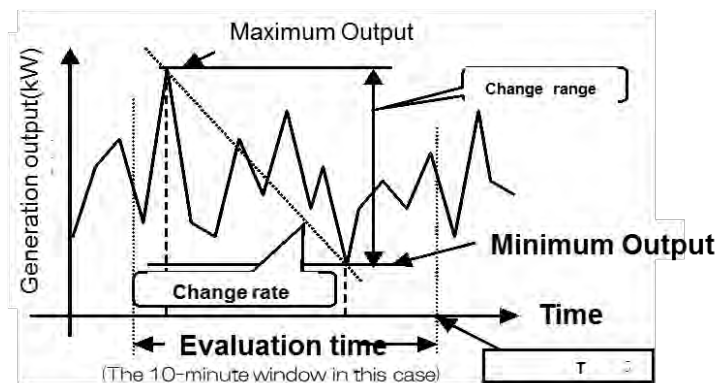


Figure 3.1.3-225 Definition of evaluation time window and output fluctuation range

① Solar radiation intensity fluctuation

In order to determine at what time period PV output fluctuations becomes large, (5-min resolution) data from 8/2014 to 8/2015 obtained from PUC was analyzed. The results are shown in Figure 3.1.3-36. Solar radiation intensity is strong from 9:00 to 15:00, and since PV output fluctuation during this period can be expected to be large, the evaluation time was set at 9:00 to 15:00.

Next, in order to clarify short-period fluctuation characteristics of PV, solar irradiance was measured at 2-sec resolution during the field survey. The results are shown in Figure 3.1.3-37 and Table 3.1.3-15. It was revealed that on days when the passing of clouds is fast, the fluctuation rate reach 100% even at 2σ . The approximate RE interconnection capacities were calculated using data of the days the load rejection tests were conducted in Mahe Island and Praslin Island (Mahe: March 17, Praslin: March 23). In addition, for probability, since there was an insufficient amount of data, the data was not used, but instead, analysis will be conducted assuming a PV fluctuation rate of 80% based on the content of the report prepared by Energynautics.

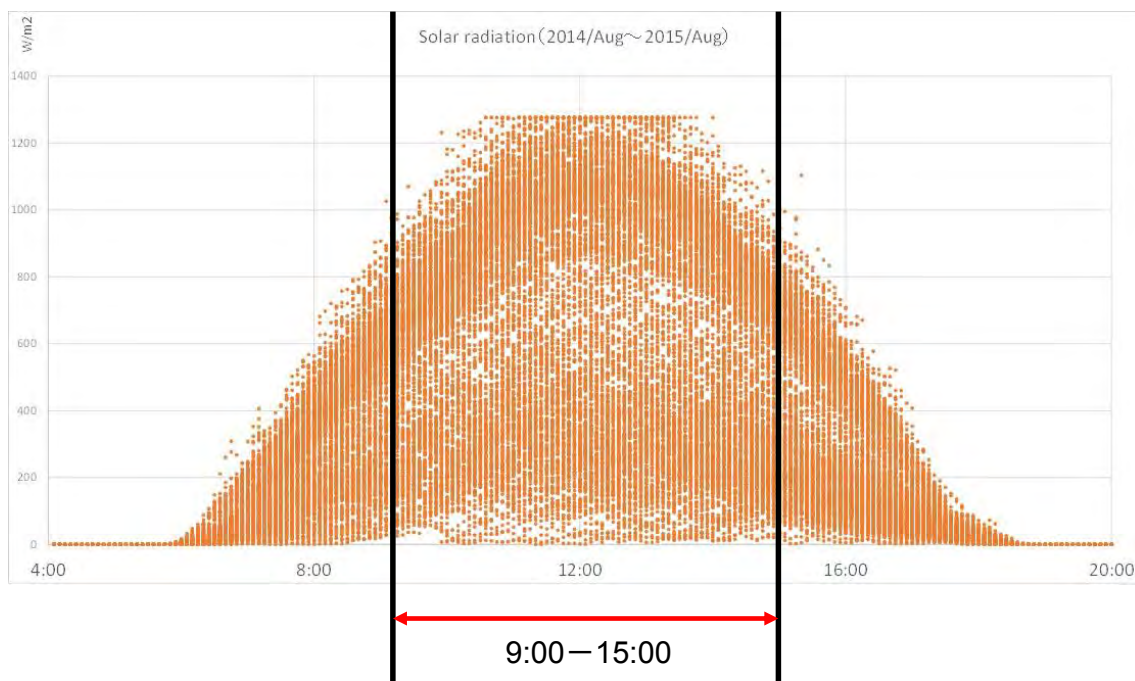


Figure 3.1.3-36 Solar radiation intensity in Mahe (8/2014 - 8/2015)

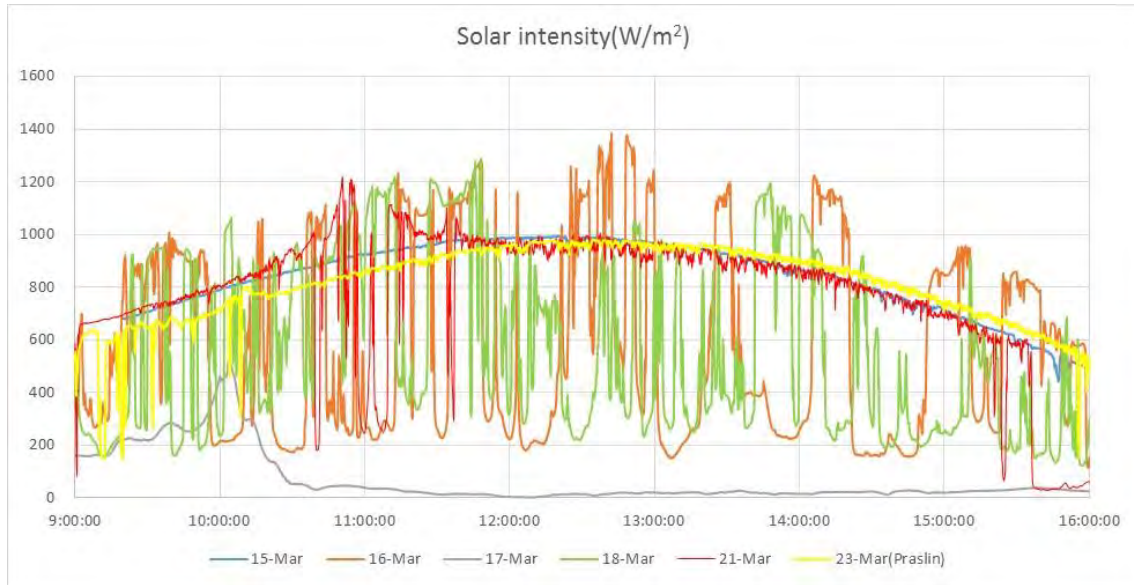


Figure 3.1.3-37 Solar radiation intensity in Mahe and Praslin measured at 2-sec resolution

Table 3.1.3-15 PV fluctuation rate calculated from solar radiation intensity

	Mahe					Praslin
	15-Mar	16-Mar	17-Mar	18-Mar	21-Mar	23-Mar
Max	13.1%	109.1%	22.8%	98.1%	103.2%	51.7%
3 σ (99.7%)	13.0%	109.1%	22.7%	98.1%	97.8%	51.7%
2 σ (95.4%)	6.5%	100.7%	16.8%	89.1%	86.5%	48.8%
σ (68%)	3.7%	85.5%	1.1%	70.9%	9.8%	5.1%

② Wind speed fluctuation rate

The analysis results for the 3 days (August 10-12) we were able to collect data are shown in Figure 38 - Figure 43 and Table 3.1.3-16 - Table 3.1.3-19. Data for WTG4 on August 11 from 14:00 and after is missing, and we could not collect data on August 12 from 12:00 to 24:00, we conducted the analysis using sound data other than the above.

When looking at the fluctuation rate of a single wind turbine, there is a 3 σ fluctuation rate of about 90%, but when combining the eight wind turbines, the 3 σ fluctuation rate is about 50% due to the smoothing effect. It is clear that fluctuations are mitigated by installing several units in a distributed manner.

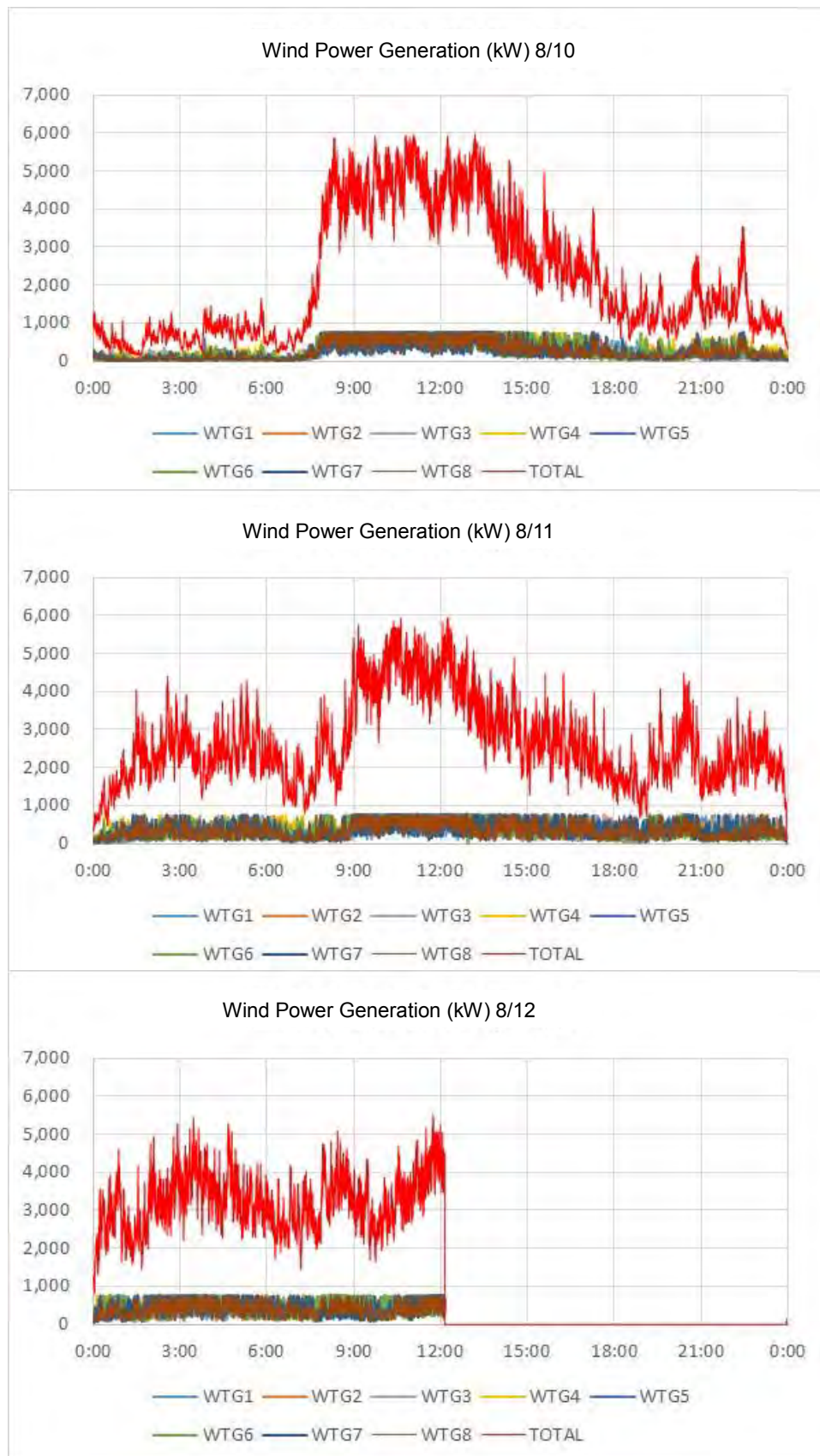


Figure 3.1.3-38 Wind power output (Mahe)

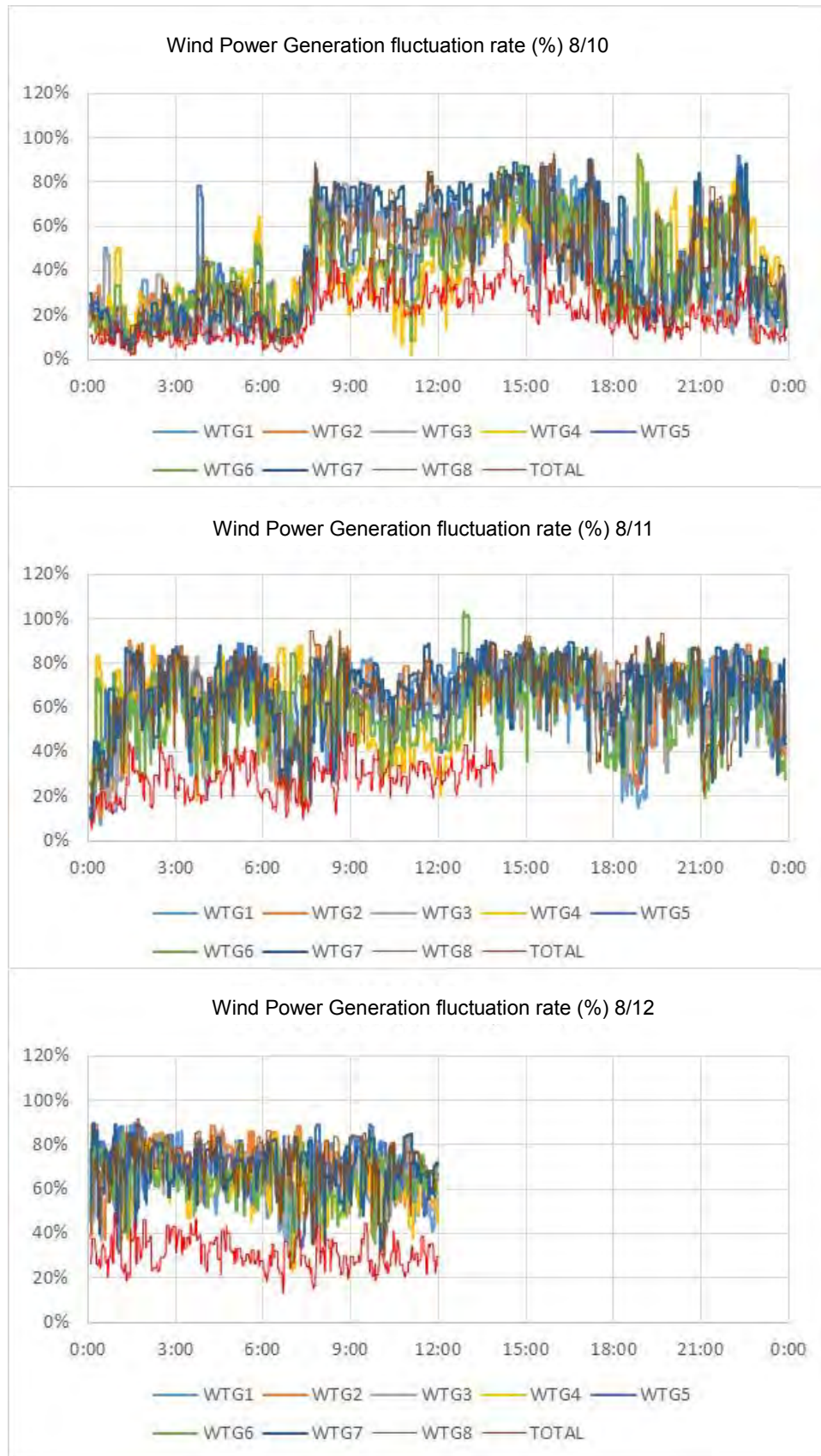


Figure 3.1.3-39 Wind power output fluctuation rate (Mahe)

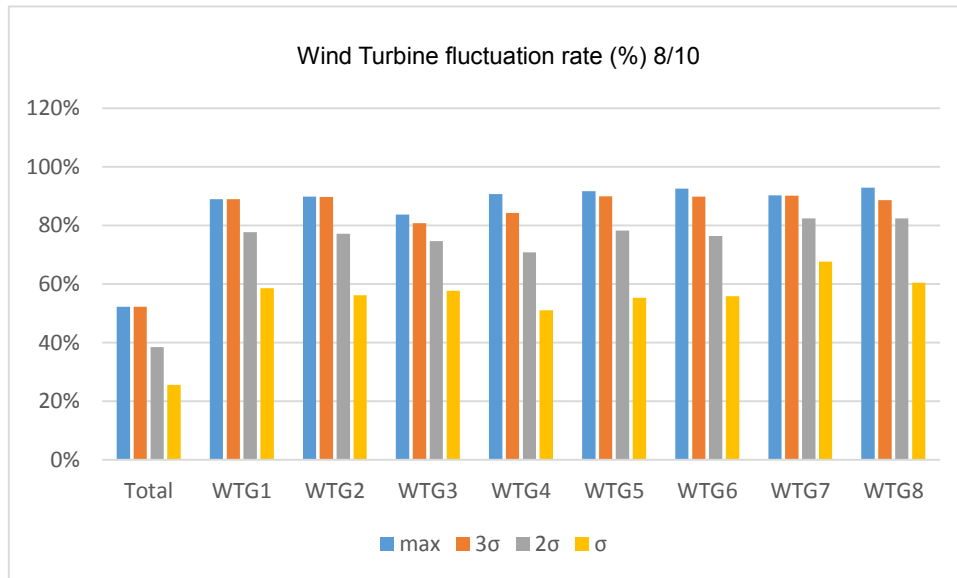


Figure 3.1.3-40 Wind turbine fluctuation rates (8/10/2015 data)

Table 3.1.3-16 Wind turbine fluctuation rates (8/10/2015 data)

	Total	WTG1	WTG2	WTG3	WTG4	WTG5	WTG6	WTG7	WTG8	Smoothing effect
max	52.2%	88.9%	89.9%	83.7%	90.7%	91.7%	92.5%	90.3%	92.9%	58.0%
3σ	52.2%	88.9%	89.7%	80.8%	84.3%	90.0%	89.9%	90.1%	88.7%	59.5%
2σ	38.4%	77.7%	77.2%	74.7%	70.8%	78.3%	76.4%	82.4%	82.4%	49.6%
σ	25.6%	58.5%	56.1%	57.7%	51.1%	55.3%	55.9%	67.6%	60.4%	44.2%

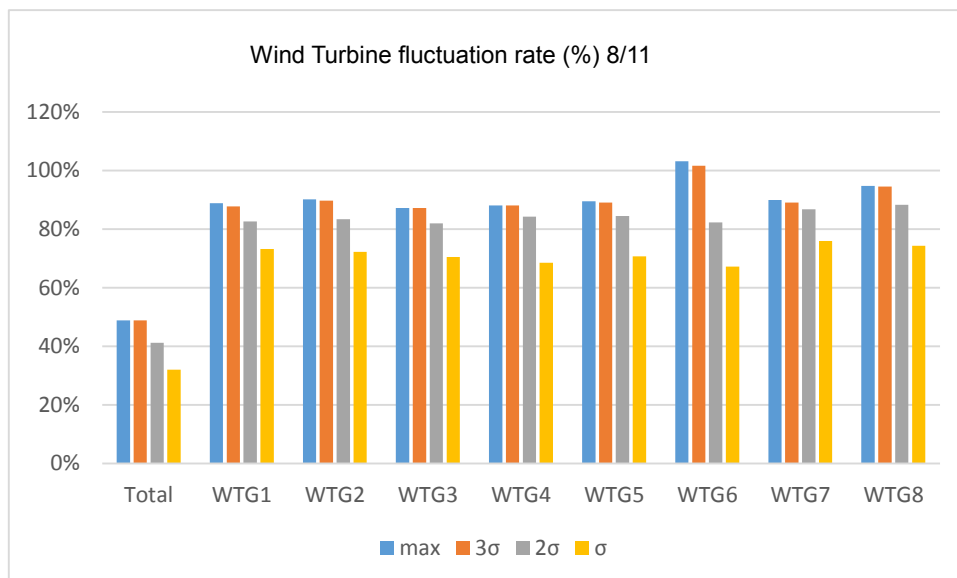


Figure 3.1.3-41 Wind turbine fluctuation rates (August 11, 2015 data)

Table 3.1.3-17 Wind turbine fluctuation rates (August 11, 2015 data)

	Total	WTG1	WTG2	WTG3	WTG4	WTG5	WTG6	WTG7	WTG8	Smoothing effect
max	48.8%	88.8%	90.1%	87.2%	88.1%	89.5%	103.2%	90.0%	94.8%	53.4%
3σ	48.8%	87.7%	89.7%	87.2%	88.1%	89.1%	101.6%	89.1%	94.5%	53.7%
2σ	41.2%	82.7%	83.3%	82.0%	84.3%	84.5%	82.3%	86.8%	88.3%	48.9%
σ	32.0%	73.2%	72.3%	70.5%	68.5%	70.7%	67.2%	76.0%	74.3%	44.7%

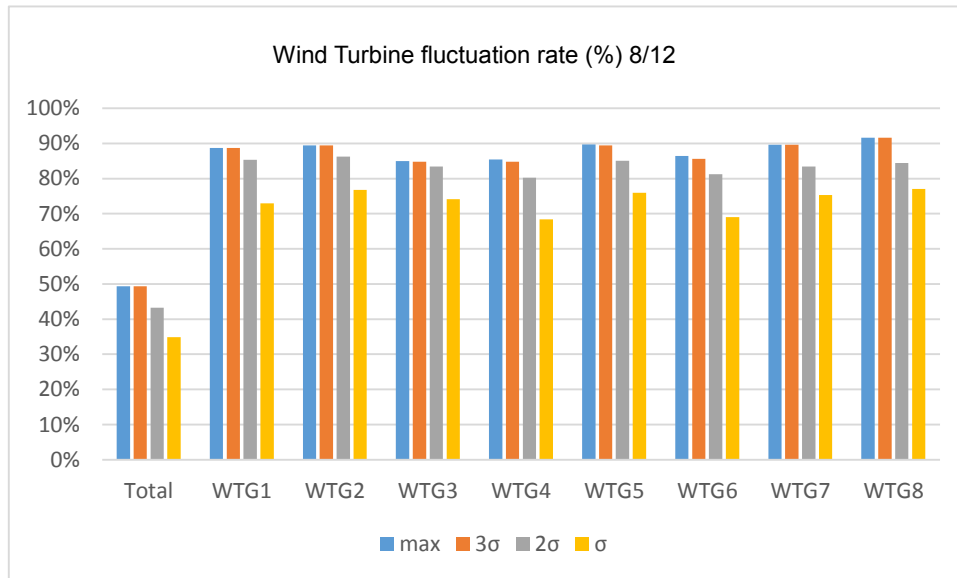


Figure 3.1.3-42 Wind turbine fluctuation rates (August 12, 2015 data)

Table 3.1.3-18 Wind turbine fluctuation rates (August 12, 2015 data)

	Total	WTG1	WTG2	WTG3	WTG4	WTG5	WTG6	WTG7	WTG8	Smoothing effect
max	49.3%	88.7%	89.5%	84.9%	85.5%	89.7%	86.4%	89.6%	91.6%	55.9%
3σ	49.3%	88.7%	89.5%	84.8%	84.8%	89.5%	85.6%	89.6%	91.6%	56.0%
2σ	43.3%	85.3%	86.3%	83.5%	80.3%	85.1%	81.2%	83.5%	84.4%	51.7%
σ	34.9%	72.9%	76.8%	74.1%	68.4%	76.0%	69.1%	75.3%	77.1%	47.3%

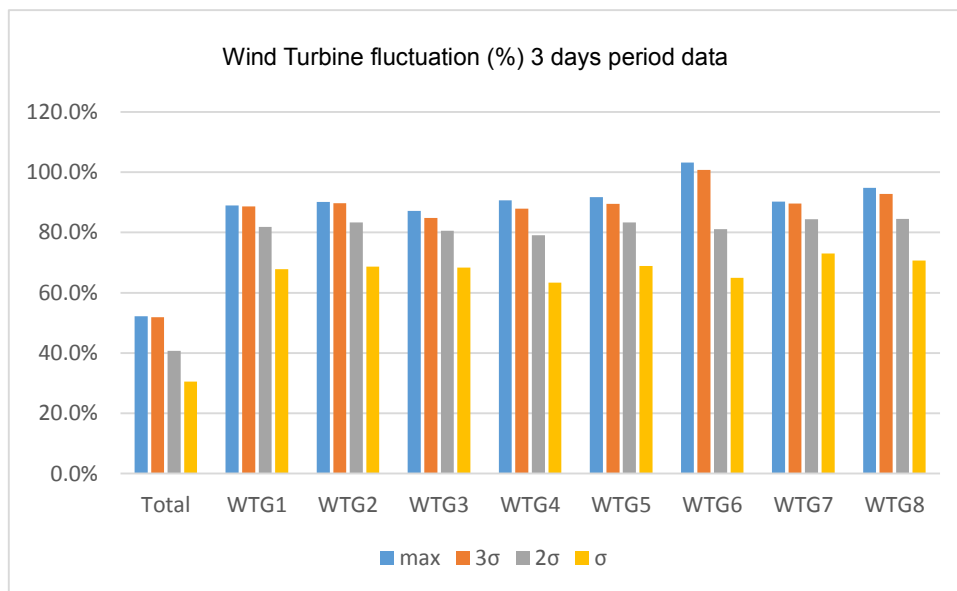


Figure 3.1.3-43 Wind turbine fluctuation rates (8/10-12/2015 data)

Table3.1.3-19 Wind turbine fluctuation rates (8/10-12/2015 data)

	Total	WTG1	WTG2	WTG3	WTG4	WTG5	WTG6	WTG7	WTG8	Smoothing effect
max	52.2%	88.9%	90.1%	87.2%	90.7%	91.7%	103.2%	90.3%	94.8%	56.7%
3σ	51.8%	88.7%	89.7%	84.8%	87.9%	89.5%	100.8%	89.6%	92.8%	57.3%
2σ	40.7%	81.9%	83.3%	80.5%	79.1%	83.3%	81.1%	84.4%	84.5%	49.5%
σ	30.6%	67.9%	68.7%	68.4%	63.3%	68.9%	64.9%	73.1%	70.7%	44.8%

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

RE interconnection capacity is calculated using the specifications mentioned above. The allowable frequency fluctuation range was set to 0.75 Hz (to avoid unnecessary operation of the under frequency relay at 49 Hz) and the stochastic element was set to 2σ (95%). Since the amount of RE to integrate will change according to demand load, interconnection capacity was calculated in accordance with the expected demand. The data shown in the following figure are the results of a calculation using the most severe conditions. In addition, for reference, the measurement values of the load rejection test (Mahe: demand 50 MW, PV fluctuation rate 100%, Praslin: demand 6.5 MW, PV fluctuation rate 50%) were used to calculate RE interconnection capacity.

① Mahe

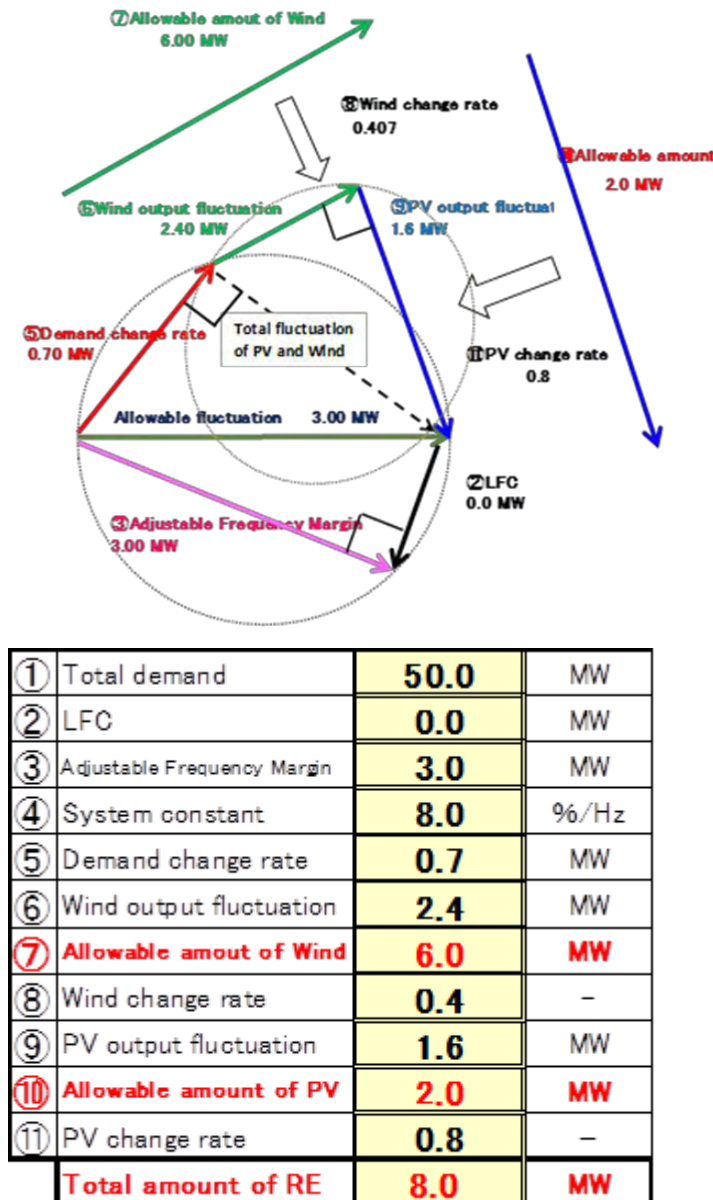


Table 3.1.3-20 Calculation results for short-period RE-interconnection capacity (Mahe)

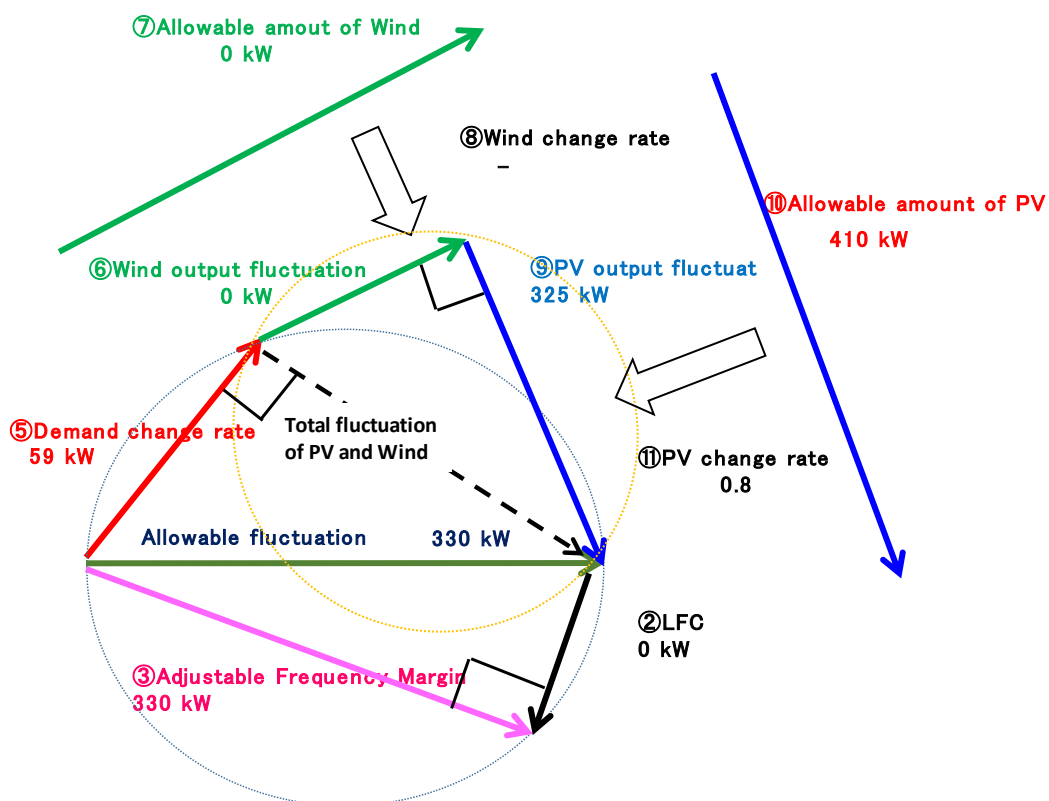
	Demand (MW)	PV fluctuation rate (%)	PV (MW)	WT (MW)	RE (MW)
Probability (95%)	32	80	0	6	6
	40		0		6
	50		2		8
16/03/2016	50	100	1.6	6	7.6

There are plans to build a 4 MW large-scale PV facility in Mahe, and currently there is public offering for the project. When integrating a 4 MW PV system, some measures must be taken. In this study, a simple calculation of the battery PCS capacity required when batteries (lithium) are deployed was conducted. The results are shown in the table below. Since the capacity of lithium-ion batteries is for short-period measures, the capacity was set at 30 minutes.

