PREPARATORY SURVEY
ON
THE PROJECT FOR
DEVELOPMENT AND INTRODUCTION OF MICRO-GRID SYSTEM
FOR THE TONGA ENERGY ROAD MAP
IN THE KINGDOM OF TONGA

THE SECOND FIELD SURVEY

FIELD REPORT

October 5th, 2012

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1. Introduction

Japan International Cooperation Agency (hereinafter referred to as "JICA") dispatched a survey team to the Kingdom of Tonga to appraise the Project for Introduction of A Micro-Grid System with Renewable Energy for the Tonga Energy Road Map in the Kingdom of Tonga (hereinafter referred to as "the Project") which was requested by the government of Tonga as Japan's Grant Aid. The Project is aimed at introducing a micro-grid system with renewable energy to control energy flows and quality, and optimize efficiency of the diesel engine generators.

Tonga Power Limited (hereinafter referred to as "TPL") and JICA Preparatory Survey Team for the Project (hereinafter referred to as "the Team") had series of technical discussion to form a mutual understanding of the contents and the scope and preconditions for outline design of the Project at the stage of 1st preparatory survey and both parties agreed to record the following points as a conclusion of the discussions.

This field report contains the findings and results of the second field survey. Components of the Project will be further examined and may be modified through the consultation with the Ministry of Foreign Affairs and JICA headquarters. It is important for both sides to understand that the Preparatory Survey is not a commitment for the future implementation of the Project.

2. Project Site Location

The Project sites are located in Tongatapu Island, the Kingdom of Tonga.

Source: JICA Study Team

Figure 1 Project Site Location

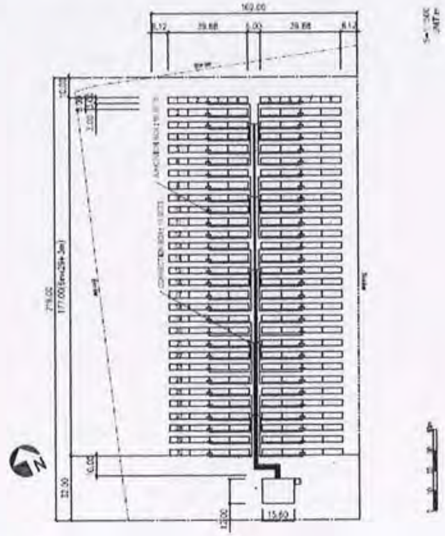
The Project is composed of procurement and installation of approximately 1 MWp of photovoltaic system, power storage system and a micro grid controller to control energy flows and quality,

and optimize efficiency of the diesel engine generators.

The Project site for the Photovoltaic (PV) system, and building for power conditioner system (PCS) and power storage system are shown in Figure 2 (areas: approximately 24,000 m^2). In the first field survey, the availability of the land is confirmed by TPL and the approval letter to use the land for the Project was issued by the Minister of Land, Environment, Climate Change and Natural Resources, who is responsible for administration of the area. The lease agreement for the Project site has been concluded between the land owner and TPL.

In addition, building for power conditioner system (PCS) and power storage system for the existing PV system of Mamma Mai, whose capacity is of 1.3 MWp, will be constructed at Popua Power Station beside the existing powerhouse for the Mak generator under the Project. It is agreed by TPL (areas: approximately 100 m^2) to use the area for the Project.

However, the area is dependent on capacity of the power storage system of the Project. More definite size will be considered by the Team based on the outline design and cost estimation in Japan, discussed between the Ministry of Foreign Affairs, JICA and the Team and explained to the Tongan side in the third field survey.



Source: JICA Study Team

Figure 2 Project Site for PV system

3. Components for the Project

3.1 Final Requested Components

The Tongan and Japanese sides were agreed on the final requested components in conformity with the Minutes of Meetings on 30th August, 2012 in the first field survey.

Table 1 Outline of the Project

	Components	Quantity or Capacity
Procurement and Installation	1.Micro-grid system at Popua Power Station	
	1.1 Micro-grid control system	
	(1) Micro-grid control panel	1 set
	(2) Control panel to stabilize output from PV system	1 set
	(3) Data management system	1 lot
	(4) Weather monitor instruments (Pyranometer, Temperature meter)	1 lot
	1.2 Power storage system	
	(1) Capacitors	Enough capacity supply 500 kW for 30 sec. from SOC 50 %
	(2) Capacitor panel	Enough capacity to include the capacitors
	(3) Capacitor connecting panel	1 lot
	(4) Power conditioner for capacitors	500 kW
	(5) Transformer for interconnection	750 kVA
	(6) High voltage transformer panel	Same as number of power conditioners for capacitors
	(7) Low voltage transformer panel	Same as number of power conditioners for capacitors
	1.3 Station service panel	1 set
	2. Micro-grid system at Vaini Project Site	
	2.1 Micro-grid control system	
	(2) Control panel to stabilize output from PV system	1 set
	(3) Data management system	1 lot
	(4) Weather monitor instruments (Pyranometer, Temperature meter)	1 lot
	2.2 Power storage system	
	(1) Capacitors	Enough capacity supply 500 kW for 30 sec. from SOC 50 %
	(2) Capacitor panel	Enough capacity to include the capacitors
	(3) Capacitor connecting panel	1 lot
	(4) Power conditioner for capacitors	500 kW
	(5) Transformer for interconnection	750 kVA
	(6) High voltage transformer panel	Same as number of power conditioners for capacitors
	(7) Low voltage transformer panel	Same as number of power conditioners for capacitors
	2.3 Photovoltaic system (PV system)	
	(1) PV module	1,000 kWp
	(2) Power conditioner	1,000 kW
	(3) Connection box	1 lot
	(4) Junction box	1 lot
	(5) Mounting structure for PV modules	1 lot
	(6) Transformer for interconnection	1,250 kVA
	(7) High voltage transformer panel	Same as number of power conditioners for capacitors
	(8) Low voltage transformer panel	Same as number of power conditioners for capacitors
	2.4 11 kV interconnection switchgear	
	(1) 11 kV switchgear	7 sets
	(2) Earthing transformer (including reactor)	1 set
	(3) DC power supply panel	1 set
	2.5 Station service panel	1 set
	3. Optical fiber communication ssystem	Approx. 10 km
Procurement	4. 11 kV interconnection switchgear at Popua Power Station	
	(1) 11 kV switchgear	4 sets
	(2) Earthing transformer (including reactor)	1 set
	(3) DC power supply panel	1 set
	5. Spare parts	1 lot
	6. Emergency spare parts	1 lot
Construction	a. Building for electrical equipment at Popua Power Station	Gross floor area: Approx. 100 m^2
	b. Building for electrical equipment at Vaini Project Site	Gross floor area: Approx. 190 m^2

Source: JICA Study Team

3.2 Drawing Lists

The following drawings are attached in the end of this field report.

D-01 Single Line Diagram
D-02 Control System Diagram
D-03 Arrangement of panels at Vaini Site
D-04 Floor and Section Plan of Building at Vaini Site
D-05 PCS and Batteries Building at Vaini Site
D-06 Floor and Section Plan of Building at Popua Power Station
D-07 PCS and Batteries Building at Popua Power Station

3.3 Technical issues discussed in the first field survey and reconfirmed in the second field survey

(1) Acquisition of approval from Mamma Mai to connect signal cables to the existing PV system

The Tongan side agreed to obtain a letter showing approval from Mamma Mai that a transducer of the Project will be located in the 11 kV switchgear of the existing photovoltaic system and connected to the current and voltage transformer in parallel to the existing transducer by 19th October, 2012.

(2) Modification work to enable the existing Mak generator to share load with the CAT ones

Based on the plan discussed between the Tongan side and Team in the first field survey, the Team consulted a major manufacturer of control devices for diesel engine generators (not the same manufacturer for the existing ones) with its feasibility in the analysis in Japan.

It was advised by the manufacturer that more careful consideration for safety operation should be carried out in such case as Popua Power Station where composition of buses is complex though the plan is feasible. Every possible accident shall be considered and safety operation shall be sorted based on TPL's own policy. It was revealed that it is difficult that such third party as a consultant may carry out the basic design for the modification work or the third party as a Japanese contractor may implement the work.

The Team explained the results and the Tongan side and Team agreed to exclude the modification work to enable the existing Mak generator to share load with the CAT ones. The work will be carried out based on the basic design planned by TPL and the original contractor of the existing Mak generator, when a new Mak generator is extended in 2013.

(3) Cost estimation for the modification work of the existing power house at the Popua Power Station

The power storage system of the Project at Popua Power Station will be connected in 11 kV. The Tongan side requested the Team to locate 11 kV switchgears of the Project in the existing powerhouse at Popua Power Station to enable the extension work of switchgears by himself in the future. The Team agreed to do so in the first field survey.

The Tongan side shall undertake modification work of the existing building such as preparation of cable trench, cable trays, walls, doors, windows and air conditioner. The modification work shall be completed prior to commencement of the work by the Japanese side, and installation work of 11 kV switchgears procured by the Japanese side. <u>It is required for the Tongan side to inform the cost to the Team by 19th October, 2012</u>.

(4) Capacity of the Power Storage system

The Tongan side agreed to apply capacitor banks as the power storage system of the Project. Based on the results of the analysis in Japan, capacity of a capacitor banks is specified as enough capacity to supply 500 kW for 30 seconds from 50% of state of charge. The capacitor bank will be provided to Popua Power Station and Vaini Project Site respectively. The results of the analysis in Japan are shown in Annex 3 of this field report.

(5) Evaluation on Potential of Wind Power Generation in Tongatapu Island

Based on discussion with the Tongan side in the first field survey, the wind power generation was excluded from the components of the Project due to procedural grounds for Environmental Impact Assessment.

However, potential evaluation for wind power generation will be conducted from the technical viewpoint and the results will be included in the Preparatory Survey Report. The results of the analysis in Japan are shown in Annex 3 of this field report and explained to the Tongan side in the second field survey.

3.4 Technical issues discussed in the second field survey

(1) Shutdown of Mak generator during PV generation

Output from PV system is fluctuated based on weather conditions. Velocity and range of such fluctuation will be reduced by the power storage system of the Project during some seconds. However, load of the diesel engine generators shall be increased or decreased finally to meet demand after the period. Load control system in consist with demand shall be provided to every diesel engine in operation to stabilize the power system with the micro-grid system of the Project,

while PV is operating and demand stays in low level.

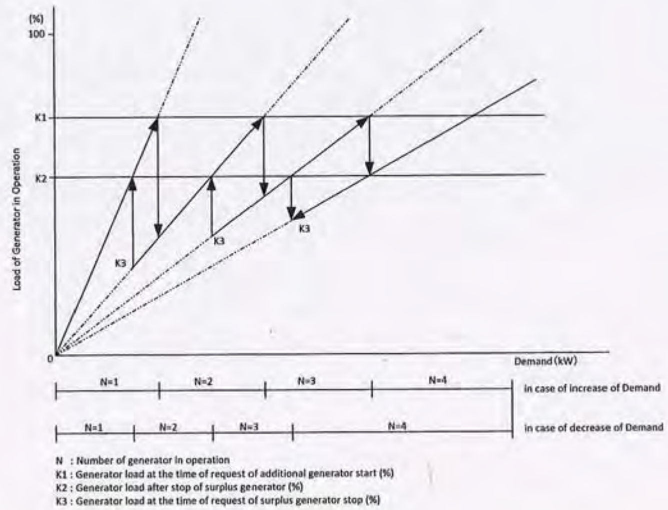
The existing Mak generator is not holding load sharing control system with the other generators. Therefore, it shall be stopped when the PV system starts operation and demand stays in low level as below 6,000 kW.

(2) Reference data for control of number of the existing CAT generators in operation

The control sequence of number of the CAT generators in operation is shown in Figure 3. The load ratios for the sequence are currently set as follows.

K1 = 85 %
K2 = 65%

The start sequence of an additional generator runs in consist with demand increase, every time load ratio increases to 85 %. And the stop sequence of a redundant generator runs in consist with demand decrease, every time load ratios decreases to 65 %.



Source: prepared by JICA Study Team based on JIS F 9800

Figure 3 Control sequence of number of generators in operation

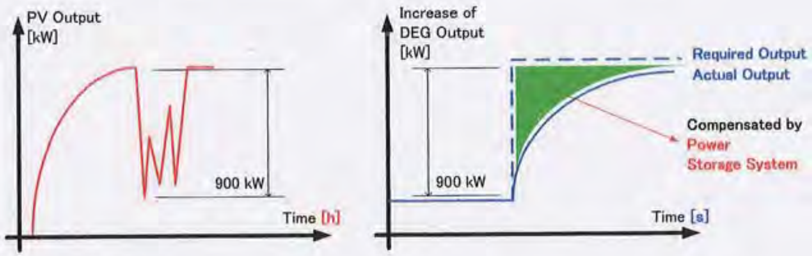
Based on the above set value, number of generator in operation is controlled in the manner shown in Table 2.

Table 2 Current conditions of operation (K1 = 85 %, K2 = 65 %)

Number in operation	K3	DEG output before a generator stops	K1	DEG output before a generator starts
N=1	0 %	0 kW	85 %	1,190 kW
N=2	33 %	910 kW	85 %	2,380 kW
N=3	43 %	1,820 kW	85 %	3,570 kW
N=4	49 %	2,730 kW	85 %	4,760 kW
N=5	52 %	3,640 kW	85 %	5,950 kW
N=6	54 %	4,550 kW	85 %	-

Source: JICA Study Team

Load of the CAT generators shall be increased or decreased finally to meet demand after the period of compensation by the power storage system and keep frequency of the power system within the management range (50 Hz ± 0.5 Hz) during PV operation as shown as Figure 4.



Source: JICA Study Team

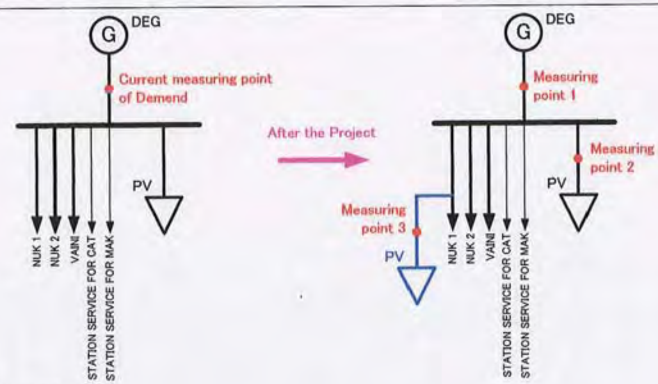
Figure 4 Compensation by the power storage system

It takes some minutes to start and synchronize a diesel engine generator, and increase load ratio up to level of load sharing. Therefore, spinning reserve shall surely be maintained against sudden decrease of PV output without additional start of a CAT generator.

Surely to keep spinning reserve, number of the CAT generator in operation shall be controlled based on demand. The current reference point of demand is shown in the left of Figure 5. Then, number of the CAT generator in operation is controlled under the condition that their required output is the actual demand minus output from PV system. Spinning reserve will be short in case of this reference method, if 1,000 kWp of the additional PV system is introduced by the Project and penetration to PV generation is increased remarkably.

In case of highly relying on PV generation, number of the CAT generator in operation shall be controlled based on the actual demand, which is obtained by totaling the power at the measuring points shown in the right of Figure 5.

The Tongan side and Team agreed to modify the reference points for the control sequence of number of the CAT generators in operation surely to keep spinning reserve.



Source: TPL

Figure 5 Reference points of demand

(3) Shutdown of a part of PV system

To prevent such condition as the CAT generators are operated below the minimum load ratio possible in the current operation, a part of PV system shall be shutdown. Such case will occur, when demand stays in the level of 4,000 kW. The minimum load ratio shown in Table 2 is 33 %. The load ratio of the CAT generators is kept over Approx. 30 % by shutting down 500 kWp of PV system of the Project, if PV starts operation and demand stays below 4,000 kW. The Tongan side and Team agreed to include such control sequence in the micro-grid system of the Project for the safety operation of the CAT generators.

3.5 Soft Components

Soft Component is also included in the Project.

Refer to ANNEX 5 for the details.

4. Environmental and Social Consideration

4.1 Environmental Legal Framework

Existing environmental legislation relevant to the Project is shown below.

Table 4.1 Existing Environmental Legislation relevant to the Project

Legislation	Year Passed	Last Amended	Objective
Environmental Impact Assessment Act 2003	2003	-	To provide for the application of environmental impact assessment to the planning of development in Tonga
Environmental Impact Assessment Regulations 2010	2010	-	To regulate major development projects and the applications of notification consistent with the EIA Act 2003)
Waste Management Act 2005	2005		To manage and oversee the function of the Waste Management Board
Parks and Reserves Act 1976	1976	1979 & 1988	To provide for the establishment of Parks and Reserves Authority and for the establishment, preservation and administration of Parks and Reserves
Hazardous Wastes and Chemicals Act 2010	2010		To provide for the regulation and proper management of hazardous wastes and chemicals in accordance with accepted international practices and the International Conventions applying to the use, transboundary movement and disposal of hazardous substances and for related purposes.
Renewal Energy Act 2008	2008	2010	To regulate the use of renewable energy in the Kingdom and related matters
Environmental Management Act 2010	2010		To establish the Ministry of Environment & Climate Change* to ensure the protection and proper management of the environment and the promotion of sustainable development

*The Ministry of Environment & Climate Change was incorporated into the MLECCNR as the Department of Environment & Climate Change due to the reorganization of government ministries in July 2012.

Source: Department of Environment & Climate Change

The Environmental Impact Assessment Act 2003 (EIA Act 2003) provides the power of the Ministry, the establishment and functions of the Environmental Assessment Committee, penalty, definition of major projects and so on. The major project is defined as a development activity which is likely to result in or increase pollution, or to have adverse impact on natural environment. A development activity which is classified as the major project is subject to conduct an appropriate environmental impact assessment. Development of electric generation station is defined as the major project even though renewal energy is used for the power generation. Therefore, the Project is subject to conduct an EIA.