Table 3.1.3-21 Grid measures for the deployment of a 4 MW PV system (Mahe)

	Demand (MW)	Allowable PV (MW)	PV required grid stabilizer (MW)	Battery(LiB) (MW) × 0.5h
Probability (95%)	32	0	4	3.2
	40	0	4	3.2
	50	2	2	1.6
16/03/2016	50	1.6	2.4	2.4

② Praslin



①	Total demand	4500	kW
②	LFC	0	kW
③	Adjustable Frequency Margin	330	kW
④	System constant	9.8	%/Hz
⑤	Demand change rate	59	kW
⑥	Wind output fluctuation	0	kW
⑦	Allowable amount of Wind	0	kW
⑧	Wind change rate	-	-
⑨	PV output fluctuation	325	kW
⑩	Allowable amount of PV	410	kW
⑪	PV change rate	0.8	-
Total amount of RE		410	kW

Table 3.1.3-22 Calculation results for short-period RE-interconnection capacity (Praslin)

	Demand (MW)	PV fluctuation rate (%)	PV (kW)	WT (kW)	RE (kW)
Probability (95%)	4.5	80	410	0	410
	5.5		500		500
	6.5		590		590
23/03/2016	6.5	50	940	0	940

There are no specific plans to construct a large-scale PV facility on Praslin Island yet, but a study was conducted on grid measures assuming a deployment of a 1 MW PV system. The results are shown in the table below. As with Mahe, the battery PCS capacity required when lithium-ion batteries are used was calculated. You can see that the capacity required changes according to the expected demand and PV fluctuation rate.

Table 3.1.3-23 Grid measures for the deployment of a 1 MW PV system (Mahe)

	Demand (MW)	Allowable PV (kW)	PV required grid stabilizer (kW)	Battery(LiB) (kW) × 0.5h
Probability (95%)	4.5	410	590	470
	5.5	500	500	400
	6.5	590	410	330
23/03/2016	6.5	940	–	–

[Considerations for these results]

It should be noted that for this study, study on the following four points were insufficient, and further analysis should be conducted in the future to improve the accuracy of RE integration capacity.

- ① Smoothing effect of distributed installation
- ② There are only a few samples of system constants
- ③ PV fluctuation rate settings
- ④ Seasonal variations in wind turbine and PV output

3.1.4 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 Seychelles and how high the goals of promoting the spread of RE will be set.

[Important factors for calculating the maximum allowable amount]

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

② To 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 3.1.4-1 and standards in Europe (EN50160) are shown in Table 3.1.4-2. In addition, allowable frequency fluctuation values according to a survey on electricity consumers in Japan are shown in Table 3.1.4-3.

After discussions with stakeholders in Seychelles, we discovered that at 2σ (95.4%), a frequency of 0.75Hz will not disrupt the stable supply of power.

Table 3.1.4-1 Frequency management targets for Japan's 10 electric power utilities

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 3.1.4-2 EN50160 Standard

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

Table3.1.4-3 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.
	Servo motor	±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., no 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)

3.1.5 Power system measures for the expansion of RE integration (measures for short period constraints)

Three major examples of countermeasures to absorb short-period fluctuations and contribute to increasing the capacity of deployment of RE.

① Improve responsiveness of existing generators (GF, AFC)

System constant is improved by changing the arbitration rate of existing generators (GF enhancements), which improves the grid's capacity to withstand frequency fluctuations. Careful consideration should be taken when making changes as we assume that the generators are capable of operating soundly. In addition, with automatic frequency control (AFC), the adjusting capacity of generators can be enhanced, and thus enables the expansion of RE deployment.

② Reduction of RE fluctuation rate with batteries

With RE ΔP change as a trigger, batteries can be controlled and deviations of power flowing to the grid can be mitigated. The size and type of batteries depend on the size, etc. of the target PV, so a detailed study is needed for a specific example.

③ Curtailment of RE output

Grid stabilization measures using batteries, etc. are effective, but the challenge is that their initial cost is expensive, and they require expenses for maintenance and personnel. On the other hand, through temporary curtailment of RE output, the ability to avoid deployment of additional equipment and little impact on the time required to recover the cost of RE deployment are cited as benefits. Therefore, it can be said that it is an effective means of efficiently disseminating RE. However, developing a system for utility scale PV can be done easily, but controlling small residential PV requires a detailed study of a control system design including communications equipment.

Aside from these three measures are hydrogen storage, enhancement of grid operation technologies based on RE power output forecasting, and demand response which entails curbing customers' use of electricity, but none of these methods have been practically applied in SY, so we believe their deployment is difficult at this stage.

3.1.6 Other survey results

- Some of the feeders in Mahe have underfrequency relay settings as shown in Table 3.1.6.-1.

Table 3.1.6-1 List of underfrequency relay settings for the Mahe grid

Parameter		Current	Feeder	Peak Loading
Stage 1	f [Hz]	49.00	Creve Coeur	2.0 MW
	df/dt	0.1		
	t [s]	5		
Stage 2	f [Hz]	48.50	La Retraite	2.0 MW
	df/dt	0		
	t [s]	1		
Stage 3	f [Hz]	48.00	Church Street	3.0 MW
	df/dt	0		
	t [s]	0.5		
Stage 3	f ₃ (Hz)	48.5	Plaisance A	3.0 MW
	t ₃ [s]	0.55		
	t _{3'} [s]	3.00		
	[3]	3.00		
Stage 4	f ₄ (Hz)	48.5	Plaisance B	3.0 MW
	t ₄ [s]	0.00		
	t _{4'} [s]	1.00		
	[3]	1.00		

The feeders of Praslin Power Plant are also equipped with under frequency relay settings as shown below. (Interviewed local electrician)

- Cote Dor Feeder : Frequency (49.0 Hz) Time (instantaneous)
- Baite Ste Anne Feeder : Frequency (48.5 Hz) Time (instantaneous)

The tripping of the Cote Dor feeder at 23:00 on August 5, when a generator tripped, was the workings of the under frequency relay.

3.2 Aid with technical and economic study on the efficient use of diesel generators

3.2.1 Efficient operation of the existing power supply to increase energy self-sufficiency

In order to aim for improving energy self-sufficiency in Seychelles, in addition to the substitution of petroleum fuels with renewable energy, it is necessary reduce fuel consumption through efficient operation of the existing power supply. The following are two ways to achieve this.

- ① Proper maintenance to prevent worsening of fuel consumption characteristics (management of each individual generator)

Properly maintain each individual generator to ensure proper fuel consumption characteristics. In addition, operate at highly efficient output by maintaining operating output range.

- ② Application of economic load dispatch (EDC) operation to optimize fuel consumption (management of power plant operation)

Reduce fuel consumption by optimizing fuel consumption of the entire power plant for each grid load taking into account the fuel consumption characteristics of each individual generator.

In this section, we will examine the application of EDC operation to diesel power plants in Seychelles. We will also identify power plant maintenance issues in this study.

3.2.2 What is EDC operation?

With EDC (Economic Dispatching Control), amid changes in demand, which generators (which have different fuel consumption characteristics) should be operated and at what output will lead to the most efficient operation is considered in advance, and the efficient operation of the generators is carried out based on the results.

3.2.3 EDC operation of diesel generators

EDC operation is broadly classified into two economic load dispatch control categories. First is the supply-demand operation plan where the start and stop of generators and their output distribution is planned by predicting demand by the previous day and considering economic efficiency. Second, is the tweaking of the output distribution of generators in operation according to the supply-demand operation plan. Loss from the start and stop of thermal and nuclear power generators is large, so the supply-demand operation plan is important. However, with diesel generators, effective EDC operation can be achieved, even if only for economic load dispatch control, as there is almost no start and stop loss, they are easy to operate, and they can start and stop in a short time.

3.2.4 EDC operation appropriate to Seychelles

Since the high cost of deploying a full-fledged EDC system with automatic control functions to small-scale power plants in Japan is not expected to be cost effective for improving fuel efficiency, such systems have not been deployed. However, even without implementing automatic EDC operation, as a rule of thumb, economic operation is conducted by determining the fuel consumption characteristics of each generator and getting more output from more fuel-efficient generators.

In this project, as an appropriate EDC operation for the small power plants in Seychelles without deploying system equipment, we transferred an EDC operation technology where commercially available PC software (Microsoft Excel) is used to calculate the economic load dispatch, and the optimal output is manually dispatched according to the calculation results.

<EDC operation technology appropriate to Seychelles>

- ① Economic load dispatch calculation is carried out with a commercial PC software (Microsoft Excel) using the fuel consumption characteristics of each generator (fuel consumption rate).
- ② Cased on the economic load dispatch calculation results, prepare an economic load dispatch table for each combination of generators.
- ③ EDC operation based on the economic load dispatch table (EDC operation is performed by manual governor operation at the power plant)

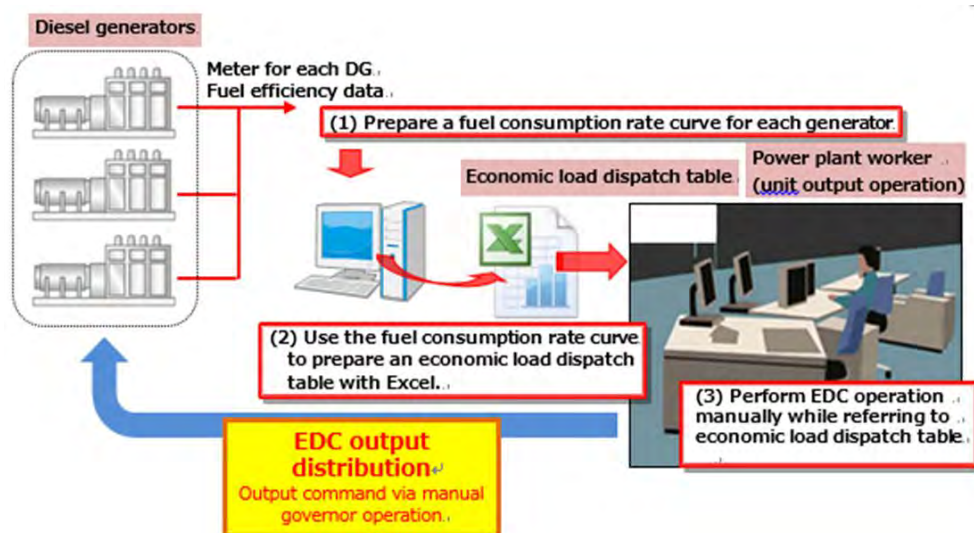


Figure 3.2.4-1 Schematic of EDC operation appropriate to Seychelles

3.2.5 Power plant analysis

The grids targeted for studying the application of EDC operation are Mahe Island and Praslin Island. Desroches Island, Curiuse Island, and La Digue Island were excluded from the study due to the following reasons.

La Digue Island: Power is supplied to it via submarine cable by the diesel power plant on Praslin Island, so it is included in the study on Praslin Island.

Desroches Island: The replacement of generators is scheduled due to changes in hotel management, so optimization of fuel consumption is encompassed in the generator capacity optimization study in section 3.3.5.5.

Curiuse Island: The grid is small operating with only one generator, so EDC operation, which is designed to maximize efficiency of multiple generators, is not expected to make a difference.

3.2.5.1 Mahe Island diesel power plants (Victoria B / Victoria C)

Table 3.2.5-1 shows the Mahe Island diesel power plant specifications. Two diesel generators with a rated capacity of 8000 kW are currently being added to Victoria C Power Plant, and after their operation begins, the operation of the generators at Victoria B Power Plant with the exception of Set 8B will be suspended. Therefore, the study was focused mainly on Victoria C Power Plant which will be the main power plant in the future. Figure 3.2.5-1 indicates the operating range at which each generator is capable of outputting, but each generator has secured an output range up to its rated capacity, and you can see that they generally can be operated at an operating point where efficiency is maximized. Figure 3.2.5-2 - Figure 3.5.2-7 show pictures of the power plant facilities. During the field survey Victoria C Power Plant SET A41 was being overhauled, and its parts were being cleaned and processed in the maintenance room. The power plant personnel are capable of performing diesel engine inspections, and assistants from India are invited to perform regular inspections according to the manufacturer's manual. The power plant is always cleaned providing for an environment such that abnormalities such as oil leaks are easily noticed. Regarding the central control room, the status of each generator can be verified on a computer, and abnormal spots can quickly be determined. We were also able to confirm that fuel flow meters and electricity meters were operating without problems, and since the fuel flow meters are calibrated once a year, it is assumed that there are no problems with the management of facilities.

On the other hand, for equipment for understanding the whole grid they only had a frequency indicator and frequency clock, and they did not have a meter which displays system load. In interviews with operators, we discovered that system load was determined by adding up the output of each generator which results in a time lag. This would complicate work and decrease feasibility of conducting EDC operation, where the load of generators is economically shared for each demand. Furthermore, due to the time lag, optimization of power output for the demand may not be possible. In addition, although they are aware of the fuel consumption characteristics of each individual generator at rated capacity, they are unaware of fuel consumption characteristics in each output range (fuel consumption curve). As a result of plant operation, although they are aware of the overall fuel consumption for a set period and use power plant efficiency as an indicator, they have little recognition for its optimization.

Table 3.2.5-1 Mahe Island diesel power plant specifications

POWER PLANT: VICTORIA B (NEW PORT) MAHE ISLAND

GENSET	SET 1B	SET 3B	SET 4B	SET 5B	SET 6B	SET 7B	SET 8B
RATED OUTPUT (kw)	2500	2500	2500	5000	5000	5000	6348
Derated Capacity (kw)	1000	1200	1500	3500	0	3500	6000
Min. Allowed output(kW)	-	-	-	-	-	-	3000
Operational output range (kW)	-	-	-	-	-	-	3000
YEAR INSTALLED	1971	1971	1978	1981	1986	1990	1998
FUEL USED	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)

POWER PLANT: VICTORIA C (ROCHE CAYMAN) MAHE ISLAND

GENSET	SET A11	SET A21	SET A31	SET A41	SET A51	SET A61	SET B11	SET B21	SET B31	SET B41	SET B51
RATED OUTPUT (kw)	6348	6348	6348	6348	8000	8000	6348	6348	6348	8000	8000
Derated Capacity (kw)	6000	6000	6000	6000	7500	7500	6000	6000	6000	7500	7500
Min. Allowed output(kW)	3000	3000	3000	3000	4000	4000	3000	3000	3000	4000	4000
Operational output range (kW)	3000	3000	3000	3000	3500	3500	3000	3000	3000	3500	3500
YEAR INSTALLED	2000	2000	2000	2000	2016(TBO)	2016(TBO)	2000	2000	2000	2011	2011
FUEL USED	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)	HFO (Heavy fuel oil)

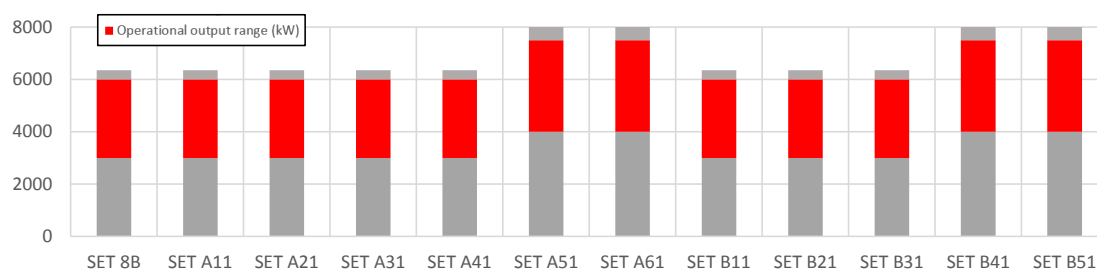


Figure 3.2.5-1 Mahe Island Diesel generator output capacity



Figure 3.2.5-2 Maintenance room



Figure 3.2.5-3 Piston liner processing



Figure 3.2.5-4 Generator room



Figure 3.2.5-5 Fuel flow meter



Figure 3.2.5-6 Electricity meter

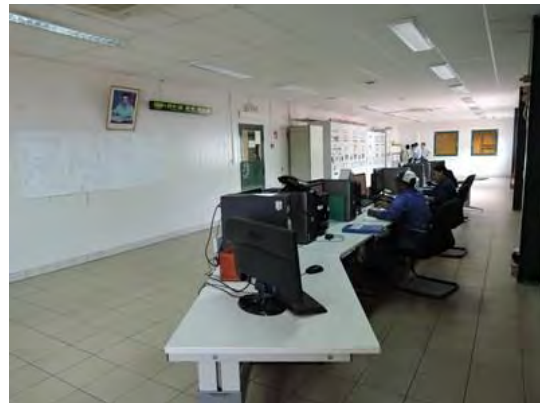


Figure 3.2.5-7 Victoria C Central Control Room

3.2.5.2 Praslin Island diesel power plant

Table 3.2.5-2 shows the Praslin Island diesel power plant specifications. During this survey, Set 5P, with a rated capacity was 2,500 kW, was added giving it a power generating facility with an effective capacity of approximately 13,350kW for a system load of 8,000 kW. Compared to Mahe Island, since there is a variation in the type of generators (rated capacity, year deployed), differences in their fuel consumption characteristics can be expected. Therefore, the reduction of fuel consumption through optimization of fuel consumption by implementing EDC operation may be more profound. In addition, since LFO is used as fuel for diesel generators in Praslin Island, power cost reduction can be expected by improving the efficiency. Regarding electricity meters and fuel flow meters required for EDC operation, the former was functioning properly, but the fuel flow meter was obviously malfunctioning. There were cases where the operators were unaware of failures despite patrolling and filling in their daily power generation records.

As with Mahe Island, there was not a device installed which displays system load, so in applying EDC operation, being aware of the system load will be an issue. In particular, at the Praslin Island Power Plant, since output must be ascertained with the control panel instrument on each individual generator, this verification work will take time.

Table 3.2.5-2 Praslin Island Power Plant Generator Specifications

GENSET	SET 1P	SET 2P	SET 3P	SET 4P	SET M4	SET M5	SET M6	SET 5P	SET 6P	SET 7P	SET 8P
RATED OUTPUT (kw)	670	670	670	670	1400	1200	1000	2500	1500	3000	3000
Derated Capacity (kw)	450	450	450	450	1200	1100	1000	2500	1400	2500	2500
Min. Allowed output(kW)	300	300	300	300	700	600	840	1250	700	1000	1000
Operational output range (kW)	150	150	150	150	500	500	160	1250	700	1500	1500
YEAR INSTALLED	1981	1981	1981	1990	1999	2000	2013	2015	1996	2003	2003
FUEL USED	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)	LFO (Diesel)

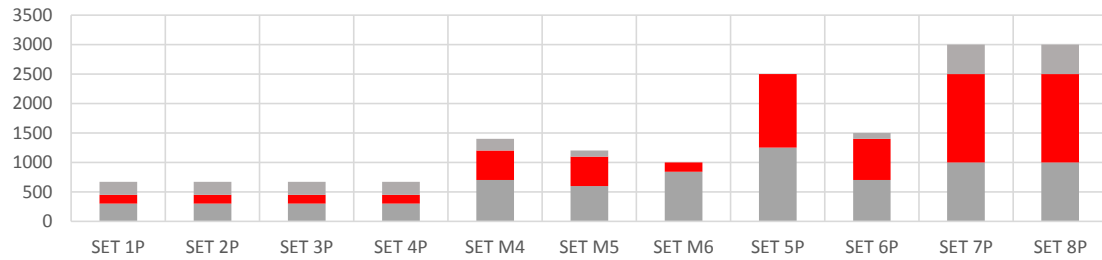


Figure 3.2.5-8 Praslin Island Diesel generator output capacity



Figure 3.2.5-8 Generator room (SET 1P-4P)



Figure 3.2.5-9 Generator room (SET 6P-8P)



Figure 3.2.5-10 Container type generator (SET M4-M6)



Figure 3.2.5-11 Fuel flow meter (SET 1P-4P)



Figure 3.2.5-12 Fuel flow meter (SET 6P-8P)



Figure 3.2.5-13 Fuel flow meter (SET M6)



Figure 3.2.5-14 Electricity meter (SET 1P-4P)



Figure 3.2.5-15 Electricity meter (SET 6P-8P)



Figure 3.2.5-16 Electricity meter (SET 6M)



Figure 3.2.5-17 Central control room

3.2.6 Transfer of EDC operation technology

Technology transfer for EDC operation was conducted with the follow these steps.

- ① Review theory and concepts of fuel consumption optimization
- ② Review how to collect the information required
- ③ Review how to use the collected information for EDC operation

3.2.6.1 EDC operation theory

■ Diesel engine performance (performance curve)

Since diesel engines vary in required output, torque, etc. depending on their application, each engine differ in fuel consumption and other performance areas. In addition, even if the generators are of the same manufacturer, model, and date of manufacture, their performance will gradually differ based on frequency of use and maintenance practices. Figure 3.2.6-1 and Figure 3.2.6-2 shows the performance curves of the diesel engine capable of performing at a rated output of approximately 18 kW (brand new).

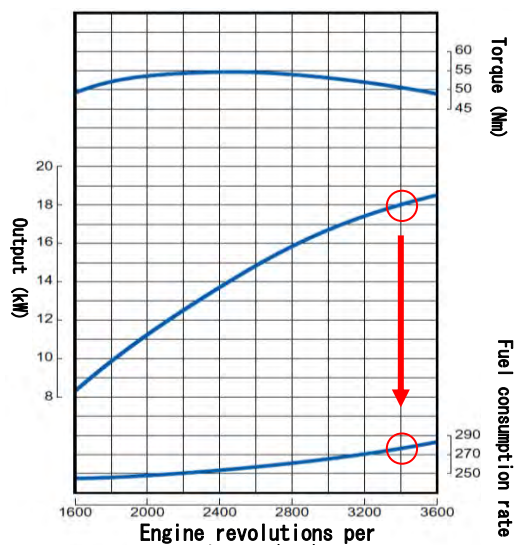


Figure 3.2.6-1 ① Performance curve and appearance of diesel engine 1
(Source: Kubota catalog)

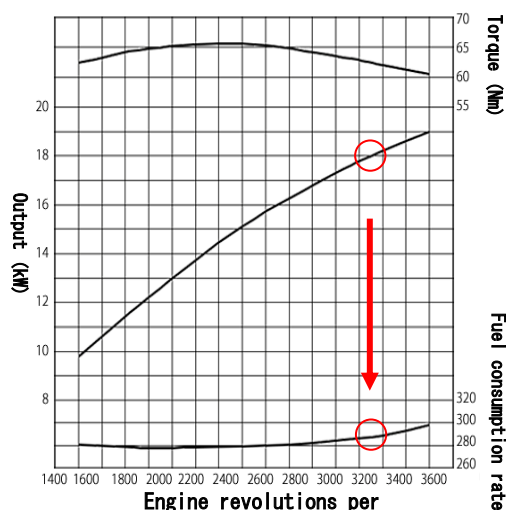


Figure 3.2.6-2 ② Performance curve and appearance of diesel engine 2
(Source: IHI Shibaura catalog)

The graph in the above figure shows torque (Nm), output (kW), and fuel consumption rate in that order from top to bottom. Observing Figure 3.2.6-1 and Figure 3.2.6-2, at the same output of 18 kW, fuel consumption for Engine I has a fuel consumption rate of approximately 280 g/kWh, while Engine II is approximately 290 g/kWh, you can see that even if you got the same output from generators of the same size, fuel consumption may differ. Since the performance of diesel generators differ in this manner, it is important for power plants that operate with multiple generators to conduct economic load dispatch where fuel costs are minimized according to the "incremental fuel cost principle."

■ The mechanism of performance drop at low load ranges

Generally, diesel engines are most energy-efficient in the vicinity of rated output, while efficiency worsens at low load ranges. Figure 3.2.6-3 shows the fuel consumption rates of Generator A (rated output 100 kW) and Generator B (rated output: 350 kW) used in the remote islands of Okinawa Prefecture. As you can see, the two diesel power generators are efficient in the vicinity of rated output, and as load drops, efficiency gets worse. Here, I will explain the mechanism of performance degradations such as the increase in fuel consumption due to operating diesel generators at low load ranges.

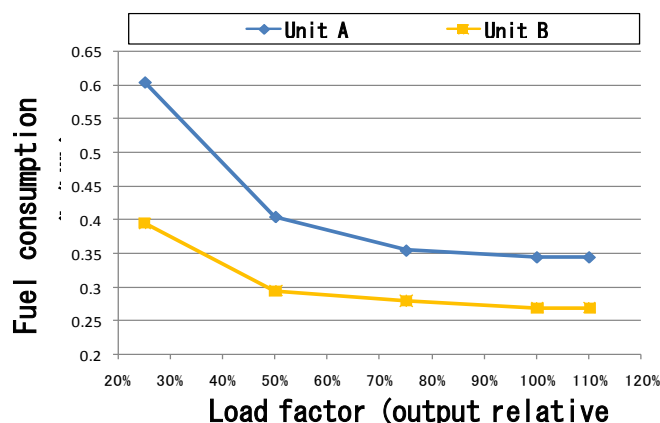


Figure 3.2.6-3 Load factor and fuel consumption rate of diesel generators

One phenomenon that occurs when diesel engines are operated at low loads is incomplete combustion. Incomplete combustion means that the air and fuel oil supplied to the cylinder does not sufficiently burn, a portion of the fuel oil burned turns into soot and black smoke is emitted, while some fuel oil is discharged intact as white smoke (liquid smoke). If all the fuel injected is not converted into thermal energy, the output required cannot be obtained, and extra fuel must be supplied. Fuel consumption rate worsens as a result.

One of the causes of incomplete combustion is reduction in the amount of air supplied into the cylinder due to a drop in manifold air pressure. As a result, both compression pressure and compression temperature drops, so it becomes more difficult to burn fuel.

Another cause is the drop in combustion fuel oil injection pressure required to supply fuel from the fuel injection pump to the fuel injection valve at low load ranges as shown in Figure 3.2.6-4. This results in an increase in the size of fuel oil particles injected by the valve, which in

turn results in insufficient diffusion of fuel and incomplete combustion as the fuel is not burned within the required time (Figure 3.2.6-5). If as a countermeasure, spraying conditions are adjusted to optimize for low load ranges, on the contrary, at high load ranges, fuel oil pressure would rise and exceed the limits of the mechanical durability of the fuel injection pump, fuel valve, etc.

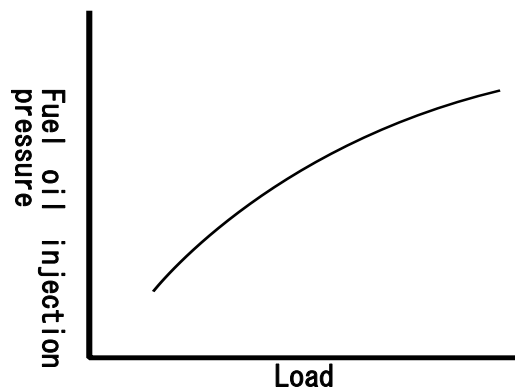


Figure 3.2.6-4 Load factor and fuel oil injection pressure

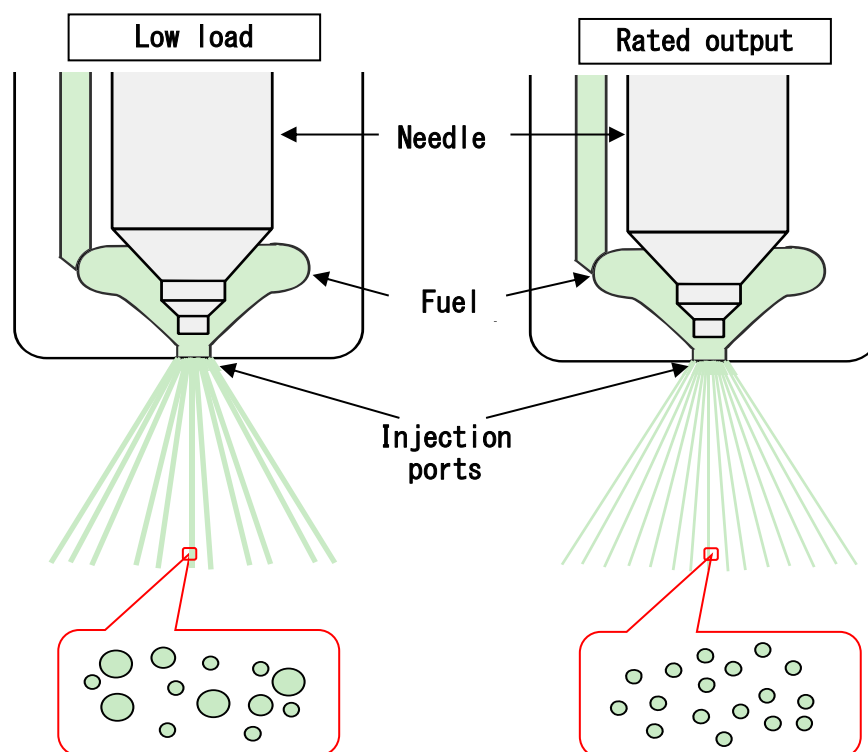


Figure 3.2.6-5 Schematic of the difference in fuel particle size due to injection pressure

■ Approach to efficient operation when operating with multiple diesel generators

We assume a model power plant operating multiple diesel generators is shown in Table 3.2.6-1. In addition, fuel consumption characteristics of each unit are set as shown in Table 3.2.6-2 and Figure 3.2.6-6.

Table 3.2.6-1 Virtual diesel generators

№	Item	Capacity (kW)	RPM (min-1)	# of cylinders	Manufacturer
1	Unit A	100	900	6	Co. A
2	Unit B	100	720	6	Co. B
3	Unit C	200	720	6	Co. C
4	Unit D	300	720	6	Co. D
5	Unit E	300	1800	12	Co. E

Figure 3.2.62 Diesel generator fuel consumption rate settings

Generation equipment			Load factor and corresponding fuel consumption rates (Unit: L/kWh)				
№	Item	Capacity (kW)	25%	50%	75%	100%	110%
1	Unit A	100	0.605	0.405	0.355	0.345	0.345
2	Unit B	100	0.550	0.395	0.355	0.335	0.330
3	Unit C	200	0.465	0.340	0.305	0.290	0.290
4	Unit D	300	0.355	0.280	0.255	0.260	0.260
5	Unit E	300	0.395	0.295	0.280	0.270	0.270

Characteristics of the above values are as follows.

- Fuel consumption is worst during low output and best in the vicinity of rated output.
- There are differences in fuel consumption rate even with generators of the same rated output.
- In general, generators with high rated output have better fuel consumption rates.