4.2 Environmental Policies in TERM

The objective of TERM is to reduce vulnerability to high and variable petroleum price with introduction of renewable energy. In order to achieve the objective, a set of key principles have been set out in TERM. Social and environmental sustainability is one of the key principles, and it is explained as follows. "Environmental and Social sustainability encompasses both minimizing local negative social and physical environmental impacts of the energy sector, as well as aligning with global goals with respect to minimizing impact on climate change where possible. New energy investments under the TERM would be subject to Environmental and Social Impact Assessment and Mitigation Plans as necessary, as per international practice. Special consideration will be given to those groups with specific needs including youth, women, religious groups and those with special needs. Investments that have major negative environmental or social impacts or

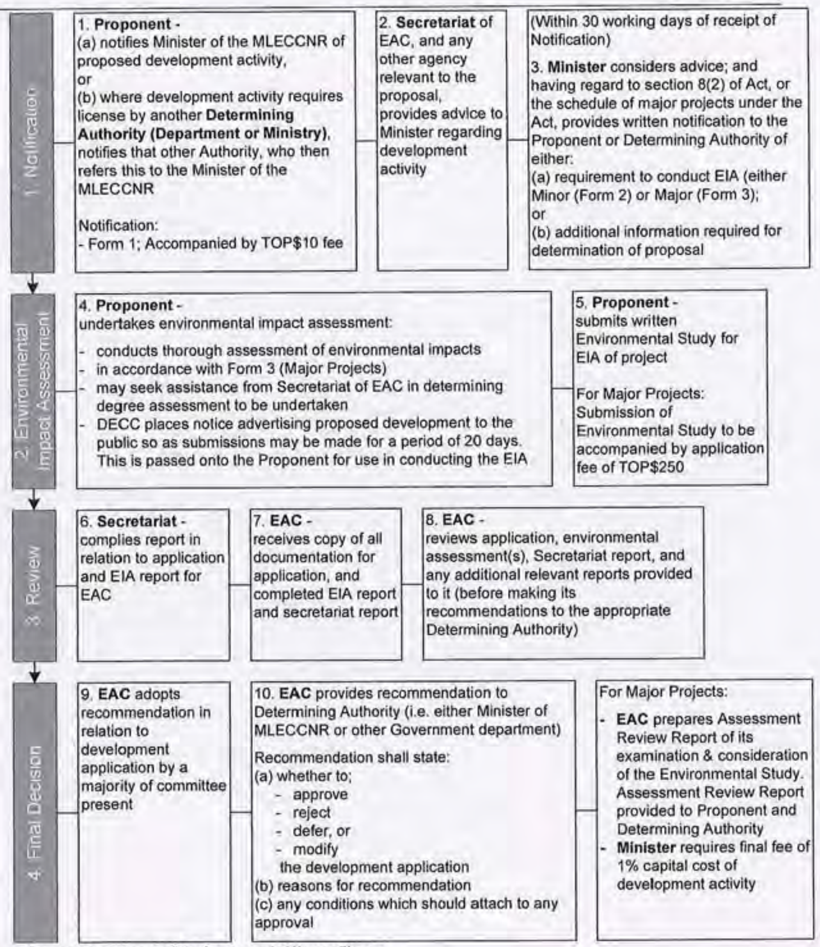
constraints that cannot be mitigated or solved will be avoided."

As mentioned above, TERM requires environmental and social impact assessment and mitigation plans as per international practice in order for development of electric generation station. In this regard, the JICA Guidelines for Environmental and Social Considerations shall be observed as well as the World Bank's Safeguard Policies and other standards of international financial organizations related to the environmental and social considerations of the Project.

4.3 Environmental Management Administration and EIA Procedures

The Environmental Management Act 2010, which created the former Ministry of Environment and Climate Change (MECC), empowered the Minister and the Director for Environment and Climate Change as well as Environmental Officers on environmental management. In relation to the EIA procedure, the Minister determines whether the proposed development is a minor or major project, and receives an assessment report and issues the approval with or without conditions, a request for further information, or a rejection. Meanwhile, the Director, who is the head of the Secretariat of the Environmental Assessment Committee (EAC) and chairs the Committee, inspects or investigates any facility or activity deemed to be causing potential impact on the environment. The Secretariat which is staffed with Environmental Officers receives application documents related to environmental impact assessment of the proposed project and gives advice on implementation of environmental study under the Director's instructions. It is deemed that the power and authority of those key actors are the same as before, although the former MECC was incorporated into the MLECCNR in July 2012.

The EIA Act 2003 has been enforced under the Environmental Impact Assessment Regulations 2010 (EIA Regulations 2010). The EIA Regulations provides the procedures of EIA for major projects classified under the EIA Act 2003. The EIA procedures, as shown in the following figure, are divided into four steps; namely, notification, environmental impact assessment, review and final decision with or without conditions.



Source: Department of Environment & Climate Change

Figure 4.1 Procedures of EIA

All development activities must be notified to the Minister who determines whether the proposed development is a major project or not. However, according to the Department of Environment and Climate Change (DECC), this Project can skip the notification because it is obviously the major project, and the proponent can step into the study of EIA, complete the EIA report and submit it to the Secretariat with an application. The Secretariat compiles a report based on the application and the EIA report, and then submits those documents to the EAC for the review. The EAC reviews the submitted documents and prepares/submits a recommendation to the Minister for final decision. According to the TPL, in case of the project of Popua 1MW Solar Firm, it took less than 3 months from the notification to the final decision by the Minister.

4.4 Outline of the Project

The components of the Project include micro grid controller, storage system, solar PV system and O&M of the equipment. Regarding the renewal energy resource, the Tongan side originally requested introduction of both 0.5MW solar PV system and 0.5MW wind turbine generator. Due to the environmental constraints, only solar PV system was adopted to the Project as the renewal energy resource.

Table 4.2 Components of the Project

Item	Components
Micro Grid Controller	• Generation and network control system integrated into TPL's SCADA at Popua power station • IP broadband and/or mesh type communications network that overlies TPL's Tongatapu network, connecting remote generation to the Popua SCADA system and micro grid controllers • Integration of battery or capacitive storage and local flow "smoothing" algorithms to monitor and control field assets and enable future demand side management
Storage System (Capacitors)	• Capacitors and controller located at either Popua or at Vaini PV Site, controlling energy flows and quality, and optimizing efficiency of the diesel generators • Conversion of the TPL 2.88 MW MAK diesel generator governor to load following capability (requires manufacturer's involvement to modify governors, TPL has discussed requirements and scope with manufacturer)
Solar PV System (1MW)	• A single solar PV array at Vaini, in central Tongatapu, injecting into the TPL 11kV network, including spares • Network voltage management (regulator or other dynamic support)
Operation & Maintenance of the Equipment	• Training TERM-IU staff and TPL staff • Operating and maintenance manuals and process documentation • O&M support

Source: JICA Study Team

4.5 Review of Alternatives

In order to optimize the environmental and social impacts by the Project, the following alternatives including zero option were reviewed.

Alternative 0: None of project implementation (zero option)
Alternative 1: Construction of 0.5MW PV plant and 0.5 wind plant, and other needed facilities
Alternative 2: Construction of 1.0MW PV plant and other needed facilities

The Alternative 1 is the original plan that was requested by the Government of Tonga, and the Alternative 2 is the agreed plan by the Tongan and Japanese sides during the First Field Survey. The results of review of those alternatives are shown in the following table.

Table 4.3 Comparison of Alternatives

Items to be reviewed	Alternative 0 (w/o Project)	Alternative 1 (0.5MW PV plant + 0.5MW wind plant)	Alternative 2 (1.0MW PV plant)
Benefit	None	• Reduction of fossil-fuel consumption and stabilization of electricity supply by development of renewal-energy-based electric generation along with introduction of micro-grid system	Same as on the left
Reduction of CO_2 Emission	None	1,268 ton/year	886 ton/year
Social Impacts	As-is (Social impacts due to the vulnerability to oil price will continue without any improvement)	• A certain decrease of agricultural product because of land use conversion from farm land to power station • Possible damage of tourism resources because of spoiling of landscape caused by existence of gigantic wind turbine	• A certain decrease of agricultural product because of land use conversion from farm land to power station
Environmental Impacts	As-is (Environmental impacts due to consumption of fossil-fuel in the existing diesel power plant will continue without any improvement)	• Minor changes of topography in the project sites are expected because of clearing and leveling of the sites • Possible soil erosion because of clearing and leveling of the sites • Possible impact of flora, fauna and biodiversity because of existence and operation of wind plant • Possible impact of landscape because of existence and operation of wind plant	• Minor changes of topography in the project sites are expected because of clearing and leveling of the sites • Possible soil erosion because of clearing and leveling of the sites
Possible Pollution	As-is	• Possible air pollution because of SPM and dust arising from operation of construction vehicles and machineries • Possible generation of construction wastes from construction activities • Possible generation of used lead-acid batteries approximately every 10 years • Possible pollution of noise arising from construction vehicles and machineries • Possible pollution of noise and low-frequency noise because of operation of wind turbine	• Possible air pollution because of SPM and dust arising from operation of construction vehicles and machineries • Possible generation of construction wastes from construction activities • Possible pollution of noise arising from construction vehicles and machineries

Source: JICA Study Team

The Alternative 0 (zero) means that the operation of existing power generating system (11.28MW diesel generating along with the newly developed Popua 1.3MW Solar Farm) continues without any changes. Therefore, it brings neither benefit nor reduction of CO_2 emission in future.

In case of the Alternative 1, it is likely to bring the most reduction of CO_2 emission compared to the other alternatives. The GOT requested to the GOJ to introduce both solar PV system and wind turbine generator system as the renewal energy source of the Project. However, the wind turbine system is hardly adopted in the Project from the viewpoint of environmental constraint.

It is unlikely that the construction, existence and operation of solar PV system have serious impacts on social and natural environment. Meanwhile as for wind turbine generator system, the following environmental items should be appropriately evaluated prior to the construction because problems of those items might be caused by wind turbine due to its mechanism.

- Noise
- Low-frequency noise
- Radio disturbance
- Shadow flicker
- Disturbance of birds' migration routes
- Spoiling of landscape

As to disturbance of birds' migration routes especially, survey of existing conditions on the migration routes generally takes one year at minimum. Accordingly, it takes one and a half year or more to obtain environmental permission from both Japanese and Tongan authorities, taking into account the required time for data analysis, assessment of the environmental impacts, information disclosure, stakeholder meetings, review of the EIA and so on. The time required for the EIA procedures does not meet the time schedule of the Project.

4.6 Scoping

(1) Specification of Factors affecting Environment

Factors (or activities) which are accompanied by the project implementation and assumed to be affecting environment in/around the project site are examined in the cases of the Alternative 1 (0.5MW PV plant + 0.5MW wind plant) and the Alternative 2 (1.0MW PV plant) as mentioned in the preceding section. The specified factors are shown below.

Table 4.4 Factors Affecting Environment

Factors affecting environment		Assumed environmental impacts
Construction Phase	Land preparation	Loss of agricultural product, topographical change, soil erosion and generation of construction wastes due to land preparation work (clearing and leveling of the sites)
	Operation of construction machineries	Air pollution, noise and vibration due to operation of construction machineries at the sites
	Transportation of equipment and materials	Air pollution, noise and vibration due to transportation of equipment and construction materials to and from the sites
	Construction of power plant	Construction wastes due to construction work of facilities
Operation Phase	Existence of PV plant	Loss of agricultural product due to existence of PV plant
	Existence of wind plant *	Loss of agricultural product, spoiling of landscape, impacts on flora, fauna and biodiversity due to existence of wind turbine
	Operation of wind plant *	Spoiling of landscape, impacts on flora, fauna and biodiversity, generation of used lead-acid batteries, noise and vibration due to operation of wind plant

Note: The marked item (*) is only applicable to the Alternative 1.

Source: JICA Study Team

(2) Review of Environmental Items

The environmental items to be examined are classified into three categories; social environment, natural environment and pollution, and 30 environmental items are specified based on the JICA Guidelines for Environmental and Social Considerations. The relationship between the environmental items and the factors affecting environment is shown in the following tables, in the both cases of the Alternative 1 and the Alternative 2.

Table 4.5 Scoping Matrix for Alternative 1 (0.5MW PV Plant + 0.5MW Wind Plant) (1/2)

Category and environmental item		Factor affecting environment	OVERALL RATING	Const. Phase: Land preparation	Const. Phase: Op. of const. machinery	Const. Phase: Transp. of equipment	Const. Phase: Const. of power plant	Op. Phase: Existence of PV plant	Op. Phase: Existence of wind plant	Op. Phase: Operation of wind plant	Description
Social Environment	1	Involuntary resettlement									There is no possibility of impact because no houses exist in the sites.
	2	Local economy such as employment and livelihood, etc.	B	B				B	B		Loss of agricultural product is expected because some coconut trees and other crops are cultivated in the sites of power plant.
	3	Land use and utilization of local resources									There is no possibility of impact because the construction and operation of power plants do not affect surrounding land use and utilization of local resources.
	4	Social institutions such as social infrastructure and local decision-making									There is no possibility of impact because there are not any social institutions in the sites.
	5	Existing social infrastructure and services									There is no possibility of impact because there are not any social infrastructure and services in the sites.
	6	The poor, indigenous and ethnic people									There is no possibility of impact because the sites have not any relationships with poor, indigenous and ethnic people.
	7	Misdistribution of benefit and damage									There is no possibility of impact because the construction and operation of power plants do not result in any misdistribution of benefit and damage.
	8	Cultural heritage									There are not any cultural heritages in the sites.
	9	Local conflict on interests									There is no possibility of impact because the construction and operation of power plants do not create any local conflict on interests.
	10	Water usage or water rights and rights of common									There is no possibility of impact because the construction and operation of power plants do not affect water usage and water rights.
	11	Sanitation									There is no possibility of impact because the construction and operation of power plants do not affect sanitation.
	12	Hazards (Risk) of infectious diseases such as HIV/AIDS									There is no possibility of impact because the construction and operation of power plants do not lead to any hazards of infectious diseases. During construction phase, hiring of local workers is expected and workers' lodging is not necessary.
Natural Environment	13	Topography and geographical features	B	B							Minor changes of topography are expected because of clearing and leveling of the sites.
	14	Soil erosion	B	B							There is a possibility of impact because of clearing and leveling of the sites during construction phase.
	15	Groundwater									There is no possibility of impact because the construction and operation of power plants do not affect groundwater.
	16	Hydrological situation									There is no possibility of impact because the construction and operation of power plants do not affect hydrological situation.
	17	Coastal zone									There is no possibility of impact because the construction and operation of power plants do not affect coastal zone.
	18	Flora, fauna and biodiversity	C						C	C	There is a possibility of impact because of the existence and operation of wind plant.
	19	Meteorology									There is no possibility of impact because the construction and operation of power plants do not affect meteorology.
	20	Landscape	C						C	C	There is a possibility of impact because of the existence and operation of wind plant.
	21	Global warming									There is no possibility of impact because the construction and operation of power plants do not affect global warming.

Table 4.5 Scoping Matrix for Alternative 1 (0.5MW PV Plant + 0.5MW Wind Plant) (2/2)

Category and environmental item		Factor affecting environment	OVERALL RATING	Const. Phase: Land preparation	Const. Phase: Op. of const. machinery	Const. Phase: Transp. of equipment	Const. Phase: Const. of power plant	Op. Phase: Existence of PV plant	Op. Phase: Existence of wind plant	Op. Phase: Operation of wind plant	Description
Pollution	22	Air pollution	B		B	B					There is a possibility of impact because of SPM and dust arising from operation of construction vehicles and machineries.
	23	Water pollution									There is no possibility of impact because the construction and operation of power plants do not lead to water pollution.
	24	Soil contamination									There is no possibility of impact because the construction and operation of power plants do not lead to soil contamination.
	25	Waste	B	B			B			B	Construction wastes arise from construction activities. Replacement of lead-acid batteries arises periodically, say every 10 years.
	26	Noise and vibration	C		B	B				C	There is a possibility of impact because of noise and vibration arising from operation of construction vehicles and machineries. Operation of wind plant generates noise and low-frequency noise.
	27	Ground subsidence									There is no possibility of impact because the construction and operation of power plants do not lead to ground subsidence.
	28	Offensive odor									There is no possibility of impact because the construction and operation of power plants do not lead to offensive odor.
	29	Bottom sediment									There is no possibility of impact because the construction and operation of power plants do not lead to bottom sediment.
	30	Accidents									There is a possibility of impact on traffic safety because of the operation of construction vehicles and machineries.

Rating
A: Serious impact is expected.
B: Some impact is expected.
C: Extent of impact is unknown. (Examination is needed. Impacts may become clear as study progress.)
No mark: No impact is expected. IEE/EIA is not necessary.

Source: JICA Study Team

In the case of the Alternative 1, eight (8) environmental items shall be examined through the study of EIA. Of these items, three (3) items are rated as C that means the extent of impact is unknown and, accordingly, those impacts have to be carefully assessed through the study of EIA. As shown in the above table, those C ratings are, incidentally, attributed to the wind turbine plant.

Table 4.6 Scoping Matrix for Alternative 2 (1.0MW PV Plant) (1/2)

Category and environmental item \ Factor affecting environment	No.	Item	OVERALL RATING	Const. Phase: Land preparation	Const. Phase: Op. of const. machinery	Const. Phase: Transp. of equipment	Const. Phase: Const. of power plant	Op. Ph.: Existence of PV plant	Description
Social Environment	1	Involuntary resettlement							There is no possibility of impact because no houses exist in the sites.
	2	Local economy such as employment and livelihood, etc.	B	B				B	Loss of agricultural product is expected because some coconut trees are cultivated in the site of PV plant.
	3	Land use and utilization of local resources							There is no possibility of impact because the construction and operation of power plants do not affect surrounding land use and utilization of local resources.
	4	Social institutions such as social infrastructure and local decision-making							There is no possibility of impact because there are not any social institutions in the sites.
	5	Existing social infrastructure and services							There is no possibility of impact because there are not any social infrastructure and services in the sites.
	6	The poor, indigenous and ethnic people							There is no possibility of impact because the site has not any relationships with poor, indigenous and ethnic people.
	7	Misdistribution of benefit and damage							There is no possibility of impact because the construction and operation of PV plant do not result in any misdistribution of benefit and damage.
	8	Cultural heritage							There are not any cultural heritages in the site.
	9	Local conflict on interests							There is no possibility of impact because the construction and operation of PV plant do not create any local conflict on interests.
	10	Water usage or water rights and rights of common							There is no possibility of impact because the construction and operation of PV plant do not affect water usage and water rights.
	11	Sanitation							There is no possibility of impact because the construction and operation of power plants do not affect sanitation.
	12	Hazards (Risk) of infectious diseases such as HIV/AIDS							There is no possibility of impact because the construction and operation of PV plant do not lead to any hazards of infectious diseases. During construction phase, hiring of local workers is expected and workers' lodging is not necessary.
Natural Environment	13	Topography and geographical features	B	B					Minor changes of topography are expected because of clearing and leveling of the site.
	14	Soil erosion	B	B					There is a possibility of impact because of clearing and leveling of the site during construction phase.
	15	Groundwater							There is no possibility of impact because the construction and operation of PV plant do not affect groundwater.
	16	Hydrological situation							There is no possibility of impact because the construction and operation of PV plant do not affect hydrological situation.
	17	Coastal zone							There is no possibility of impact because the construction and operation of PV plant do not affect coastal zone.
	18	Flora, fauna and biodiversity							There is no possibility of impact because the construction and operation of PV plant do not affect flora, fauna and biodiversity.
	19	Meteorology							There is no possibility of impact because the construction and operation of PV plant do not affect meteorology.
	20	Landscape							There is no possibility of impact because the construction and operation of PV plant do not affect landscape.
	21	Global warming							There is no possibility of impact because the construction and operation of PV plant do not affect global warming.

Table 4.6. Scoping Matrix for Alternative 2 (1.0MW PV Plant) (2/2)

Category and environmental item \ Factor affecting environment	No.	Item	OVERALL RATING	Const. Phase: Land preparation	Const. Phase: Op. of const. machinery	Const. Phase: Transp. of equipment	Const. Phase: Const. of power plant	Op. Ph.: Existence of PV plant	Description
Pollution	22	Air pollution	B		B	B			There is a possibility of impact because of SPM and dust arising from operation of construction vehicles and machineries.
	23	Water pollution							There is no possibility of impact because the construction and operation of power plants do not lead to water pollution.
	24	Soil contamination							There is no possibility of impact because the construction and operation of power plants do not lead to soil contamination.
	25	Waste	B	B			B		Construction wastes arise from construction activities.
	26	Noise and vibration	B		B	B			There is a possibility of impact because of noise and vibration arising from operation of construction vehicles and machineries.
	27	Ground subsidence							There is no possibility of impact because the construction and operation of power plants do not lead to ground subsidence.
	28	Offensive odor							There is no possibility of impact because the construction and operation of power plants do not lead to offensive odor.
	29	Bottom sediment							There is no possibility of impact because the construction and operation of power plants do not lead to bottom sediment.
	30	Accidents							There is a possibility of impact on traffic safety because of the operation of construction vehicles and machineries.

Rating
A: Serious impact is expected.
B: Some impact is expected.
C: Extent of impact is unknown. (Examination is needed. Impacts may become clear as study progress.)
No mark: No impact is expected. IEE/EIA is not necessary.

Source: JICA Study Team

In the case of the Alternative 2, six (6) environmental items shall be examined through the study of EIA. Those 6 items are all rated as B that means some impact is expected. The degrees of those impacts are deemed to be very limited and, in fact, reliable mitigation measures can be done against those impacts.

4.7 Emission Reduction

The effect of emission reduction by both cases of the Alternative 1 and Alternative 2 can be estimated from the offset of diesel fuel with the electric generation by the renewal energy resource respectively. The results of the estimation are shown below.

Table 4.7 Emission Reduction in the cases of Alternative 1 and Alternative 2 (Tentative)

	Alternative 1 (0.5MW PV plant + 0.5MW wind plant)	Alternative 2 (1.0MW PV plant)
Rated Capacity of System (MW)	1.0	1.0
Estimated Electricity Output (MWh/year)	1,874	1,308
Reduced Quantity of Diesel Oil (kl/year)	468	327
Reduction of CO_2 Emission (t-CO_2/year)	1,268	886

Source: JICA Study Team

In the case of Alternative 1, the reduction of CO_2 emission will be 1,268 tons. On the other hand, 886 tons of CO_2 reduction is expected in the case of Alternative 2. The effect of emission reduction in Alternative 2 is less than the case of Alternative 1 because solar PV plant does not generate electricity during nighttime. The detailed estimation of the emission reduction by both cases of the Alternative 1 and Alternative 2 is shown below.

Case of the Alternative 1

The estimated electricity output in the case of the Alternative 1 is as follows.

Estimated Electricity Output by 0.5MW PV Plant: 654 MWh/year

Estimated Electricity Output by 0.5MW Wind Plant: 1,220 MWh/year

Total Output: 1,874 MWh/year

The estimated electricity output can be converted to reduced quantity of diesel oil based on the actual fuel consumption of the diesel power plant in Tongatapu as follows.

Reduced Quantity of Diesel Oil = 1,874 MWh/year ÷ 4 kWh/l = 468 kl/year

The reduction of CO2 emission is calculated using the unit calorific value (39.1GJ/kl) and the emission factor (0.0693kg-CO2/l) of diesel oil as follows.

Reduction of CO2 Emission = 468 kl/year × 39.1 GJ/kl × 0.0693 kg-CO2/l = 1,268 t-CO2/year

Case of the Alternative 2

The estimated electricity output in the case of the Alternative 2 is as follows.

Estimated Electricity Output by 1.0MW PV Plant: 1,308 MWh/year

In the same way, the estimated electricity output can be converted to reduced quantity of diesel oil based on the actual fuel consumption of the diesel power plant in Tongatapu as follows.

Reduced Quantity of Diesel Oil = 1,307.8 MWh/year ÷ 4 kWh/l = 327 kl/year

The reduction of CO2 emission is calculated as follows.

Reduction of CO2 Emission = 326.9 kl/year × 39.1 GJ/kl × 0.0693 kg-CO2/l = 886 t-CO2/year

4.8 Mitigation Measures

As shown in the following table, the mitigation measures are examined in the case of the Alternative 2 that is the agreed plan between the Tongan and Japanese sides.

Table 4.8 Assumed Mitigation Measures

Items	Rating	Possible Impact	Assumed Mitigation Measures
Local economy such as employment and livelihood, etc.	B	Loss of agricultural product is expected because some coconut trees are cultivated in the site of PV plant.	The project site for PV plant is currently owned by a noble and covered by bush with some coconut trees. Those trees and bush will be cut down and cleared. TPL will lease the site from the noble and compensation for the loss of agricultural product will be included in the land lease.
Topography and geographical features	B	Minor changes of topography are expected because of clearing and leveling of the site.	The degree of the topographic change is very small because the magnitude of land preparation work is very limited and soil transportation to/from the site is not expected. Impacts such as soil erosion resulting from topographic change can be avoided or mitigated with appropriate measures such as covering over turned soil by tarpaulin.
Soil erosion	B	There is a possibility of impact because of clearing and leveling of the site during construction phase.	During construction phase, soil erosion can be avoided or mitigated with appropriate measures such as covering over turned soil by tarpaulin.
Air pollution	B	There is a possibility of impact because of SPM and dust arising from operation of construction vehicles and machineries.	During construction phase, occurrence of dust will be avoided or mitigated by watering or dustproof covering on turned soil. As for SPM and dust arising from transportation of construction materials and equipment from wharf to the site, the impact will be mitigated with careful selection of transportation route and operation hour avoiding the center of town.
Waste	B	Construction wastes arise from construction activities.	Construction waste will be treated at the nearby landfill site located at approx. 500 meters on the north of the project site, in accordance with law.
Noise and vibration	B	There is a possibility of impact because of noise and vibration arising from operation of construction vehicles and machineries.	The noise and vibration caused by vehicle operation for transportation of construction materials and equipment from wharf to the site will be mitigated with careful selection of transportation route and operation hour avoiding the center of town. In addition, operation of construction vehicles and machineries will be limited during daytime hours in order to avoid impact of noise and vibration at night.

Source: JICA Study Team

4.9 Monitoring Plan

As a whole, the impacts of the Project on the natural and social environment are not significant as mentioned in the previous section. The most of the impacts are deemed to occur during construction phase, and those impacts can be avoided or mitigated with daily construction management. Accordingly, there are not any environmental items to be monitored.

4.10 Land System

The prime feature of land system in the Kingdom of Tonga is that "all the land of the Kingdom is the property of the Crown", as declared in the Land Act. The Minister of the MLECCNR is responsible for the land administration of the Kingdom's land as the representative of the Crown. There are two types of landownership; one is the Crown Land and the other, estate so-called "Tofia". The Crown Lands include Royal Estates, Royal Family Estates, lands for public purposes such as road and cemetery, and so on, while the Tofias, which are entitled to privilege of hereditary transfer, have been given to only so many people such as nobles provided in the Land Act. People (or Commoner) can only lease the Crown Lands or Tofias with conditionality of less than 99 years' lease period because the Land Act places a ban on sale of the Kingdom's land.

4.11 Landownership of the Project Site for Solar PV System

The project site for the solar PV system at Vaini is owned by Lord Ma'afu who is the Minister for the MLECCNR. Lord Ma'afu has accepted TPL's request for the lease of the land, and sent the confirmation letter to TPL during the First Field Survey on August 2012. At present (as of October 2nd, 2012), the document of the lease contract has been finalized through the negotiation between TPL and the legal advisor for Lord Ma'afu. According to TPL, the lease contract will be concluded within a week or so, along with a signing ceremony. The compensation for orchard trees such as mango and coconut palm is included in the lease contract.

In general, the documents of the lease contract will be submitted to the MLECCNR for approval and registration. The submitted lease contract will be deliberated in the Cabinet and, if it is acceptable, the Minister of the MLECCNR will approve the lease contract with the Cabinet's consent. And then, the project site will be surveyed and registered by the MLECCNR. According to the Planning & Urban Management Agency of the MLECCNR, it generally takes one month from submission of the lease contract to the registration.

In this case, however, the MLECCNR conducted the survey of the Project Site and identified the boundary prior to conclusion of the lease contract, because of the urgent need of topographic survey of the Project Site.

4.12 Preparation of Environmental Checklist

Through the consultation between TPL and the JICA study team, the environmental checklist for the Project (refer to ANNEX. 4) was prepared in order to confirm the situation of EIA procedures and the environmental items to be considered.

4.13 Perspective on EIA Report and Environmental Permit

In accordance with advice of the Secretariat of EAC in the Department of Environment & Climate Change, TPL will submit a series of documents based on the results of the Second Field Survey to the Secretariat, in order to obtain a pre-approval for the Project and to shorten the time period required to the EIA procedure. In relation to the preparation of the EIA report, TPL will implement an environmental and social survey including stakeholder meetings. A series of finalized drawings and specifications, which will be provided by the JICA mission to TPL during the Third Field Survey in this December, will be necessary to submit the EIA report for the formal application to the Secretariat.

5. Work Demarcations for Both of the Tongan and Japanese Side

In the implementation of the Grant Aid Project, the recipient country is required to undertake such necessary measures as shown as Table 5.1.

Table 5.1 Work Demarcations for Both of the Tongan and Japanese Side

No.	Items	To be covered by Grant Aid	To be covered by Recipient Side
1	to secure [a lot] /[lots] of land necessary for the implementation of the Project and to clear the [site]/[sites];		●
2	To construct the following facilities		
	1) The building	●	
	2) The gates and fences in and around the site		●
	3) The parking lot	●	
	4) The road within the site	●	
	5) The road outside the site		●
	6) The gate house if needed		●
3	To provide facilities for distribution of electricity, water supply and drainage and other incidental facilities necessary for the implementation of the Project outside the [site]/[sites]		
	1)Electricity		
	a. The distributing power line to the site		●
	b. The drop wiring and internal wiring within the site	●	
	c. The main circuit breaker and transformer	●	
	2) Water Supply		
	a. The city water distribution main to the site		●
	b. The supply system within the site (receiving and elevated tanks)	●	
	3) Drainage		
	a. The city drainage main (for storm sewer and others to the site)		●
	b. The drainage system (for toilet sewer, common waste, storm drainage and others) within the site	●	
	4) Gas Supply		
	a. The city gas main to the site		●
	b. The gas supply system within the site	●	
	5) Telephone System		
	a. The telephone trunk line to the main distribution frame/panel (MDF) of the building		●
	b. The MDF and the extension after the frame/panel	●	
	6) Furniture and Equipment		
	a. General furniture		●
	b. Project equipment	●	
4	To connect the PV system to the existing grid		
	1) Procurement of underground Cable long enough to connect to the existing pole	●	
	2) Installation of the cable to the existing grid		●
5	To ensure prompt unloading and customs clearance of the products at ports of disembarkation in the recipient country and to assist internal transportation of the products		
	1) Marine (Air) transportation of the Products from Japan to the recipient country	●	
	2) Tax exemption and custom clearance of the Products at the port of disembarkation		●
	3) Internal transportation from the port of disembarkation to the project site	●	
6	To ensure that customs duties, internal taxes and other fiscal levies which may be imposed in the recipient country with respect to the purchase of the products and the services [be exempted] / [be borne by the Authority without using the Grant]		●
7	To accord Japanese nationals whose services may be required in connection with the supply of the products and the services such facilities as may be necessary for their entry into the recipient country and stay therein for the performance of their work		●
8	To ensure that [the Facilities and the products]/[the Facilities]/ [the products] be maintained and used properly and effectively for the implementation of the Project		●
9	To bear the following commissions paid to the Japanese bank for banking services based upon the B/A		
	1) Advising commission of A/P		●
	2) Payment commission		●
10	To give due environmental and social consideration in the implementation of the Project.		●
11	To bear all the above expenses, other than those covered by the Grant, necessary for the implementation of the Project		●

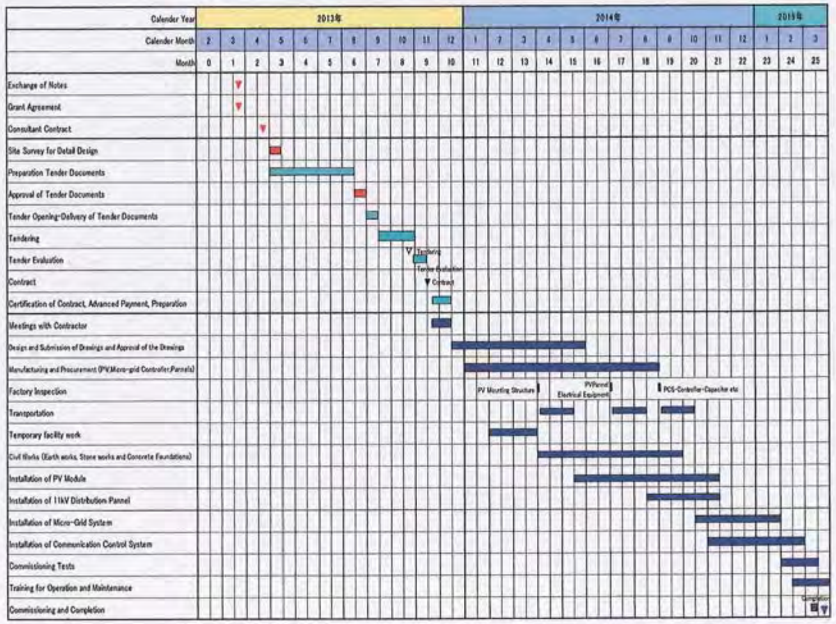
*1 B/A: Banking Arrangement, A/P: Authorization to pay) *2 If the environmental screening category is C, No.10 is unnecessary

6. Project Implementation Schedule

The tentative implementation schedule is shown as Table 6.1. In case that the Project is committed by the Japanese Government, the Project will proceed as follows in case of the earliest scenario, as shown as Table 6.1. The construction work will be commenced at the beginning of 2013.

- ➢ The Exchange of Notes and Grant Agreement between the Tongan and Japanese Government will be signed in March, 2013.
- ➢ The Tender Opening will be held in September, 2013.
- ➢ Construction work of the Project will start in May, 2014.
- ➢ Commissioning of the Project will be in March, 2015.

Table 6.1 Tentative Implementation Schedule of the Project



7. Other Relevant Issues

(1) Submission of data of possible minimum demand during PV operation to the Team with information of occurrence frequency

The Tongan side agreed to submit data of possible minimum demand during PV operation to the Team based on the analysis of data for the past one year with information of occurrence frequency during the second field survey as official opinions from TPL.

(2) Submission of data showing control characteristics of the existing MaK generators for dynamic analysis to the Team

The Tongan side request the Team to carry out the dynamic analysis under the load sharing conditions by the Mak generators for reference, based on the data showing control characteristics of the existing MaK generators. The Team agreed to do so, based on the following data submitted by the Tongan side during the second field survey.

- ➢ Control block diagram of AVR and Governor both for control device and mechanical device
- ➢ Set value of above mentioned devices such as gains, time constants, control limit and etc.
- ➢ Inertia constant of engine and generator

(3) Meeting to examine the control of the micro-grid system of the Project between the concerned parties for technical issues

Prior to the commencement of procurement and installation of the Project, the concerned parties such as TPL, the manufacturer of the Micro-grid system of the Project, manufacturer or contractor of the existing CAT generator and Consultant shall be gathered to examine the control of the grid system. The meeting shall be held in Tongatapu Island after conclusion of the Contract of the Project.

The Tongan side and Team agreed that the Japanese side shall bear the cost to dispatch engineers of the manufacturer of the Micro-grid system of the Project and Consultant, and the Tongan side shall bear the cost to dispatch engineers of the manufacturer or contractor of the existing CAT generator.

(4) Conditions for introduction of Renewable Energy after the Project

Power supply in Tongatapu Island after the Project will highly rely on renewable energy which fluctuates steeply in accordance with change of weather condition. The Team advised to the Tongan side that introduction of power storage system should condition upon further introduction of power source from renewable energy, and type, capacity and control method of the storage system should carefully be examined based on the capacity and characteristics of introduced type of renewable energy.

ANNEX

1. Members of the Team
2. Schedule of the Second Field Survey
3. Presentation Documents
   (Findings of the Second Field Survey)
4. Environmental Check list
5. Activities and Technology Transfer Method of Soft Component

ANNEX 1

Member of the Team

Members of the Team

Name	Assignment	Organization
Mitsuhisa NISHIKAWA	Chief Consultant / Distribution System Design	Yachiyo Engineering Co., Ltd.
Kyoji FUJII	Deputy Chief Consultant/ Operation of Diesel Engine Generator	Yachiyo Engineering Co., Ltd.
Hidekazu SATO	Micro-Grid System 1(Grid Control) / Battery Equipment Plan	Yachiyo Engineering Co., Ltd.
*1)Masahiko TAKEMURA	Micro-Grid System 2 (Grid Stability Analysis)	Yachiyo Engineering Co., Ltd.
Shozo KURASHIMA	Renewable Energy 1	Yachiyo Engineering Co., Ltd.
Shinya KONDO	Renewable Energy 2	West Japan Engineering Consultants, Inc.
Kazunari NOGAMI	Procurement Plan/ Cost Estimation 1	Yachiyo Engineering Co., Ltd.
Kenji OHARA	Natural Condition Survey/ Cost Estimation 2	Yachiyo Engineering Co., Ltd.
Shigeki TAKASHIMA	Social and Environmental Considerations	Yachiyo Engineering Co., Ltd.
Yusuke Katsuta	Economic and Financial Analysis	Yachiyo Engineering Co., Ltd.
Masao YAMAKAWA	Coordinator/ Assistance for Micro-Grid Design	Yachiyo Engineering Co., Ltd.

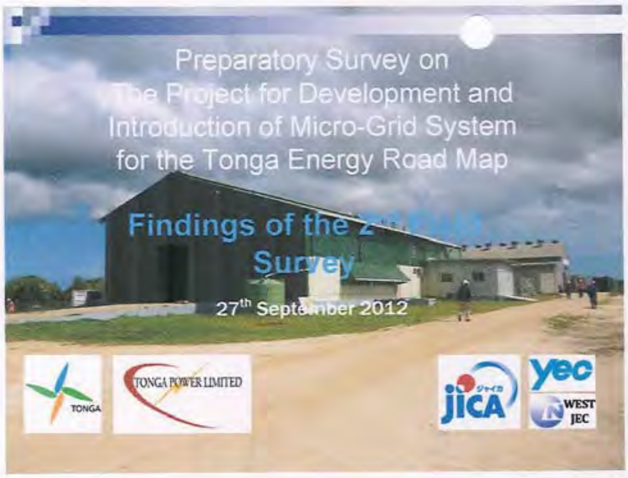
Remarks: *1) He will attend Analysis in Japan.