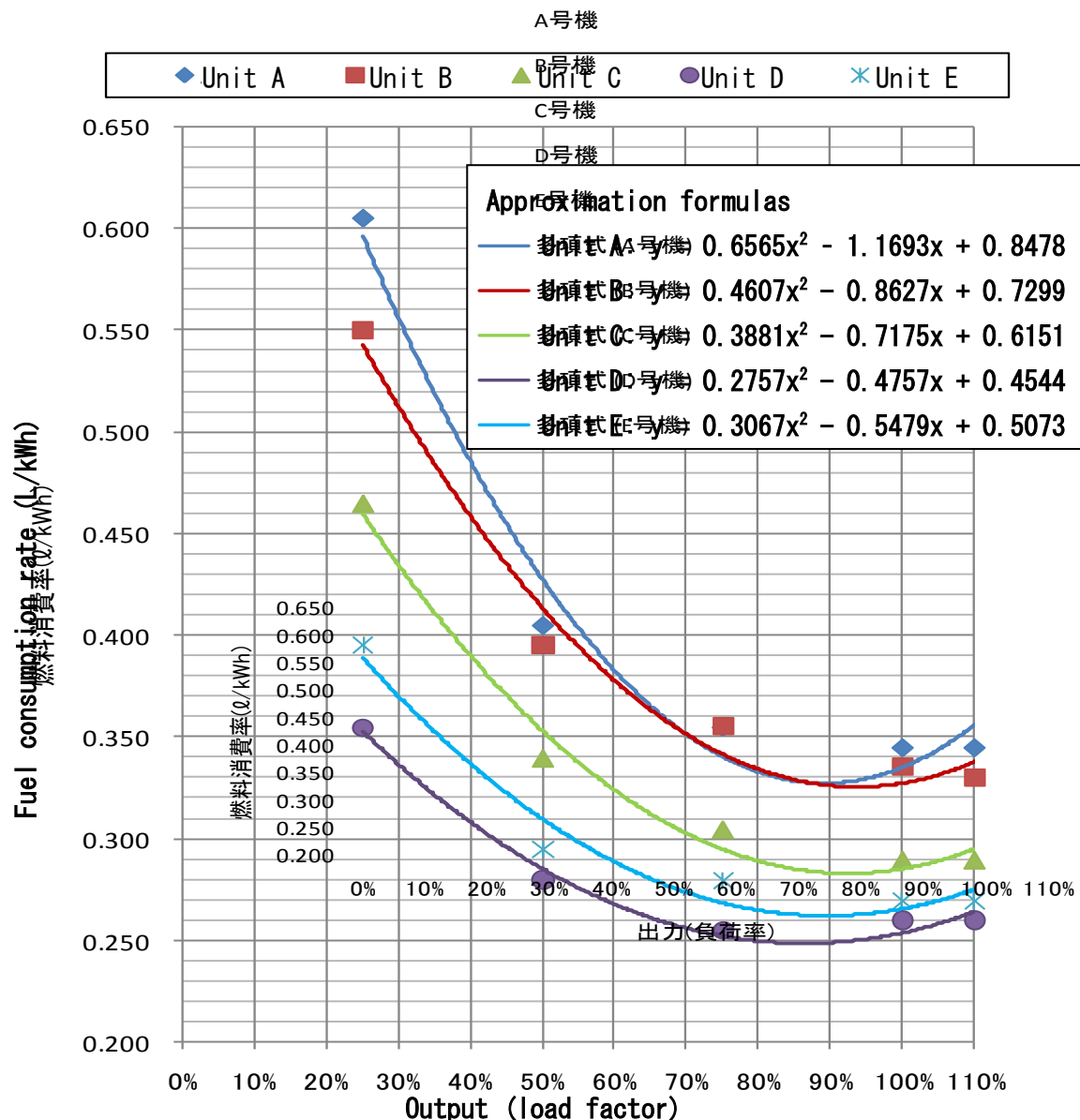


Figure 3.2.6-6 Fuel consumption rate curve of diesel generators

■ Differences in fuel consumption due to differences in operating patterns

Of the operating patterns using the generators above, we will verify the differences in fuel consumption due to differences in two particular operating patterns (load-sharing).

Pattern A: Operating the newest generator (Unit E) as the main unit.

Pattern B: Operating Unit D considered very efficient according to the fuel consumption curve as the main unit.

Table 3.2.6-3 and 3.2.6-4 show the fuel consumed and fuel consumption rates for each operating pattern. You can see that operating pattern B resulted in lower fuel consumption overall compared to operating pattern A, and fuel costs would be reduced. However, with a 400 kW demand, maximizing the use of the generator with the best fuel consumption rate is not necessarily the lowest cost operation.

In addition, the deployment of EDC operation can be applied to actual power plant operation in Seychelles as introduced in this section, but the amount of work required would grow enormously in terms of increase in the number of generators and expected demand. Therefore, it would be desirable to implement some degree of automated calculation. This time, we used an Excel based calculation tool as shown in Section 3.2.4.

Table 3.2.6-3 Fuel consumption and overall fuel consumption rate for operating pattern A

Generation equipment			Demand load and generator output						
№	Item	Capacity (kW)	200kW	300kW	400kW	500kW	600kW	700kW	800kW
1	Unit A	100	Stopped	Stopped	Stopped	Stopped	Stopped	50	50
2	Unit B	100	Stopped	Stopped	Stopped	Stopped	50	50	50
3	Unit C	200	Stopped	Stopped	Stopped	100	150	150	150
4	Unit D	300	Stopped	100	200	200	200	200	250
5	Unit E	300	200	200	200	200	200	250	300
A	Fuel consumption (L/h)		55.7	88.4	107.7	141.7	173.3	203.8	229.3
	Overall fuel consumption rate (L/kWh)		0.279	0.295	0.269	0.283	0.289	0.291	0.287

Table 3.2.6-4 Fuel consumption and overall fuel consumption rate for operating pattern B

Generation equipment			Demand load and generator output						
№	Item	Capacity (kW)	200kW	300kW	400kW	500kW	600kW	700kW	800kW
1	Unit A	100	Stopped	Stopped	Stopped	Stopped	Stopped	Stopped	Stopped
2	Unit B	100	Stopped	Stopped	Stopped	Stopped	Stopped	50	100
3	Unit C	200	Stopped	Stopped	Stopped	Stopped	100	150	200
4	Unit D	300	200	250	300	250	250	250	250
5	Unit E	300	Stopped	50	100	250	250	250	250
B	Fuel consumption (L/h)		52.0	83.6	113.9	128.3	162.3	193.9	219.8
	Overall fuel consumption rate (L/kWh)		0.260	0.279	0.285	0.257	0.271	0.277	0.275

3.2.6.2 Measuring fuel consumption rate

As indicated in the previous section, in aiming to optimize fuel consumption, it is important to know the fuel consumption characteristics of each generator. In the 2nd and 3rd Field surveys, we conducted fuel consumption measurement tests at Mahe Island Power Plant and Praslin Island Power Plant and confirmed the testing methods with the C/P. Figure 3.2.6-7 and 3.2.6-8 show the testing conditions. Both power plants have a precise understanding of measuring methods, and the C/P should have no problems with continuing to take periodic measurements independently after this survey is completed. However, since the study will be conducted on the basis of these measurement test results, we advised them to strive to collect detailed data by following these measurement procedures completely. As shown in Table 3.2.6-5, the

measurement procedure is not complicated, and we confirmed that the C/P is fully capable of conducting the test when we conducted the measurement test in the field survey.

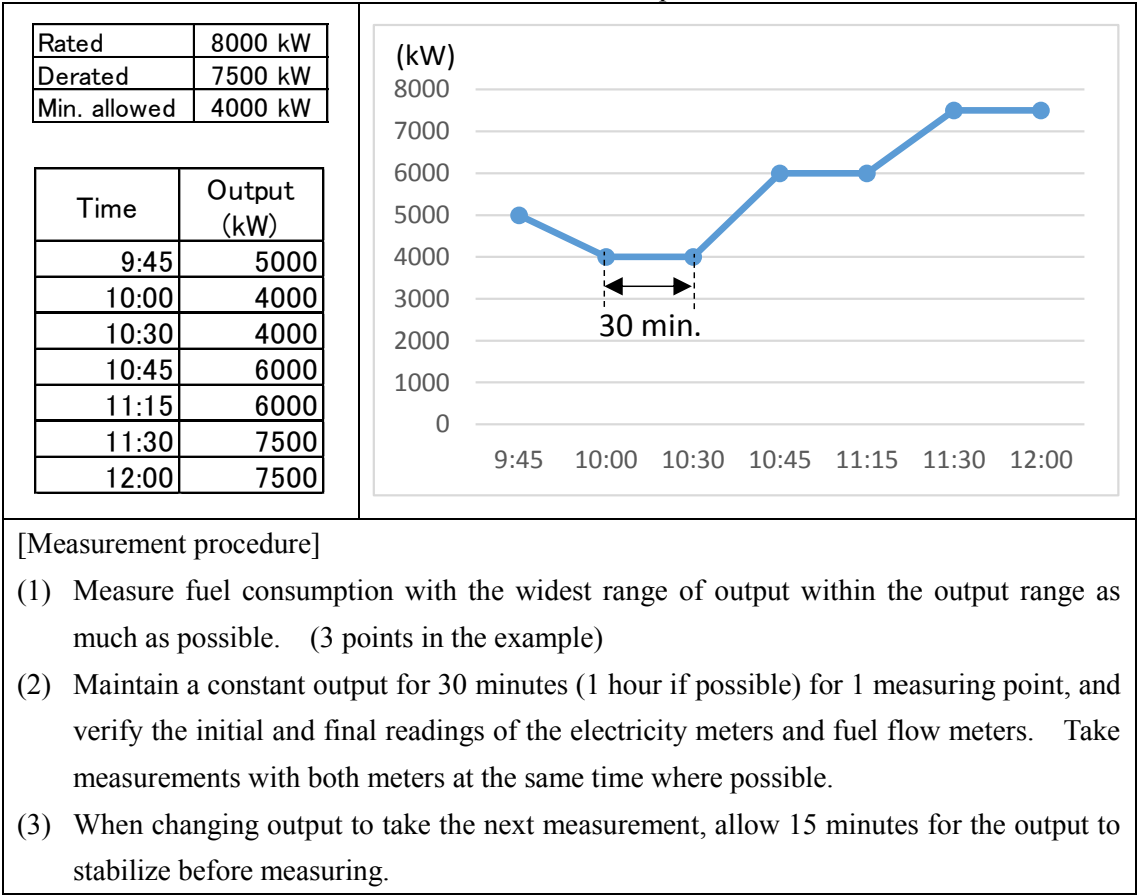


Figure 3.2.6.-7 Measuring fuel consumption (Mahe)



Figure 3.2.6-8 Confirming electricity amount (Praslin)

Table 3.2.6-5 Procedure for fuel consumption rate measurement test



■ Measurement test results (Mahe Island)

Figure 3.2.6-9 shows the measurement test results for Mahe Island Victoria C Power Plant. The existing diesel generators at Mahe Island have rated capacities of 6,348 kW and 8,000 kW, and they have similar fuel consumption characteristics. In addition, the operating time of Units

A2, A3, and A4 (the measured generators) after their overhaul are compared in Table 3.2.6-6. Since we could not confirm the deterioration of fuel consumption with operating time, judging only from these measurement results, it is assumed that Victoria C Power Plant is properly maintained.

Victoria C_B5

Rated output	8000 kW		
KW	4000	6000	7500
%	50%	75%	94%
L/KWH	0.257	0.232	0.230

Victoria C_A4

Rated output	6348 kW		
KW	5500	4500	3000
%	87%	71%	47%
L/KWH	0.238	0.239	0.249

Victoria C_A2

Rated output	6348 kW		
KW	3000	4500	5500
%	47%	71%	87%
L/KWH	0.249	0.242	0.240

Victoria C_A3

Rated output	6348 kW		
KW	3000	4500	5500
%	47%	71%	87%
L/KWH	0.252	0.238	0.239

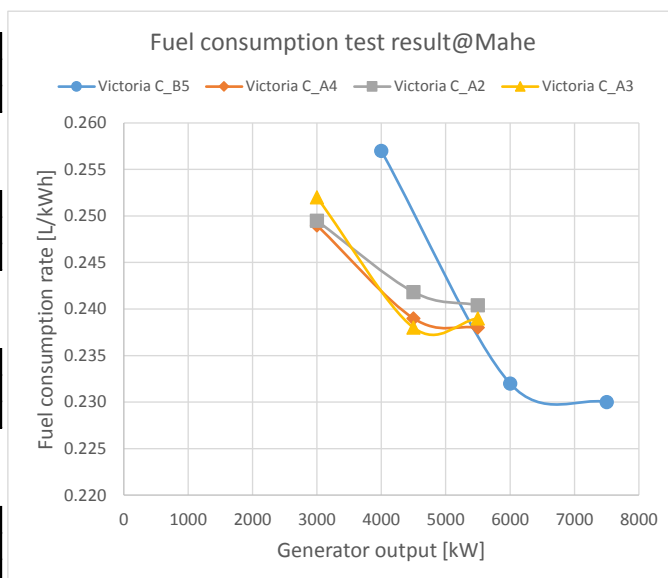


Figure 3.2.6-9 Fuel consumption rate measurement test results for Mahe Island Victoria C Power Plant

Table 3.2.6-6 Comparison of operating time after overhaul

Unit	A2	A3	A4
Operating time after overhaul	11,200	1,263	10,964

■ Measurement test results (Praslin Island)

Figure 3.2.6-10 shows the measurement test results for Praslin Island Power Plant. Since SET M6 is operated only at the fixed output of 840 kW, so it was measured only at 1 point. The measurement for SET 5P was conducted right after its installation, so its measurement values were less than those of SET 7P which is of the same capacity.

In addition, in selecting the generators for this measurement test, we found many units that have a faulty fuel system including the fuel flow meter. Table 3.2.6-7 shows a list of fuel system defects of Praslin Island Power Plant, and Figures 3.2.6-11 and 3.2.6-12 show defects of SET 8P. The local C/P technical staff pointed out that the flow meters of some units were replaced (SET 1P and 2P), so it was confirmed that patrol inspections and verification of abnormalities in the daily power generation records by the operator may not have been properly conducted. For EDC operation, since it is assumed that each generator and peripheral devices are functioning soundly, a study including a review of the maintenance system is needed for its deployment.

Praslin 6P			
Rated output 1500 kW			
KW	800	1040	1300
%	53%	69%	87%
L/KWH	0.282	0.275	0.271

Praslin 7P			
Rated output 3000 kW			
KW	1000	1700	2000
%	54%	73%	81%
L/KWH	0.2837	0.2729	0.2723

Praslin 4P			
Rated output 670 kW			
KW	548	444	296
%	82%	66%	44%
L/KWH	0.276	0.278	0.296

Praslin M6			
Rated output 1000 kW			
KW	840		
%	84%		
L/KWH	0.261		

Praslin 5P			
Rated output 3000 kW			
KW	2084	1576	1216
%	0.694667	0.525333	0.405333
L/KWH	0.260	0.272	0.292

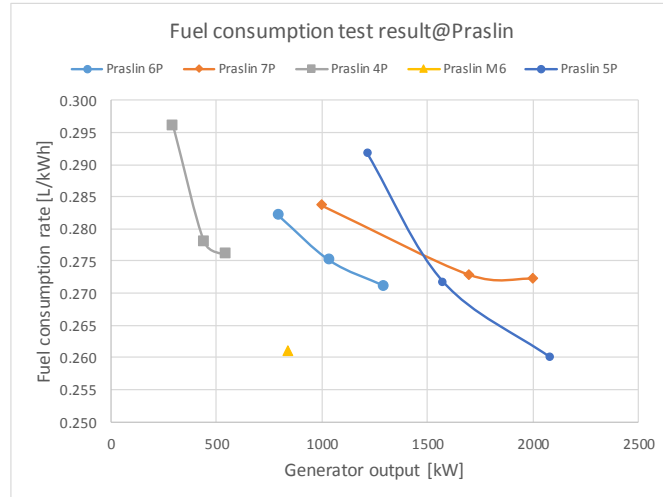


Figure 3.2.6-10 Fuel consumption rate measurement test results for Praslin Island Power Plant

Table 3.2.6-7 A list of fuel system defects of Praslin Island Power Plant

Unit	Fuel flow meter	Defect content
1P	Failure	Fuel flow meter failure
2P	Failure	Fuel flow meter failure
3P	Failure	Fuel flow meter failure
M4	Failure	Fuel flow meter failure
M5	Failure	Fuel flow meter failure
8P	Sound	Fuel flow cannot be measured due to failure of the bypass valve just before the return fuel flow meter.



Figure 3.2.6-11 SET 7P Around the flow meter (Sound)



Figure 3.2.6-12 SET 8P Around the flow meter (Valve failure)

3.2.6.3 Preparing an economic load dispatch table

We taught the C/P how to actually carry out EDC operation based on the test results obtained in the preceding section. Since the aim of this survey is to use a simplified method without introducing additional equipment, we proposed calculating the optimal load distribution for each demand portion using commercial PC software (Microsoft Excel) and having operators

operate the generators using this tables. Figure 3.2.6-13 - Figure 3.2.6-16 show pictures of the lectures. We confirmed that the C/P is capable of independently preparing an economic load dispatch table despite their unfamiliarity with calculations using Excel. We also confirmed that regular measurement of fuel consumption, which is affected by aging and environmental changes, is conducted. As an example, a load dispatch table for Praslin Island Power Plant is shown in Table 3.2.6-8. The example shows the optimal load for each unit for each demand load if you were to operate with SET 4P, SET 5P, SET 6P, SET 7P, and SET 8P. This table will be prepared for each unit combination and implement for actual generator operation.



Figure 3.2.6-13 Lecture 1 on preparing an economic load dispatch table (Praslin Island Power Plant)

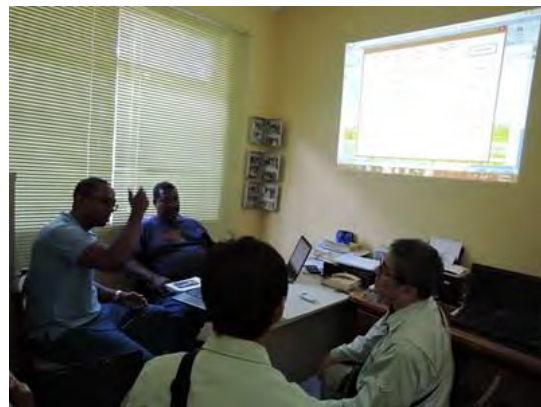


Figure 3.2.6-14 Lecture 2 on preparing an economic load dispatch table (Praslin Island Power Plant)



Figure 3.2.6-15 Lecture 1 on preparing an economic load dispatch table (Mahe Island Victoria C Power Plant)



Figure 3.2.6-16 Lecture 2 on preparing an economic load dispatch table (Mahe Island Victoria C Power Plant)

Table 3.2.6-8 Example load dispatch table for Praslin Island Power Plant

System load 【kW】	DEG output (Ecomic output) 【kW】				
	DG:4P	DG:5P	DG:6P	DG:7P	DG:8P
9,000	450	2,650	1,400	2,000	2,500
8,900	400	2,650	1,350	2,000	2,500
8,800	400	2,600	1,350	2,000	2,450
8,700	400	2,600	1,350	2,000	2,350
8,600	400	2,600	1,350	2,000	2,250
8,500	400	2,600	1,350	2,000	2,150
8,400	400	2,600	1,350	2,000	2,050
8,300	400	2,600	1,350	2,000	1,950
8,200	400	2,600	1,350	2,000	1,850
8,100	400	2,600	1,350	2,000	1,750
8,000	400	2,600	1,350	2,000	1,650
7,900	400	2,600	1,350	2,000	1,550
7,800	400	2,600	1,350	2,000	1,450
7,700	400	2,600	1,350	2,000	1,350
7,600	400	2,600	1,350	2,000	1,250
7,500	400	2,600	1,350	2,000	1,150
7,400	400	2,600	1,350	2,000	1,050
7,300	400	2,600	1,350	1,950	1,000
7,200	400	2,600	1,350	1,850	1,000
7,100	400	2,600	1,350	1,750	1,000
7,000	400	2,600	1,350	1,650	1,000
6,900	400	2,600	1,350	1,550	1,000
6,800	400	2,600	1,350	1,450	1,000
6,700	400	2,600	1,350	1,350	1,000
6,600	400	2,600	1,350	1,250	1,000
6,500	400	2,600	1,350	1,150	1,000
6,400	400	2,600	1,350	1,050	1,000
6,300	400	2,600	1,300	1,000	1,000
6,200	400	2,600	1,200	1,000	1,000
6,100	400	2,600	1,100	1,000	1,000
6,000	400	2,600	1,000	1,000	1,000
5,900	400	2,600	900	1,000	1,000
5,800	400	2,600	800	1,000	1,000
5,700	400	2,600	700	1,000	1,000
5,600	400	2,500	700	1,000	1,000
5,500	400	2,400	700	1,000	1,000
5,400	400	2,300	700	1,000	1,000
5,300	400	2,200	700	1,000	1,000
5,200	400	2,100	700	1,000	1,000
5,100	400	2,000	700	1,000	1,000
5,000	400	1,900	700	1,000	1,000
4,900	400	1,800	700	1,000	1,000
4,800	400	1,700	700	1,000	1,000
4,700	400	1,600	700	1,000	1,000
4,600	400	1,500	700	1,000	1,000
4,500	300	1,500	700	1,000	1,000

3.2.7 EDC operation application process

■ Effect of deploying EDC operation

We performed trial calculations on the effect of actually deploying EDC operation. The calculations were conducted on Mahe Island Victoria C Power Plant, and for the units not measured for fuel consumption, we used the values of units with the same capacity. The trial calculation conditions are as follows.

【Trial calculation conditions】

- Mahe Island Victoria C Power Plant was the target power plant.
- The target period was 11/1/2014 (Saturday) - 11/7/2014 (Friday) for a total of 7 days.
- Fuel consumption are not actual values, but instead calculated from the measured fuel consumption and actual generator output values.
- For the estimated fuel consumption after the application of EDC operation, we used fuel consumption when load is optimally shared for actual system loads.
- The fuel consumption average for SET A2, A3, and A4 was used for SET B8, A1, B1, B2, and B3.
- The fuel consumption average for SET B5 was used for SET B4.

The trial calculation results are shown in Table 3.2.6-9. From the trial calculations using the above conditions, we found that compared to before EDC operation, fuel consumption may be reduced by approximately 1.6%. In reality, results are greatly influenced by changes in the environment such as temperature and humidity and the condition of generators, but you can see that reducing fuel consumption is possible without incurring large expenses by steadily implementing EDC operation.

Table 3.2.6-9 Trial calculation results on the effect of implementing EDC operation at Mahe Island Victoria C Power Plant.

01-Nov-14	Fuel consumption (t)	Without EDC	190,972	05-Nov-14	Fuel consumption (t)	Without EDC	221,058
		With EDC	190,275			With EDC	220,501
	Reduction	[t]	697		Reduction	[t]	557
		[%]	0.365%			[%]	0.252%
02-Nov-14	Fuel consumption (t)	Without EDC	189,546	06-Nov-14	Fuel consumption (t)	Without EDC	229,285
		With EDC	189,173			With EDC	228,872
	Reduction	[t]	373		Reduction	[t]	413
		[%]	0.197%			[%]	0.180%
03-Nov-14	Fuel consumption (t)	Without EDC	217,722	07-Nov-14	Fuel consumption (t)	Without EDC	219,332
		With EDC	217,268			With EDC	218,845
	Reduction	[t]	454		Reduction	[t]	487
		[%]	0.209%			[%]	0.222%
04-Nov-14	Fuel consumption (t)	Without EDC	222,207	TOTAL	Fuel consumption (t)	Without EDC	1,490,123
		With EDC	221,844			With EDC	1,486,777
	Reduction	[t]	364		Reduction	[t]	3,346
		[%]	0.164%			[%]	1.588%

■ Improvements for applying EDC operation

The following two points are areas of improvement for the local C/P to continue to perform EDC operation independently in the future.

① Digitization of daily power generation records

At the Praslin Island Power Plant, there were cases where malfunctioning instruments were not properly found, so routine patrol inspections and daily power generation records is an area for improvement. Specifically, since records are kept on paper, personnel are preoccupied with recording work, and checking for abnormal meter readings is difficult. If these recordings were entered into a spreadsheet such as Excel in parallel, abnormal conditions can be detected immediately by having the spreadsheet display an error when a value exceeding the default value is entered. In addition, when preparing economic load dispatch tables, which is important for performing EDC operation, since a study which takes into account actual system load must be conducted, digitization of daily power generation records is very important.

② Understanding system load

As mentioned in section 3.2.5, there are no meters at Mahe and Praslin Island Power Plants which constantly display system load, so there is no way to know the ever-changing demand. This is lacking synchronism required to optimize load dispatch of generators for each demand portion and perform EDC operation, which minimizes fuel consumption. In addition, this may make it difficult for the operators, and they may not perform it sufficiently. Furthermore, in operating the grid, there is a tendency of setting reserve high and operating at higher frequency because of the inability to see system load, so there may be wasteful fuel consumption. Meters such as totalizer which add up the output of each generator and displays the total as system load are required to appropriately perform EDC operation.

3.2.8 Summary

In this survey, concerning technical and economic study pertaining to the efficient use of diesel generators, we held discussions focusing on the transfer of EDC operation technology with the local C/P. As described in Section 3.2.1, in order to efficiently operate diesel power plants, (1) preventing the deterioration of fuel consumption characteristics through proper maintenance (management of each individual generator) and (2) optimization of fuel consumption through application of EDC operation (management of power plant operation) are essential. With EDC operation, in the short term, due to weather conditions and the condition of generators, you often do not get the calculated results, but by keeping the fuel consumption characteristics of each generator in mind when conducting operations, it will lead to improvement in maintaining efficiency of each generator and the plant as a whole in the long term. In addition, in performing EDC operation, it is important that each operator develops awareness from day-to-day management such as changes in the fuel consumption rates inferred from generator abnormalities. From there, an opportunity for each operator to become actively involved in the overall efficiency and operation of the entire power plant will be provided, and by repeating this cycle, the foundation for improving the skills of the operators and proper maintenance of power plants will be formed.

3.3 Aid with planning and designing PV-diesel hybrid power generation equipment

3.3.1 Basic system configuration

With small-scale power systems, due to limitations on scale and adjustment capacity, they are sensitive to the output fluctuations of renewable energy such as grid-connected PV systems, and if these fluctuations are large, balancing supply and demand and securing power quality become difficult. Therefore, when integrating a high percentage of grid-connected PV systems, a hybrid system which supplies power in coordination with the existing diesel generators is regarded as promising.

In Okinawa, in order to reduce the amount of fuel consumed by diesel generators for power supply, grid-connected PV systems have been deployed on small remote islands as a hybrid system coordinated with diesel generators. This section explains the use of PV-diesel hybrid system development technology developed in Okinawa. Moreover, we will present the following 3 basic system configurations.

- PV-diesel hybrid system
- PV-WT-diesel hybrid system
- PV-battery-diesel hybrid system

Keeping in mind that in any case, the deployment will take place on 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 repair are not easy.

(1) PV-diesel hybrid system

In most cases, a system stabilizing device such as storage batteries is incorporated in PV-diesel hybrid systems. However, power system stabilizers are expensive, so if such equipment is incorporated, the economic burden on Seychelles to deploy the system alone is heavy and makes 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 of the PCSs that come with the PV systems
- A system that takes into account low-output diesel generator operation measures through quantity control of power conditioners (PCS)

Hybrid system functions (PCS quantity control)

- ① Monitor grid frequency to control the number of PCSs (Frequency stability measure)
- ② Monitor DG output/grid load to control the number of PCSs

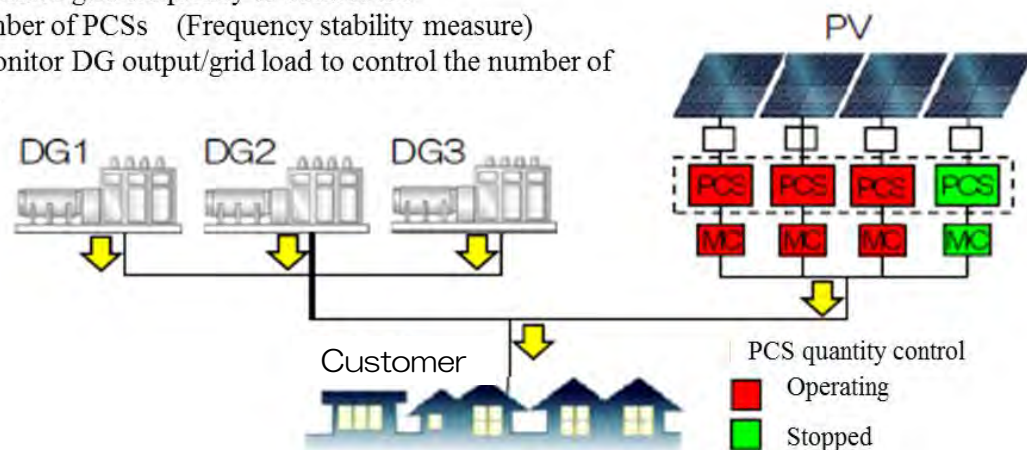


Figure 3.3.1-1 Schematic diagram of a PV-diesel hybrid system (not equipped with batteries)

<Features/advantages of the system>

- As each PCS can be switched on and off individually, limiting output can be done in a stepwise fashion.

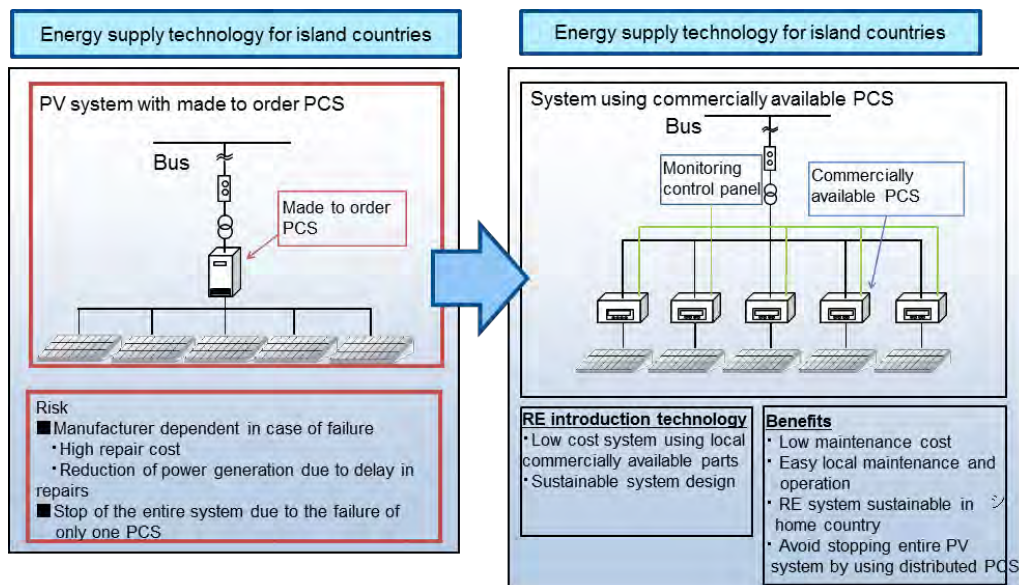
Complex control equipment are not required in performing output limit control

- 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 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.).



Ex. Sustainable PV System configuration

Figure 3.3.1-2 A PV system configuration that makes operation and maintenance sustainable

Since the power supply structure in Seychelles is dependent on diesel fuel, it is susceptible to high oil prices which make it very vulnerable. Power costs have become more expensive especially on remote islands.

Large-scale deployment of PV systems is an effective way to resolve such issues. However, various problems such as the loss of power quality, supply reliability, and low output operation of diesel generators may occur with the mass deployment of PV systems, so in order to introduce PV systems, measures to prevent these problems are required. Therefore, the deployment 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 fluctuation in PV system output, the number of PCS units in operation is reduced (quantity control) to reduce the PV system output fluctuation range, and thus the grid frequency fluctuation is mitigated. In addition, for low load diesel generator operation, diesel generators are monitored, and when output drops below the output lower limit, quantity control is performed on the PV system to prevent low load diesel generator 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 maximum 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.