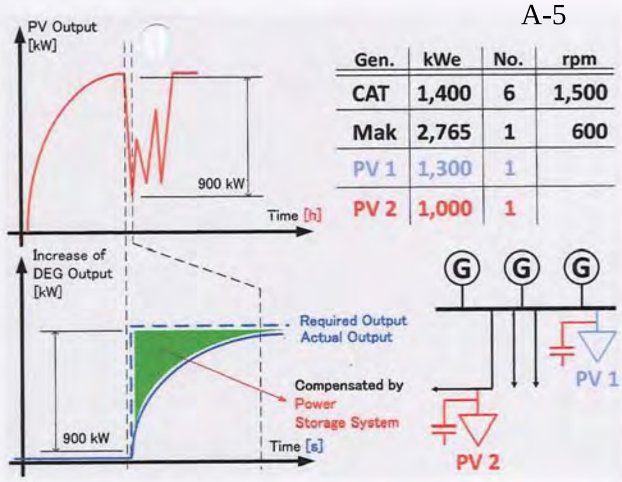
ANNEX 2

Schedule of the Second Field Survey

Schedule of the Second Field Survey

No.	Date	Consultant members Nishikawa, Fujii, Satoh, Kurashima, Kondo, Nogami, Takashima, Ohara, Katsuta, Yamakawa	Stay at
1.	18 Sep.(Tue)	① Trip from Tokyo (19:00) to Auckland (09:00+1) by NZ-090	On flight
2.	19 Sep.(Wed)	① Trip from Auckland (15:30) to Nuku'alofa (19:00) by NZ-974 ② Concluding the Contract with Soil investigation company and coordinating the actual schedule(during transit time at the airport)	Nuku'alofa
3.	20 Sep.(Thu)	① Courtesy call and explanation of planned survey schedule, Contents of survey, etc. 1) JICA Tonga Office at 9:00 a.m. (Mr. Tsujimoto, Mr. Ishigaki) 2) TERM (Tonga Energy Road Map) at 11:00 a.m. (Mr. Inoke) 3) TPL (Tonga Power Limited) at 14:00 p.m.(Mr. John van Brink) ② Survey of Popua Power Station (P/S) (Specifications of Equipment/machineries, Operation records, etc.) ③ Concluding the Contract with Topographic survey company and coordinating the actual schedule, site location, etc.	Nuku'alofa
4.	21 Sep.(Fri)	① Technical discussions with TPL 1) Explanation of the analysis results for battery capacities, wind turbine potentials, etc. 2) Explanation of the Environmental comparisons such as Zero option, etc. 3) Discussions for Organization of O & M section and financial planning/records, etc. ② Survey of Popua P/S (Specifications of Equipment/machineries, Operation records, etc.) ③ Confirmation of Vaini PV site (Clearing situation of the site, Topographic survey points, etc.)	Nuku'alofa
5.	22 Sep.(Sat)	① Technical discussions with TPL 1) Explanation of the analysis results for battery, grid control system, etc. 2) Explanation of the Environmental comparisons such as Zero option, etc. 3) Discussions for Organization of O & M section and financial planning/records, etc. ② Survey of Popua P/S (Specifications of Equipment/machineries, Operation records, etc.) ③ Collection of amount of isolation data ④ Confirmation of Topographic survey points at Popua PS. ⑤ Collection of Local construction cost	Nuku'alofa
6.	23.Sep.(Sun)	① Internal meeting ② Arranging the data and information collecting ③ Local market survey	Nuku'alofa
7.	24 Sep.(Mon)	① Technical discussions with TPL 1) Explanation of the analysis results for grid control system, battery capacities, etc. 2) Explanation of the Environment and social consideration (scoping plan, etc.) 3) Discussions for Organization of O & M section and financial planning/records, etc. ② Survey of Popua P/S (Specifications of Equipment/machineries, Operation records, etc.) ③ Collection of amount of isolation data ④ Confirmation of Topographic survey and soil investigation works at Vaini PV site.. ⑤ Collection of Local construction cost	Nuku'alofa
8.	25 Sep. (Tue)	① Report to TERM about Progress of 2nd field survey, and discussion for Organization and budget of Term. ② Technical discussions with TPL 1) Micro grid controller, capacity of Batteries etc. 2) Explanation of the Environment and social consideration (scoping plan, etc.) 3) Discussions for Organization of O & M section and financial planning/records, etc. ③ Report to JICA about Progress of 2nd field survey. ④ Distribution lines survey ⑤ Survey of Local contractor situations	Nuku'alofa
9.	26 Sep. (Wed)	① Preparation of report to TPL ② Continuing discussions with TPL and MLECCNR for Environment and social consideration ③ Continuing the progress of Topographic survey and Soil investigation. ④ Meetings in the Team ⑤ Courtesy call to JICA (Katsuta, Yamakawa) ⑥ Preparation of Quantity survey	Nuku'alofa
10.	27.Sep. (Thu)	① Report to TPL ② Confirmation of the scheme of the Japanese Grant to the Ministry of Finance and Planning. ③ Continuing discussions with TPL and MLECCNR for Environment and social consideration ④ Continuing confirmation of Topographic survey and Soil investigation. ⑤ Preparation of Quantity survey	Nuku'alofa
11.	28 Sep (Fri)	① Report to TERM ② Continuing confirmation of Topographic survey and Soil investigation. ③ Check of the progress at Vaini Site ④ Continuing discussions with TPL ⑤ Preparation of Quantity survey	Nuku'alofa
12.	29 Sep (Sat)	① Continuing survey of Popua P/S ② Preparation of Field Report ③ Preparation of Quantity survey	Nuku'alofa
13.	30.Sep.(Sun)	① Internal meeting ② Arranging the data and information collecting ③ Preparation of Field Report	Nuku'alofa
14.	01 Oct.(Mon)	① Supplementary survey for each assignment ② Preparation of Field Report	Nuku'alofa
15.	02 Oct. (Tue)	① Supplementary survey for each assignment ② Preparation of Field Report	Nuku'alofa
16.	03 Oct. (Wed)	① Supplementary survey for each assignment ② Preparation of Field Report	Nuku'alofa
17.	04 Oct. (Thu)	① Explanation of Field Report to TPL and TERM ② Correction of Field Report (If any) ③ Supplementary survey	Nuku'alofa
18.	05 Oct. (Fri)	① Obtaining the Confirmation of Field Report from TERM & TPL ② Report to JICA Tonga Office ③ Report to the Embassy of Japan to Tonga	Nuku'alofa
19.	06 ct. (Sat)	① Trip from Nuku'alofa (10:20) to Auckland (12:20) by NZ-273	Auckland
20	07 Oct. (Sun)	① Trip from Auckland (09:25) to Tokyo(16:50) by NZ-099	Japan





Gen.	kWe	No.	rpm
CAT	1,400	6	1,500
Mak	2,765	1	600
PV 1	1,300	1	
PV 2	1,000	1	

Agenda

1. Introduction of PV (Nogami)
2. Conceptual model for suppression of output instability (Kondo)
3. Type of Power Storage System (Sato)
4. Proposed Micro-grid System in Tonga (Nogami)
5. Introduction example on Micro-grid System in Japan (Kondo)
6. Reduction of CO2 Emission by the Project (Takashima)
7. Potential Evaluation for Wind Power (Kondo, for your information and guidance)
8. Conclusion (Nishikawa)

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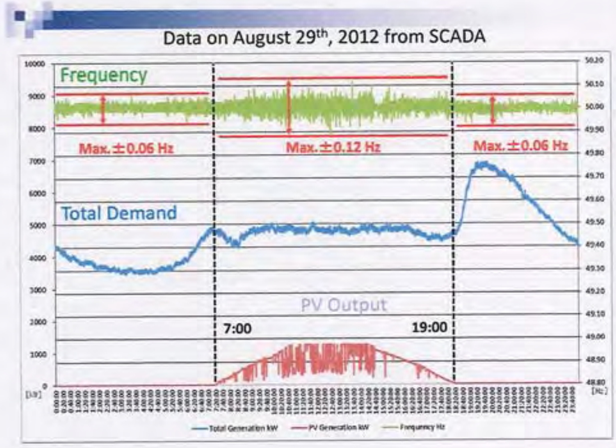


ANNEX 3

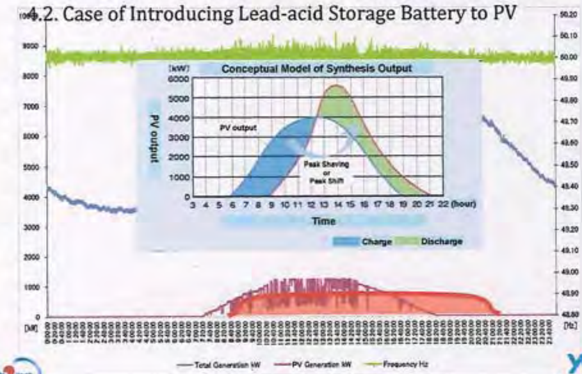
Presentation Documents

to Tonga Power Limited on 27th September, 2012 and
to Tonga Energy Road Map Committee on 28th September, 2012

(Findings of the Second Field Survey)

4. Proposed Micro-grid System in Tonga

4.2. Case of Introducing Lead-acid Storage Battery to PV



4. Proposed Micro-grid System in Tonga

【In case of minimum demand during PV operation】

Conditions;
Demand: 4,500kW
PV Output: 2,300kW

Number of DEG in operation: 1,400 x 4units = 5,600kW
> 4,500kW

DEG road ratio:
DEG Output/Total DEG capacity
= (Demand – PV output)/ Total DEG capacity
= (4,500 – 2,300)/(1,400 x 4) = **40%**

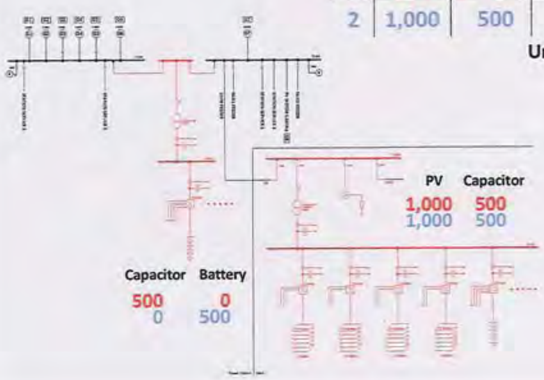
Thus, minimum load ratio of DGE should be changed 65% to 40%.
If minimum demand is under 4,500kW, PV output should be reduced by stopping one of 500kW PV system or charging battery.

4. Proposed Micro-grid System in Tonga

*There was a mistake in the capacity of the capacitor at the presentation.
The capacity shall be 10kWh.

Plan	PV	Capacitor	Battery
1	1,000	1,000	0
2	1,000	500	500

Unit : kW

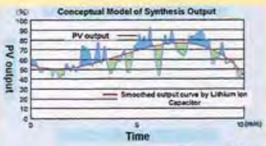


2. Conceptual model for suppression of output instability

Suppression of short-period output instability

Advantage:
Suppression of frequency instability

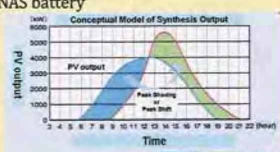
Power storage Device:
Lithium Ion Capacitor or
Electrical Double Layer Capacitor



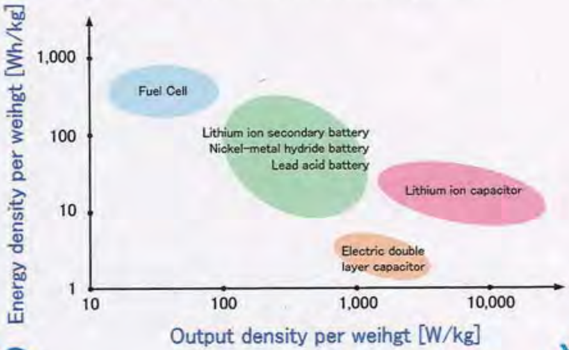
Suppression of long-period output instability and peak-shaving

Advantage:
Peak-shaving (shifting) and improving low load operation of DEG

Power storage battery:
Lead-acid battery or
Lithium ion battery or
NAS battery



3. Type of Power Storage System

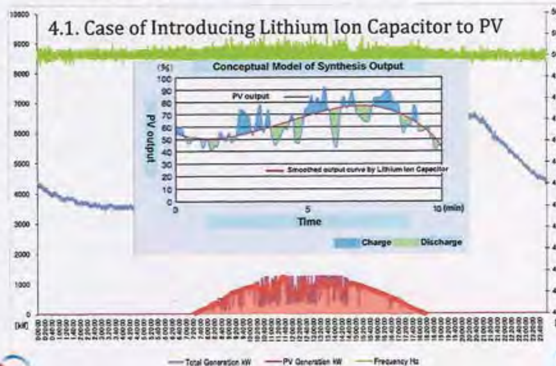


3. Type of Power Storage System

Item	Storage Device		Storage Battery	
	Electric Double-Layer Capacitor	Li-Ion Capacitor	Lead-Acid Battery	Lithium-Ion Battery
Principal	Physical phenomenon	Physical phenomenon	Chemical reaction	Chemical reaction
Voltage (V per cell)	2.5	3.8	2	4.2
Energy Density (Wh/liter)	△ (2~6 Wh/L)	○ (10 Wh/L)	◎ (60~75 Wh/L)	◎ (250~360 Wh/L)
High-Rate Discharge	◎	◎	×	△
Duration of Discharge	Very short (up to few second)	Up to 1 minitue	Up to 10 hours	Up to 5 hours
High Temperature Confidence	○	◎	○	△
Temperature Rage	-20 ~ +60 ℃	-20 ~ +80 ℃	-30 ~ +50 ℃	-20 ~ +60 ℃
Cyclic Life	100,000 cycles	100,000 cycles	Approx. 8 to 10 years at 50% D.O.D.	3,000 to 5,000 cycles
Environmental	No heavy metal	No heavy metal	Use of heavy metal	Use of heavy metal
Recycling	Not specified	Not specified	Required	Required
Application	Short Term Power Interruption Compensator (UPS)	Stabilization for Renewable Energy	Peak shift for renewable energy	Electric automobile

4. Proposed Micro-grid System in Tonga

4.1. Case of Introducing Lithium Ion Capacitor to PV



[Conditions] Fluctuation of PV output : 50 %/10sec
Introduction of power storage system : 500 kW × 2 sites

"500 kW × 2 sites" is enough to keep the current level of quality.

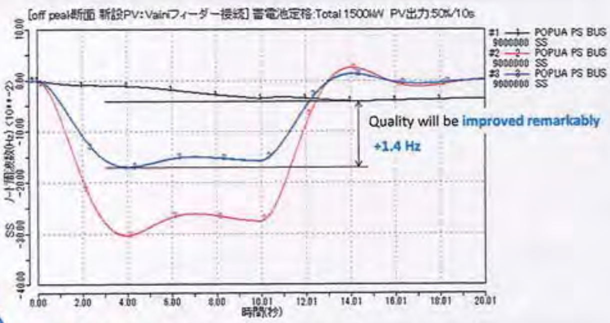
5. Introduction example on Micro-grid System for Isolated Islands in Japan

Introduction example (Verification Phase)		MIYAKO Island	TATARA Island	YONAKUNI Island	KITADAITO Island
Maximum Demand (approx.)		50,000kW	1,160kW	2,160kW	860kW
Existing Diesel Engine Generators		74,000kW	1,590kW	2,910kW	1,540kW
Existing Renewable-Energy	PV	490kW			40kW
	WP	4,200kW		1,200kW	
	HP	650kW			
New Introduced Renewable-energy	PV	4,000kW	250kW	150kW	100kW
New Introduced Storage Battery	NAS	4,000kW			
	LIB	100kW			
	LIC		250kW	150kW	100kW
Max Demand/PV ratio		8%	22%	7%	12%

Legend; PV: Photovoltaic Power, WP: Wind Power, HP: Hydraulic Power
NAS: Natrium-sulfer Battery, LIB: Lithium Ion Battery, LIC: Lithium Ion Capacitor

Project name:
Demonstration project of micro-grid system on Isolated Islands in Okinawa region
Implementing Agency:
Okinawa Electrical Power Corporation

[Conditions] Fluctuation of PV output : 50 %/10sec
Introduction of power storage system : 750 kW × 2 sites



"750 kW × 2 sites" will improve quality of power supply.
Replacement cost for capacitor or battery will increase too much.

5. Introduction example on Micro-grid System for Isolated Islands in Japan

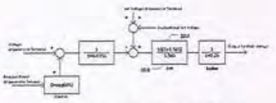
Introduction example (Verification Phase)		KURO Island	TAKE Island	NAKANO Island	SUWANOSE Island	KODAKARA Island	TAKARA Island
Maximum Demand (approx.)		193kW	83kW	193kW	78kW	71kW	125kW
Existing Diesel Engine Generators		240kW	190kW	253kW	160kW	110kW	200kW
New Introduced Renewable-energy	PV	60kW	7.5kW	15kW	10kW	7.5kW	10kW
	WP	10kW					
New Introduced Storage Battery	LEAD	256kW		80kW	80kW	80kW	80kW
	LIB	66kW	33kW				
Max Demand/PV ratio		31%	9%	8%	13%	11%	8%

Legend; PV: Photovoltaic Power, WP: Wind Power
LEAD: Lead-acid Battery, LIB: Lithium Ion Battery

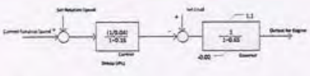
Project name:
Demonstration project of micro-grid system on Isolated Islands in Kyushu region
Implementing Agency:
Kyushu Electrical Power Corporation

Power flow analysis for consideration of capacity of power storage system

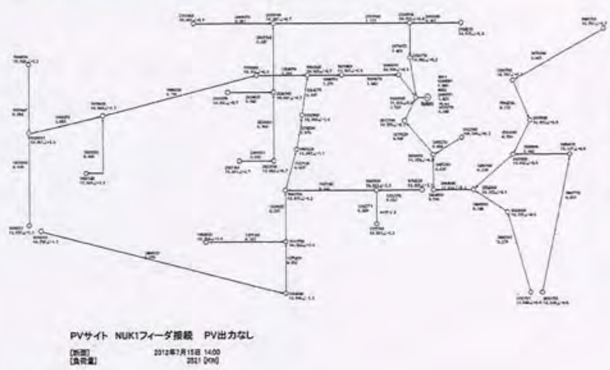
[Conditions] Demand : 3,500 kW
Number of diesel engine generator in operation : 1,400kW × 3 units
Fluctuation of PV output : 50 %/10sec
Introduction of power storage system : 250 kW × 2 sites
500 kW × 2 sites
750 kW × 2 sites

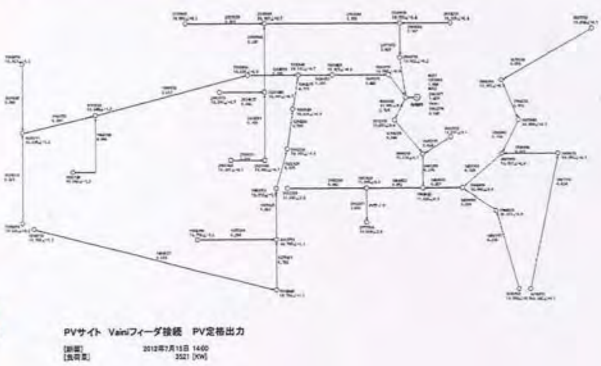


Control Block for AVR

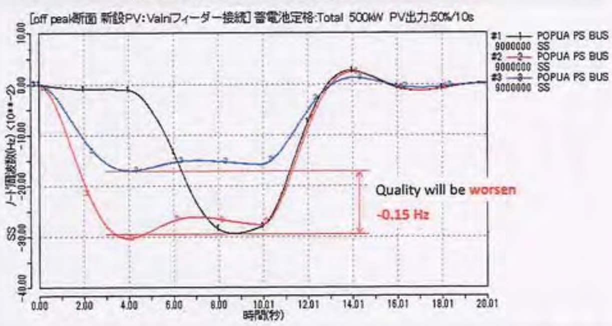


Control Block for Governor





[Conditions] Fluctuation of PV output : 50 %/10sec
Introduction of power storage system : 250 kW × 2 sites



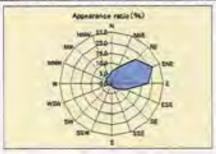
"250 kW × 2 sites" is not enough to keep the current level of quality.

7. Potential Evaluation for Wind Power (for your information and guidance)

6.2 Appearance ratio at different direction (GH: 50m)

(unit: %)

	[illegible]	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Data amount
Jan-11	0.0	9.9	14.7	21.6	18.7	5.8	0.7	0.9	0.5	0.1	0.0	0.3	0.3	0.5	2.8	9.7	13.4	744
Feb-11	0.0	6.0	11.2	12.6	22.0	9.2	4.0	1.8	0.1	0.6	1.5	4.2	5.7	5.4	5.7	7.4	2.7	672
Mar-11	0.0	13.4	9.8	14.5	18.5	11.2	5.0	1.9	1.1	0.9	0.3	0.0	0.3	3.9	7.1	4.0	8.1	744
Apr-11	0.0	11.8	10.0	11.8	10.8	16.4	5.0	2.4	1.7	1.0	1.7	1.3	2.4	6.4	6.7	7.2	3.6	720
May-11	0.0	7.1	13.2	24.5	14.4	21.2	4.3	1.5	1.5	0.4	0.8	1.2	3.2	1.7	1.7	0.8	2.4	744
Jun-11	0.0	4.7	9.0	21.8	21.4	15.7	11.9	5.6	3.3	0.7	0.0	0.0	0.0	0.0	0.1	1.9	3.8	720
Jul-11	0.0	4.0	9.0	5.1	14.8	15.7	10.5	5.2	4.0	2.6	4.0	5.0	5.2	5.6	3.5	2.8	2.8	744
Aug-10	0.0	5.2	8.7	21.6	21.4	18.1	12.0	2.8	1.6	0.7	0.8	0.7	1.6	1.1	1.2	1.1	1.3	744
Sep-10	0.0	0.8	7.1	17.9	35.7	19.4	10.0	4.0	2.8	1.0	0.1	0.4	0.0	0.0	0.0	0.3	0.4	720
Oct-10	0.0	2.2	3.5	9.5	20.0	30.1	14.2	9.3	1.3	0.5	0.7	0.8	1.5	1.7	1.5	1.5	1.5	744
Nov-10	0.0	2.5	2.8	7.4	12.5	35.8	12.5	10.0	0.7	0.3	0.4	0.3	1.3	0.8	2.5	5.7	4.6	720
Dec-10	0.0	1.2	2.2	26.7	45.7	12.9	1.1	0.7	0.1	0.8	0.4	0.7	0.7	1.3	1.5	3.2	0.8	744
For the year	0.0	5.8	8.4	16.3	21.3	17.7	7.6	3.8	1.6	0.8	0.9	1.2	1.8	2.4	2.8	3.8	3.8	8760



8. Conclusion

Preconditions

MAC Generator : Out of service during PV operation

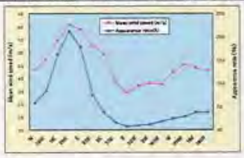
CAT Generator: Minimum Low-load ratio _40%

7. Potential Evaluation for Wind Power (for your information and guidance)

6.3 Mean Wind Speed and Appearance ratio at different direction

(unit: %)

Wind speed	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
0≤V<1	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1≤V<2	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.1
2≤V<3	0.5	0.4	0.5	0.4	0.6	0.5	0.3	0.3	0.1	0.1	0.2	0.3	0.3	0.2	0.3	0.4
3≤V<4	1.4	1.8	1.4	0.5	0.8	0.6	0.3	0.3	0.3	0.3	0.3	0.5	0.4	0.3	0.7	0.3
4≤V<5	1.6	1.8	2.0	1.7	1.5	0.8	0.4	0.4	0.1	0.2	0.2	0.4	0.4	0.8	0.8	0.8
5≤V<6	0.7	1.7	2.7	2.0	1.7	1.1	0.6	0.1	0.0	0.1	0.1	0.2	0.8	0.5	0.6	0.5
6≤V<7	0.4	0.8	2.4	2.2	2.6	1.2	0.5	0.1		0.0	0.1	0.1	0.3	0.4	0.3	0.4
7≤V<8	0.5	0.6	2.2	2.2	2.3	1.1	0.5	0.0	0.0		0.1	0.0	0.1	0.2	0.3	0.2
8≤V<9	0.2	0.6	1.8	2.9	1.8	0.8	0.2	0.0			0.0	0.0	0.0	0.1	0.2	0.1
9≤V<10	0.3	0.3	1.0	2.8	1.9	0.6	0.2	0.0		0.0			0.0	0.1	0.1	0.1
10≤V<11	0.1	0.1	0.9	2.3	1.5	0.5	0.1						0.0	0.0		0.0
11≤V<12	0.0	0.1	0.7	1.8	1.7	0.2	0.0									0.0
12≤V<13		0.0	0.4	1.1	0.8	0.1	0.0									
13≤V<14	0.0	0.0	0.1	0.5	0.5	0.0	0.0									
14≤V<15			0.2	0.1	0.1	0.0	0.0									
Mean wind speed (m/s)	4.7	5.5	6.9	6.2	7.6	6.5	5.9	3.7	2.9	3.4	3.6	3.5	4.3	5.1	4.6	4.5
Appearance ratio (%)	5.8	8.4	16.3	21.3	17.7	7.6	3.8	1.6	0.8	0.9	1.2	1.8	2.4	2.8	3.8	3.8



8. Conclusion

Requested data:

- ➢CAT Generator: Minimum Low-load ratio _**%
- ➢Minimum demand during peak PV output
  (Winter Weekday, Winter Sunday,
  Summer Weekday, Summer Sunday)

6. Reduction of CO2 Emission by the Project

Rated Capacity of the Solar PV System	1.0 MW
Estimated Electricity Output	1,308 MWh/year
Ratio of Electricity Output to TPL's Actual Power Generation 2011/12 *	2.5 %
Reduced Quantity of Diesel Oil	327 kl/year
Reduction of CO_2 Emission	886 t-CO_2/year

* TPL's actual power generation 2011/12: 52,391 MWh/year

7. Potential Evaluation for Wind Power (for your information and guidance)

Attribution	Analysis items	Meaning
Wind conditions characteristics	Mean wind speed	To determine whether the development of wind power
	Appearance ratio of wind direction	To determine prevailing wind direction
	Hourly appearance ratio of wind direction	To determine the fluctuation characteristics of wind direction
	Mean wind speed and appearance ratio for each wind direction	To determine the relationship between wind speed and wind direction
	Wind profile	To determine the wind shear for each wind direction
	Turbulence intensity	To determine the magnitude of the turbulence
	Maximum instantaneous wind speed	To determine the survival wind speed
	Appearance ratio of wind speed	To determine the wind speed distribution
Energy characteristics	Density of wind energy	To determine whether the development of wind power
	Availability	
	Available wind energy, Capacity factor	

7. Potential Evaluation for Wind Power (for your information and guidance)

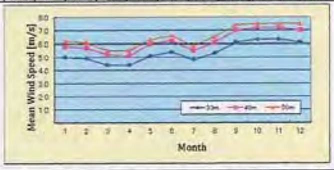
Data Source:

Imprementation Agency	MLECCER
Mesurement Period	from July 2010 to October 2011
Observation point	Lapaha Site
Adoption Period for analysis	from 1st August 2010 to 31st July 2011

7. Potential Evaluation for Wind Power (for your information and guidance)

6.1 Mean Wind Speed at different altitude

Ground Height	2011							2010					Ave.
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
30m	5.0	4.9	4.4	4.4	5.1	5.4	4.8	5.3	6.1	6.3	6.3	6.1	5.3
40m	5.8	5.7	5.2	5.1	6.0	6.2	5.5	6.1	7.0	7.2	7.2	7.0	6.2
50m	6.2	6.1	5.5	5.5	6.3	6.6	5.8	6.5	7.4	7.5	7.5	7.5	6.5



Feasibility Criteria (rough standard)

Mean Wind Speed ≧ 6m/s

ANNEX 4

Environmental Checklist for Micro Grid Controller, Solar PV System and Storage System (1)

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
1 Permits and Explanation	(1) EIA and Environmental Permits	1) Have EIA reports been already prepared in official process?	N	The EIA reports have not been prepared yet. TPL will complete the EIA reports and obtain environmental permit from the competent authority by the time when the E/N between the GOJ and the GOT is signed.
		2) Have EIA reports been approved by authorities of the host country's government?	N	The EIA report has not been approved yet.
		3) Have EIA reports been unconditionally approved? If conditions are imposed on the approval of EIA reports, are the conditions satisfied?	N	The EIA report has not been approved yet.
		4) In addition to the above approvals, have other required environmental permits been obtained from the appropriate regulatory authorities of the host country's government?	N	No other environmental permits are required.
	(2) Explanation to the Local Stakeholders	1) Have contents of the project and the potential impacts been adequately explained to the local stakeholders based on appropriate procedures, including information disclosure? Is understanding obtained from the local stakeholders?	N	Tongan environmental legislation does not require information disclosure to the public. However, TPL will identify stakeholders and has stakeholder meetings as soon as the Project's contents are decided and the potential impacts are clarified. The understanding of the local stakeholders can be obtained without difficulty because the existence and operation of PV plant does not cause any environmental problems to the surrounding.
		2) Have the comment from the stakeholders (such as local residents) been reflected to the project design?	N	Comments from stakeholders have not been obtained because contents of the project and the potential impacts have not been explained to the stakeholders.
	(3) Examination of Alternatives	1) Have alternative plans of the project been examined with social and environmental considerations?	Y	The alternative plans including zero-option have been examined in the preparatory survey implemented by JICA.
2 Pollution Control	(1) Water Quality	1) Is there any possibility that soil runoff from the bare lands resulting from earthmoving activities, such as cutting and filling will cause water quality degradation in downstream water areas? If the water quality degradation is anticipated, are adequate measures considered?	Y	Although earthmoving activities will be expected at the site, there is hardly any possibility of water quality degradation in downstream. Because magnitude of the earthmoving is very small and countermeasures will be taken against soil erosion in the construction stage.
	(2) Wastes	1) Are wastes, such as storage battery, generated by the plant operations properly treated and disposed of in accordance with the country's regulations?	Y	TPL will entrust the treatment of used batteries to a Tongan recycling firm who is qualified for the exportation of wastes under the Basel Convention.
		2) In the case that the wastes are treated by transboundary movement, do the activities comply with the recipient country' law, and international treaties and conventions such as Basel Convention?	Y	The wastes are treated by transboundary movement, and the activities comply with the recipient country's law, international treaties and conventions.

ANNEX 4

Environmental Check list

ANNEX 4

Environmental Checklist for Micro Grid Controller, Solar PV System and Storage System (3)

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
4 Social Environment	(1) Resettlement	6) Does the resettlement plan pay particular attention to vulnerable groups or people, including women, children, the elderly, people below the poverty line, ethnic minorities, and indigenous peoples?	N	Not applicable
		7) Are agreements with the affected persons obtained prior to resettlement?	N	Not applicable
		8) Is the organizational framework established to properly implement resettlement? Are the capacity and budget secured to implement the plan?	N	Not applicable
		9) Are any plan developed to monitor the impacts of resettlement?	N	Not applicable
		10) Is the grievance redress mechanism established?	N	Not applicable
	(2) Living and Livelihood	1) Is there a possibility that the project will adversely affect the living conditions of inhabitants? Are adequate measures considered to reduce the impacts, if necessary?	N	The project will not have any adverse impact on living conditions of surrounding inhabitants.
		2) Is there a possibility that the amount of water (e.g., surface water, groundwater) used and discharged to effluents by the project will adversely affect the existing water uses and water area uses?	N	Not applicable
	(3) Heritage	1) Is there a possibility that the project will damage the local archeological, historical, cultural, and religious heritage? Are adequate measures considered to protect these sites in accordance with the country's laws?	N	Not applicable
	(4) Landscape	1) Is there a possibility that the project will adversely affect the local landscape? Are necessary measures taken?	N	Not applicable
	(5) Ethnic Minorities and Indigenous Peoples	1) Are considerations given to reduce impacts on the culture and lifestyle of ethnic minorities and indigenous peoples?	N	Not applicable
		2) Are all of the rights of ethnic minorities and indigenous peoples in relation to land and resources respected?	N	Not applicable
	(6) Working Conditions	1) Is the project proponent not violating any laws and ordinances associated with the working conditions of the country which the project proponent should observe in the project?	N	The project will not violate any laws and ordinances associated with working conditions.

ANNEX 4

Environmental Checklist for Micro Grid Controller, Solar PV System and Storage System (2)

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
2 Pollution Control	(3) Soil Contamination	1) Has the soil in the project site been contaminated in the past? Are adequate measures taken to prevent soil contamination?	N	Not applicable
3 Natural Environment	(1) Protected Areas	1) Is the project site located in protected areas designated by the country's laws or international treaties and conventions? Is there a possibility that the project will affect the protected areas?	N	Not applicable
	(2) Ecosystem	1) Does the project site encompass primeval forests, tropical rain forests, ecologically valuable habitats (e.g., coral reefs, mangroves, or tidal flats)?	N	Not applicable
		2) Does the project site encompass the protected habitats of endangered species designated by the country's laws or international treaties and conventions?	N	Not applicable
		3) If significant ecological impacts are anticipated, are adequate protection measures taken to reduce the impacts on the ecosystem?	N	Not applicable
	(3) Hydrology	1) Is there a possibility that hydrologic changes due to installation of the structures, such as weirs will adversely affect the water flows, waves and tides?	N	Not applicable
	(4) Topography and Geology	1) Is there a possibility that the project will cause a large-scale alteration of the topographic features and geologic structures in the surrounding areas?	N	Not applicable
4 Social Environment	(1) Resettlement	1) Is involuntary resettlement caused by project implementation? If involuntary resettlement is caused, are efforts made to minimize the impacts caused by the resettlement?	N	The project does not cause any involuntary resettlement.
		2) Is adequate explanation on compensation and resettlement assistance given to affected people prior to resettlement?	N	Not applicable
		3) Is the resettlement plan, including compensation with full replacement costs, restoration of livelihoods and living standards developed based on socioeconomic studies on resettlement?	N	Not applicable
		4) Are the compensation going to be paid prior to the resettlement?	N	Not applicable
		5) Are the compensation policies prepared in document?	N	Not applicable

ANNEX 5

Activities and Technology Transfer Method

of

Soft Component

Environmental Checklist for Micro Grid Controller, Solar PV System and Storage System (4)

ANNEX 4

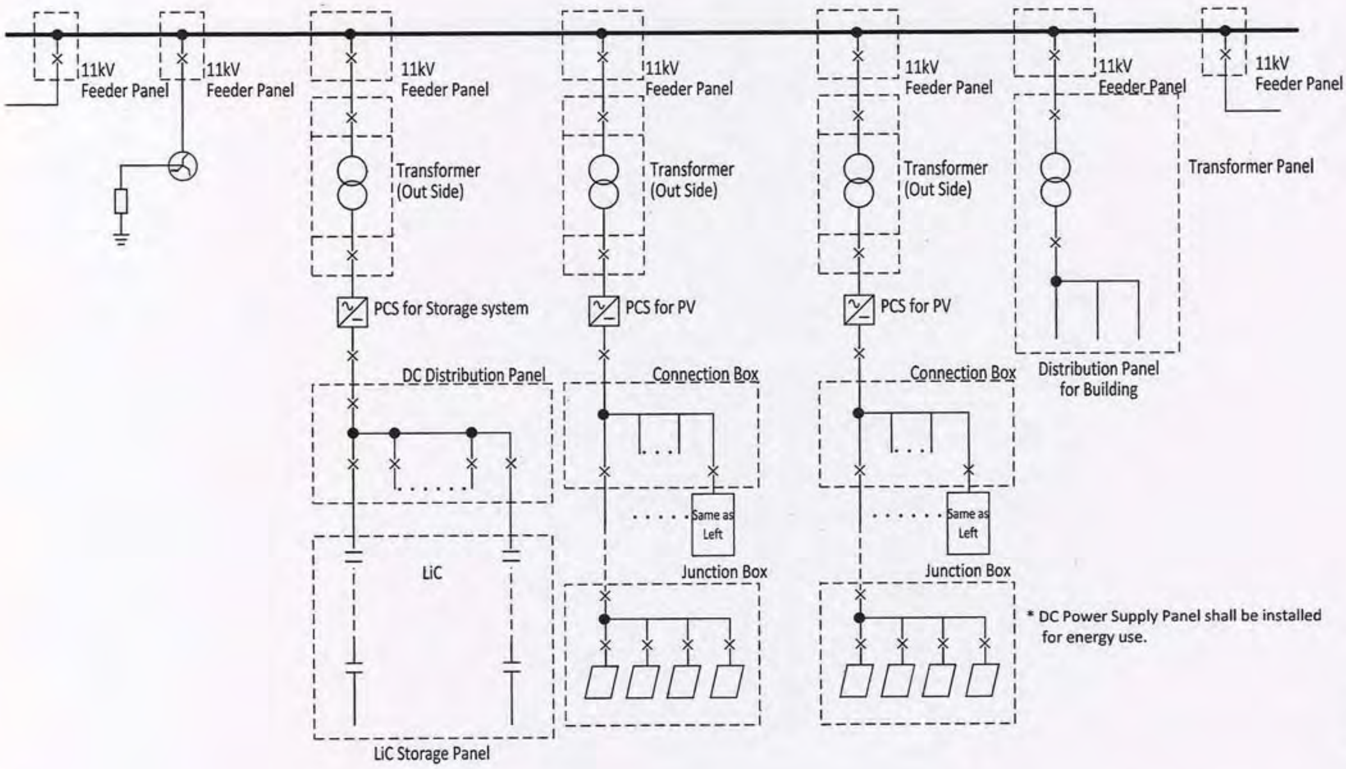
Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
4 Social Environment	(6) Working Conditions	2) Are tangible safety considerations in place for individuals involved in the project, such as the installation of safety equipment which prevents industrial accidents, and management of hazardous materials?	Y	Tangible safety considerations are in place based on TPL's safety policy and regulations.
		3) Are intangible measures being planned and implemented for individuals involved in the project, such as the establishment of a safety and health program, and safety training (including traffic safety and public sanitation) for workers etc.?	Y	Intangible measures are planned and implemented for individuals involved in the project, based on TPL's safety policy and regulations.
		4) Are appropriate measures taken to ensure that security guards involved in the project not to violate safety of other individuals involved, or local residents?	Y	There are appropriate measures being taken to ensure that security guards involved in the project do not violate safety of other individuals involved, or local residents.
5 Others	(1) Impacts during Construction	1) Are adequate measures considered to reduce impacts during construction (e.g., noise, vibrations, turbid water, dust, exhaust gases, and wastes)?	Y	Adequate measures are considered to reduce impacts during construction.
		2) If construction activities adversely affect the natural environment (ecosystem), are adequate measures considered to reduce impacts?	Y	Adequate measures are considered to reduce impacts.
		3) If construction activities adversely affect the social environment, are adequate measures considered to reduce impacts?	Y	Adequate measures are considered to reduce impacts.
	(2) Monitoring	1) Does the proponent develop and implement monitoring program for the environmental items that are considered to have potential impacts?	Y	TPL will develop and implement monitoring program for necessary environmental items. However, at this stage, there are not any major environmental items requiring to be monitored.
		2) What are the items, methods and frequencies of the monitoring program?	N/A	Not applicable
		3) Does the proponent establish an adequate monitoring framework (organization, personnel, equipment, and adequate budget to sustain the monitoring framework)?	N/A	Not applicable
		4) Are any regulatory requirements pertaining to the monitoring report system identified, such as the format and frequency of reports from the proponent to the regulatory authorities?	N /A	Not applicable