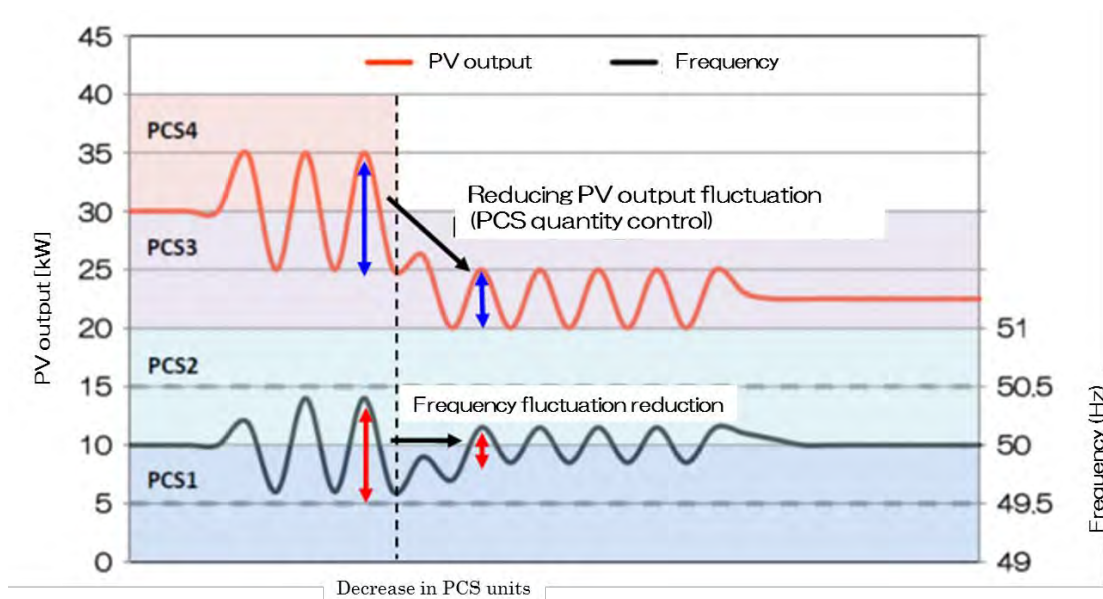


Figure 3.3.1-3 Schematic of frequency stabilization measures through PCS quantity control

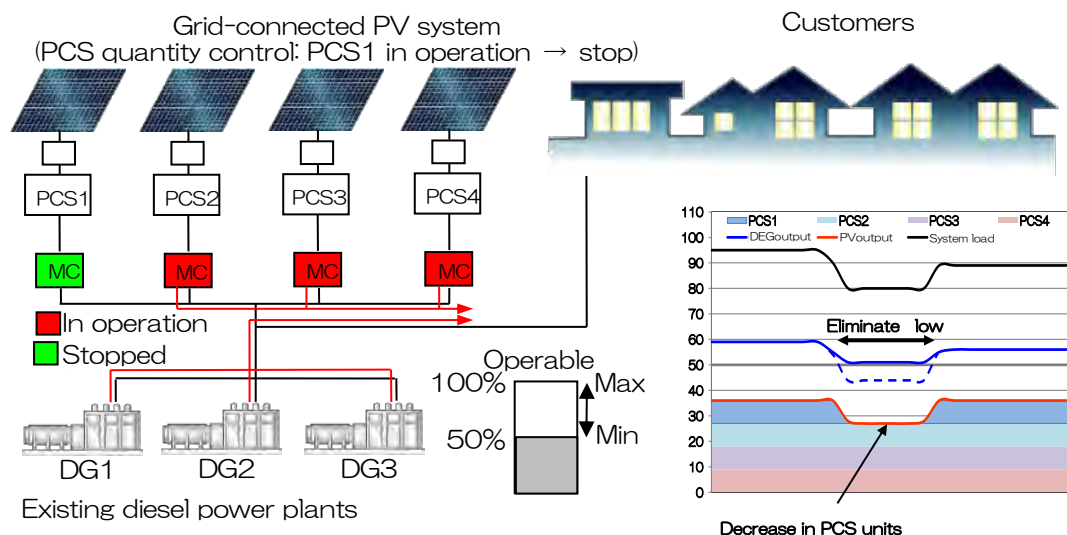


Figure 3.3.1-4 Schematic of measures for low-load diesel generator operation through PCS quantity control

(2) PV-WT-diesel hybrid system

This system is similar to the PV-diesel hybrid system in general.

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

An example system is described below.

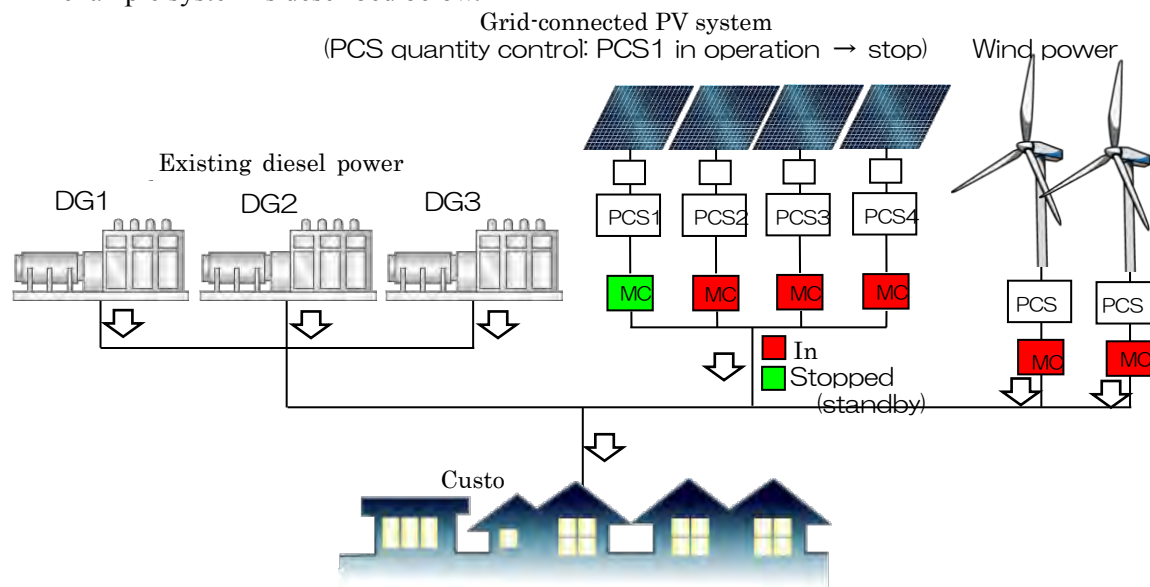


Figure 3.3.1-5 Schematic diagram of a PV-WT-diesel hybrid system (not equipped with batteries)

(3) PV-battery-diesel hybrid system

This system is similar to the PV-diesel hybrid system in general.

The RE supply percentage can be increased to a high percentage by using batteries to absorb PV fluctuations and surplus power. A WT can also be included.

However, storage battery equipment is very expensive.

An example system is described below.

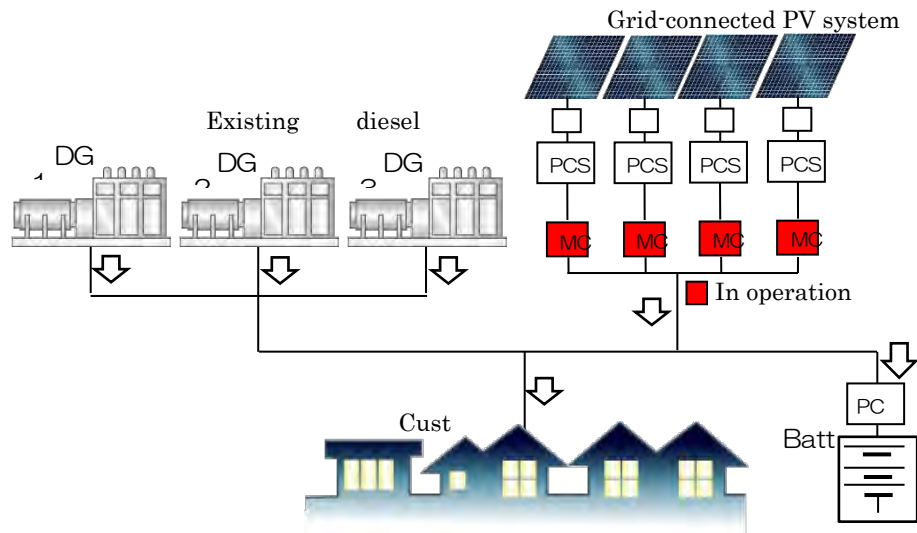


Figure 3.3.1-6 Schematic of a PV-battery-diesel hybrid system

3.3.2 Basic data and how to understand them

3.3.2.1 Introduction

In studying a hybrid system, there are a variety of study methods, 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 constraints of each must be evaluated.

HOMER Pro (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 (annual 1 hour resolution)
Solar irradiance data	: Data for 8,760 hours (annual 1 hour resolution). (HOMER Pro is equipped with this.)
Wind speed data	: Data for 8,760 hours (annual 1 hour resolution). (HOMER Pro is equipped with this.)
Diesel generator	: rated output and low-output operating range of the diesel generator
PV	: installed PV capacity
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 irradiance, and wind speed, the so-called long-period fluctuation analysis. Short period output changes, etc. within one hour, e.g. a few seconds or minutes, are not included.

Regarding whether or not such short-period fluctuations are acceptable to the power system, see "3.1 Aid with evaluation method to determine the RE integration capacity."

3.3.2.2 Basic data for each remote island

(1) Mahe

1) Status of the power plant

There are two power plants on Mahe, the main island of Seychelles. Details of the plant are as follows.

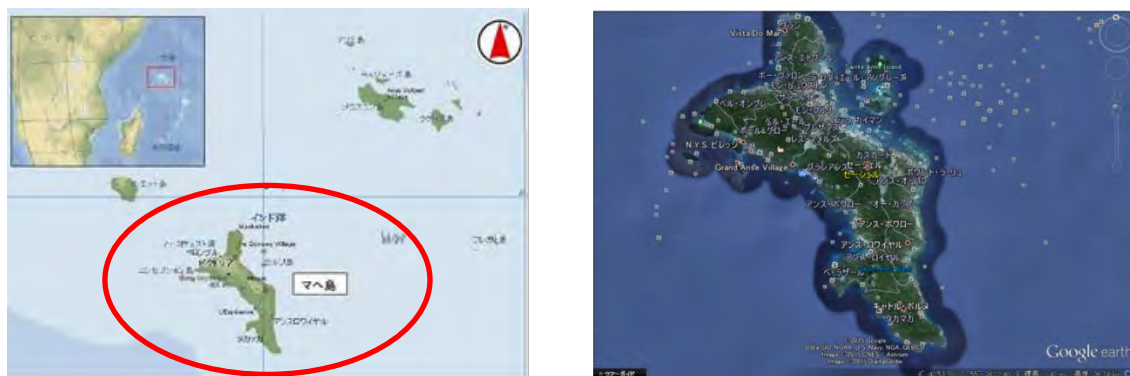


Figure 3.3.2-1 Power plant location: (Source: Google Earth)

Table 3.3.2-1 Victoria B Power Plant generator specifications

Engine#	1B	3B	4B	5B
ENGINE MAKE	Blackstone	Blackstone	Blackstone	Blackstone
ENGINE MODEL	K8 MAJOR	K8 MAJOR	K8 MAJOR	KV12 MAJOR
Rated output (kW)	2,500	2,500	2,500	5,000
Maximum output (kW)	1,000	1,200	1,500	3,500
SPEED (RPM)	500	500	500	600
YEAR INSTALLED	1971	1971	1978	1981
Engine#	6B	7B	8B	
ENGINE MAKE	Sulzer	Sulzer	Wartsila	
ENGINE MODEL	8ZAL40	8ZAL40S	18V32LN	
Rated output (kW)	5,000	5,000	6,348	
Max. output (kW)	0	3,500	6,000	
SPEED (RPM)	600	500	750	
YEAR INSTALLED	1986	1990	1998	

Table 3.3.2-2 Victoria C Power Plant generator specifications

Engine#	A11	A21	A31	A41	A51	A61
ENGINE MAKE	Wartsila	Wartsila	Wartsila	Wartsila	Wartsila	Wartsila
ENGINE MODEL	18V32LN	18V32LN	18V32LN	18V32LN	18V32	18V32
Rated output (kW)	6,348	6,348	6,348	6,348	8,000	8,000
Max. output (kW)	6,000	6,000	6,000	6,000	8,000	8,000
SPEED (RPM)	750	750	750	750	750	750
YEAR INSTALLED	2000	2000	2000	2000	2015	2015
Engine#	B11	B21	B31	B41	B51	
ENGINE MAKE	Wartsila	Wartsila	Wartsila	Wartsila	Wartsila	
ENGINE MODEL	18V32LN	18V32LN	18V32LN	18V32LN	18V32LN	
Rated output (kW)	6,348	6,348	6,348	8,000	8,000	
Maximum output (kW)	6,000	6,000	6,000	8,000	8,000	
SPEED (RPM)	750	750	750	750	750	
YEAR INSTALLED	2000	2000	2000	2011	2011	

Reference Information

Operating conditions:

- Load sharing with droop control (4%). Operating at 75-80% of rated output.
- Capable of operating at a minimum of 30% of rated output (only for a short time)
- The annual peak load is approx. 50 MW.
- It trended between 22 and 50 MW throughout the year.
- There are plans to enhance the grid in the southern region, so the load is expected to increase. (Hotels, etc. currently not connected to the grid plan to connect)

2) Load changes

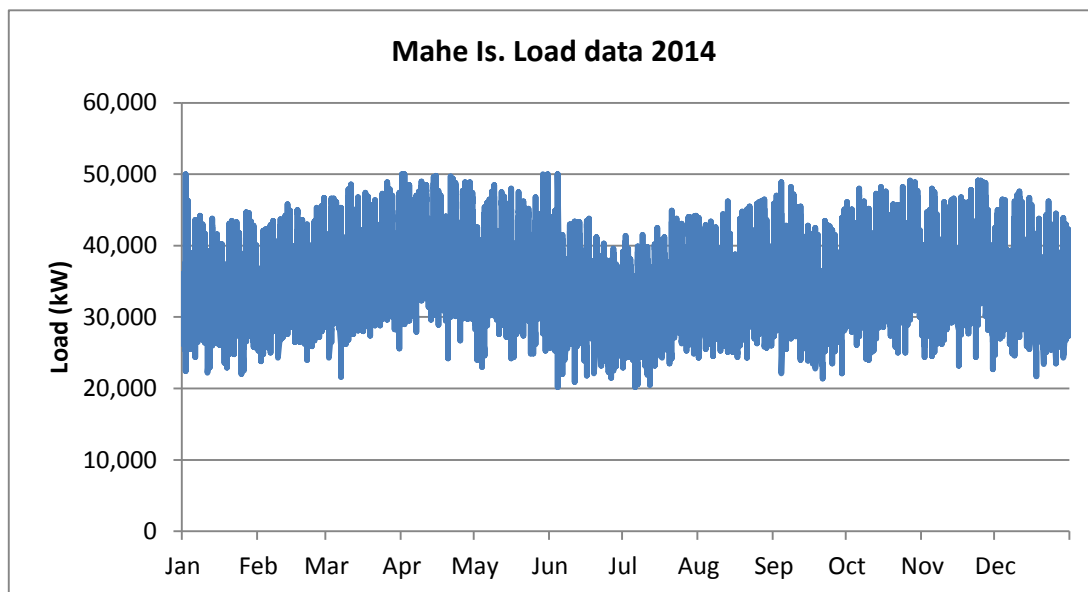


Figure 3.3.2-2 Mahe load changes (2014) hourly data

3) Solar irradiance data

By specifying Mahe's location in HOMER Pro, the solar irradiance data to be used will be downloaded and imported to HOMER Pro.

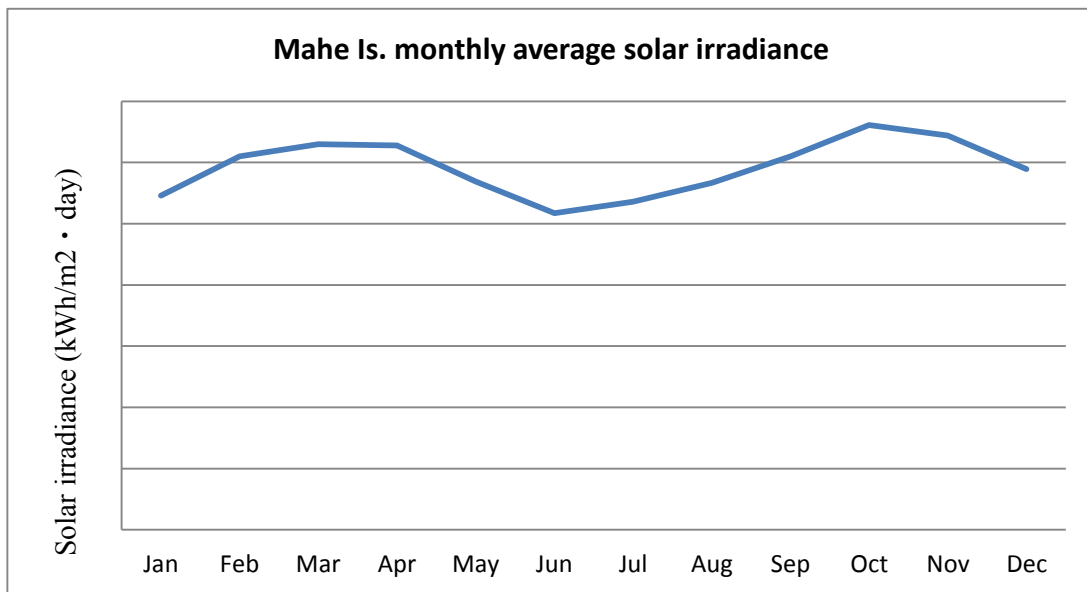


Figure 3.3.2-3 Mahe solar irradiance data

* For solar irradiance data required to perform the trial calculations for the amount PV generated power, 8,760 hours' worth of data for hourly values is loaded in HOMER Pro, simulation software.

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

4) Wind speed data

By specifying Mahe's location in HOMER Pro, the wind speed data to be used will be downloaded and imported to HOMER Pro. However, since wind speed varies depending on region, it must actually be measured.

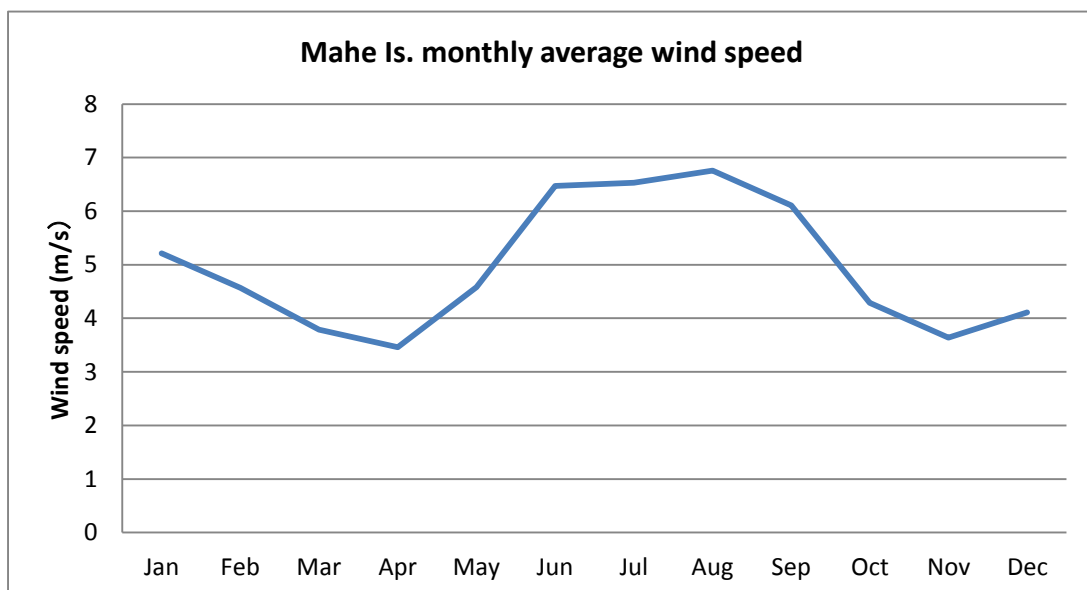


Figure 3.3.2-4 Mahe wind speed data

(2) Praslin

1) Status of the power plant

There is one power plant on Praslin, the next largest island after Mahe, the main island of SY. Details of the plant are as follows.

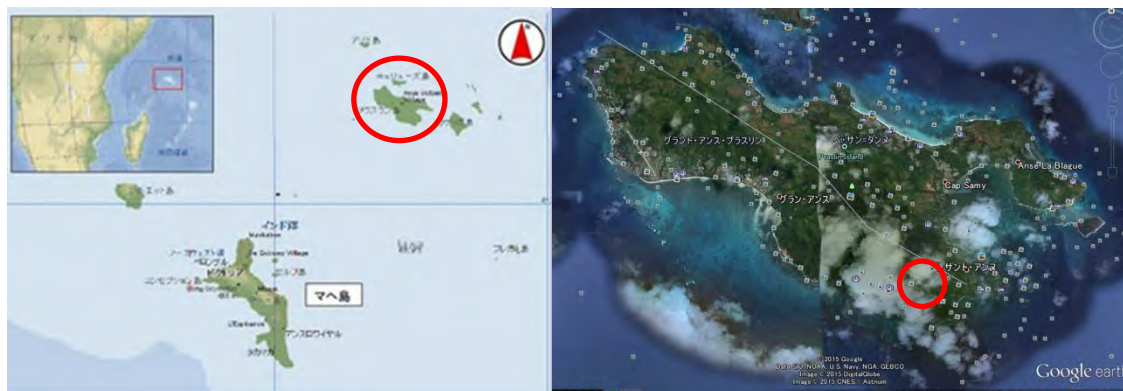


Figure 3.3.2-5 Power plant location: (Source: Google Earth)

Table 3.3.2-3 Praslin Power Plant generator specifications

Engine#	1P	2P	3P	4P
ENGINE MAKE	Blackstone	Blackstone	Blackstone	Blackstone
ENGINE MODEL	ESL8	ESL8	ESL8	ESL8
Rated output (kW)	670	670	670	670
Max. output (kW)	450	450	450	0
SPEED (RPM)	750	750	750	750
YEAR INSTALLED	1981	1981	1981	1990
Engine#	M4	M5	M6	5P
ENGINE MAKE	Caterpillar	Caterpillar	Cummins	Wartsila
ENGINE MODEL	3516	3516	KTA50G3	W6L32
Rated output (kW)	1,400	1,200	1,000	2,500
Maximum output (kW)	1,200	1,100	1,000	2,500
SPEED (RPM)	1,500	1,500	1,500	750
YEAR INSTALLED	1999	2000	2013	2015
Engine#	6P	7P	8P	
ENGINE MAKE	Wartsila	Wartsila	Wartsila	
ENGINE MODEL	6SW280	12SW280	12SW280	
Rated output (kW)	1,500	3,000	3,000	
Max. output (kW)	1,400	2,500	2,500	
SPEED (RPM)	750	750	750	
YEAR INSTALLED	1996	2003	2003	

Reference Information

Operating conditions:

- Droop control
- Capable of operating at a minimum of 30% of rated output (only for a short time)
- The annual peak load is approx. 8MW.

2) Load trend

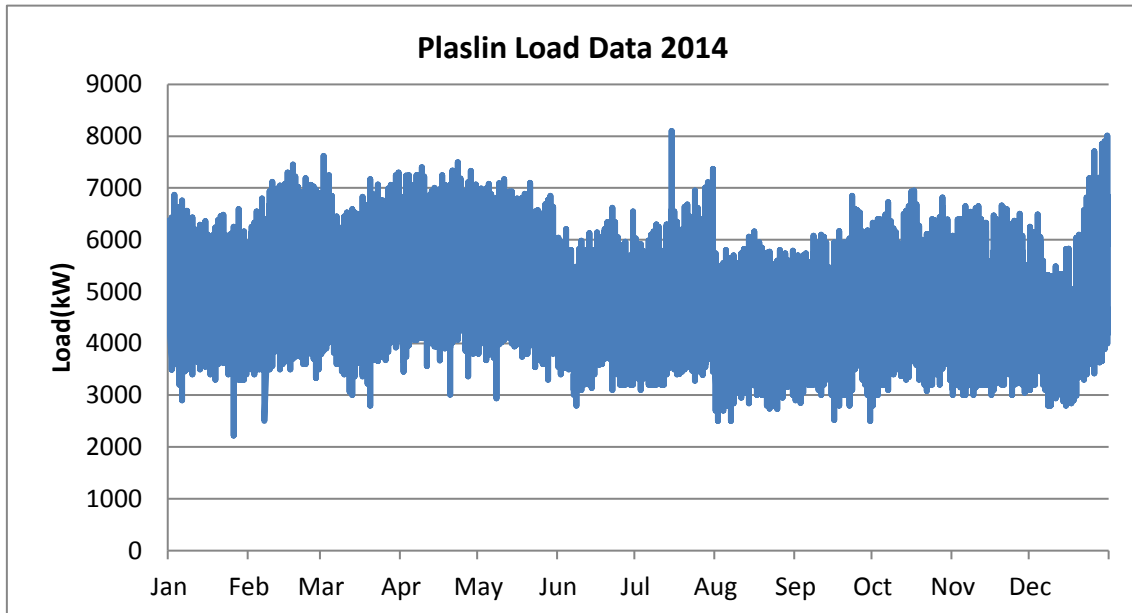


Figure 3.3.2-6 Praslin load trend (2014) hourly data

3) Solar irradiance data

By specifying Mahe's location in HOMER Pro, the solar irradiance data to be used will be downloaded and imported to HOMER Pro.

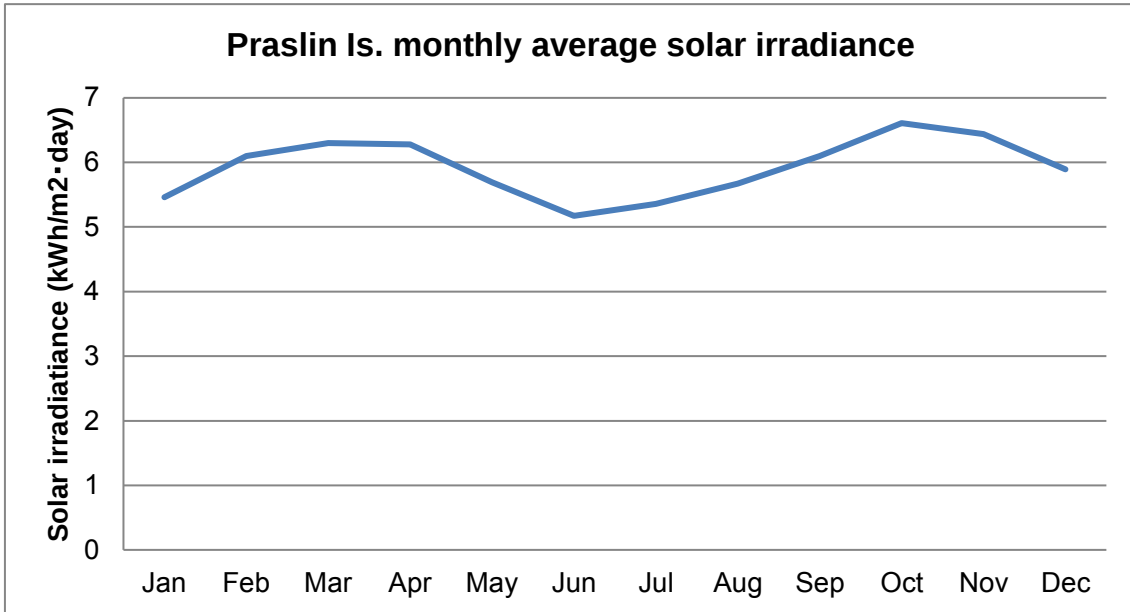


Figure 3.3.2-7 Praslin solar irradiance data

* For solar irradiance data required to perform the trial calculations for the amount PV generated power, 8,760 hours' worth of data for hourly values is loaded in HOMER, a simulation software.

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

4) Wind speed data

By specifying Praslin's location in HOMER, the wind speed data to be used will be downloaded and imported to HOMER. However, since wind speed varies depending on region, it must actually be measured.

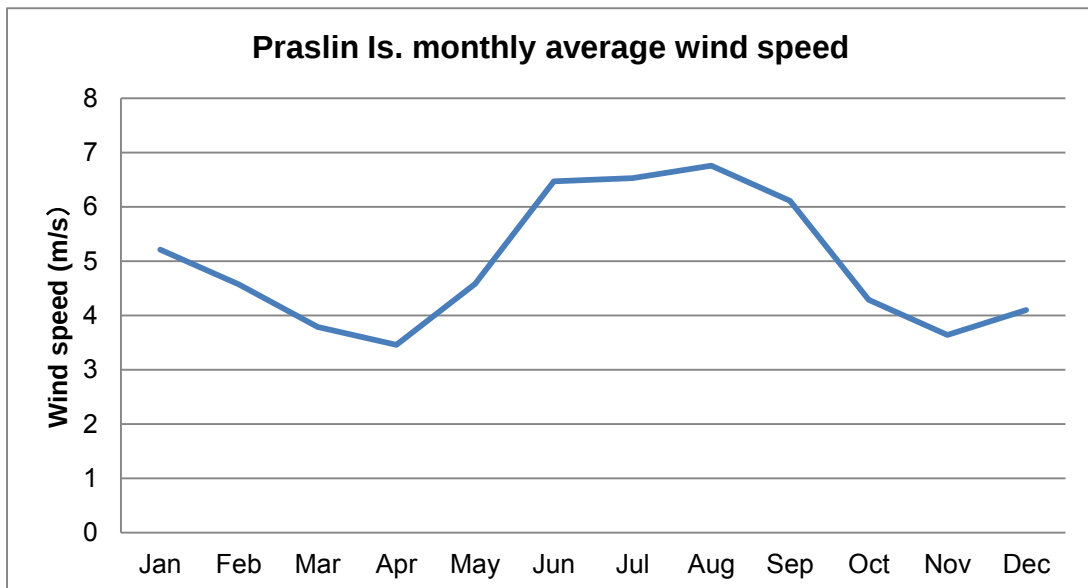


Figure 3.3.2-8 Praslin wind speed data

(3) Desroches

1) Status of the power plant

Details of the plant are as follows.



Figure 3.3.2-9 Power plant location: (Source: Google Earth)

Table 3.3.2-4 Desroches Power Plant generator specifications

Engine#	1	2	3
ENGINE MAKE	Caterpillar		
ENGINE MODEL	800F	800F	800F
NAMEPLATE RATING (kW)	580	580	580
Max. output (kW)	580	580	580
SPEED (RPM)	1,500	1,500	1,500
YEAR INSTALLED	—	—	—

Operating range: Unknown However, estimated at 20% or more based on 2014 operating data for each unit.

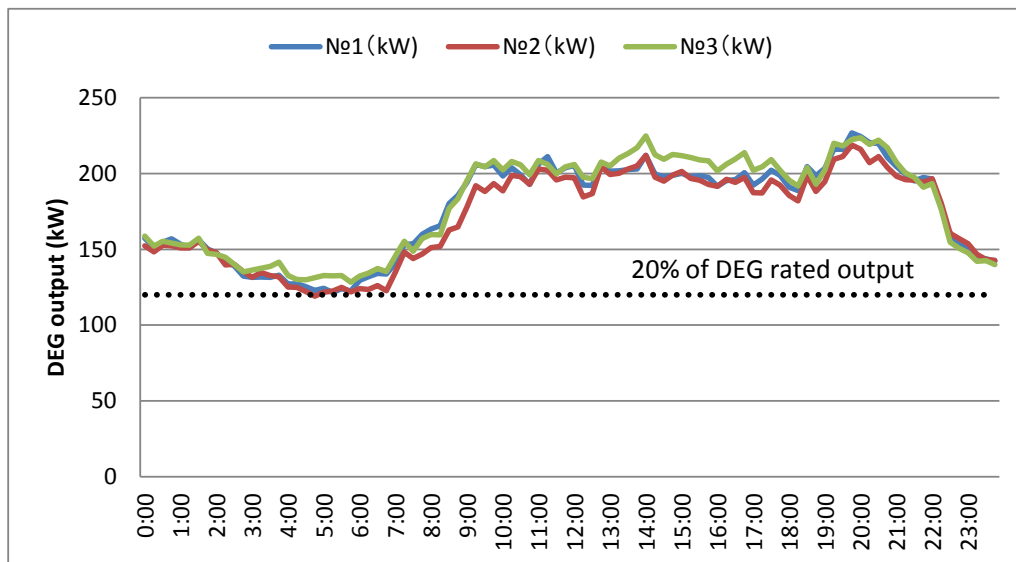


Figure 3.3.2-10 Operating data for each unit

Reference Information

Operating conditions:

- Control method: isochronous, load sharing
- Capable of operating at a minimum of 20% of rated output (only for a short time)
- The annual peak load is approx. 550kW.

2) Load trend

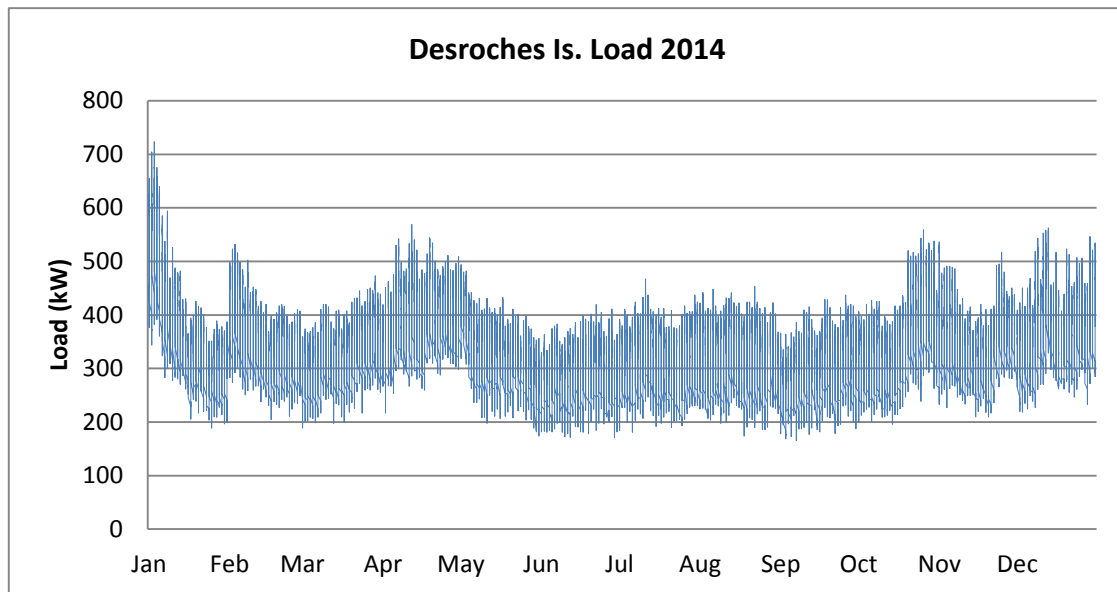


Figure 3.3.2-11 Desroches load trend (2014) hourly data

3) Solar irradiance data

By specifying Desroches' location in HOMER, the solar irradiance data to be used will be downloaded and imported to HOMER.

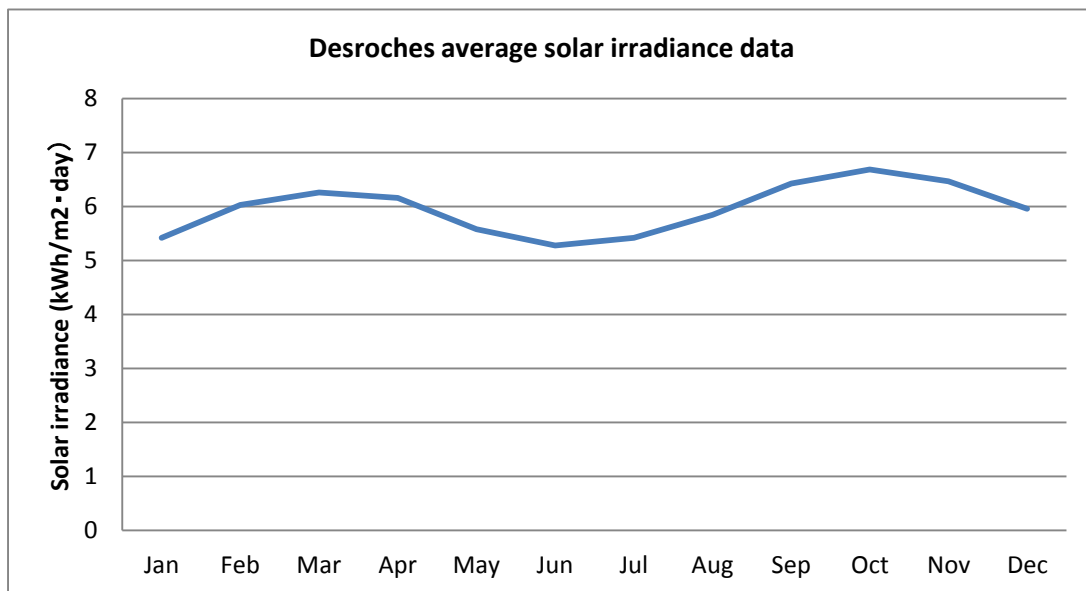


Figure 3.3.2-12 Desroches solar irradiance data

* For solar irradiance data required to perform the trial calculations for the amount PV generated power, 8,760 hours' worth of data for hourly values is loaded in HOMER, simulation software.

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

4) Wind speed data

By specifying Desroches' location in HOMER Pro, the wind speed data to be used will be downloaded and imported to HOMER Pro. However, since wind speed varies depending on region, it must actually be measured.

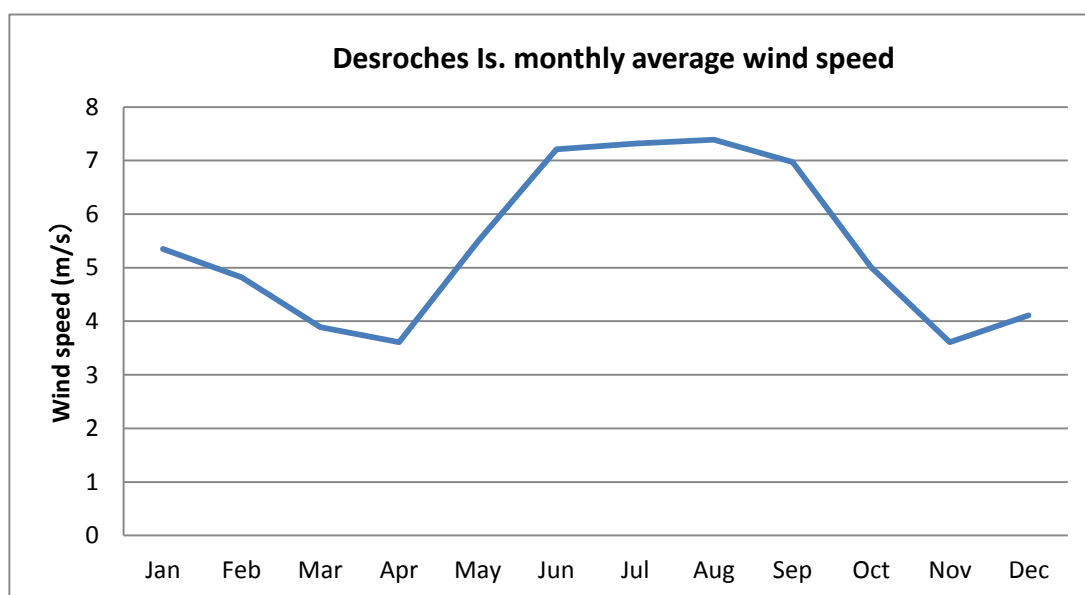


Figure 3.3.2-13 Desroches average wind speed data

3.3.3 Sites for PV installation (proposed)

(1) Mahe

1) List of sites for PV installation

From the field survey results, candidate PV installation sites were as follows.

Table 3.3.3-1 Candidate PV installation sites for Mahe

Target sites	Area available for installation	Max. installable PV capacity
a: Islands with wind turbines installed	Approx. 190,000m ²	5,000 kW
b: Victoria C Power Plant building roof	Approx. 3,000 m ²	300 kW
c: Lagoon	Approx. 60,000m ²	6,000 kW

2) Islands with wind turbines installed

Concerning installation sites for the hybrid system, sites where control and operation can be performed easily, such as on power plant premises on remote islands, are preferable. However, there is an uninhabited island near Mahe Island which already has wind turbines installed with a remote monitoring system, so we believe installing a hybrid system there would also be effective.



Figure 3.3.3-1 Islands with wind turbines installed

SketchUp layout schematic



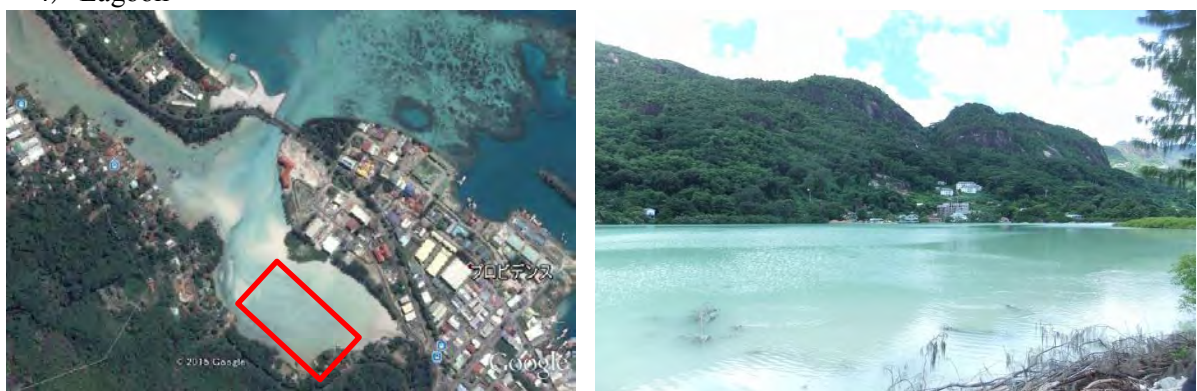
Figure 3.3.3-2 Schematic of PV installed on an island with wind turbines installed

3) Power plant building roof



Victoria C Power Plant premises

4) Lagoon



Lagoon

* Lagoon is a candidate 4 MW PV installation site for an IPP.

(2) Praslin

1) List of sites for PV installation

From the field survey results of the remote islands, candidate PV installation sites were as follows.

Table 3.3.3-2 Candidate PV installation sites for Praslin

Target sites	Area available for installation	Max. installable PV capacity
a: Power plant building roof	Approx. 1,500m ²	150 kW
b: PUC desalination plant	Approx. 500m ²	50 kW

2) Power plant building roof

Concerning installation sites for the hybrid system, sites where control and operation can be performed easily, such as on power plant premises on remote islands, are preferable. The large-scale deployment of renewable energy is desired, but it is assumed that the scale will be limited to within the power plant premises for the time being.



Figure 3.3.3-3 Power plant building roof



SketchUp layout schematic



Figure 3.3.3-4 Schematic of installation on power plant building roof

3) PUC desalination plant



PUC desalination plant materials yard

* Appears to be a suitable site as it is PUC-owned land, and PUC staff are stationed at the seawater desalination plant.

(3) La Digue

1) List of sites for PV installation

From the field survey results of the remote islands, candidate PV installation sites were as follows.

Table 3.3.3-3 Candidate PV installation sites for La Digue

Target sites	Area available for installation	Max. installable PV capacity
a. La Digue school	Approx. 2,000m ²	100 kW
b. LOGAN HOSPITAL	Approx. 300m ²	30 kW

2) La Digue School

There are almost no public facilities on La Digue Island, and among those, since La Digue School has a large roof, it is a promising installation site.



SketchUp layout schematic



Figure 3.3.3-5 Schematic of installation on school building roof

3) Logan Hospital



Logan Hospital

(4) Curieuse

1) List of sites for PV installation

From the field survey results of the remote islands, candidate PV installation sites were as follows.

Table 3.3.3-4 Candidate PV installation sites for Curieuse

Target sites	Area available for installation	Max. installable PV capacity
a. Nesting area for sea turtles	Approx. 300m ²	30 kW

2) Nesting area for sea turtles

Curieuse Island is used as a sea turtle protection island, and there are no residents other than the rangers, and the only residential area is the rangers' quarters. Therefore, PV installation sites would be limited to the residential area.



SketchUp layout schematic



Figure 3.3.3-6 Schematic of installation on the protected area

(5) Desroches

1) List of sites for PV installation

From the field survey results of the remote islands, candidate PV installation sites were as follows.

Table 3.3.3-5 Candidate PV installation sites for Desroches

Target sites	Area available for installation	Max. installable PV capacity
a. Vacant land beside the runway	Approx. 10,000 m ²	1,000 kW

2) Vacant land beside the runway

There appears to be no problems as a PV installation site as it is close to power plants, which makes maintenance easier, and it is land owned by IDC. However, it appears studies on the impact of reflection to airplanes as it is close to the runway and on the impact of shadows cast by the trees covering it are needed.



SketchUp layout schematic



Figure 3.3.3-7 Schematic of installation on the vacant land beside the runway

3.3.4 Supply-demand balance simulation

3.3.4.1 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 the processing of hourly load fluctuations, solar irradiance, and wind speed, the so-called long-period fluctuation analysis. Short period output changes, etc. within one hour, e.g. a few seconds or minutes, are not included.

Regarding whether or not such short-period fluctuations are acceptable to the power system, see "3.1 Aid with evaluation method to determine the RE integration capacity."

HOMER Pro, a simulation software used widely around the world, is recommended as a tool for evaluation.

HOMER Pro calculates the energy balance of each time zone for one year or 8,760 hours to simulate. HOMER Pro 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 Pro 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. Construction costs, replacement costs, maintenance costs, fuel costs, interest, and other expenses are considered when calculating the cost of the system.

Optimization

Once simulations of all possible system configurations have been completed, HOMER Pro 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 Pro repeats the optimization process for each sensitivity variable specified. For example, if wind speed is defined as a sensitivity variable, HOMER Pro simulates the system configuration for the wind speed range specified by the user.

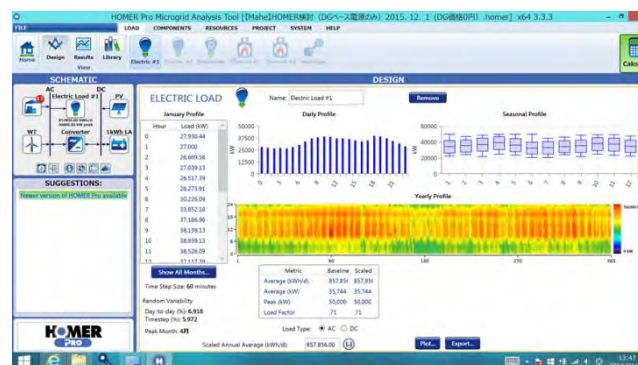


Figure 3.3.4-1 HOMER Pro screenshot

3.3.4.2 Simulation results for each remote island

The supply and demand balance simulation results for each remote island using HOMER Pro is shown below. The main input conditions for performing simulations with HOMER Pro are as follows.

Table 3.3.4-1 HOMER Pro input conditions

Input items		Mahe	Praslin	Curieuse	Desroches
System load		Measurement value	Measurement value	Expected value	Measurement value (Future expected value)
Solar irradiance		NASA data	NASA data	NASA data	NASA data
Wind speed		NASA data	NASA data	NASA data	NASA data
DEG	Capital (\$/kW)	1000	1000	—	0
	Replacement (\$/kW)	750	750	—	750
	O&M (\$/hr)	0.125	0.125	—	0.125
	Minimum Load (%)	50	50	—	50
	Lifetime (Hours)	175,000	175,000	—	175,000
	Fuel Price(\$ /L)	0.32 ¹	0.49 ²	—	1.23 ³
PV	Capital (\$/kW)	2,000 ⁴	2,000	2,500	2,500
	Replacement (\$/kW)	833	833	833	833
	O&M(\$ /year/kW)	0.042	0.042	0.042	0.042
	Lifetime (years)	25	25	25	25
WT	Capital (Yen/kW)	0	—	—	—
	Replacement (Yen/unit)	0	—	—	—
	O&M (\$/year/unit)	8,700	—	—	—
	Lifetime (years)	10	—	—	—
	Hub Height(m)	50	—	—	—
PCS	Capital (\$/kW)	500 ⁵	500	500	500
	Replacement (\$/kW)	500	500	500	500
	O&M (\$/year/kW)	0	0	0	0
	Lifetime (years)	15	15	15	15
	Efficiency (%)	90	90	90	90
BTB	Capital (\$/kWh)	500	500	500	500
	Replacement (\$/kWh)	500	500	500	500
	O&M (\$/year/kWh)	0	0	0	0
Economics	Discount rate(%)	8	8	8	8
	Inflation rate(%)	2	2	2	2
	Annual shortage (%)	0	0	0	0
	Project life time	25	25	25	25

¹ 0.32SCR(2016.3.16 HFO price)

² 0.49SCR (2016.3.16 LFO price)

³ 1.23SCR (SEYPEC jan price)

⁴ Seychelles market average price

⁵ Seychelles market average price

(1) Mahe Island

HOMER Pro simulation results for Mahe Island are as follows.

Table 3.3.4.2 Simulation results (Mahe)

Components				electricity tariff	Power generation amount	excess of energy	PV generation rate	WT generation rate	RE	RE max	cost
RE implementation (kW)	PV(kW)		WT(kW)	\$ / kWh	kWh	%	%	%	%	%	\$
	PUC	Domestic									
7,200	0	1,200	6,000	0.232	313,118,144	0.0	0.66	2.89	3.55	24.4	0
8,200	1,000	1,200	6,000	0.232	313,365,056	0.0	1.21	2.88	4.09	26.2	2,300,000
9,200	2,000	1,200	6,000	0.233	313,611,904	0.1	1.76	2.88	4.64	28.8	4,600,000
10,200	3,000	1,200	6,000	0.233	313,858,816	0.1	2.32	2.88	5.20	34.0	6,900,000
11,200	4,000	1,200	6,000	0.233	314,105,824	0.1	2.87	2.88	5.75	34.0	9,200,000
12,200	5,000	1,200	6,000	0.233	314,352,640	0.1	3.41	2.87	6.28	36.6	11,500,000
13,200	6,000	1,200	6,000	0.233	314,599,616	0.2	3.96	2.87	6.83	39.3	13,800,000
14,200	7,000	1,200	6,000	0.234	314,846,400	0.2	4.51	2.87	7.38	41.9	16,100,000
15,200	8,000	1,200	6,000	0.234	315,093,408	0.2	5.06	2.87	7.93	44.5	18,400,000
16,200	9,000	1,200	6,000	0.234	315,340,320	0.2	5.60	2.87	8.47	47.1	20,700,000
17,200	10,000	1,200	6,000	0.234	315,588,032	0.3	6.15	2.86	9.01	49.7	23,000,000
18,200	11,000	1,200	6,000	0.235	315,836,896	0.3	6.69	2.86	9.55	52.4	25,300,000
19,200	12,000	1,200	6,000	0.235	316,086,528	0.3	7.24	2.86	10.10	55.0	27,600,000
20,200	13,000	1,200	6,000	0.235	316,338,784	0.3	7.78	2.86	10.64	57.6	29,900,000
21,200	14,000	1,200	6,000	0.235	316,596,576	0.4	8.32	2.85	11.17	60.2	32,200,000
22,200	15,000	1,200	6,000	0.235	316,863,328	0.4	8.86	2.85	11.71	62.8	34,500,000
23,200	16,000	1,200	6,000	0.236	317,142,912	0.4	9.40	2.85	12.25	65.5	36,800,000
24,200	17,000	1,200	6,000	0.236	317,435,776	0.5	9.93	2.85	12.78	68.6	39,100,000
25,200	18,000	1,200	6,000	0.236	317,748,736	0.5	10.46	2.84	13.30	71.6	41,400,000
26,200	19,000	1,200	6,000	0.236	318,088,960	0.6	11.00	2.84	13.84	74.7	43,700,000
27,200	20,000	1,200	6,000	0.237	318,463,776	0.7	11.53	2.84	14.37	77.8	46,000,000
28,200	21,000	1,200	6,000	0.237	318,882,176	0.7	12.06	2.83	14.89	80.8	48,300,000
29,200	22,000	1,200	6,000	0.237	319,357,376	0.8	12.58	2.83	15.41	83.9	50,600,000
30,200	23,000	1,200	6,000	0.237	319,900,928	1.0	13.10	2.82	15.92	86.9	52,900,000
31,200	24,000	1,200	6,000	0.238	320,519,296	1.1	13.62	2.82	16.44	90.0	55,200,000
32,200	25,000	1,200	6,000	0.238	321,218,208	1.3	14.13	2.81	16.94	93.0	57,500,000
33,200	26,000	1,200	6,000	0.238	321,998,944	1.5	14.63	2.81	17.44	96.1	59,800,000
34,200	27,000	1,200	6,000	0.239	322,856,640	1.7	15.12	2.80	17.92	99.1	62,100,000
35,200	28,000	1,200	6,000	0.239	323,794,272	2.0	15.62	2.79	18.41	102.2	64,400,000
36,200	29,000	1,200	6,000	0.240	324,805,664	2.3	16.10	2.78	18.88	105.2	66,700,000
37,200	30,000	1,200	6,000	0.240	325,886,912	2.6	16.58	2.77	19.35	108.3	69,000,000

① Study results

We conducted simulations on supply and demand balance if 1,000 - 30,000 kW of PV were deployed taking into account 1,200 kW of PV deployed by the private sector and 6 MW of wind turbines owned by PUC. By increasing the deployment of PV, electric rates tend to increase. This is due to the decline in fuel prices. In addition, the long-period PV integration capacity is expected to be approximately 10,000 kW, which is a penetration rate of more than 50% (maximum). When deploying more than 10,000 kW of PV, long-period measures such as batteries should be considered. Therefore, aiming for deployments of 10,000 kW of PV, which requires no batteries, is recommended on Mahe Island. Furthermore, long-period capacity of 10,000 kW of PV mentioned here refers to the deployment of distributed PV systems of 50 kW or less.

② Sensitivity analysis on fuel prices and electric rates

The correlation between fuel prices and electric rates if PV deployment increased was calculated using HOMER Pro. From the results, benefits from PV deployment were gained from fuel prices of approximately 0.8 USD/l (currently: 0.533 USD).

Table 3.3.4-3 Correlation between fuel prices and electric rates (Mahe)

Fuel cost (\$/L)	0.5	0.6	0.7	0.8	0.9	1
Actual	0.278	0.303	0.328	0.353	0.378	0.404
PV5,000kW(\$/kWh)	0.279	0.303	0.328	0.353	0.377	0.402
PV10,000kW(\$/kWh)	0.280	0.304	0.328	0.352	0.376	0.400
PV15,000kW(\$/kWh)	0.281	0.304	0.328	0.351	0.375	0.398
PV20,000kW(\$/kWh)	0.282	0.305	0.328	0.351	0.373	0.397

③ Correlation between battery deployment capacity and electric rates

From HOMER Pro results, PV integration capacity for the long-period constraints was calculated at approximately 10,000 kW. Therefore, a sensitivity analysis on the correlation of battery capacity and electric rates was conducted using HOMER Pro when deploying more than 10,000 kW of PV. As a result, electric rates tended to decrease when batteries were deployed.

Table 3.3.4-4 Correlation between battery capacity and electric rates (Mahe)

unit:US\$								
Cost of energy		unit	output limit	Long term issues battery implementation				
Battery system capacity		kWh	0	30,000	50,000	100,000	150,000	200,000
PCS output		kW	0	30,000	50,000	100,000	150,000	200,000
RE implementation	WT	PV						
現状	6,000	1,200	0.232	-	-	-	-	-
計画	-	-	-	-	-	-	-	-
1,000	0	1,000	0.232	-	-	-	-	-
2,000	0	2,000	0.233	-	-	-	-	-
3,000	0	3,000	0.233	-	-	-	-	-
4,000	0	4,000	0.233	-	-	-	-	-
5,000	0	5,000	0.233	-	-	-	-	-
6,000	0	6,000	0.233	-	-	-	-	-
7,000	0	7,000	0.234	-	-	-	-	-
8,000	0	8,000	0.234	-	-	-	-	-
9,000	0	9,000	0.234	-	-	-	-	-
10,000	0	10,000	0.234	0.233	0.236	0.254	0.272	0.290
11,000	0	11,000	0.235	0.229	0.236	0.255	0.272	0.291
12,000	0	12,000	0.235	0.229	0.237	0.255	0.273	0.290
13,000	0	13,000	0.235	0.228	0.235	0.254	0.271	0.289
14,000	0	14,000	0.235	0.228	0.235	0.253	0.271	0.289
15,000	0	15,000	0.235	0.228	0.235	0.253	0.271	0.289
16,000	0	16,000	0.236	0.228	0.235	0.253	0.271	0.288
17,000	0	17,000	0.236	0.227	0.234	0.253	0.270	0.288
18,000	0	18,000	0.236	0.226	0.234	0.252	0.270	0.287
19,000	0	19,000	0.236	0.225	0.232	0.251	0.269	0.287
20,000	0	20,000	0.237	0.225	0.231	0.250	0.268	0.286
21,000	0	21,000	0.237	0.225	0.230	0.249	0.267	0.285
22,000	0	22,000	0.237	0.224	0.228	0.247	0.266	0.284
23,000	0	23,000	0.237	0.225	0.227	0.246	0.265	0.283
24,000	0	24,000	0.238	0.225	0.226	0.245	0.263	0.282
25,000	0	25,000	0.238	0.225	0.225	0.243	0.262	0.280
26,000	0	26,000	0.238	0.226	0.224	0.241	0.260	0.279
27,000	0	27,000	0.239	0.226	0.224	0.240	0.259	0.278
28,000	0	28,000	0.239	0.227	0.225	0.239	0.257	0.276
29,000	0	29,000	0.240	0.227	0.225	0.237	0.256	0.275
30,000	0	30,000	0.240	0.227	0.226	0.236	0.255	0.274

(2) (Praslin Island)

HOMER Pro simulation results for Praslin Island are as follows.

Table 3.3.4-5 Simulation results (Praslin)

Components		electricity tariff	Power generation amount	excess of energy	PV generation rate	RE	cost
RE implementation (kW)	PV(kW) IDC	\$ /kWh	kWh	%	%	%	\$
0	0	0.264	42,872,584	0.0	0.00	0.0	0
100	100	0.264	42,897,248	0.0	0.40	2.5	230,000
200	200	0.264	42,921,928	0.0	0.81	5.0	460,000
300	300	0.263	42,946,596	0.0	1.21	7.4	690,000
400	400	0.263	42,971,300	0.1	1.61	9.9	920,000
500	500	0.263	42,995,992	0.1	2.01	12.4	1,150,000
600	600	0.262	43,020,696	0.1	2.42	14.9	1,380,000
700	700	0.262	43,045,356	0.1	2.82	17.4	1,610,000
800	800	0.262	43,070,060	0.2	3.22	19.9	1,840,000
900	900	0.261	43,094,724	0.2	3.62	22.3	2,070,000
1,000	1,000	0.261	43,119,432	0.2	4.02	24.8	2,300,000
1,100	1,100	0.261	43,144,100	0.2	4.42	27.3	2,530,000
1,200	1,200	0.260	43,168,776	0.2	4.82	29.8	2,760,000
1,300	1,300	0.260	43,193,468	0.2	5.21	32.3	2,990,000
1,400	1,400	0.260	43,218,180	0.3	5.61	34.7	3,220,000
1,500	1,500	0.259	43,242,864	0.3	6.01	37.2	3,450,000
1,600	1,600	0.259	43,267,564	0.3	6.41	39.7	3,680,000
1,700	1,700	0.259	43,292,244	0.3	6.80	42.2	3,910,000
1,800	1,800	0.258	43,316,940	0.3	7.20	44.7	4,140,000
1,900	1,900	0.258	43,341,616	0.4	7.59	47.2	4,370,000
2,000	2,000	0.257	43,366,316	0.4	7.99	49.6	4,600,000
2,100	2,100	0.257	43,391,004	0.4	8.38	52.1	4,830,000
2,200	2,200	0.257	43,415,672	0.4	8.78	54.6	5,060,000
2,300	2,300	0.256	43,223,656	0.4	9.17	57.1	5,290,000
2,400	2,400	0.256	43,238,916	0.5	9.57	59.6	5,520,000
2,500	2,500	0.256	43,489,760	0.5	9.96	62.1	5,750,000
2,600	2,600	0.255	43,269,444	0.5	10.35	64.5	5,980,000
2,700	2,700	0.255	43,284,720	0.5	10.74	67.0	6,210,000
2,800	2,800	0.255	43,300,000	0.5	11.13	69.5	6,440,000
2,900	2,900	0.254	43,315,244	0.5	11.53	72.0	6,670,000
3,000	3,000	0.254	43,613,208	0.6	11.92	74.5	6,900,000

① Study results

We conducted a simulation on supply and demand balance if 100 kW - 3,000 kW of PV were deployed. Even if PV deployment were increased, electric rates remained the same. This is due to the decline in fuel prices. In addition, the long-period PV integration capacity is expected to be approximately 2,000 kW, which is a penetration rate of more than 50% (maximum). When deploying more than 2,000 kW of PV, long-period measures such as batteries should be considered. Therefore, aiming for deployments of 2,000 kW of PV, which requires no batteries, is recommended on Praslin Island. Furthermore, long-period capacity of 2,000 kW of PV mentioned here refers to the deployment of distributed PV systems of 50 kW or less.

② Correlation between battery deployment capacity and electric rates

From HOMER Pro results, PV integration capacity for the long-period constraints was calculated at approximately 2,000 kW. Therefore, a sensitivity analysis on the correlation of battery capacity and electric rates was conducted using HOMER Pro when deploying more than 2,000 kW of PV. As a result, electric rates tended to decrease with a battery capacity ranging 1,500 kWh – 2,000 kWh.

Table 3.3.4-6 Correlation between battery capacity and electric rates (Praslin)

unit : US \$

Cost of energy		unit	output limit	Long term issues battery implementation					
Battery system capacity		kWh	0	1,000	3,000	5,000	8,000	10,000	
PCS output		kW	0	1,000	3,000	5,000	8,000	10,000	
RE implementation	WT	PV							
現状	0	0	0.264	—	—	—	—	—	—
計画	—	—	—	—	—	—	—	—	—
100	0	100	0.264	—	—	—	—	—	—
200	0	200	0.264	—	—	—	—	—	—
300	0	300	0.263	—	—	—	—	—	—
400	0	400	0.263	—	—	—	—	—	—
500	0	500	0.263	—	—	—	—	—	—
600	0	600	0.262	—	—	—	—	—	—
700	0	700	0.262	—	—	—	—	—	—
800	0	800	0.262	—	—	—	—	—	—
900	0	900	0.261	—	—	—	—	—	—
1,000	0	1,000	0.261	—	—	—	—	—	—
1,100	0	1,100	0.261	—	—	—	—	—	—
1,200	0	1,200	0.260	—	—	—	—	—	—
1,300	0	1,300	0.260	—	—	—	—	—	—
1,400	0	1,400	0.260	—	—	—	—	—	—
1,500	0	1,500	0.259	—	—	—	—	—	—
1,600	0	1,600	0.259	—	—	—	—	—	—
1,700	0	1,700	0.259	—	—	—	—	—	—
1,800	0	1,800	0.258	—	—	—	—	—	—
1,900	0	1,900	0.258	—	—	—	—	—	—
2,000	0	2,000	0.257	0.254	0.257	0.262	0.269	0.275	
2,100	0	2,100	0.257	0.254	0.257	0.262	0.269	0.274	
2,200	0	2,200	0.257	0.254	0.256	0.261	0.269	0.274	
2,300	0	2,300	0.256	0.253	0.256	0.261	0.268	0.274	
2,400	0	2,400	0.256	0.253	0.256	0.261	0.268	0.273	
2,500	0	2,500	0.256	0.253	0.256	0.261	0.268	0.273	
2,600	0	2,600	0.255	0.252	0.255	0.260	0.267	0.273	
2,700	0	2,700	0.255	0.252	0.255	0.260	0.267	0.272	
2,800	0	2,800	0.255	0.252	0.255	0.260	0.267	0.272	
2,900	0	2,900	0.254	0.252	0.254	0.259	0.266	0.272	
3,000	0	3,000	0.254	0.251	0.254	0.259	0.266	0.271	

(3) Desroches Island

1) Study on current load

HOMER Pro simulation results for Desroches Island are as follows.