Target	Expected outcome		Activities	Methods	Trainee
2. Operation and maintenance for grid-connected PV system, power storage device and charge/discharge control system is continuously implemented.	2-1	Operation and maintenance manual and troubleshooting manual for grid-connected PV system, power storage device and charge/discharge control system are completed.	• Preparation of O&M manual and troubleshooting manual	• Class room training and preparation • Virtual operation and troubleshooting based on manuals	TPL Power Generation Dept.
	2-2	Operation manual and troubleshooting manual for existing diesel generators when PV system, power storage device and charge/discharge control system are connected to the grid are completed.	• Preparation of operation manual for existing diesel generators including allowable range of partial output rate, number of units in service, criteria for start-up/shut-down of units in case of load increase/decrease, etc. • Preparation of troubleshooting manual	• Class room training and preparation • Virtual operation and troubleshooting based on manuals	TPL Power Generation Dept.
3. The distribution grid where PV system, power storage device and charge/discharge control system are connected is operated in a stable condition.	3-1	Basics of power system operation (maintaining power demand and supply balance, system frequency control, system voltage control) are under stood by TPL's staffs.	• Lecture on basic theories of power system operation • Items to be analyzed in case further intermittent renewable generation (ex. wind power) is connected to the grid.	• Classroom training	TPL Power Generation Dept. and Distribution Network Dept.
	3-2	Basic theories of power system analysis (power flow analysis and stability analysis) are understood by TPL's staffs.	• Lecture on basic theories of power system analysis.	• Classroom training	TPL Power Generation Dept. and Distribution Network Dept.
	3-3	Troubleshooting methods for distribution system in which PV system, power storage device and charge/discharge control system are connected are established.	• Preparation of O&M and troubleshooting manuals.	• Virtual operation and troubleshooting based on manuals	TPL Power Generation Dept. and Distribution Network Dept.

ANNEX 5

Activities and Technology Transfer Method of Soft Component

Target	Expected outcome		Activities	Methods	Trainee
1. TPL is able to start the operation and maintenance of the grid-connected PV system, power storage device and charge/discharge control system smoothly after the completion of the Project.	1-1	An organization for the operation and maintenance of grid-connected PV system, power storage device and charge/discharge control system is established within TPL.	• Establishment of the O&M organization and assignment of persons in charge • Preparation of job descriptions for O&M staffs • Preparation of a draft maintenance contract with a manufacturer	• Class room training and group discussion • Class room training and group discussion • Class room training and group discussion	TPL Power Generation Dept.
	1-2	Outline and characteristics of grid-connected PV system, power storage device and charge/discharge control system are understood by TPL's staffs.	• Lecture on the basic theory and knowledge of grid-connected PV system, power storage device and charge/discharge control system • Lecture on the economic life and replacement criteria of power storage device • Lecture on the characteristics and protective function of grid-connected PV system, power storage device and charge/discharge control system	• Classroom training • Classroom training • Classroom training	TPL Power Generation Dept.
	1-3	Situation of a grid and responses of power storage device, charge/discharge control system and diesel generators are understood by TPL staffs in case PV output fluctuates in the grid in which those devices are connected.	• Lecture on power system stability and response of devices based on power system analysis.	• Classroom training	TPL Power Generation Dept.
	1-4	TPL's staffs acquire necessary technical knowledge and skills necessary for the operation and maintenance of grid-connected PV system, power storage device and charge/discharge control system.	• Technical transfer on operation • Technical transfer on maintenance • Technical transfer on periodical checkup • Instruction on monitoring	• Practical training • Practical training • Practical training • Practical training	TPL Power Generation Dept.

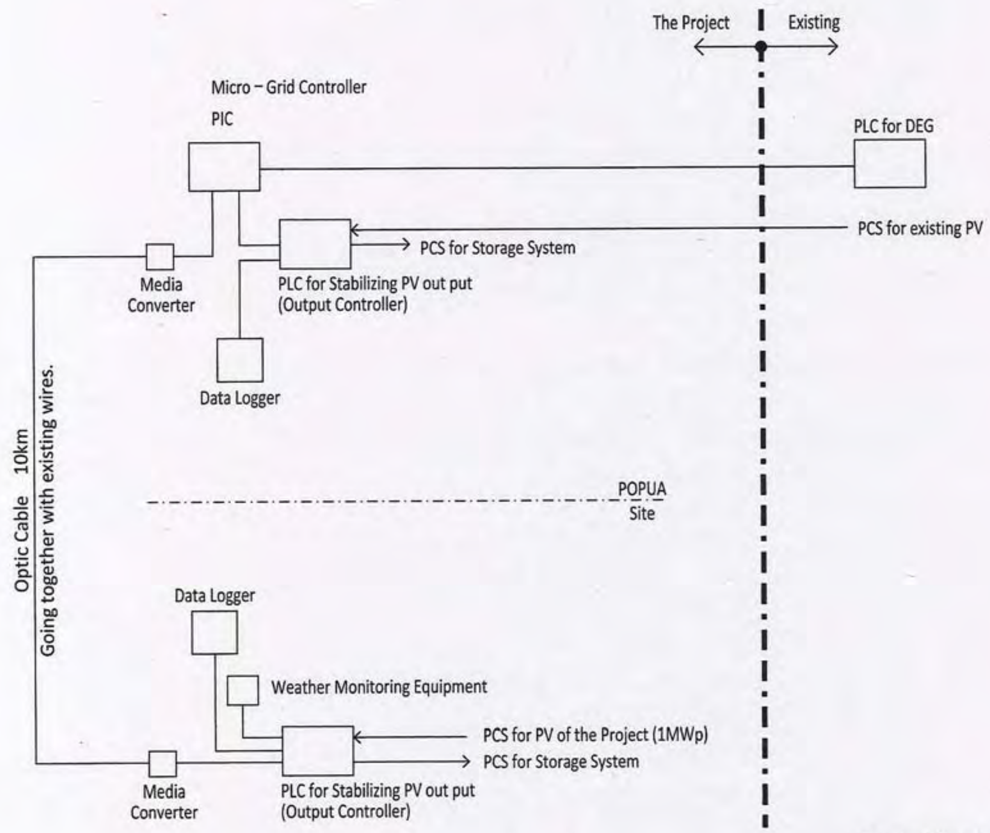


Power System Drawings
PV Site

D-01① (Reference Only)

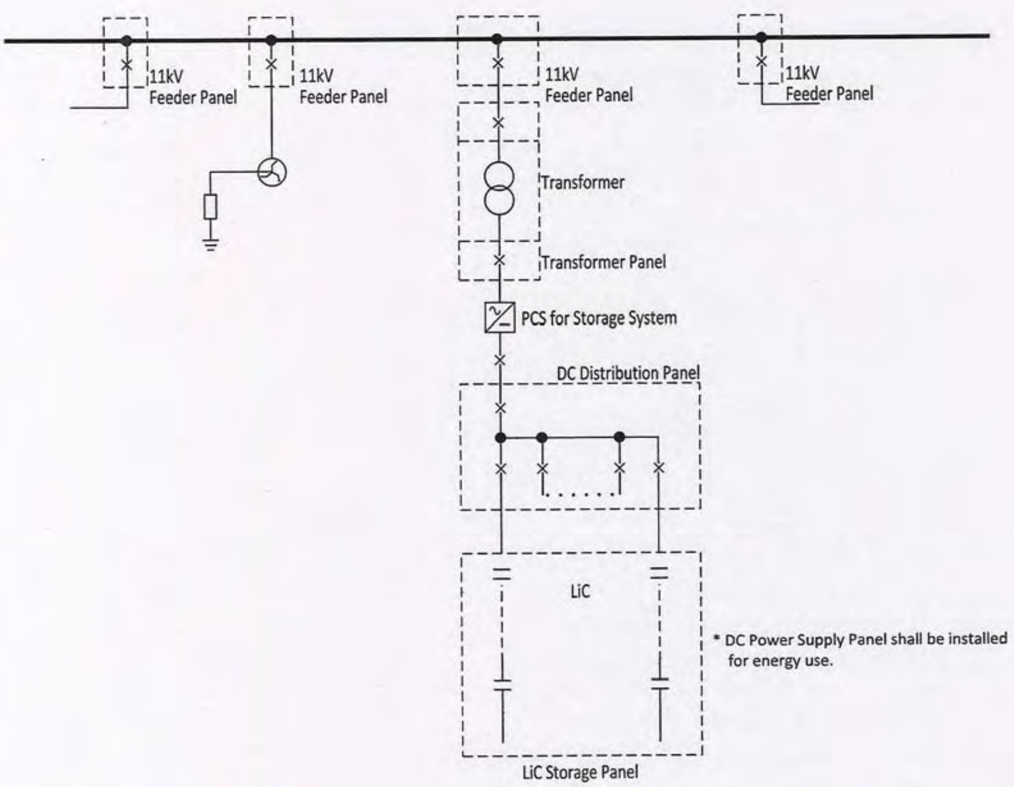
Drawings

D-01 Single Line Diagram
D-02 Control System Diagram
D-03 Arrangement of panels at Vaini Site
D-04 Floor Plan of Building at Vaini Site
D-05 Section Plan of Building at Vaini Site
D-06 Floor Plan of Building at Popua Power Station
D-07 Section Plan of Building at Popua Power Station



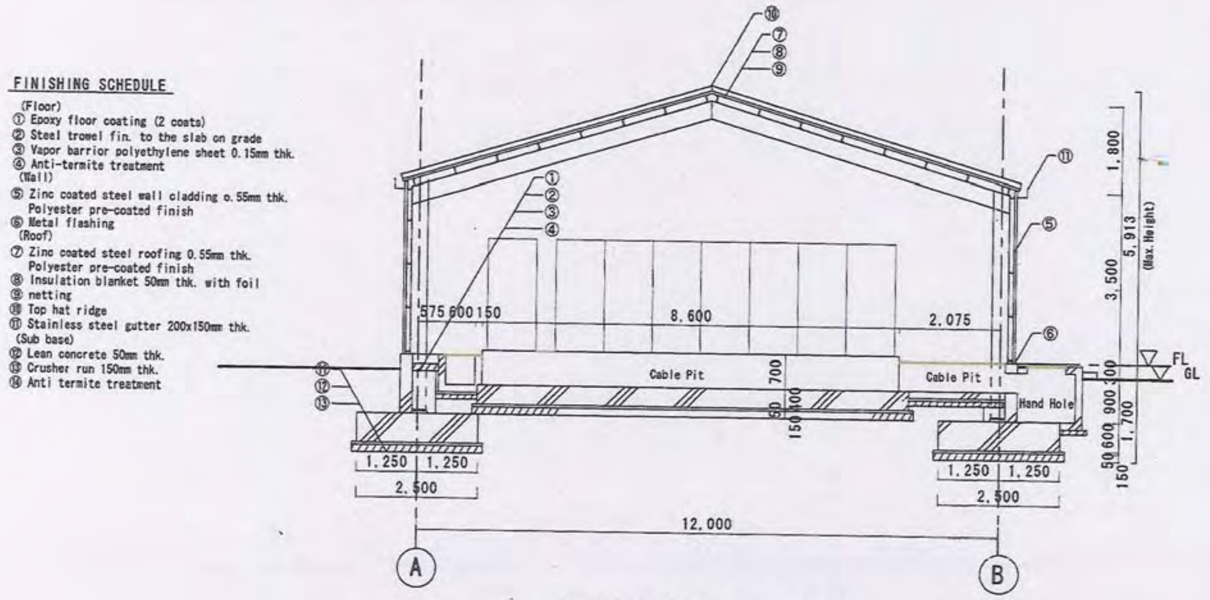
Controlling System

D-02 (Reference Only)



Power System Drawings
PAPUA Power Station

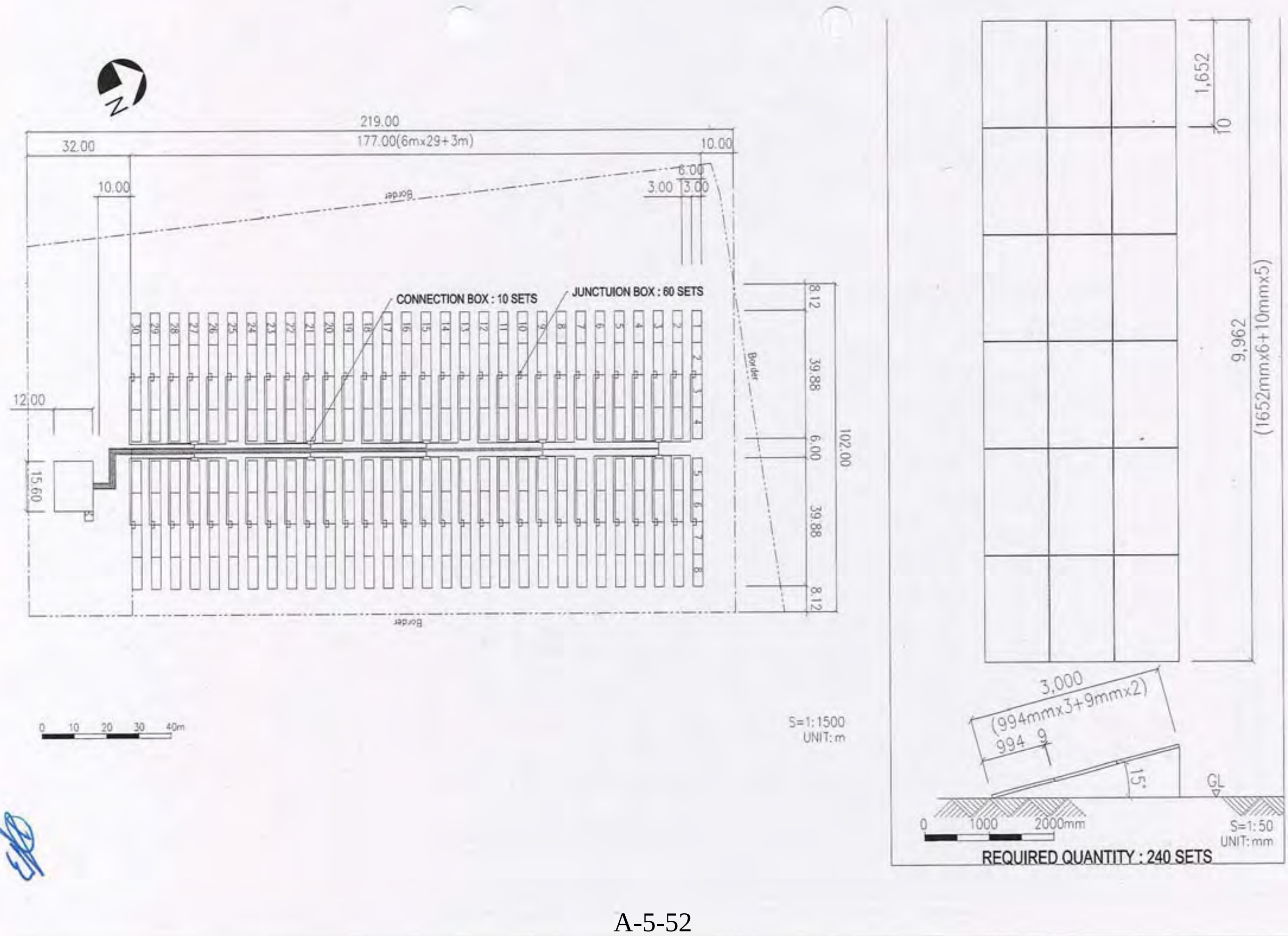
D-01② (Reference Only)



SECTION A-A Scale: 1/100

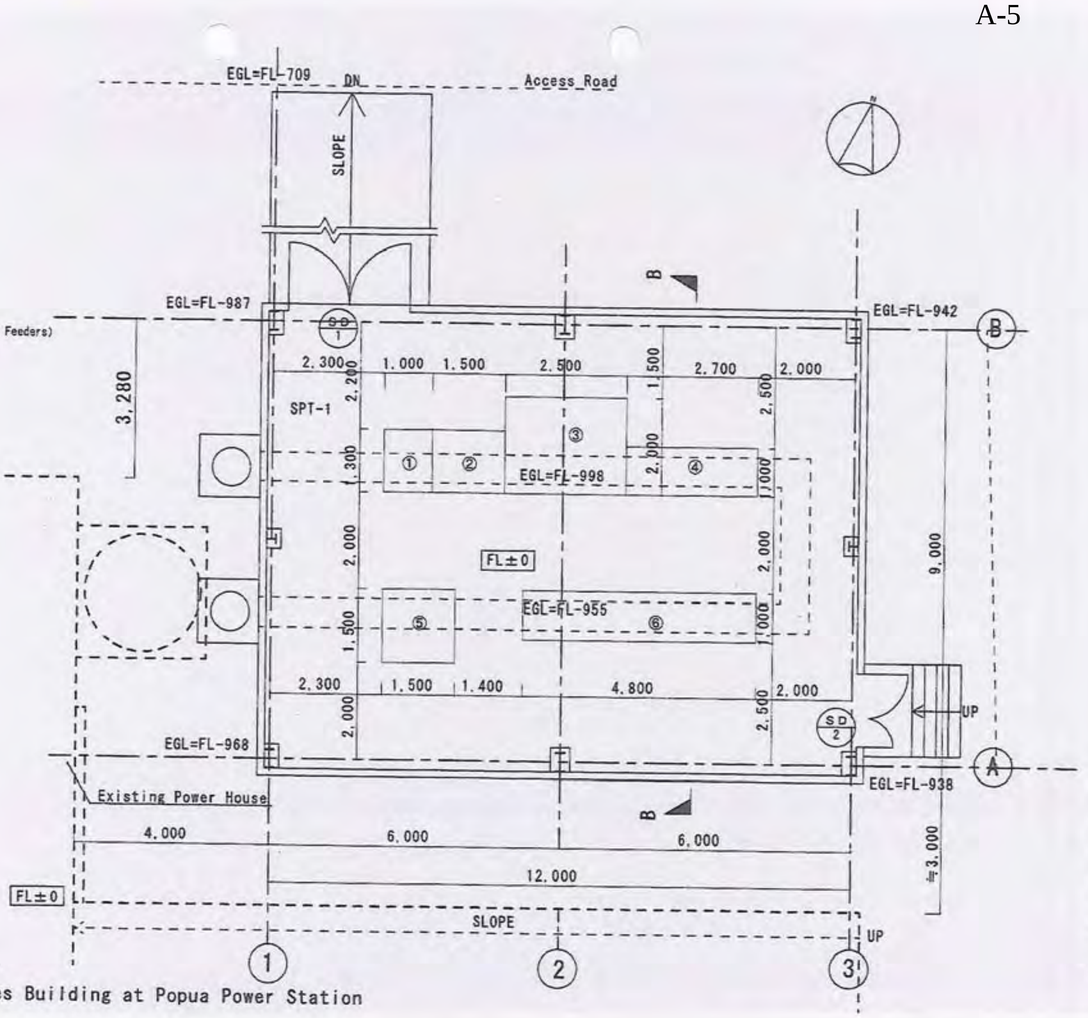
Power Conditioner System and Power Storage Devices Building at Vaini Site

D-05 (Reference Only)



D-03 (Reference Only)

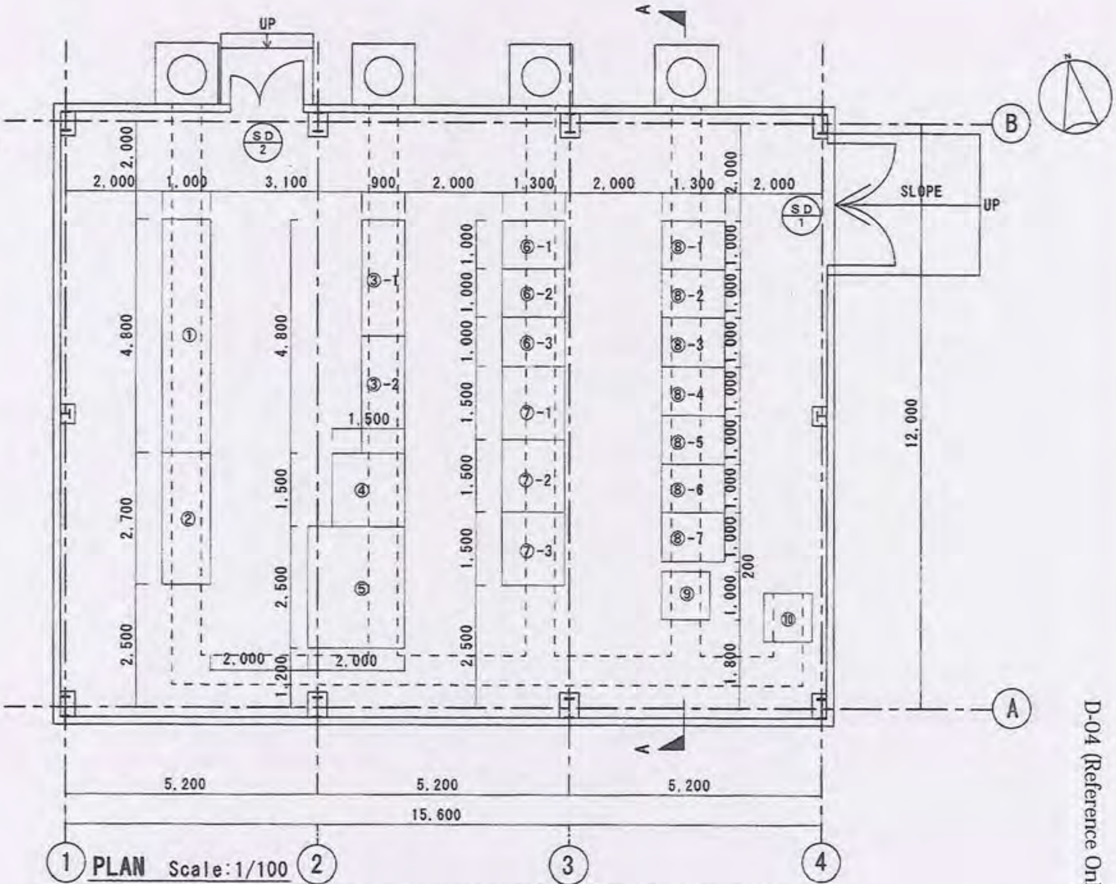
【EQUIPMENT SCHEDULE】
機器リスト
① 11kV LiC Trans Panel
11kV蓄電設備用トランス盤
② 400V LiC Trans Panel
400V蓄電設備用トランス盤
③ PCS for LiC 500kW
500kW蓄電設備用PCS
④ Distribution Board for LiC (32 Feeders)
LiC用直流分電盤 (32フィーダー)
⑤ PV Out let Contraol Unit
PV出力制御盤
⑥ LiC 320 sets
キャパシター収納盤 (320セット)



PLAN Scale: 1/100
Power Storage Devices Building at Popua Power Station

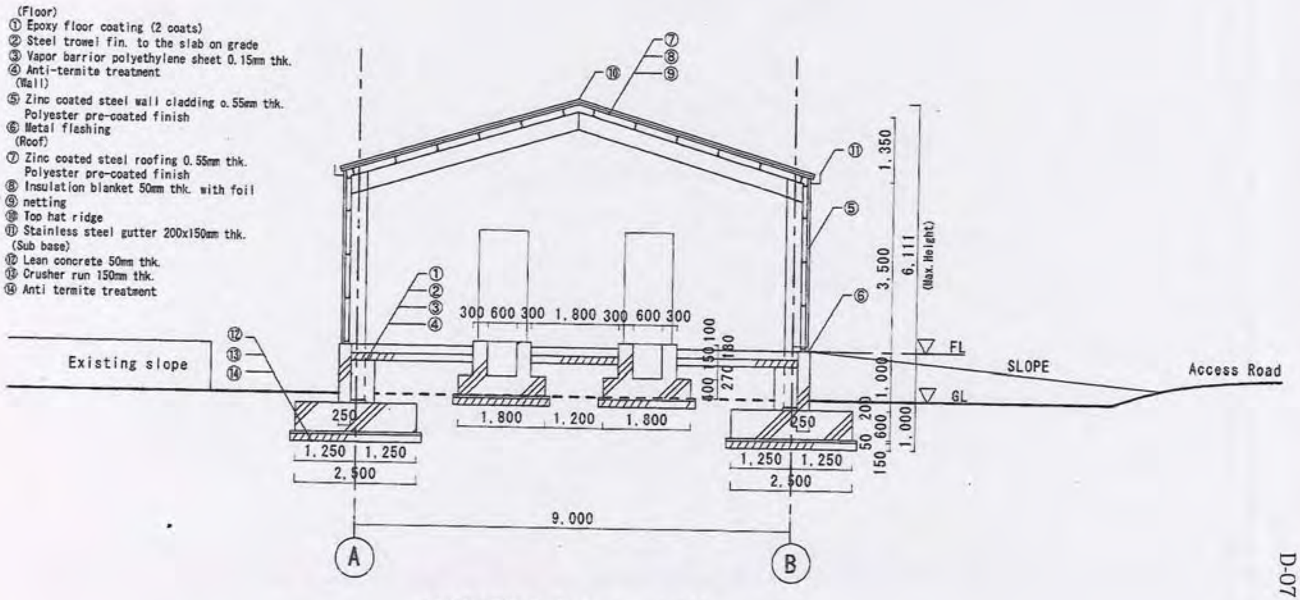
D-06 (Reference Only)

【EQUIPMENT SCHEDULE】
機器リスト
① LiC 320 sets
キャパシター収納盤 (320セット)
② Distribution Board for LiC 32 Feeders
LiC用直流分電盤 (32フィーダー)
③-1 PCS for PV1 500kw
PV1用PCS
③-2 PCS for PV2 500kw
PV2用PCS
④ PV Outlet Control Unit
PV出力制御盤
⑤ PCS for LiC 500kw
500kw蓄電設備用PCS
⑥-1 11kV LiC Trans Panel
11kV蓄電設備用トランス盤
⑥-2 11kV PV1 Trans Panel
11kV PV1用トランス盤
⑥-3 11kV PV2 Trans Panel
11kV PV2用トランス盤
⑦-1 400V LiC Trans Panel
400V蓄電設備用トランス盤
⑦-2 400V PV1 Trans panel
400V PV1用トランス盤
⑦-3 400V PV2 Trans Panel
400V PV2用トランス盤
⑧-1 11kV In-coming Panel
11kV入力トランス盤
⑧-2 11kV LiC Feeder Panel
11kV蓄電設備用フィーダー盤
⑧-3 11kV PV1 Feeder Panel
11kV PV1用フィーダー盤
⑧-4 11kV PV2 Feeder Panel
11kV PV2用フィーダー盤
⑧-5 11kV Station Feeder Panel
11kV所内フィーダー盤
⑧-6 11kV Earth Trans Panel
接地用トランス盤
⑧-7 11kV Out-going Panel
11kV出力トランス盤
⑨ DC Panel
直流電源盤
⑩ Station Service Panel
所内用分電盤



PLAN Scale:1/100
Power Conditioner System and Power Storage Devices Buiding at Vaini Site

D-04 (Reference Only)



SECTION B-B Scale: 1/100

Power Storage Devices Building at Popua Power Station

D-07 (Reference Only)

A-6 Soft Component Plan

THE PROJECT
FOR
INTRODUCTION OF A MICRO-GRID SYSTEM
WITH
RENEWABLE ENERGY
FOR
THE TONGA ENERGY ROAD MAP
IN
THE KINGDOM OF TONGA

Soft Component Plan

October 2012

YACHIYO ENGINEERING CO., LTD

WEST JAPAN ENGINEERING CONSULTANTS, INC.

CONTENTS

1. Background of Soft Component

The Project aims to procure and install grid-connected photovoltaic system (1.0MWp) and microgrid system to stabilize the power grid in Vaini Project Site and on the premises of the existing Popua Power Station.

Because of the geological condition as an archipelago country, import of petroleum-based fuel accounts for 25% of total imports, equivalent to 10% of GDP. Moreover, Tonga relies on diesel power generation using imported fuel for 98% or more of electricity supply. In such situations, the country is susceptible to fluctuations in the global crude oil prices and thus fairly vulnerable from the energy security perspective. The soaring of the global crude oil prices in 2008 obliged the Tongan authority to raise electricity charges to TOP 1.00/kWh (approx. USD 0.5/kWh), causing serious impact on economic activities and the peoples' lives in the country. Having learnt from this experience, the Cabinet of Tonga dissolved in 2009 a policy goal of "increasing the proportion of renewable energy to 50% of the entire electricity supply by 2012" to deal with two crucial issues: greenhouse gas emissions reductions and improvement in energy security. The government also formulated a Tonga Energy Road Map 2010-20 (hereinafter called the "TERM") as an implementation policy to achieve the policy goal. Despite these efforts, Tonga still needs to adopt renewable energy systems further to achieve the target of "50% of electricity from renewable sources by 2012". But it is difficult to stably supply electricity and secure the quality of electricity if the proportion of wind and photovoltaic power generation is substantially increased since the output level of these renewables are fairly fluctuating. In these circumstances, it is necessary to adopt renewable energy sources further and at the same time stably supply electricity and minimize the fluctuation in frequencies of the grid system by utilizing microgrid systems[1]. The Project aims to contribute to the achievement of the objectives of the TERM as well as to stabilize the power grid in Tongatapu.

Thanks to the support from various countries, Solar Home System (SHS) was introduced in Outer Island and with the support of New Zealand (NZAID), the Government of Tonga built a grid-connected photovoltaic system of output of 1.3MW and started in July this year the operation in Tongatapu Island. However, TPL did not obtain knowledge on operation and maintenance of PV system since a private company from New Zealand, on consignment from the Government of Tonga, controls grid-connected PV system for 5 years from the commencement of operation. TPL supplies energy to the grid of Tongatap Island, Eua Island, Ha'apai Island and Vavau Island with diesel engine generator. Micro-grid system to be introduced under the Project is new to TPL while TPL is used to operate and maintain diesel engine generators and grids. The aim of Soft component is to support TPL so that power generation department of the TPL can smoothly start to operate, maintain and manage the grid-connected PV system, electrical energy storage systems and charge/discharge control systems and to sustainably operate, maintain and manage the equipment procured under the Project. Soft Component also includes necessary technical transfer of grid control or accident control after the introduction of microgrid system.

[1] A system in a grid with conventional power supply and grid-connected renewable energy for stabilizing the grid by compensating fluctuations of renewable energy with power storage devices.

2. Objectives of Soft Component

Objectives of Soft Component are listed below. The effectiveness of the Grant Aid Project shall be sustained by the achievement of the objectives.

(1) TPL is able to start the operation and maintenance of the grid-connected PV system, power storage device and charge/discharge control system smoothly after the completion of the Project.

(2) Operation and maintenance for grid-connected PV system, power storage device and charge/discharge control system is continuously implemented.

(3) The distribution grid where PV system, power storage device and charge/discharge control system are connected is operated in a stable condition.

3. Outcome of Soft Component

Outcome of Soft Component shall be the achievement listed below.

Table 3-1 Outcome of Soft Component

Target	Expected outcome	Trainee
1. TPL is able to start the operation and maintenance of the grid-connected PV system, power storage device and charge/discharge control system smoothly after the completion of the Project.	1-1 An organization for the operation and maintenance of grid-connected PV system, power storage device and charge/discharge control system is established within TPL. 1-2 Outline and characteristics of grid-connected PV system, power storage device and charge/discharge control system are understood by TPL's staffs. 1-3 Situation of a grid and responses of power storage device, charge/discharge control system and diesel generators are understood by TPL staffs in case PV output fluctuates in the grid in which those devices are connected.	TPL Power Generation Dept.
2. Operation and maintenance for grid-connected PV system, power storage device and charge/discharge control system is continuously implemented.	2-1 Operation and maintenance manual and troubleshooting manual for grid-connected PV system, power storage device and charge/discharge control system are completed. 2-2 Operation manual and troubleshooting manual for existing diesel generators when PV system, power storage device and charge/discharge control system are connected to the grid are completed.	TPL Power Generation Dept.
3. The distribution grid where PV system, power	3-1 Basics of power system operation (maintaining power demand and supply balance, system frequency control,	TPL Power Generation Dept.

Target	Expected outcome	Trainee
storage device and charge/discharge control system are connected is operated in a stable condition.	system voltage control) are under stood by TPL's staffs. 3-2 Basic theories of power system analysis (power flow analysis and stability analysis) are understood by TPL's staffs. 3-3 Troubleshooting methods for distribution system in which PV system, power storage device and charge/discharge control system are connected are established.	and Distribution Network Dept.

4. Measures for Improvement

The outcome of the Soft Component shall be measured by the manuals edited through the Soft Component and the reports written by the trainee. The measures shall be done according to the measures listed in the table below. The manual shall be examined from the view point of the coverage of the contents such as organization and roles for O&M, daily maintenance, periodic check, troubleshooting and etc, and of the accuracy of the technical matters. In addition, some advice and support shall be given according to the needs. The report shall be evaluated by the contents acquired in the class by the trainee so as to evaluate the understandings of the lesson. Makeup class shall be done according to their understandings.

Table 4-1 Outcome and Measures of Soft Component

Trainee	Expected outcome	Measures
TPL Power Generation Dept.	1-1 An organization for the operation and maintenance of grid-connected PV system, power storage device and charge/discharge control system is established within TPL.	• Organization Chart and Internal Regulations
	1-2 Outline and characteristics of grid-connected PV system, power storage device and charge/discharge control system are understood by TPL's staffs.	• Report
	1-3 Situation of a grid and responses of power storage device, charge/discharge control system and diesel generators are understood by TPL staffs in case PV output fluctuates in the grid in which those devices are connected.	• Report
	2-1 Operation and maintenance manual and troubleshooting manual for grid-connected PV system, power storage device and charge/discharge control system are completed.	• Manual
	2-2 Operation manual and troubleshooting manual for existing diesel generators when PV system, power storage device and charge/discharge control system are connected to the grid are completed.	• Manual

Trainee	Expected outcome	Measures
TPL Power Generation Dept. and Distribution Network Dept.	3-1 Basics of power system operation (maintaining power demand and supply balance, system frequency control, system voltage control) are under stood by TPL's staffs. 3-2 Basic theories of power system analysis (power flow analysis and stability analysis) are understood by TPL's staffs. 3-3 Troubleshooting methods for distribution system in which PV system, power storage device and charge/discharge control system are connected are established.	• Report • Report • Manual

5. Activities of Soft Component（Input Plan）

5-1 Contents and Activities of Soft Component

Activities of Soft Component, as listed in table 5-1, cover from PV system, power storage devices, basics of power system to preparation of O&M manual and troubleshooting. Technical transfer shall be done through class room training, group discussion (preparation of O&M manual by trainee) and practical training. PV module, power storage devices, charge/discharge control system, measurement equipment and tools, which are to be installed to TPL shall be utilized in the practical training. The trainee includes staffs from TERM-IU (Tonga Energy Road Map Implementing Unit) depending on their needs.