Table 3.3.4-7 Simulation results (Desroches)

Components		electricity tariff	Difference of electricity tariff	Power generation amount	excess of energy	PV generation rate	RE	cost	electricity tariff savings	investment recovery
RE implementation	PV(kW) IDC	\$ /kWh	\$ /kWh	kWh	%	%	%	\$	\$ /kWh	年
0	0	0.597			0.0	0.00	0.0	0		
10	10	0.596	0.001	2,972,472	0.7	0.59	2.8	28,000	2,972	10
20	20	0.595	0.002	2,975,077	0.7	1.17	5.6	56,000	5,950	10
30	30	0.594	0.003	2,977,858	0.8	1.76	8.5	84,000	8,934	10
40	40	0.593	0.004	2,980,565	0.8	2.34	11.3	112,000	11,922	10
50	50	0.592	0.005	2,983,536	0.9	2.92	14.1	140,000	14,918	10
60	60	0.591	0.006	2,986,574	0.9	3.51	16.9	168,000	17,919	10
70	70	0.590	0.007	2,989,585	0.9	4.09	19.7	196,000	20,927	10
80	80	0.590	0.007	2,992,604	1.0	4.66	22.5	224,000	20,948	11
90	90	0.589	0.008	2,995,911	1.1	5.24	25.4	252,000	23,967	11
100	100	0.588	0.009	2,999,512	1.1	5.82	28.2	280,000	26,996	11
110	110	0.588	0.009	3,003,287	1.2	6.39	31.0	308,000	27,030	12
120	120	0.587	0.010	3,006,968	1.3	6.96	33.8	336,000	30,070	12
130	130	0.587	0.010	3,010,220	1.3	7.53	36.6	364,000	30,102	13
140	140	0.586	0.011	3,014,242	1.4	8.10	39.5	392,000	33,157	12
150	150	0.585	0.012	3,017,994	1.5	8.67	42.3	420,000	36,216	12
160	160	0.585	0.012	3,021,284	1.5	9.24	45.1	448,000	36,255	13
170	170	0.584	0.013	3,024,576	1.6	9.81	47.9	476,000	39,319	13
180	180	0.584	0.013	3,027,970	1.6	10.37	50.7	504,000	39,364	13
190	190	0.584	0.013	3,030,734	1.7	10.94	53.6	532,000	39,400	14
200	200	0.583	0.014	3,034,014	1.7	11.50	56.4	560,000	42,476	14
210	210	0.583	0.014	3,037,246	1.8	12.06	59.2	588,000	42,521	14
220	220	0.582	0.015	3,040,473	1.8	12.62	62.0	616,000	45,607	14
230	230	0.582	0.015	3,042,647	1.9	13.19	64.8	644,000	45,640	15
240	240	0.582	0.015	3,045,296	1.9	13.75	67.6	672,000	45,679	15
250	250	0.581	0.016	3,047,397	1.9	14.31	70.5	700,000	48,758	15
260	260	0.581	0.016	3,049,407	1.9	14.88	73.3	728,000	48,791	15
270	270	0.580	0.017	3,051,010	1.9	15.44	76.1	756,000	51,867	15
280	280	0.580	0.017	3,053,120	1.9	16.00	78.9	784,000	51,903	16
290	290	0.579	0.018	3,055,697	1.9	16.56	81.7	812,000	55,003	15
300	300	0.579	0.018	3,058,179	2.0	17.12	84.6	840,000	55,047	16

① Study results

We conducted a simulation on supply and demand balance if 10 kW - 3,000 kW of PV were deployed. By increasing the deployment of PV, electric rates tended to decrease. This is due to fuel prices are higher (\$1.23) compared to Mahe Island, Praslin, etc. In addition, the long-period PV integration capacity is expected to be approximately 180 kW, which is a penetration rate of more than 50% (maximum). When deploying more than 180 kW of PV, long-period measures such as batteries should be considered. Therefore, aiming for deployments of 180 kW of PV, which requires no batteries, is recommended on Desroches Island. Furthermore, long-period capacity of 180 kW of PV mentioned here refers to the deployment of distributed PV systems of 50 kW or less.

In addition, in terms of the optimal PV deployment, it would be good to first deploy 70 kW of PV, the amount with the lowest investment payback time (10 years), and increase deployment while gaining operation and maintenance experience.

Thus, we recommend 70kW for PV deployment on Desroches Island. The ratio of PV supplied power to power supply in this case is 4.09%.

② Correlation between battery deployment capacity and electric rates

From HOMER Pro results, PV integration capacity for the long-period constraints was calculated at approximately 180 kW. Therefore, a sensitivity analysis on the correlation of battery capacity and electric rates was conducted using HOMER Pro when deploying more than 180 kW of PV. As a result, electric rates tended to decrease with a battery capacity ranging 150 kWh – 200 kWh.

Table 3.3.4-8 Correlation between battery capacity and electric rates (Desroches)

Unit :US\$							
COE	unit	ouput restriction	Long term issues battery implementation				
Battery	kWh	0	100	150	200	250	300
PCS	kW	0	100	150	200	250	300
RE implement	PV						
Actual	0	0.597	-	-	-	-	-
Plan			-	-	-	-	-
10	10	0.596	-	-	-	-	-
20	20	0.595	-	-	-	-	-
30	30	0.594	-	-	-	-	-
40	40	0.593	-	-	-	-	-
50	50	0.592	-	-	-	-	-
60	60	0.591	-	-	-	-	-
70	70	0.590	-	-	-	-	-
80	80	0.590	-	-	-	-	-
90	90	0.589	-	-	-	-	-
100	100	0.588	-	-	-	-	-
110	110	0.588	-	-	-	-	-
120	120	0.587	-	-	-	-	-
130	130	0.587	-	-	-	-	-
140	140	0.586	-	-	-	-	-
150	150	0.585	-	-	-	-	-
160	160	0.585	-	-	-	-	-
170	170	0.584	-	-	-	-	-
180	180	0.584	0.587	0.587	0.589	0.591	0.592
190	190	0.584	0.587	0.586	0.588	0.590	0.592
200	200	0.583	0.587	0.586	0.587	0.589	0.591
210	210	0.583	0.587	0.585	0.587	0.589	0.591
220	220	0.582	0.587	0.585	0.586	0.588	0.590
230	230	0.582	0.587	0.585	0.586	0.588	0.590
240	240	0.582	0.588	0.585	0.585	0.587	0.589
250	250	0.581	0.588	0.584	0.585	0.587	0.588
260	260	0.581	0.588	0.584	0.584	0.586	0.588
270	270	0.580	0.588	0.584	0.584	0.585	0.587
280	280	0.580	0.589	0.584	0.583	0.585	0.587
290	290	0.579	0.589	0.584	0.583	0.584	0.586
300	300	0.579	0.590	0.584	0.582	0.584	0.585

③ Proposed system configuration

Diesel generators + new PV (70 kW)

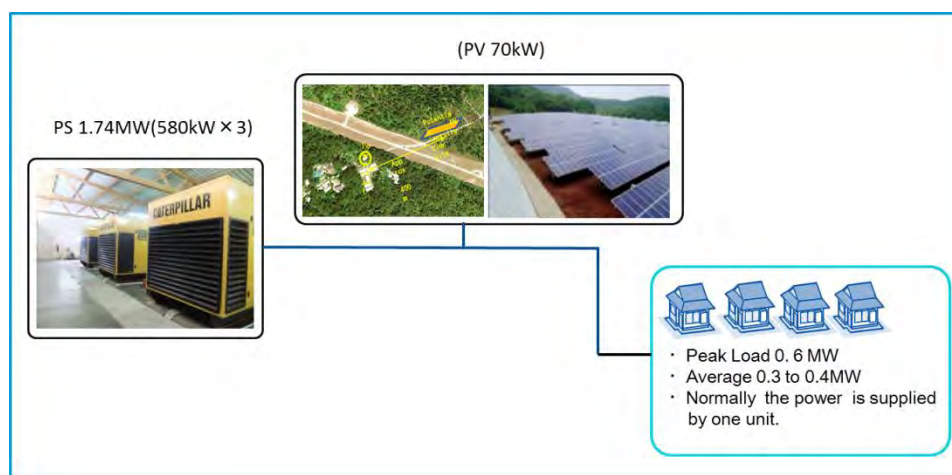


Figure 3.3.4-2 System configuration (proposed)

2) Study on future load

In the 3rd Field Survey, IDC reported that the system load on Desroches Island is expected to grow from the current peak load of 600 kW to approximately 2,000kW as there are plans for the construction of hotels and other facilities. In addition, since the existing diesel power generators are aging, they plan to replace all of them. Therefore, we conducted a simulation on the optimal diesel generator capacity and number of units and the optimal PV deployment capacity assuming the system load increased to 2,000 kW using HOMER Pro.

The HOMER Pro simulation results are as follows.

i) Study on the optimal diesel generator capacity and number of units

Table 3.3.4-5 Simulation results (Desroches)

DG1	DG2	DG3	DG4	Dispatch	Cost/COE (\$)
750	750	750		LF	0.550
750	750	750	750	LF	0.555
1000	1000	1000		LF	0.577
1000	1000	1000	1000	LF	0.583
1500	1500			LF	0.580
1500	1500	1500		LF	0.589
1500	1500	1500	1500	LF	0.598
2000	2000			LF	0.684
2000	2000	2000		LF	0.696

<Study results>

Simulations on combinations of diesel generator capacities ranging 750-2000 kW and 2-4 units were conducted, and the optimal combination was 750 kW x 3 units. Therefore, for diesel generators, a deployment of 750 kW x 3 units is recommended.

ii) Study on the optimal PV capacity

A simulation on the optimal PV capacity if the optimal diesel generator combination of 750 kW $\times$ 3 units were deployed was conducted. The HOMER Pro simulation results are as follows.

PV (kW)	DEG1 (kW)	DEG2 (kW)	DEG3 (kW)	Converter (kW)	Dispatch	Cost/COE (\$)
450	750	750	750	300	LF	0.534
450	750	750	750	300	CC	0.534
450	750	750	750	270	LF	0.534
450	750	750	750	270	CC	0.534
450	750	750	750	240	LF	0.535
450	750	750	750	240	CC	0.535
450	750	750	750	210	LF	0.537
450	750	750	750	210	CC	0.537
450	750	750	750	180	LF	0.539
450	750	750	750	180	CC	0.539
450	750	750	750	150	LF	0.541
450	750	750	750	150	CC	0.541
450	750	750	750	120	LF	0.544
450	750	750	750	120	CC	0.544
450	750	750	750	90	LF	0.547
450	750	750	750	90	CC	0.547
450	750	750	750	60	LF	0.551
450	750	750	750	60	CC	0.551
450	750	750	750	30	LF	0.556
450	750	750	750	30	CC	0.556

<Study results>

The optimal combination for a diesel generator capacity of 750 kW $\times$ 3 units for the power system was 450 kW PV + 300 kW PCS. In addition, by deploying 450 kW of PV, electric rates would be cheaper than if no PV were deployed.

(No PV deployment: 0.55 USD; PV 450 kW: 0.534 USD)

Thus, a PV deployment of 450 kW is recommended for Desroches Island assuming an increase in load.

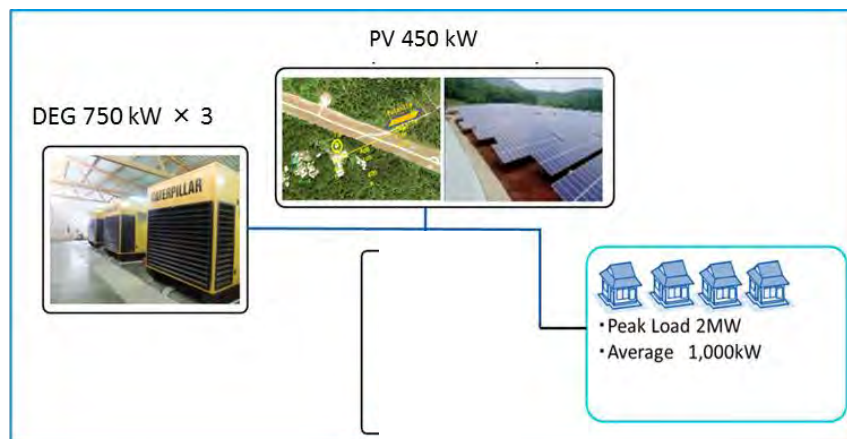


Figure 3.3.4-5 System configuration (proposed)

(4) Curieuse Island

Curieuse Island differs from other islands as there are no power plants. The power there is currently supplied by small diesel generators, but considering fuel transport and maintenance, a system which combines PV and batteries is considered optimal moving forward. Therefore, HOMER Pro was used to examine an optimal system.

HOMER Pro simulation results for Curieuse Island are as follows.

Table 3.3.4-6 Simulation results (Curieuse)

Components			electricity tariff	Amount of power generation	excess of energy	PV gen. rate	cost
PV (kW)	CON (KW)	BTT (kWh)	\$ /kWh	kWh	%	%	\$
40	10	350	1.16	69,290	40.2	100	280,000
40	15	350	1.17	69,290	40.2	100	282,500
40	20	350	1.18	69,290	40.2	100	285,000
50	10	300	1.19	86,612	52.3	100	280,000
25	25	350	1.19	69,290	40.2	100	287,500
50	15	300	1.20	86,612	52.3	100	282,500
40	30	350	1.20	69,290	40.2	100	290,000
50	20	300	1.20	86,612	52.3	100	285,000
40	35	350	1.21	69,290	40.2	100	292,500
40	10	400	1.21	69,290	40.2	100	305,000

① Study results

A simulation on the optimal combination with 10-50 kW PV, 10-50 kW PCS, and 50-400 kWh BTT for PV deployment was conducted. The results showed that a system combining 40 kW of PV + 350 kWh of batteries + 10 kW PCS is the best in terms of electric rates.

Therefore, we recommend 40 kW PV + 350 kWh BTT + 10 kW PCS as a system for Curieuse Island.

The entire load for Curieuse Island and can be supplied with the PV in the system mentioned above. In addition, since Curieuse Island lacks a backup power supply in case the above system fails, installing a 10 kW diesel generator as emergency backup is recommended.

② Proposed system configuration

New (40 kW) PV + 350 kW BTT + 10 kW PCS

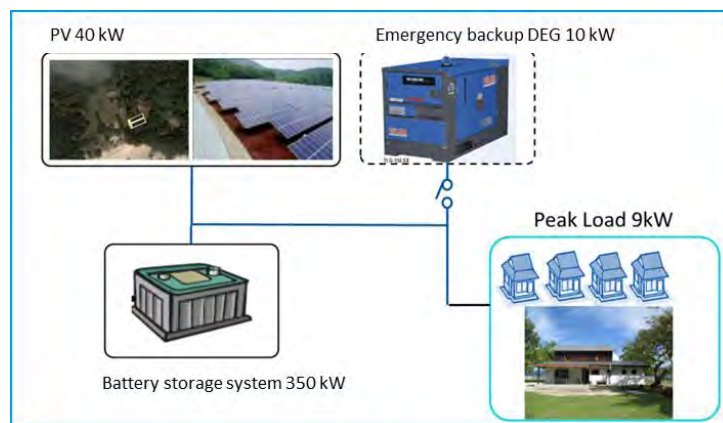


Figure 3.3.4-6 System configuration (proposed)

3.3.5 System design exercise

3.3.5.1 System design method

How to design 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 module serial connections, array configuration and layout, and a method to estimate the amount of power generated annually will be explained in Section 3.3.5.2.

In addition, trial calculation examples for Okinawa 1,000 kW and Mahe 1,000 kW are shown for reference in Sections 3.3.5.3 and 3.3.5.4.

The optimal tilt angle for SY is 5° as shown in the figure below.

Moreover, when the tilt angle is 30° or less, azimuth angle is not dependent on orientation 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.

Estimated Solar irradiance in Seychelles
Analysis of the relationship between the azimuth angle and tilt angle using Ret Screen software
Optimal direction and angle is azimuth 180° North, tilt angle 5°
From result analysis for 5° tilt inclination, there is only little influence in the azimuth

Estimated Solar irradiance according to the tilt angle and azimuth angle																				kWh/m ² ·year
Azimuth	Inclination angle																			
	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	
0° (South)	2,160	2,140	2,110	2,070	2,020	1,960	1,890	1,810	1,720	1,630	1,520	1,420	1,310	1,200	1,110	1,020	940	860	790	
±30°	2,160	2,150	2,120	2,080	2,040	1,980	1,920	1,840	1,760	1,680	1,580	1,490	1,390	1,300	1,200	1,110	1,030	950	880	
±60°	2,160	2,150	2,130	2,100	2,060	2,020	1,960	1,910	1,840	1,770	1,700	1,620	1,540	1,460	1,380	1,300	1,220	1,140	1,070	
±90°	2,160	2,150	2,140	2,120	2,090	2,050	2,010	1,960	1,990	1,840	1,770	1,700	1,630	1,550	1,480	1,400	1,320	1,240	1,170	
±120°	2,160	2,160	2,150	2,130	2,110	2,070	2,020	1,970	1,910	1,850	1,780	1,700	1,620	1,540	1,460	1,380	1,290	1,210	1,130	
±150°	2,160	2,160	2,160	2,140	2,110	2,070	2,020	1,960	1,890	1,820	1,740	1,650	1,550	1,460	1,380	1,260	1,170	1,070	990	
±180° (North)	2,160	2,170	2,160	2,140	2,110	2,070	2,020	1,950	1,880	1,800	1,710	1,610	1,510	1,400	1,290	1,180	1,090	1,000	910	

Comparison of the solar irradiance between the tilt angle and the optimal tilt angle

Comparison of the solar irradiance between the tilt angle and the optimal tilt angle																			
Azimuth	Inclination angle																		
	0°	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
±180° (North)	0.995	1	0.995	0.986	0.972	0.954	0.931	0.899	0.866	0.829	0.788	0.742	0.696	0.645	0.594	0.544	0.502	0.461	0.419

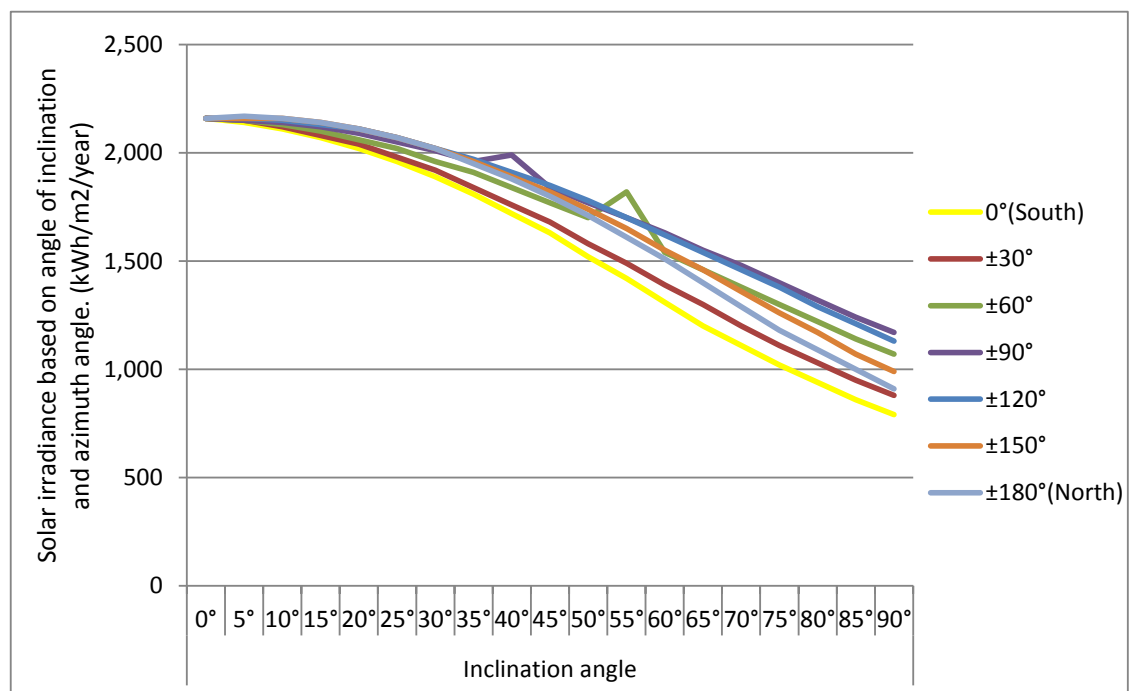


Figure 3.3.5-1 Relationship between tilt angle and azimuth angle in Seychelles

3.3.5.2 Mega solar facility planning [practice exercise]

(1) The process of mega solar facility planning in this practice exercise

Planning for a 1 MW mega solar facility will be conducted in this exercise. In planning the mega solar facility, data on natural conditions, such as solar irradiance and temperature in each country, will be used. In addition, environmental conditions (snowfall, etc.) in each country will also be considered.

Figure 3.3.5-2 shows facility plans for this exercise. In this exercise, facility planning for a 1 MW (power conditioner AC terminal) mega solar facility and trial calculations for its annual power generation will be conducted. Array frames and foundations are to be excluded. In addition, a study on system configuration for grid interconnection in each country will be conducted.

In actual facility planning, costs must be estimated after deciding on a system configuration to evaluate the economic feasibility, but this exercise will only go as far as examining system configuration.

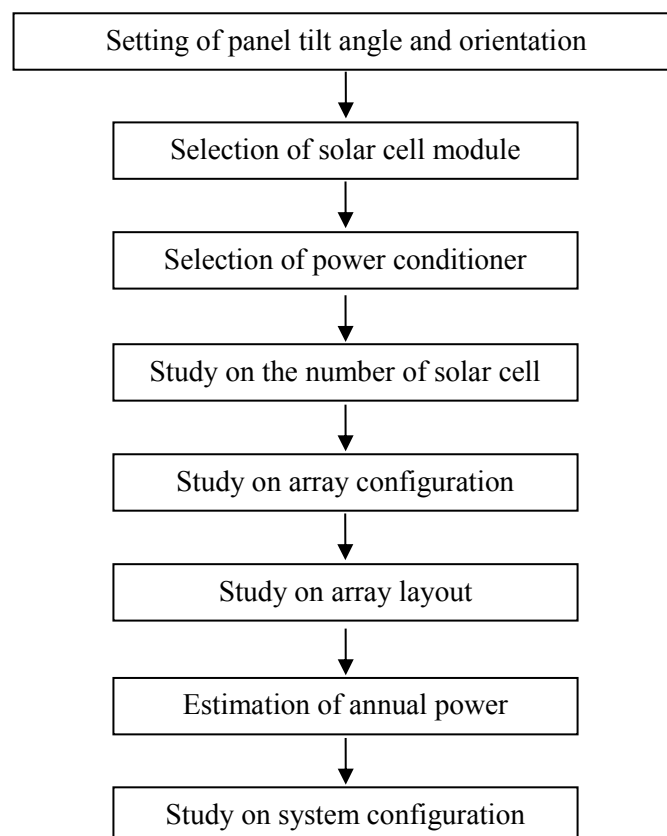


Figure 3.3.5-2 Mega solar facility planning steps

(2) Mega Solar Facility Planning

1) Selection of panel tilt angle and orientation

HOMER Pro (<https://users.homerenergy.com/>) or RETScreen (<http://www.etscreen.net/>) will be used to select the optimal panel angle and orientation for each country. Solar irradiance (average daily solar irradiance for each month) and average temperature (monthly) will be recorded.

2) Selection of solar cell module

Solar cell modules will be selected from the list of solar cell modules in Table 3.3.5-1.

Table 3.3.5-1 List of solar cell modules

	Solar cell module A	Solar cell module B	Solar cell module C	Solar cell module D
Type	Monocrystalline silicon (HIT Power 240S)	Polycrystalline silicon (KD250GX-LF B2)	Multi-junction hybrid (F-NJ150)	CIS (SF160-S)
Nominal maximum output (P_{max})	240W	240W	150W	160W
Module conversion efficiency:	19.0	14.6	9.60	12.6
Nominal maximum output operating voltage (V_{pm})	43.7V	29.3V	125.8V	84.0V
Nominal maximum output operating 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%/°C	+0.060%/°C	+0.055%/°C	+0.01%/°C
Temperature coefficient of open circuit voltage (V_{oc})	−0.24%/°C	−0.36%/°C	−0.39%/°C	−0.30%/°C
Temperature coefficient of maximum output (P_{max})	−0.30%/°C	−0.46%/°C	−0.35%/°C	−0.31%/°C

* The temperature coefficient of output operating voltage is the same as the temperature coefficient of open circuit voltage.

3) Selection of power conditioner

A power conditioner will be selected from the list of power conditioners in Table 3.3.5-2.

Table 3.3.5-2 List of power conditioners

		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	0-600 V	0~650V	0-600 V	0-600 V
	Maximum power tracking range	200-550 V	315-600 V	320-550 V	320-550 V
	Phase number	3-phase 3-wire	3-phase 3-wire	3-phase 3-wire	3-phase 3-wire
AC output	Rated voltage	202V	202V	415V	210V
	Rated frequency	50 or 60 Hz	50 or 60 Hz	50 or 60 Hz	50 or 60 Hz
	Power conversion efficiency	94.5%	95.3%	95.7%	96.8%

* The following website lists specifications of various solar modules and power conditioners, and it is useful in making selections. (<http://www.enfsolar.com/>)

4) Study on the number of solar cell module serial connections

Examine the number of solar cell module serial connections from the specifications of the solar cell module and power conditioner selected. For the number of serial connections, the value of maximum operating voltage of the solar cell module minus 110% of the power conditioner rated voltage (DC side) is the standard. In addition, the number of serial connections is ultimately determined considering the following points.

- Do changes due to the temperature characteristics of the string's open circuit voltage fall within the power conditioner's DC voltage range (not exceeding the upper limit of DC voltage range)?
 - Do changes due to the temperature characteristics of the string's output operating voltage fall within the power conditioner's maximum power load tracking range?
 - The highest and lowest module temperatures are calculated with the following formulas.
Highest module temperature = annual temperature high + weighted average solar cell module temperature increase ΔT
Minimum module temperature = annual temperature low + weighted average solar cell module temperature ΔT
- ※ Average weighted solar cell module temperature increase ΔT is set to 18.4 (°C) as the module is an open back type (frame installation type). (JIS C 8907 Method for estimating the amount of power generated by a PV system)

5) Consideration of array configuration

In the study on array configuration, the number of parallel connections for the strings within the array is decided, and then the number of columns and rows in which to arrange the solar cell modules is decided. If the size of the array is specified, the study will be conducted such that the configuration will fit into the specified size. The array will consist of a number of modules equal to an integer multiple of the determined number of serial connections.

[Array configuration conditions]

Condition 1: Array width shall not exceed 25 m. (Inspection efficiency considered)

Condition 2: Maximum array height shall not exceed 2.0 m from ground level.

(Should be reachable by hand)

The bottom of the panel shall be 0.5 m from ground level. (To minimize the impact of insects, small animals, and grass)

See Figure 3.3.5-3 (* Consideration of solar cell module thickness is not required)

Condition 3: There should be a space of 50 mm between solar cell modules and at the end of the modules. (Spaced with mounting brackets. There are cases of 10 mm if mounting brackets have been determined.)

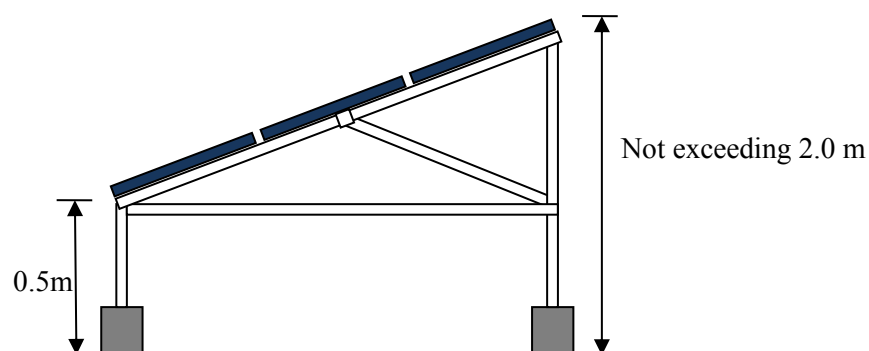


Figure 3.3.5-3 Array configuration condition 2

6) Study on array layout

The study on array layout will be conducted such that the number of arrays equals 1 MW (power conditioner AC terminal).

When determining the number of arrays, PCS conversion efficiency and DC loss (2%) shall be considered. The array deployment site should be assumed flat, and the layout should be made as square as possible.

[Array layout conditions]

Condition 1: 10 m × 10 m of space should be secured for the installation of the power collection board, PCS, transformer board, interconnection panel, etc.

Condition 2: The arrays oriented in the North-South direction are spaced such that each array is not affected by the shadow of the array in front of it. See Figure 3.3.5-4

Condition 3: The arrays oriented in the East-West direction shall be spaced at least 1.5 m apart. See Figure 3.3.5-5

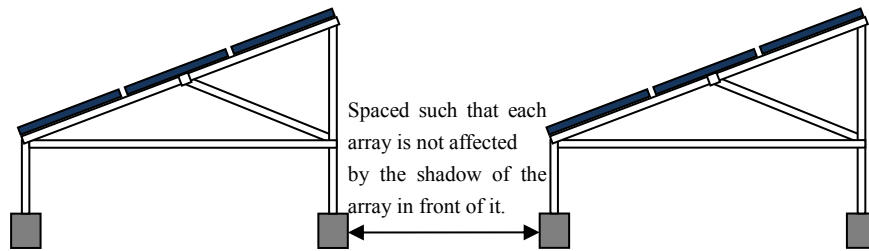


Figure 3.3.5-4 Array layout condition 2

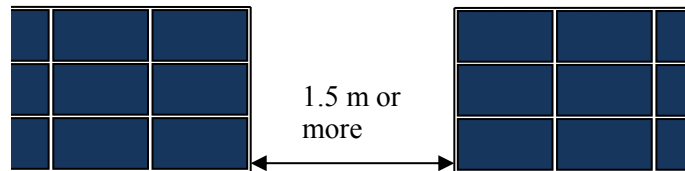


Figure 3.3.5-5 Array layout condition 3

7) Estimation of annual power generation

Annual power generation is estimated from PV array capacity.

The following equation is used to calculate the estimated annual power generation power (E_p).

$$E_p = \sum H_A / G_s \cdot K \cdot P_{AS}$$

- E_p = Estimated annual power generation (kWh/yr)
- H_A = Avg. monthly solar irradiance for installation surface (kWh/m²/day)
- G_s = Solar radiation intensity in the standard state (kW/m²) = 1 (kW/m²)
- K = General design coefficient = $K_d \cdot K_t \cdot \eta_{INV}$
 - * DC correction coefficient K_d :
Set at 0.9 considering compensation for soiling of the surface of the solar cell, compensation for losses due to variation in solar radiation intensity, and compensation for differences in solar cell characteristics.
 - * Temperature correction coefficient K_t :
Correction coefficient for variation in conversion efficiency due to the rise in the temperature of the solar cell caused by solar radiation

$$K_t = 1 + \alpha (T_m - 25) / 100$$
 - α : Temperature coefficient of maximum output (%/°C)
 - T_m : Module temperature (°C) = $T_{av} + \Delta T$
 - T_{av} : Avg. monthly temperature (°C)
 - ΔT : Module temperature rise (°C) = 18.4 (°C)
 - * PCS efficiency η_{INV} : Inverter DC-AC conversion efficiency
- P_{AS} = Standard state solar array output (kW)
Standard state: AM 1.5, solar radiation intensity 1 kW/m², solar cell temperature 25°C

8) Study on system configuration

As shown in the figure below, PV generation reaches 90% or more only for a few percent of the annual number of hours.

Therefore, generation will not exceed PCS rated output, but to effectively increase annual power generation, the installation should be oversized such that the total PV module output is 10% more than PCS rated capacity.

<Example>

PCS output = solar module output DC 9.88 kW × DC loss 98% (-2%)
 × PCS conversion efficiency 95% = AC 9.20kW

PCS output = solar module output DC 11.4 kW × DC loss 98% (-2%)
 X PCS conversion efficiency 95% = AC 10.61 kW → PCS rated output and in reality AC 10 kW

DC 9.88 kW - AC 10 kW	DC 11.4 kW - AC 10 kW
11,251 kWh/year	12,852 kWh/year
(9.88 kW × 8,760 h × 0.13)	(11.4 kW × 8,760 h × 0.13 × 0.99)

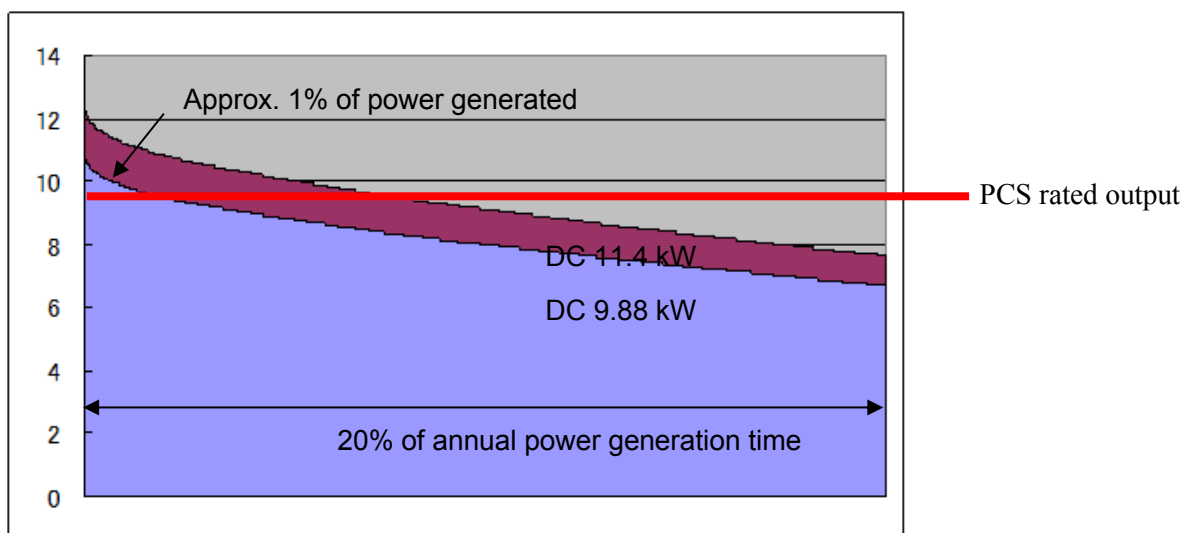


Figure 3.3.5-6 PV output duration curve (1-sec. measurement)

Other considerations in the study on system configuration are the specifications of equipment other than the PV array and PCS.

The number of circuits for the junction boxes and collection boards and the number of units required will be examined. 4, 8, 10, 12, or 16 circuits will be selected to calculate the required number of junction boxes.

For the junction boxes, 1 junction box shall be secured for each PCS unit, and the number of circuits required will be calculated accordingly.

In addition, a system configuration for grid interconnection in each country will be required (installation of transformers to step-up voltage to grid voltage, etc.).

3.3.5.3 Trial calculation example [Okinawa]

Planned mega solar installation site: [Country] Japan [Region] Naha

(1) Panel tilt angle 18°

Orientation South

Solar irradiance for the above tilt angle and orientation

Table 3.3.5-3 Annual solar irradiance

Month	Daily irradiance (kWh/m ² /day)	Air temp. (°C)
Jan	2.89	17.4
Feb	3.13	17.4
Mar	3.79	19.1
Apr	4.54	21.7
May	4.99	24.3
Jun	5.46	26.9
Jul	6.57	29.1
Aug	6.22	28.9
Sep	5.66	27.8
Oct	4.79	25.5
Nov	3.70	22.6
Dec	3.11	19.2
Annual	4.58	17.4

(2) Specifications of selected solar cell module

Table 3.3.5-4 Solar cell module specifications

	Solar cell module B
Type	Polycrystalline silicon
Nominal maximum output ($P_{\max}$)	240W
Module conversion efficiency:	14.6
Nominal maximum output operating voltage (V_{pm})	29.3V
Nominal maximum output operating 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%/°C
Temperature coefficient of open circuit voltage	−0.36%/°C
Temperature coefficient of maximum output	−0.46%/°C

(3) Specifications of selected power conditioner

Table 3.3.5-5 Power conditioner specifications

	PCS-A
Output capacity	10kW
DC input	Rated voltage
	400V
	DC voltage range
	0-600 V
AC output	Maximum power tracking range
	200-550 V
	Phase number
	3-phase 3-wire
AC output	Rated voltage
	202V
	Rated frequency
	50 or 60 Hz
	Power conversion efficiency
	94.5%

(4) Number of serial connections 16

String open circuit voltage (module temperature 25°C) : 590.4 V
(Maximum module temperature 54.0°C) : 528.76 V
(Minimum module temperature 25.0°C) : 590.40 V
String output operating voltage (module temperature 25°C) : 468.8 V
(Maximum module temperature 54.0°C) : 419.86 V
(Minimum module temperature 25.0°C) : 468.80 V

(Calculation)

1) Calculation of the number of serial connections based on power conditioner rated voltage and nominal maximum output voltage of the solar cell modules

Power conditioner rated voltage: 400 V, nominal maximum output voltage of the solar cell modules: 29.3 V

$$400 \text{ V} \times 1.1 = 440 \text{ V} \quad 440 \text{ V} \div 29.3 \text{ V} \approx 15.02 \approx \underline{16 \text{ serial connections}}$$

2) Calculation of the highest and lowest module temperatures

Naha temperature high: 35.6°C, Naha temperature low: 6.6°C

$$\text{Maximum module temperature} = 35.6 + 18.4 = \underline{54.0^\circ\text{C}}$$

$$\text{Minimum module temperature} = 6.6 + 18.4 = \underline{25.0^\circ\text{C}}$$

* Frame installation type weighted average = 18.4 (JIS C 8907)

3) Calculation of string open circuit voltage at the highest and lowest module temperatures

Temperature coefficient of solar cell module open circuit voltage: $-0.36\%/^\circ\text{C}$

$$\text{String open circuit voltage at a module temperature of } 25^\circ\text{C} \quad 36.9 \text{ V} \times 16 = \underline{590.4 \text{ V}}$$

String open circuit voltage at a module temperature of 54.0°C

$$590.4 \text{ V} \times \{1 - 0.0036 \times (54.0 - 25)\} \approx \underline{528.76 \text{ V}}$$

String open circuit voltage at the minimum module temperature (25.0°C)

$$590.4 \text{ V} \times \{1 - 0.0036 \times (25.0 - 25)\} = \underline{590.40 \text{ V}}$$

4) Calculation of string output operating voltage at the highest and lowest module temperatures

* Temperature coefficient of solar cell module output operating voltage: $-0.36\%/^\circ\text{C}$
(same as the temperature coefficient of open circuit voltage)

$$\text{String output operating voltage at a module temperature of } 25^\circ\text{C} \quad 29.3 \text{ V} \times 16 = \underline{468.8 \text{ V}}$$

String output operating voltage at the maximum module temperature (54.0°C)

$$468.8 \text{ V} \times \{1 - 0.0036 \times (54.0 - 25)\} \approx \underline{419.86 \text{ V}}$$

String output operating voltage at the minimum module temperature (25.0°C)

$$468.8 \text{ V} \times \{1 - 0.0036 \times (25.0 - 25)\} = \underline{468.80 \text{ V}}$$

(Verification of DC voltage range and maximum power tracking range)

DC voltage range: For a power conditioner DC voltage range of 0-600 V, string open circuit

voltage operates within a range of 537.7-553.6V, so there are no problems.

Maximum power tracking range: For a power conditioner DC voltage range of 200-550 V, string output operating voltage operates within a range of 419.86-468.80 V, so there are no problems.

(5) Array configuration 4 rows 12 columns (48 solar cell modules)

16 in series 3 in parallel

Array output 11.52 kW

Array size (W) 20.594 m × (L) 4.004 m (horizontal projection), max array height 1.801 m

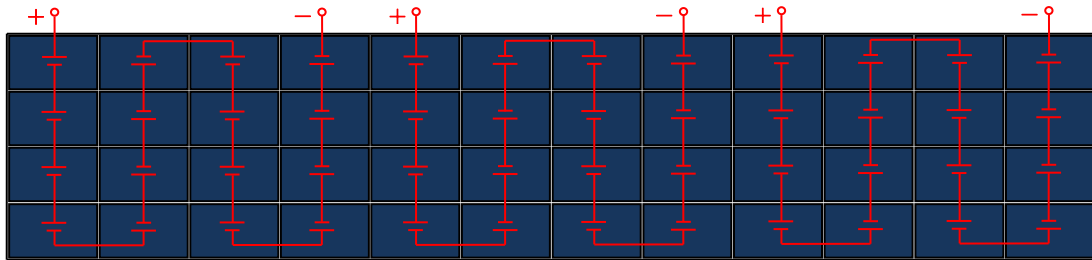


Figure 3.3.5-7 Array wiring schematic

(Calculation)

1) Calculation of the maximum number of rows and columns in the array

Maximum number of rows in the array a

Maximum array height: Not exceeding 2.0 m from the ground (panel is 0.5 m above ground at its lowest point), panel tilt angle: 18°

Solar module depth: 990 mm, $(2.0 \text{ m} - 0.5 \text{ m}) = 1.5 \text{ m}$

$1.5 \text{ m} \geq X \times \sin 18^\circ \Rightarrow 4.854 \text{ m} \geq X (\sin 18^\circ = 18 \times \pi / 180)$, $4.854 \div 0.99 \approx 4.9$ a = 4 rows

Maximum number of columns in the array b

Maximum array width: Not exceeding 25 m, Solar cell module width: 1,662 mm

$25 \div 1.662 \approx 15.1$ b = 15 columns

The maximum number of solar cell modules according only to array configuration conditions is 60 with 4 rows of 15 columns

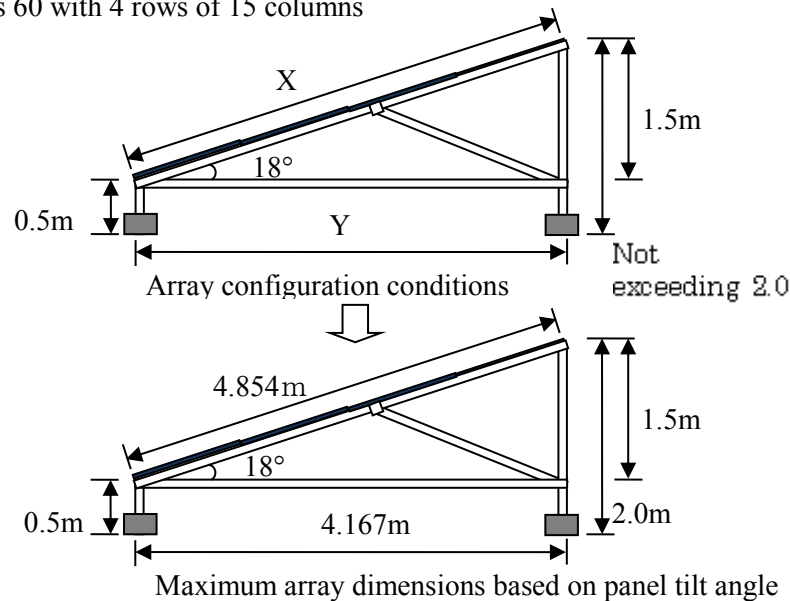


Figure 3.3.5-8 Array size

- 2) Calculation of the maximum number of parallel connections and number of modules from the number of serial connections

Maximum number of solar cell modules according only to array configuration conditions:

60

Number of serial connections: 16

$$60 \div 16 \approx 3.75 : \underline{3}$$

16 serial connections x 3 parallel connections = 48 modules

- 3) Calculation of array output from the number of modules

Solar cell module nominal maximum output: 240 W

$$240 \text{ W} \times 48 = 11,520 \text{ W} \Rightarrow \underline{11.52 \text{ kW}}$$

- 4) Calculation of the number of columns for the array from the number of modules

Number of modules: 48, Maximum number of rows: 4

$$48 \div 4 = 12 \quad \underline{12 \text{ columns}}$$

- 5) Calculation of array size from the number of rows and columns in the array

Panel surface dimensions: $(0.99 \times 4) + \{0.05 \times (4 + 1)\} = 4.21 \text{ m}$

Module depth: 990 mm, Space between solar cell modules and at the end of the modules: 50 mm

Maximum array height: $(4.21 \text{ m} \times \sin 18^\circ) + 0.5 \text{ m} = 1.801 \text{ m}$

Panel tilt angle: 18° , Height of panel bottom: 0.5 m above ground

Array depth L(horizontal projection): $4.21 \text{ m} \times \cos 18^\circ = 4.004 \text{ m}$

Array width W: $(1.662 \times 12) + \{0.05 \times (12 + 1)\} = 20.594 \text{ m}$

Module width: 1,662 mm

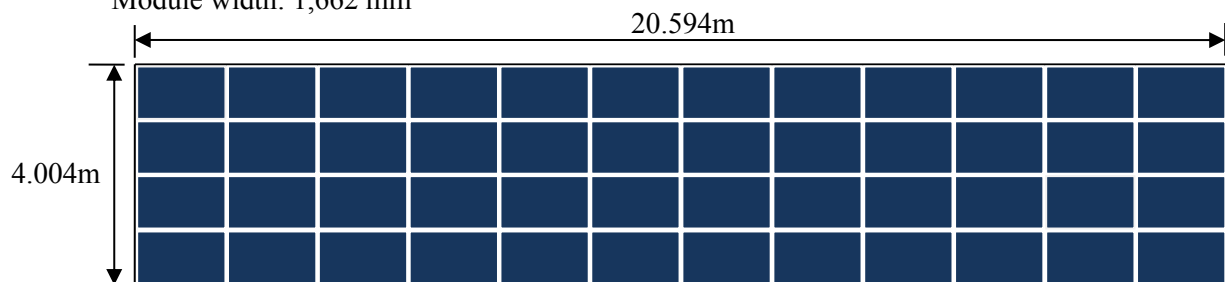


Figure 3.3.5-9 Array size (horizontal projection)

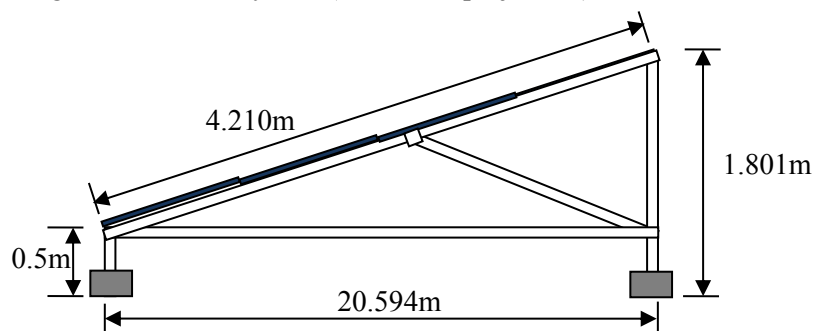


Figure 3.3.5-10 Array size

(6) Array layout

Number of arrays 100

Total output of the arrays 1,152 kW

(Calculation)

1) Calculation of total output of the arrays

$$11.52 \text{ kW} \times 100 = \underline{1,152 \text{ kW}}$$

2) Calculation of North-South direction shadow magnification

Naha latitude and longitude: 26.1312 N, 127.4048 E

Solar elevation h: 19.35°, Azimuth angle: 50.11 °

*Winter solstice (2012.12.21) 9:00 AM data, Azimuth angle is set at 0° S

Shadow magnification $R = LS/l = \cot h \times \cos \alpha -$

$$= \cot (19.35^\circ) \times \cos (50.11^\circ) = 1.826$$

(Length of shadow in North-South direction LS made by panel height L)

3) Calculation of array spacing in the North-South direction

Maximum array height: 1,801 m

$$(1.801 - 0.5) \times 1.826 \approx 2.375 \text{ m}$$

4) Array layout and total area

Examined with SketchUp which is used to design the layout in accordance with the site.

(7) Annual power generation

Annual power generation calculated using the RETScreen is shown in Table 3.3.5-6.

Table 3.3.5-6 Annual power generation

Month	Power generated (kWh)
Jan	75,760
Feb	79,720
Mar	106,110
Apr	127,780
May	142,370
Jun	148,980
Jul	174,980
Aug	159,650
Sep	137,570
Oct	117,970
Nov	86,460
Dec	77,220
Annual	1,434,560

* Annual power generation is the total of the estimated monthly power generation.

Annual power generation can be estimated using HOMER Pro

(<https://users.homerenergy.com/>) or RETScreen (<http://www.etscreen.net/>).

The operational calculation method is as follows.

(Calculation)

1) Calculation of estimated monthly power generation [Jan] (kWh/month)

Installation surface average solar irradiance H_A : 2.89 kWh/m²/day, Standard state solar radiation intensity G_s : 1 kW/m²

PCS conversion efficiency η_{INV} : 94.5%, DC correction coefficient K_d : 0.9, Maximum output temperature coefficient α :-0.46%/K

Average monthly temperature T_{av} : 17.4 °C, Weighted average solar cell module temperature increase ΔT : 18.4°C

Module temperature $T_m = T_{av} + \Delta T = 17.4 + 18.4 = 35.8^\circ\text{C}$

Temperature correction coefficient $K_t = 1 + \alpha (T_m - 25)/100 = 1 - 0.46(35.8 - 25)/100 = 0.95032$

General design coefficient $K = K_d \times K_t \times \eta_{INV} = 0.9 \times 0.95032 \times 0.945 = 0.808247$

Estimated monthly power generation $E_p = \Sigma H_A/G_s \times K \times P_{AS} = 31 \times 2.89/1 \times 0.808247 \times 1152 \approx \underline{83,417 \text{ kWh}}$

(8) Proposed system configuration

- Generation scale 1000 kW (AC)
- Number of arrays 100
- Array output 1152 kW (DC)
- Number of PCS units 100

3.3.5.4 Trial calculation example [Mahe]

Planned mega solar installation site: [Country] Seychelles [Region] Mahe

(1) Panel tilt angle 5°

Orientation North

Solar irradiance for the above tilt angle and orientation

Table 3.3.5-7 Annual solar irradiance and temperature (Mahe)

Month	Daily irradiance (kWh/m ² /day)	Air temp. (°C)	Avg. temp. high (°C)	Avg. temp. low (°C)
Jan	5.32	27.0	29.8	24.1
Feb	6.00	27.7	30.4	24.6
Mar	6.29	28.0	31.0	24.8
Apr	6.38	28.3	31.4	25.0
May	5.87	27.9	30.5	25.4
Jun	5.37	26.7	29.1	24.6
Jul	5.55	26.1	28.3	23.9
Aug	5.79	26.0	28.4	23.9
Sep	6.13	26.7	29.1	24.2
Oct	6.53	27.1	29.6	24.3
Nov	6.27	27.1	30.1	24.0
Dec	5.71	27.1	30.0	23.9
Annual	5.93	27.1	29.8	24.4

(2) Specifications of selected solar cell module

Table 3.3.5-8 Solar cell module specifications

	Solar cell module B
Type	Polycrystalline silicon
Nominal maximum output ($P_{\max}$)	240W
Module conversion efficiency:	14.6
Nominal maximum output operating voltage (V_{pm})	29.3V
Nominal maximum output operating 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%/°C
Temperature coefficient of open circuit voltage	−0.36%/°C
Temperature coefficient of maximum output	−0.46%/°C

(3) Specifications of selected power conditioner

Table 3.3.5-9 Power conditioner specifications

	PCS-A
Output capacity	10kW
DC input	Rated voltage
	400V
	DC voltage range
	0-600 V
AC output	Maximum power tracking range
	200-550 V
	Phase number
	3-phase 3-wire
AC output	Rated voltage
	202V
	Rated frequency
	50 or 60 Hz
	Power conversion efficiency
	94.5%

(4) Number of serial connections 16

String open circuit voltage (module temperature 25°C) : 590.4 V
 (Maximum module temperature 48.6°C) : 540.24 V
 (Minimum module temperature 43.0°C) : 552.14 V
 String output operating voltage (module temperature 25°C) : 468.8 V
 (Maximum module temperature 48.6°C) : 428.97 V
 (Minimum module temperature 43.0°C) : 438.42 V

(Calculation)

- 1) Calculation of the number of serial connections based on power conditioner rated voltage and nominal maximum output voltage of the solar cell modules

Power conditioner rated voltage: 400 V, nominal maximum output voltage of the solar cell modules: 29.3 V

$$400 \text{ V} \times 1.1 = 440 \text{ V} \quad 440 \text{ V} \div 29.3 \text{ V} \approx 15.02 \approx \underline{16 \text{ serial connections}}$$

- 2) Calculation of the highest and lowest module temperatures

Mahe temperature high: 31.4°C, Majuro temperature low: 23.9°C

$$\text{Maximum module temperature} = 31.4 + 18.4 = \underline{49.8^\circ\text{C}}$$

$$\text{Minimum module temperature} = 23.9 + 18.4 = \underline{42.3^\circ\text{C}}$$

3) Calculation of string open circuit voltage at the highest and lowest module temperatures

Temperature coefficient of solar cell module open circuit voltage: $-0.36\%/^{\circ}\text{C}$

String open circuit voltage at a module temperature of 25°C $36.9 \text{ V} \times 16 =$
590.4 V

String open circuit voltage at a module temperature of 49.8°C

$590.4 \text{ V} \times \{1 - 0.0036 \times (49.8 - 25)\} \approx$ 537.7 V

String open circuit voltage at the minimum module temperature (42.3°C)

$590.4 \text{ V} \times \{1 - 0.0036 \times (42.3 - 25)\} \approx$ 553.6 V

4) Calculation of string output operating voltage at the highest and lowest module temperatures

* Temperature coefficient of solar cell module output operating voltage: $-0.36\%/^{\circ}\text{C}$
 (same as the temperature coefficient of open circuit voltage)

String output operating voltage at a module temperature of 25°C $29.3 \text{ V} \times 16 =$
468.8 V

String output operating voltage at the maximum module temperature (49.8°C)

$468.8 \text{ V} \times \{1 - 0.0036 \times (49.8 - 25)\} \approx$ 426.9 V

String output operating voltage at the minimum module temperature (42.3°C)

$468.8 \text{ V} \times \{1 - 0.0036 \times (42.3 - 25)\} =$ 439.6V

(Verification of DC voltage range and maximum power tracking range)

DC voltage range: For a power conditioner DC voltage range of 0-600 V, string open circuit voltage operates within a range of 537.7-553.6 V, so there are no problems.

Maximum power tracking range: For a power conditioner DC voltage range of 200-550 V, string output operating voltage operates within a range of 426.9-439.6 V, so there are no problems.

(5) Array configuration 4 rows 12 columns (48 solar cell modules)

16 serial connections 3 parallel connections

Array output 11.52 kW

Array size (W) 20.594 m $\times$ (L) 4.194 m (horizontal projection), max array height 0.867 m

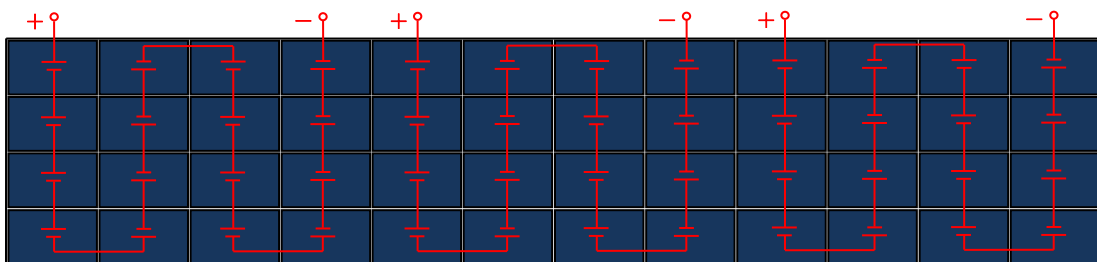


Figure 3.3.5-11 Array wiring schematic

(Calculation)

1) Calculation of the maximum number of rows and columns in the array

Maximum number of rows in the array a

Maximum array height: Not exceeding 2.0 m from the ground (panel is 0.5 m above ground at its lowest point), panel tilt angle: 5°

Solar module depth: 990 mm, $(2.0 \text{ m} - 0.5 \text{ m}) = 1.5 \text{ m}$

$1.5 \text{ m} \geq X \times \sin 5^\circ \Rightarrow 17.21 \text{ m} \geq X$ ($\sin 5^\circ = 5 \times \pi/180$), $17.21 \div 0.99 \approx 17.273$ a = 17 rows → 4 rows

Maximum number of columns in the array b

Maximum array width: Not exceeding 25 m, Solar cell module width: 1,662 mm

$25 \div 1.662 \approx 15.1$ b = 15 columns

The maximum number of solar cell modules according only to array configuration conditions is 60 with 4 rows of 15 columns

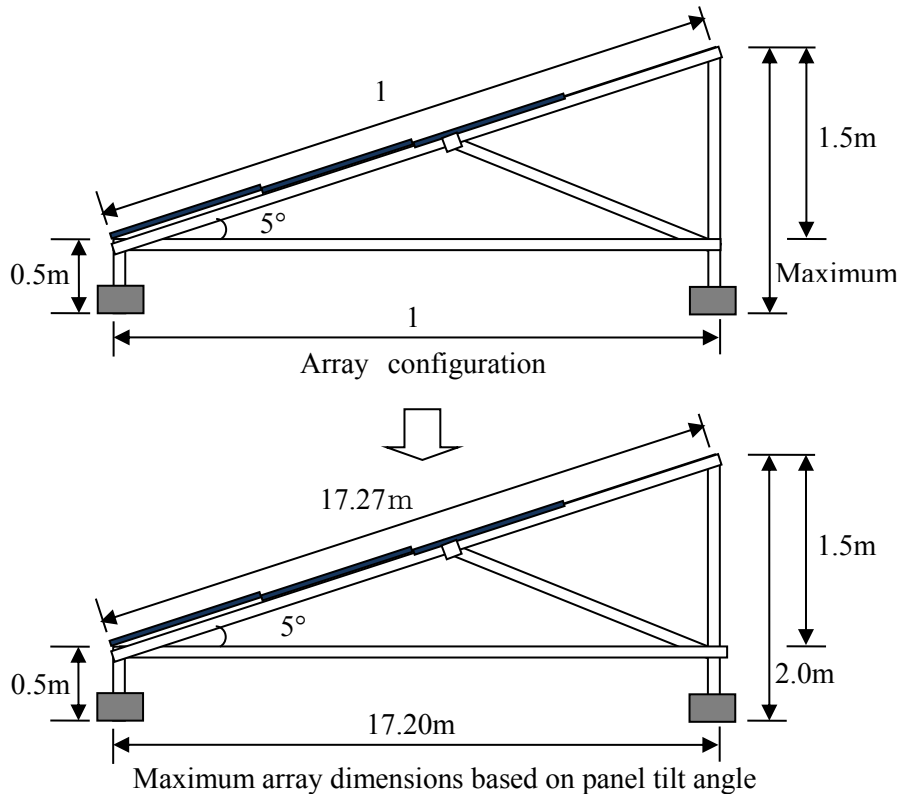


Figure 3.3.5-12 Array size

2) Calculation of the maximum number of parallel connections and number of modules from the number of serial connections

Maximum number of solar cell modules according only to array configuration conditions: 60

Number of serial connections: 16

$60 \div 16 \approx 3.75$ 3

16 serial connections x 3 parallel connections = 48 modules

3) Calculation of array output from the number of modules

Solar cell module nominal maximum output: 240 W

$$240 \text{ W} \times 48 = 11,520 \text{ W} \Rightarrow \underline{11.52 \text{ kW}}$$

4) Calculation of the number of columns for the array from the number of modules

Number of modules: 48, Maximum number of rows: 4

$$48 \div 4 = 12 \quad \underline{12 \text{ columns}}$$

5) Calculation of array size from the number of rows and columns in the array

Panel surface dimensions: $(0.99 \times 4) + \{0.05 \times (4 + 1)\} = 4.210 \text{ m}$

(Module depth: 990 mm, Space between solar cell modules and at the end of the modules: 50 mm)

$$\text{Maximum array height: } (4.210 \text{ m} \times \sin 5^\circ) + 0.5 \text{ m} = \underline{0.867 \text{ m}}$$

(Panel tilt angle: 5° , Height of panel bottom: 0.5 m above ground)

$$\text{Array depth L (horizontal projection)} : 4.210 \text{ m} \times \cos 5^\circ = \underline{4.194 \text{ m}}$$

$$\text{Array width W: } (1.662 \times 12) + \{0.05 \times (12 + 1)\} = \underline{20.594 \text{ m}}$$

(Module width: 1,662 mm)

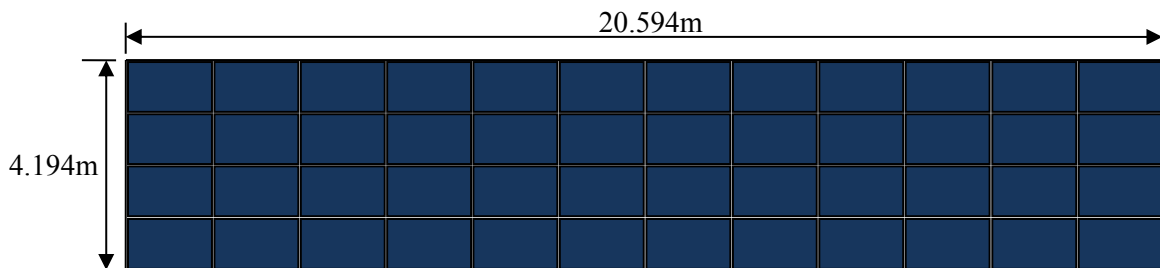


Figure 3.3.5-13 Array size (horizontal projection)

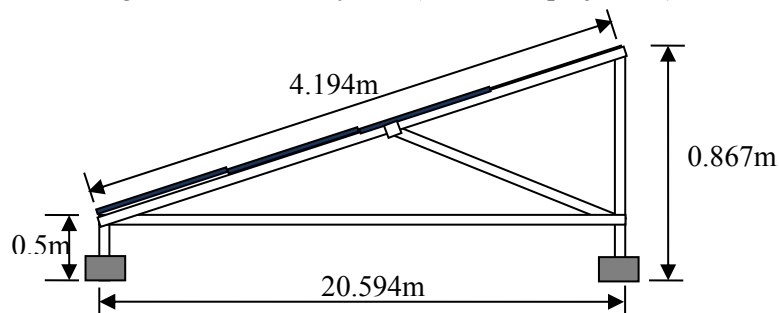


Figure 3.3.5-14 Array size

(6) Array layout

Number of arrays 100

Total output of the arrays 1,152 kW

(Calculation)

1) Calculation of total output of the arrays

$$11.52 \text{ kW} \times 100 = \underline{1,152 \text{ kW}}$$

2) Calculation of North-South direction shadow magnification

Examined with SketchUp which is used to design the layout in accordance with the site.

The operational calculation method is as follows.

Mahe latitude & longitude: 4.6230 S, 55.4553 N

Solar elevation h: 33.78°, Azimuth angle: 122.32°

*Winter solstice (2015.6.22) 9:00 AM data, Azimuth angle is set at 0°S

Shadow magnification $R = L_s/l = \cot h \times \cos \alpha = \cot (33.78^\circ) \times \cos (122.32^\circ) = 0.995$

(Length of shadow in North-South direction L_s made by panel height L)

3) Calculation of array spacing in the North-South direction

Maximum array height: 0.867m

$(0.867 - 0.5) \times 0.995 \approx \underline{0.365\text{m}}$

4) Array layout and total area

Examined with SketchUp which is used to design the layout in accordance with the site.

(7) Annual power generation

Annual power generation calculated using the RETScreen is shown in Table 3.3.5-10.

Table 3.3.5-10 Annual power generation

Month	Power generated (kWh)
Jan	163,800
Feb	165,100
Mar	190,800
Apr	186,600
May	178,400
Jun	159,500
Jul	170,500
Aug	177,700
Sep	181,000
Oct	198,100
Nov	184,700
Dec	174,900
Annual	2,131,200

* Annual power generation is the total of the estimated monthly power generation.

Annual power generation can be estimated using HOMER Pro (<https://users.homerenergy.com/>) or RETScreen (<http://www.etscreen.net/>).

The operational calculation method is as follows.

(Calculation)

1) Calculation of estimated monthly power generation [Jan] (kWh/month)

Installation surface average solar irradiance H_A : 5.32 kWh/m²/day, Standard state solar radiation intensity G_s : 1 kW/m²

PCS conversion efficiency η_{INV} : 94.5%, DC correction coefficient K_d : 0.9, Maximum output temperature coefficient α :- -0.46%/K

Average monthly temperature T_{av} : 27.0 °C , Weighted average solar cell module temperature increase ΔT : 18.4°C

Module temperature $T_m = T_{av} + \Delta T = 27.0 + 18.4 = 45.4^\circ\text{C}$

Temperature correction coefficient $K_t = 1 + \alpha (T_m - 25)/100$
 $= 1 - 0.46(45.4 - 25)/100 = 0.90616$

General design coefficient $K = K_d \times K_t \times \eta_{INV} = 0.9 \times 0.90616 \times 0.945 = 0.77069$

Estimated monthly power generation $E_p = \frac{\Sigma H_A/G_s \times K \times P_{AS}}{1152} = \frac{31 \times 5.32/1 \times 0.77069}{1152} \approx 146,421 \text{ kWh}$

(8) Proposed system configuration

- Generation scale 1,000 kW (AC)
- Number of arrays 100
- Array output 1,152 kW (DC)
- Number of PCS units 100

3.3.6 Layout design method (SketchUp)

As a layout design method for PV arrays, we recommend Google SketchUp, a free software used around the world.

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.

With this layout design method, we conducted a deployment planning exercise where a 10 kW PV array is deployed on an island off the coast of Victoria, which has existing wind turbines (750 kw $\times$ 5 units), considering the impact of shadows cast by the wind turbines. Moreover, using the size of the results of the trial calculation example from Section 3.3.5-4, the PV array was set to a tilt angle to 5°, and for azimuth, the topography of the land was considered to ensure the layout is efficient.



Figure 3.3.6-1 PV array layout diagram

3.3.7 Summary

3.3.7.1 Study results

(1) Hybrid system

We will present the following 3 basic system configurations.

- PV-diesel 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-load operation of diesel generators 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-existing WT-diesel hybrid system

This is a hybrid system which combines existing WT ($750 \text{ kW} \times 8 \text{ units}$), PV, and diesel generators.

- PV-battery-diesel hybrid system

The RE supply percentage can be increased to a high percentage by using batteries 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 SY including Mahe is 0° . Moreover, when the tilt angle is 30° or less, azimuth angle is orientation-independent. In other words, it is thought that the amount of power generated annually will be the same regardless of orientation.

(3) Supply-demand balance simulation

The results of the supply and demand balance simulation using HOMER Pro (considering long period fluctuations) are shown in the following section.

3.3.7.2 HOMER Pro study results for each island (summary)

(1) Mahe

- The integration capacity for long period constraints on Mahe Island was approximately 10,000 kW.
- The cost benefits of PV integration in Mahe Island is low with the current fuel price of 5.33 USD.

- Cost benefits of PV integration arise when fuel prices exceed the 0.8 USD.
- According to the battery capacity sensitivity analysis, electric rates tended to decrease when batteries were deployed.
- For the time being, aiming for deployments of 10,000 kW of PV, which requires no batteries, is recommended.

(2) Praslin

- The integration capacity for long period constraints on Praslin Island was approximately 2,000 kW.
- The cost benefits of PV integration in Praslin Island is low with the current fuel price of 5.33 USD.

Electric rates tended to decrease with a battery capacity ranging 1,500 kWh – 2,000 kWh.

- For the time being, aiming for deployments of 2,000 kW of PV, which requires no batteries, is recommended.

(3) Desroches

- The integration capacity for long period constraints on Desroches Island was approximately 180 kW.
- By increasing the deployment of PV, electric rates in Desroches Island tended to decrease.
- Electric rates tended to decrease with a battery capacity ranging 150 kWh – 200 kWh.
- In terms of the optimal PV deployment, it would be good to first deploy 70 kW of PV, the amount with the lowest investment payback time (10 years).

■ Diesel generators + new PV (70 kW)

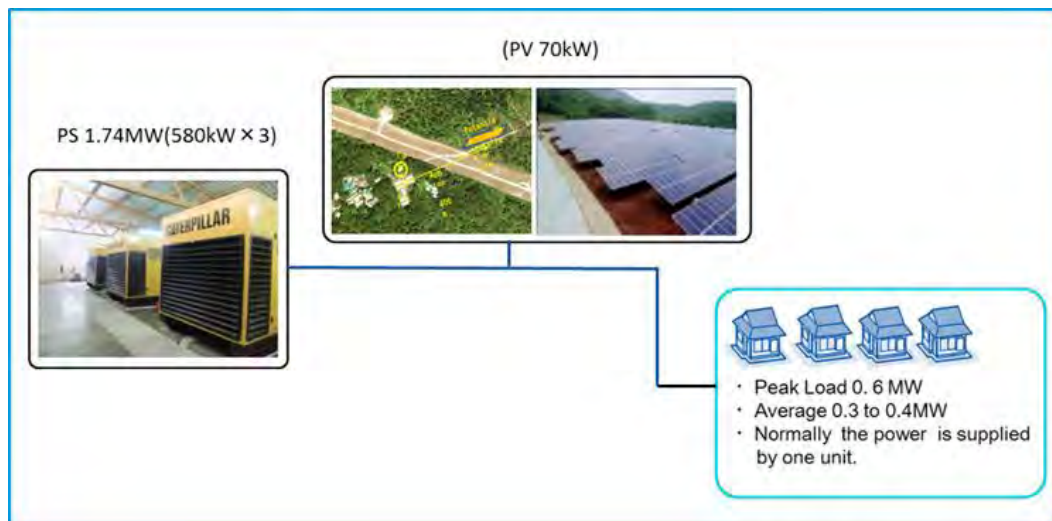


Figure 3.3.7-1 System configuration (proposed)

2) Study on future load

- Simulations on combinations of diesel generator capacities ranging 750-2000 kW and 2-4 units were conducted, and the optimal combination was 750 kW x 3 units.
- The optimal PV deployment for a diesel generator capacity of 750 kW x 3 units for the power

system was 450 kW. Thus, a PV deployment of 450 kW is recommended for Desroches Island assuming an increase in load.

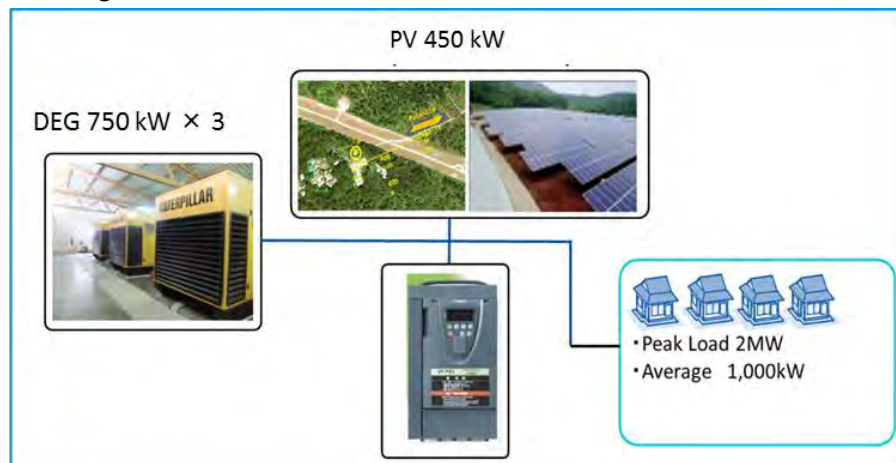


Figure 3.3.7-2 System configuration (proposed)

(4) Curieuse

A simulation on the optimal combination with 10-50 kW PV, 10-50 kW PCS, and 50-400 kWh BTT for PV deployment was conducted. The results showed that a system combining 40 kW of PV + 350 kWh of batteries + 10 kW PCS is the best in terms of electric rates. Therefore, we recommend 40 kW PV + 350 kWh BTT + 10 kW PCS as a system for Curieuse Island.

The entire load for Curieuse Island can be supplied with the PV in the system mentioned above. In addition, since Curieuse Island lacks a backup power supply in case the above system fails, installing a 10 kW diesel generator as emergency backup is recommended.

■ Proposed system configuration

New (40 kW) PV + 350 kWh BTT + 10 kW PCS

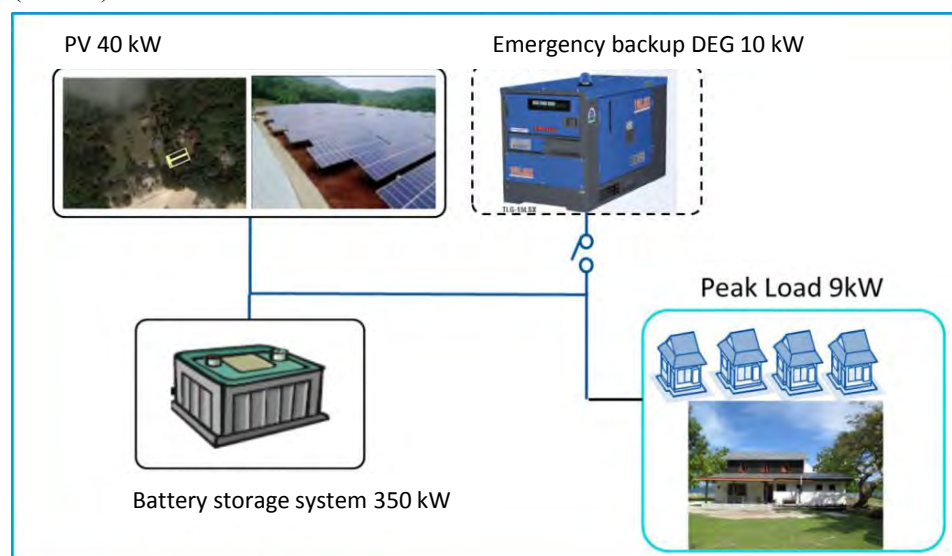


Figure 3.3.7-3 System configuration (proposed)

3.4 Possibility of expanding PV integration by utilizing the water supply facilities on Mahe Island

3.4.1 Purpose of the study

If the deployment of PV grows on the small power system in Seychelles, issues such as the impact on system frequency due to PV output fluctuations are expected, and there are concerns that it may prevent Seychelles from achieving its ultimate renewable energy goal of "15% renewable energy deployment rate by 2030." Therefore, in order for Seychelles to promote the deployment of PV in the future, it would need to mitigate the impact PV output fluctuations have on the grid.

In addition, in Okinawa Prefecture, an island region similar to Seychelles, as one measure for the issue mentioned above, a PV output fluctuation suppression method using a water pump control system composed of a water pump and water tank has been established through demonstration in Miyako Island. It may be possible to use the pumps of the water supply facilities operated and managed by PUC to develop an effective scheme to suppress PV output fluctuations and thus contribute to the expansion of PV deployment in Seychelles.

With such a background, a study was conducted on what effect there would be if a PV output fluctuation suppression method using the water supply facilities in Seychelles based on the results of the demonstration test conducted in Miyako Island were established.

3.4.2 Overview of the water pump control system in Miyako Island

Figure 3.4.2-1 shows the schematic of the water pump control system developed in the demonstration conducted in Miyako Island. The main components include a PV array, power conditioner (PCS), water pump, and control inverter. This system mitigates PV output fluctuations by changing the water pump output with a controller while maintaining the target water level in the water tank for every hour.

According to the report on the demonstration, if the control system were integrated in major waterworks and agricultural water pumps in Miyako Island, under a certain prerequisite, it is estimated that the PV integration capacity for the short-period constraints released by Okinawa Electric Power Company can be expanded by approximately 1.38 MW.

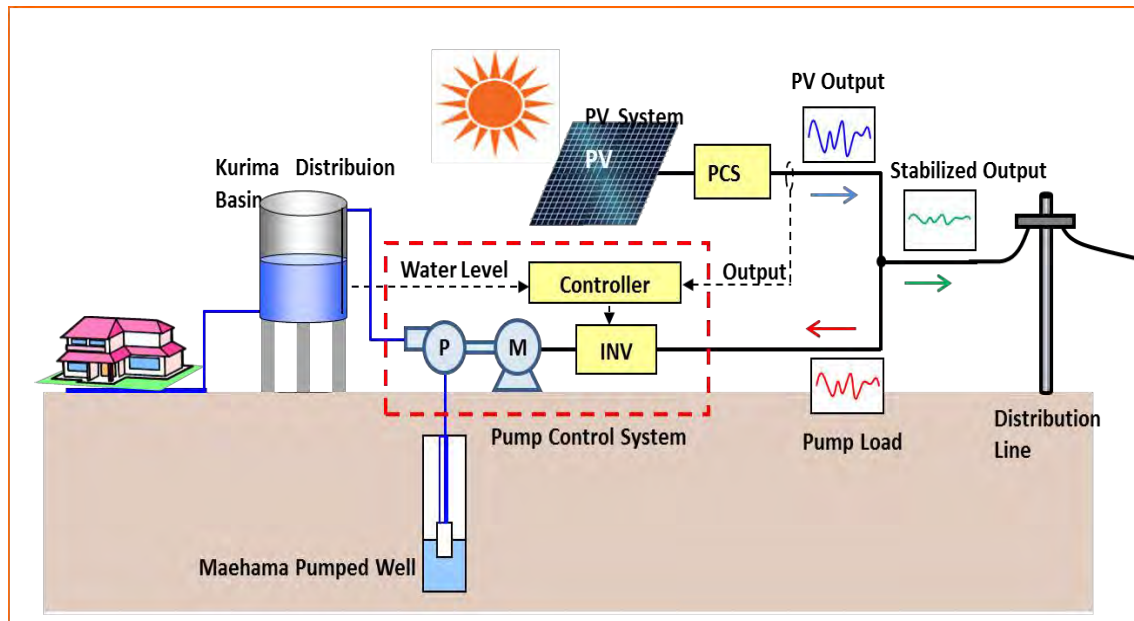


Figure 3.4.2-1 Water Pump Control System

Table 3.4.2-1 Miyako Island PV integration capacity trial calculation results

①	Pump capacity (MW)	9.10
②	Pump's controllable capacity (MW)	7.28
③	PV integration capacity (MW) (Values released by Okinawa Electric Power Company)	9.83
④	PV integration capacity (MW) (After using pump)	11.21
⑤	PV integration expansion (MW)	1.38

3.4.3 Feasibility study on the utilization of the water pump control system in Mahe Island

3.4.3.1 Field survey

Facility information was obtained from PUC, who manages water supply facilities, and a field survey was conducted to investigate the feasibility of deploying Miyako Island's (Okinawa Prefecture) water pump control system in Mahe Island.

There are two dams which use rivers on Mahe Island, and the water from the dams are purified and delivered to the reservoir through gravity flow. A water pump is used to pump water from the reservoir to a relay tank; water is then distributed from the tank to each region using gravity flow and pumps. In this manner, on Mahe Island, water is basically delivered from highland by gravity flow, and water pumps are used to pump water from reservoirs where gravity flow is not possible to relay tanks and to each region. These small capacity pumps (1.1-30 kW) are installed in a distributed fashion on Mahe Island. In addition, since these pumps are operated to maintain the supply tanks at near capacity, they are operating for almost 24 hours without breaks.

Considering these conditions, the capacity of Mahe Island's water supply facilities is small, and they are operated constantly, so it would be unfeasible to use them to mitigate PV output.

Figure 3.4.3-1 shows the field survey conditions; Table 3.4.3-1 and Figure 3.4.3-2 shows a list of water supply facilities on Mahe Island and their locations on the island.

Field survey conditions (1) Dam discharge	Field survey conditions (2) Reservoir
	
Field survey conditions (3) Water pump	Field survey conditions (4) PUC interview
	

Figure 3.4.3-1 Field survey conditions

Table 3.4.3-1 List of water supply facilities on Mahe Island

Sr No	Pump Station	No of Pumps	Capacity m ³ /hr per Pump	Pump Details(CR)	Motor Size(kW)	Total Motor Size(kW)	Present Operation
1	Glasis Cemetry	2	45	CR45-6	22	44	02Duty
2	L'Ilot Glacis	2	3	CR3-19	1.5	3	01 duty 01 Stabdbv
3	Carana(Machabee)	2	16	CR16-10	11	22	01 duty 01 Stabdbv
4	North East Point (Gopal)	2	16	CR 16-70	7.5	15	01 duty 01 Stabdbv
5	NEP Bonta	2	15	CR15-8	7.5	15	01duty 01 stand by
6	North East Point (Village)	2	20	CR 20-8	11	22	02 Duty
7	N.E. Point La Retraite	2	32	CR 32-7	15	30	02 Duty
8	La Retraite(Booster)	2	17	TPD 100-200	5.5	11	01 duty 01 Stabdbv
9	La Gogue Village	2	10	CR 10-12	4	8	01 duty 01 Stabdbv
10	Maldiva Upper	2	15	CR15-9	7.5	15	01 duty 01 Stabdbv
11	Maldiva Lower	2	32	CR32-8	15	30	01 duty 01 Stabdbv
12	Quincy Village	2	64	CR64-6	30	60	01 duty 01 Stabdbv
13	Mont Buxton	2	32	CR 32-8	15	30	01 duty 01 Stabdbv
14	Mont Signal upper	2	5	CR 5-20	4	8	01 duty 01 Stabdbv
15	Dan Lenn	2	8	CR8-8	3	6	01 duty 01 Stabdbv
16	Sorento Glacis	2	4	CR4-9	4	8	01 duty 01 Stabdbv
17	Mare Anglaise/La Batie	2	32	CR 32-10	18.5	37	01 duty 01 Stabdbv
18	Mare Anglaise/Creve Coeur	2	10	CR 10-12	4	8	01 duty 01 Stabdbv
19	Mont Simpson/Le Niol	2	10	CR 10-14	4	8	02 Duty
20	Mt Simson Raw water transfer	2	32	CR 32-9	15	30	02 Duty
21	Danzilles(Dan Bernard)	2	8	CR 8-14	5.5	11	01 duty 01 Stabdbv
22	Dan Gala Le Niol	2	8	CR8-10	4	8	01 duty 01 Stabdbv
23	Le Niol Treatment Works	2	5	CR5-18	3	6	02 Duty
24	Rochon Treatment	3	45	Caprari	30	90	02 duty 01 Stabdbv
25	Salazie Pump Stn	3	54	Caprari	75	225	02 duty 01 Stabdbv
26	Port Glaud- Foret noire)	1	16	CR16-7	7.5	7.5	01 Duty
27	Port Launay Pressure Filter Station	4	64	CR 64-3	18.5	74	03 Duty 01 standby
28	Port Glaud/Mahe Beach	3	64	CR64-5	30	90	03 Duty
29	Beoliere(upper)	2	5	CR5-18/CR3-15	3/1.1	4.1	02 Duty
30	Beoliere Lower1	2	5	CR5-20	4	8	01 duty 01 Stabdbv
31	Beoliere Lower2/Beoliere Upper	2	32	CR32-7	15	30	02 Duty
32	La Misere Satellite	2	64	CR64-5	30	60	01 duty 01 Stabdbv
33	Fairview Lower/Satalite	2	20	CRN20-7	7.5	15	01 duty 01 Stabdbv
34	Fairview Lower/Upper	2	8	CR8-50	2.2	4.4	02 Duty
35	Fair view Upper	2	10	CR10-9	3	6	01 duty 01 Stabdbv
36	Basin Rouge	2	32	CR32-7	15	30	01 duty 01 Stabdbv
37	Basin Bleu	2	32	CR32-7	15	30	01 duty 01 Stabdbv
38	Copolia Pumping Station	2	10	CR10-14	5.5	11	01 duty 01 Stabdbv
39	Barbaron Land Bank	2	16	CR16-5	5.5	11	01 duty 01 Stabdbv
40	Hermitage	3	64	CR64-4	22	66	3 Duty
41	Cascade(cemetery)	2	32	CR32-7	15	30	01 duty 01 Stabdbv
42	Cascade(UPPER)	1	4	CR4-16	3	3	01 Duty
43	Anse Des Genets	2	15	CR15-9	7.5	15	01 duty 01 Stabdbv
44	Point La Rue(Nageon Estate)	2	45	CR45-6	22	44	02 Duty
45	Point La Rue Upper(Dan Santol)	2	10	CR10-9/CR20	4/7.5	11.5	02 Duty
46	Bodamier Lower(Dan Tol)/A/s Pin	2	20	CR20-8	11	22	01 duty 01 Stabdbv
47	Dan Bodamier upper A/s aux Pin	1	30	CR30-8	15	15	01 Duty
48	Anse Royal Treatment/Mt Plaisir	1	45	CR45-4	18.5	18.5	01 Duty
49	Les Cannelle	2	64	CR64-6	30	60	01 duty 01 Stabdbv
50	Santa Maria	3	64	CR64-4	22	66	03 Duty
51	Bougainville	2	8	CR8-8	3	6	01 duty 01 Stabdbv
52	Fairy land	2	8	CR8-14	5.5	11	01 duty 01 Stabdbv
53	Anse Forban Pump Stn	3	32	CR32-6	11	33	01duty 01 stand by
54	Intendence(Takamaka)	2	16	CR16-10	11	22	02 duty
55	Val D'endor Pressure Filter	2	32	CR32-7	15	30	01duty 01 stand by
56	Baie Lazare /Anse Soleil	1	32	CR32-6	11	11	01 duty
57	Baie Lazare	2	8	CR 8-16	5.5	11	02 Duty
58	Dam Le Roi/Au Sed	2	4	CR4-12	2.2	4.4	01duty 01 stand by
59	Dam Le va	2	10	CR10-14	5.5	11	01duty 01 stand by
60	Quatre Bornes Treatment Works	2	16	CR16-10	11	22	02 Duty
61	Ex Hunt	2	15	CR15-10	11	22	01duty 01 stand by
62	Ex Albert	2	20	CR20-7	7.5	15	02 Duty
63	Anse Louis	2	32	CR32-8	15	30	01duty 01 stand by
64	Mt Posee 1	2	15	CR15-9	7.5	15	01duty 01 stand by
65	Mt Posee 2	2	15	CR15-8	7.5	15	01duty 01 stand by
66	Mt Posee 3 (Prison)	1	32	CR32-6	11	11	01duty 01 stand by
67	Montange Posse	2	15	CR15-9	7.5	15	01duty 01 stand by
68	Tar Plant	2	15	CR 15-8	7.5	15	01duty 01 stand by
69	Maconstance/Hanga	2	5	CR5-24	4	8	02 Duty
70	Caiman raw water	2	45	CR45-7	30	60	01duty 01 stand by
71	Laurencine(STA)	2	15	CR 15-12	11	22	01duty 01 stand by
72	Muscat/La Misere	1	20	CR 20-4	5.5	5.5	01 Duty
73	La Misere/New Filter Pstn	1	5	CR 5-20	4	4	01 Duty
74	Providence/Cascade	3	60	Lowra	30	90	03 Duty
75	Il Persiverence/Quincy 1000lts tank	3	45	CRN45-7	30	90	03 Duty
76	Macabee/Bowse unload	1	45	CR 45-3	11	11	01 Duty
77	Belombre Desalination	3	24	Lowra	11	33	03 Duty
78	Sava Sava Farm	1	10	CR45-4	15	15	01 Duty
79	Roche Bois	2	10	CR10-14	7.5	15	01duty 01 stand by
80	Mont Signal Lower	2	8	CR8-11	5.5	11	01duty 01 stand by
81	Anse aux Pin Treatment	1	20	CR 20-14	11	11	01 Duty
82	Rochon/ Sans Souci	2	8	CR 8-6	2.2	4.4	01duty 01 stand by
83	Sailfish	2	2	CR 2-18	2.2	4.4	01duty 01 stand by
84	Calvert	1	3	CR 3-8	4	4	01 Duty
					total	2,170	

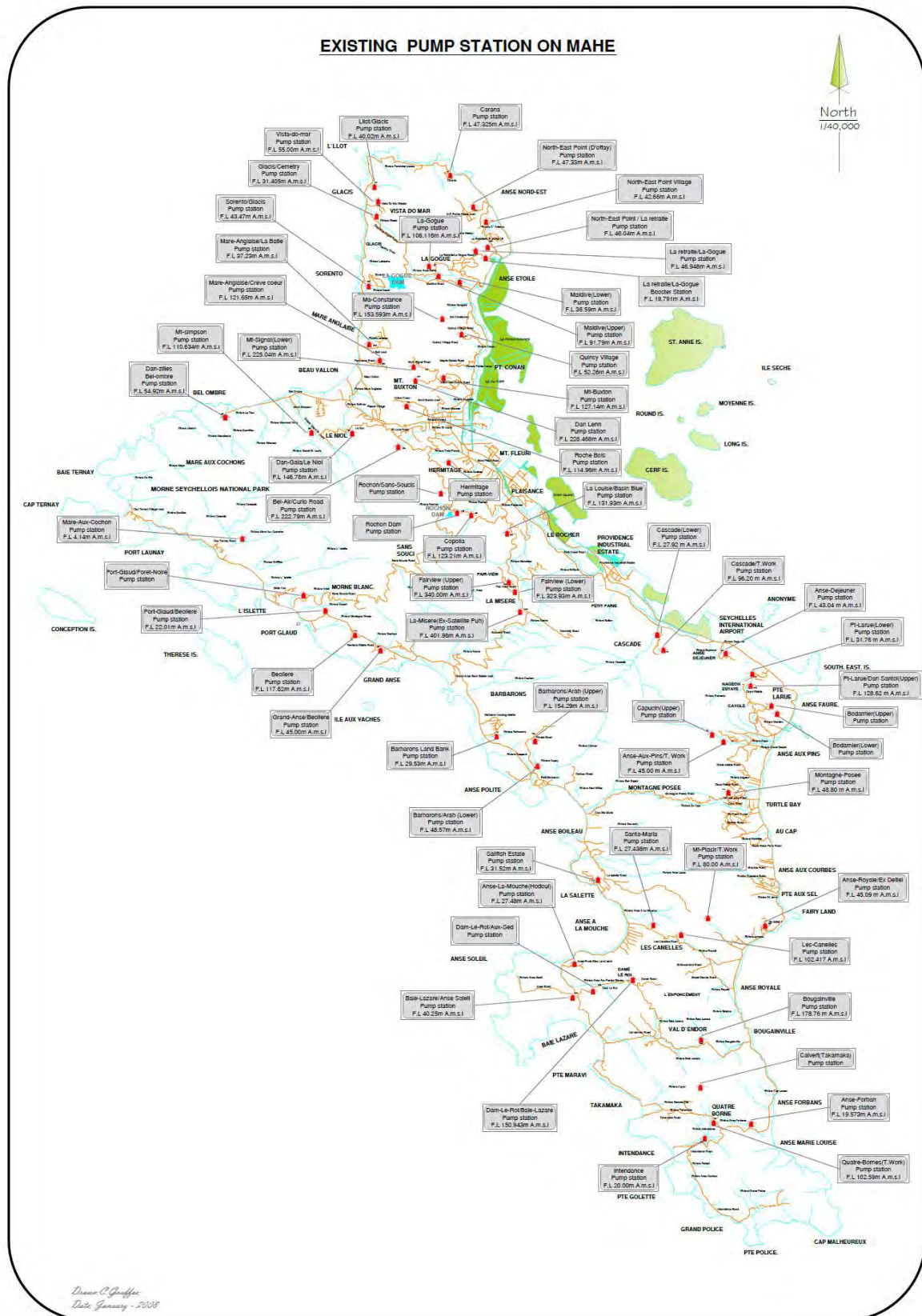


Figure 3.4.3-2 Location of water supply facilities on Mahe Island

3.4.3.2 PV expansion trial calculation

In the survey, it was revealed that the capacity of the pumps on Mahe Island are small, and they are constantly running, so using them as a water pump control system is unfeasible. However, assuming that these pumps can be used for the said system, trial calculations were conducted assuming the 20 pumps out of the pumps listed in Table 3.4.3-1 with a rated capacity of 30 kW (total capacity of 600 kW) would be used.

【Trial calculation conditions (prerequisite)】

- ① Eight water supply pumps operated and managed by PUC (30 kW × 20 units = 600 kW) will be used.
- ② The water pump control system will as a general rule use the PV output.
- ③ All motors for the pumps are variable-speed motors (inverters).
- ④ Constraints on water operations are not considered. (Only used for PV output fluctuation suppression)
- ⑤ The reduction rate used in the trial calculation is the value of the Miyako Island demonstration test results (linear approximation of the reduction rate for PV and pump pumping capacity ratio).

[Calculation Results]

The results are shown in Table 3.4.3-2. If waterworks pumps were used as a water pump control system in Mahe Island, it would reduce the short-period PV integration capacity calculated in "3.1.3.5 Calculation results on the maximum allowable amount using the algebraic method" of Chapter 3 by approximately 0.12 MW, so the result was that it cannot contribute to the expansion of PV deployment.

Table 3.4.3-2 Mahe Island PV integration trial calculation results

Pump capacity (MW)	P rated	0.6
Controllable capacity (MW)	P active	0.48
PV integration capacity – short-period constraints (MW)	K	1.60
Linear approximation coefficient	α	0.62
	β	-27.99
PV integration capacity after using pump (MW)	PpV	1.48
PV expansion (MW)	ΔP_{pv}	-0.12

➤ Various formulas

• Output fluctuation reduction rate $R_m = \frac{PV \text{ output fluc.} - \text{System output fluc.}}{PV \text{ output fluc.}}$

$= \alpha X + \beta \quad \cdot \cdot \cdot \textcircled{1} \quad \text{*linear approximation (Figure 3.4.3-3)}$

(X: controllable load capacity ratio for PV capacity α : linear approximation coefficient β .)

- Mahe Island total pump capacity P rated (0.6 MW)
- Controllable capacity P active = 0.8 x P rated $\cdot \cdot \cdot \textcircled{2}$
- PV integration capacity (short-period constraints) K

(*See Chapter 3 3.1.3.5 Calculation results on the maximum allowable amount using the algebraic method)

• PV integration capacity after using pump $P_{pv} = (K / (100 - R_m)) \times 100 \cdot \cdot \cdot \textcircled{3}$

From equations ①, ②, and ③

$$\therefore P_{pv} = (K + 0.8 \alpha \text{Prated} / (100 - \beta)) \times 100$$

In Figure 3.4.3-3, since PV output fluctuations are expected to have little impact on the grid, linear approximations were conducted with data of two patterns: PV output fluctuations of 10% or less excluded and 20% or less excluded. For the trial calculation in Table 3.4.3-2, the pattern which excludes PV output fluctuations of 10% or less was used.

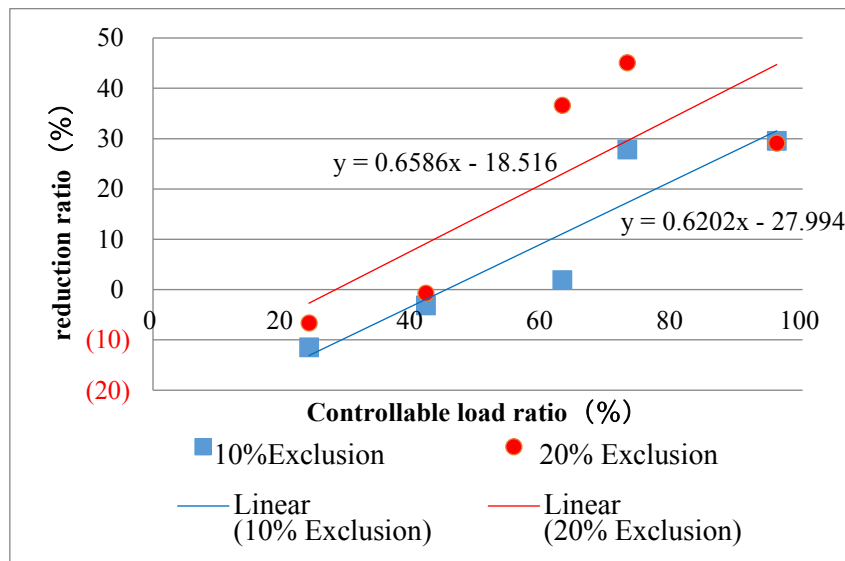


Figure 3.4.3-3 Relationship between reduction rate and controllable load ratio (linear approximation) (Miyako Island demonstration test results)

3.4.3.3 Summary

In Mahe Island, it was revealed through field surveys and trial calculations that the deployment of the water pump control system developed in the demonstration conducted in Miyako Island, Okinawa is not feasible.

Moreover, since the said water pump control system requires it to use the PV power output, it requires PV systems of suitable capacity to be installed near each pump to be used for the said system on the island. Therefore, issues such as securing property and high equipment installation costs are likely to occur.

In addition, as shown in Figure 3.4.3-4, in order to expand PV integration in Mahe Island with the water pump control system, it would require over 0.90 MW of pump capacity. The current total capacity of all pumps for water supply facilities on Mahe Island is 2.17 MW (Table 3.4.3-1), a capacity of at least 0.90 MW, but considering the capacity of each facility is small and their operating conditions, using them as a water pump control system would be unfeasible.

However, deployment would be feasible in the future if there were major changes to the status quo such as an increase in water demand and centralization of the distributed water supply facilities (increase pump unit capacity).

Figure 3.4.3-4 PV expansion according to Mahe Island pump capacity