Table 5-1 Activities and Technology Transfer Method of Soft Component

Target	Expected outcome	Activities	Methods	Trainee
1. TPL is able to start the operation and maintenance of the grid-connected PV system, power storage device and charge/discharge control system smoothly after the completion of the Project.	1-1 An organization for the operation and maintenance of grid-connected PV system, power storage device and charge/discharge control system is established within TPL.	• Establishment of the O&M organization and assignment of persons in charge • Preparation of job descriptions for O&M staffs • Preparation of a draft maintenance contract with a manufacturer	• Class room training and group discussion • Class room training and group discussion • Class room training and group discussion	TPL Power Generation Dept.
	1-2 Outline and characteristics of grid-connected PV system, power storage device and charge/discharge control system are understood by TPL's staffs.	• Lecture on the basic theory and knowledge of grid-connected PV system, power storage device and charge/discharge control system • Lecture on the economic life and replacement criteria of power storage device • Lecture on the characteristics and protective function of grid-connected PV system, power storage device and charge/discharge control system	• Classroom training • Classroom training • Classroom training	TPL Power Generation Dept.
	1-3 Situation of a grid and responses of power storage device, charge/discharge control system and diesel generators are understood by TPL staffs in case PV output fluctuates in the grid in which those devices are connected.	• Lecture on power system stability and response of devices based on power system analysis.	• Classroom training	TPL Power Generation Dept.
2. Operation and maintenance for grid-connected PV system, power storage device and	2-1 Operation and maintenance manual and troubleshooting manual for grid-connected PV system, power storage device and charge/discharge control system are	• Preparation of O&M manual and troubleshooting manual	• Class room training and preparation • Virtual operation and troubleshooting based on manuals	TPL Power Generation Dept.

Target	Expected outcome	Activities	Methods	Trainee
charge/discharge control system is continuously implemented.	completed.			
	2-2 Operation manual and troubleshooting manual for existing diesel generators when PV system, power storage device and charge/discharge control system are connected to the grid are completed.	• Preparation of operation manual for existing diesel generators including allowable range of partial output rate, number of units in service, criteria for start-up/shut-down of units in case of load increase/decrease, etc. • Preparation of troubleshooting manual	• Class room training and preparation • Virtual operation and troubleshooting based on manuals	TPL Power Generation Dept.
3. The distribution grid where PV system, power storage device and charge/discharge control system are connected is operated in a stable condition.	3-1 Basics of power system operation (maintaining power demand and supply balance, system frequency control, system voltage control) are under stood by TPL's staffs.	• Lecture on basic theories of power system operation • Items to be analyzed in case further intermittent renewable generation (ex. wind power) is connected to the grid.	• Classroom training	TPL Power Generation Dept. and Distribution Network Dept.
	3-2 Basic theories of power system analysis (power flow analysis and stability analysis) are understood by TPL's staffs.	• Lecture on basic theories of power system analysis.	• Classroom training	TPL Power Generation Dept. and Distribution Network Dept.
	3-3 Troubleshooting methods for distribution system in which PV system, power storage device and charge/discharge control system are connected are established.	• Preparation of O&M and troubleshooting manuals.	• Virtual operation and troubleshooting based on manuals	TPL Power Generation Dept. and Distribution Network Dept.

5-2 Input Plan

(1) Procurement of necessary resources for Soft Component (Japanese side)

The trainee shall be able to operate and maintain PV system, power storage device and charge/discharge control system with proper understandings after this Soft Component through activities listed in table 5-1. In addition to the technical transfer of the O&M method for the equipment introduced by the Project, technical transfer of the O&M method of distribution line connected with existing diesel engine shall also be implemented. The consultant shall dispatch 4 trainers of trainer 1(PV system), trainer 2 (power storage device), trainer 3 (diesel generator), and trainer 4 (grid control) as listed in table 5-2.

Table 5-2 Plan for dispatching trainers for Soft Component

Name		Grade	Period	Times	Contents
1.	Establishment of the O&M organization				
	trainer 1(PV system)	3	0.50Month	1	Establishment of the O&M organization Lecture on the basic theory of PV system
	trainer 2 (power storage device)	3	0.50Month	1	Establishment of the O&M organization Lecture on the basic theory of power storage system
2.	Technical transfer				
	trainer 1(PV system)	3	1.00Month	1	Technical transfer on PV system
	trainer 2 (power storage device)	3	1.00Month	1	Technical transfer on power storage device
	trainer 3 (diesel generator)	3	0.50Month	1	Preparation of O&M manual for diesel engine generator
	trainer 4 (grid control)	3	0.50Month	1	Technical transfer on grid control

(2) Procurement of necessary resources for Soft Component (Tongan side)

In order to implement the Soft Component effectively and efficiently, trainee shall be chosen, O&M organization shall be established and main body shall be constructed by Tongan side. The detail shall be shown in the figure below.

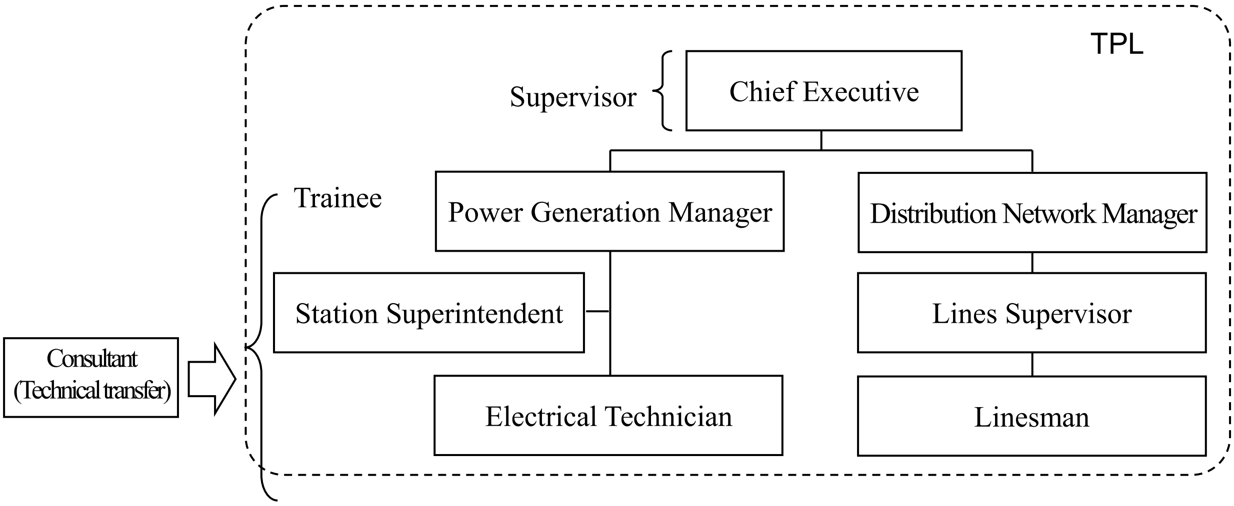


Figure 5-1 Organization chart for the implementation of Soft Component

6. Procurement Plan for the Resources of Soft Component

Trainers dispatched to Tonga shall be Japanese technician because the trainers must be familiar with Japanese PV system, since the main equipment procured by the Project such as grid-connected PV system, power storage device and charge/discharge control system are the products of Japan. The trainees are not used to grid-connected PV system of Japan since grid-connected PV system introduced in July 2012 in the Kingdom of Tonga is the products of the US or European country. In addition to the country of the trainer, the experience of the trainee shall be taken into account since the trainees does not have much experience of grid-connected PV system.

7. Implementation Schedule of Soft Component

The implementation schedule is shown in table 7-1.

Trainers dispatched from Japan implement Soft Component according to the categories listed in the table. The implementation time of each category is as follows:

Establishment of O&M:	Establishment of O&M shall be done prior to the installation of equipment in order to nourish senses of ownership of the trainees by clarifying the role of each trainee.
Technical transfer on O&M:	Technical transfer of installation, check, and operation shall be implemented by utilizing the equipment installed by the Project. The transfer shall be finished before completion of installation work.

Table 7-1 Implementation Schedule of Soft Component

Months		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Equipment Installation Work		━	━	━	━	━	━	━	━	━	━				
Trial operation and adjustment												━	━		
Initial operational guidance (by the Contractor)														━	━
Commissioning and handover															━
Soft Component (Technical transfer by the Consultant)	Establishment of O&M organization, Lecture on basic theories, etc.	━													
	Technical transfer on O&M, preparation of manuals, etc.										━	━			
Deliverables	O&M manuals														▼
	Progress report			▼											▼
	Final report														▼

8. Deliverables

Deliverables of this Soft Component are shown in the table 7-1 such as O&M manuals (including trouble shooting), Progress report, Final report and Teaching aid utilized in Soft Component.

9. Obligation of Implementing Agency

(1) TPL shall establish the O&M committee for this Soft Component.

(2) TPL shall prepare rooms such as class rooms, conference rooms and etc. in case the rooms are needed for this Soft Component.

(3) TPL shall send some people appropriate as trainee.

(4) TPL shall prepare O&M manual by themselves through discussion with Consultant. TPL shall revise and update the O&M manual after the commencement of operation.

(5) TPL shall operate and maintain grid-connected PV system, power storage device and charge/discharge control system according to the O&M manual. When a staff in charge is transferred to other division, the staff shall implement technical transfer to the successor by utilizing deliverables of Soft Component.

A-7 Power Flow Analysis of the Grid

Analysis for evaluation of voltage and frequency in Tongatapu Island

Contents

1. Formulation of Model
2. Evaluation of fluctuation of voltage
3. Evaluation of fluctuation of frequency (The evaluation shall be conducted with four steps in the table below.)

	Step	Analysis condition
1.	The permissible value of the fluctuation shall be determined, as the first step, in accordance with the short-period compensation method for power fluctuation of PV output. Requisite capacity shall be evaluated assuming four kinds of PV output.	Assumed fluctuation of PV output ➢ 50% decrease of installed PV capacity in 10sec In ramp function ➢ 50% decrease of installed PV capacity in 5sec In ramp function ➢ 80% decrease of installed PV capacity in 10sec In ramp function ➢ 80% decrease of installed PV capacity in 5sec In ramp function
2.	Simulation shall be conducted based on the limitation of change rate of the governor to be installed and requisite capacity shall be evaluated, as the second step, so as to formulate a model with as similar value to the actual value of load following capability of diesel generators as possible.	Assumed limit of change rate of the governor ➢ 5%/1sec Assumed fluctuation of PV output ➢ 50% decrease of installed PV capacity in 10sec In ramp function ➢ 50% decrease of installed PV capacity in 5sec In ramp function ➢ 50% decrease of installed PV capacity in 10msec In step function
3.	Requisite capacity shall be evaluated, as the third step, so as to evaluate validity of the capacity of the power storage system, in addition to the short-period output capacity and the load following capability of control system, assuming four kinds of variable time constant characteristics.	Assumed characteristics of power storage system ➢ 60sec continuance of requisite output ➢ 40sec continuance of requisite output ➢ 20sec continuance of requisite output ➢ 10sec continuance of requisite output
4.	Load following capability and capacity of power storage system of the Project shall be evaluated, as the forth step, assuming middle-speed generator to be installed by TPL in 2013 and configuring the limit of governor change rate of the generator.	Assumed limit of governor change rate ➢ Increasing 1.8%/1sec ➢ Decreasing 3.6%/1sec Assumed fluctuation of PV output ➢ 50% decrease of installed PV capacity in 10sec In ramp function ➢ 50% decrease of installed PV capacity in 5sec

		In ramp function ➢ 50% decrease of installed PV capacity in 10msec In step function

1．Formulation of Model

Conditions for modeling are as follows.

Table 1.1-1 Conditions for Modeling Part 1

Item	Methodology	Remarks	Back Data
Distribution system	Network ・Single Line Diagram of TPL ・*1 file as a supplementaryinformation	Base Capacity of the system : 10MVA Branch and pole mounted transformers are simulated to be located at same intervals	・Single_Line_Symbols.xlsx ・All Data_TPL_2011.xlsx*1
	Capacity of Capacitor	—	All Data_TPL_2011.xlsx
	Conductors	Calculated based on conductor specifications and arrangement of poles	・OverheadAluminiumConductors.pdf ・All Data_TPL_2011.xlsx ・Fujikura Ltd. Electric wire Handbook
	Arrangement of poles ・2012/09/06 data obtained in the first field survey		20120905162856849.tif
Generation facilities	Network ・simulated to be a bus ・Transformers for interconnection	Impedance of interconnection transformers ％Ｚ : 4.5% (Simulated to be of capacity as same as storage system)	・Data of the first field survey ・Single line diagram of Popua Power Station ・Text book “Introduction of Power System Analysisa (Typical values for %Z)
PV system of the Project	Network ・1000kW ・Incoming feeder100m COCKROACH (250mm)	Capacity of transformer : 1250kVA Impedance of interconnection transformers ％Ｚ : 4.5%	・Data of the first field survey ・Single line diagram of Popua Power Station ・Text book “Introduction of Power System AnalysisP (Typical values for %Z)
Demand conditions	Weekend in Winter (July) [Off peak] In Summer (January) [Peak]	At 14:00, Sun, 15, July ※Profile at off peak load among July At 14:15, Wed, 18, January	Generator_Feederdata.xls

Table 1.1-2 Conditions for Modeling Part 2

Item	Methodology	Remarks	Back Data
Power Generator	○Power GeneratorModeling ・Constants: obtained ・Saturation: obtained ・Inertia Constants: obtained	・Inertia Constant of 7sec is obtained from Back Data ・Applied the model included in the application taansforme	・Tongatapu Power Station Protection Coordination Review
	○Mak for base load ・Constants: obtained ・Saturation: not obtained ・Inertia Constants: not Obtained	－	
ＡＶＲ	Control Block is assumed based on Grid-interconnection Code	－	・Grid-interconnection Code ・SETTING DATA
ＧＯＶ	○ＯＶＴ ・Constant rotational frequency control PI Control ・Engine: Primary Delay	・PI Control ・Engine: Primary Delay Primary Delay T is set to 0.6sec based on Grid-interconnection Code ※Governor coordinates a gain with PI control so that the output depending on a frequency change appears than an actual survey wave pattern	・proddocspdf_2_445 DSLC.pdf ・SETTING DATA ・Grid-interconnection Code
	○Mak	※No information	－
Storage Battery	Controlled individually ・Controlof Storage Battery：Reset circuit ・Response of converter：Takes 100msec for generating power to be 90 % of ordered value	・reduce generating power by Reset circuit ・Charging capacity is Not considered.	・Data from Fuji Electric ・Battery juxtaposition wind-generated electricity introduction possibility investigation February,2000 NEDO
ＰＶ ＰＣＳ	Simulated in ramp-shape（constant power characteristic)	－	－

２. Evaluation of fluctuation of voltage

２．１　Outline of Results

We carried out static stability analysis（power flow calculation）, and evaluated fluctuation of voltage. Analysis conditions and evaluation methods are as follows.

① Parameter

・Demand of Analysis：2patterns
/Profile at off peak[14:00, 15, Jul, 2012],
Profile at peak[14:15, 18, Jan, 2012]

・Location of newly placed PV system：2 locations
2 types of grids are formulated by switching 2 opening points
/Vaini Feeder, NUK1 Feeder

・PV outputs：2 patterns
/with the PV System of the Project, Peak Output

② Modeling

Outline of the modeling is as follows

〇Distribution system

・Distribution system model below includes the power generator BUS.
・The sending voltage is set to be rated value of 11kV
・Sending power flow values of all feeders are adjusted for each demand
・Load is distributed proportionally according to the ratio of the capacity of each pole mounted transformer.
・Modeling does not include pole mounted transformer.

③ Methodology for evaluation

・Evaluation is conducted with conditions whether the fluctuation of voltage is maintained within the management range, 230range,

２．２　List of conditions of analysis for fluctuation of voltage

8 conditions for analysis consisting of 2.1 are as follows.

Table 2.1　List of conditions of analysis for fluctuation of voltage

Cases	Section	Feeder the PV system of the Project is connected	PV output
V1-Vaini-OP	At off peak load	Vaini	Without PV
V2-Vaini-OP-PV			Peak Output
V3-NUK1-OP		NUK1	Without PV
V4-NUK1-OP-PV			Peak Output
V5-Vaini-P	At peak load	Vaini	Without PV
V6-Vaini-P-PV			Peak Output
V7-NUK1-P		NUK1	Without PV
V8-NUK1-P-PV			Peak Output

２．３　Evaluation of Analysis Results

〇Profile at off peak load

Analysis results of profiles at off peakload of voltage and active power flow on main observation points are summarized in figure 2.1. Power flow diagrams in profile at off peakload in each cases are shown on figure 2.2 - 2.5.

Case 1 (Connected to Vaini feeder)：

Fluctuation of voltage for PV peak output takes maximum value of 2.71 [V] in the vicinity of PV site. Fluctuation of voltages in main observation points falls in the voltage evaluation standard range, 230±10[V].

Case 2 (Connected to NUK1 feeder)：

Fluctuation of voltage for PV peak output takes maximum value of 3.34 [V] in the vicinity of PV site, as in the case of Vaini. Fluctuation of voltages in main observation points falls in the voltage evaluation standard range.

〇Profile at peak load

Analysis results of profiles at peak load of voltage and active power flow on main observation points are summarized in figure 2.6. Power flow diagrams in profile at peak load in each cases are displayed on figure 2.7 - 2.10.

Case 1 (Connected to Vaini feeder)：

Fluctuation of voltage near the PV site was figured out at 2.74[V]. Fluctuation of voltages in main observation points falls in the voltage evaluation standard range.

Case 2 (Connected to NUK1 feeder)：

Fluctuation of voltage near the PV site was figured out at 3.43 [V]. Fluctuation of voltages in main observation points falls in the voltage evaluation standard range.

※Notes：It is recommendable to confirm following points by checking the real system, in order to verify the validity of this analysis result.

It shall be conducted to measure the end-voltage voltage distribution lines BUS voltage and east-west lines of the current state of Tongatapu Island power plant, to confirm the validity of the resulting voltage decline trend power flow analysis.

Voltage value at the end of the distribution system in the case of sending voltage of 11[kV], for profile at off peak load, without newly placed PV system.（figure 2.2）

10.83 [kV] at eastern end [T0170] (figure 2.2 blue circle)

10.82 [kV] at western end [T0410](figure 2.2 red circle)

Power flow analysis result of Tongatapu Island (profile at off peak load)

[Profile]	14:00, 15, Jul, 2012		
[Load]	3521 [KW]		
[Sending Power Flow]	NUK1[KW]	NUK2[KW]	Vaini[KW]
	1443	1429	649
[Sending Voltage]	11 [KV]		
[Newly Placed PV Site]	1000 [KW]		
[Voltage Evaluation Standar	230±10 [V]		

Case 1 (Connected to Vaini feeder)

BUS	Without PV Conversion in 11KV	Peak Output Conversion in 11KV	Fluctuation of Voltage Conversion in 11KV	Fluctuation of Voltage Conversion in 230V
GEN	11	11	0	0
H00001	10.9967	10.9967	0	0
H00046	10.9252	10.9252	0	0
H00264	10.9098	10.9098	0	0
H00294	10.8812	10.8812	0	0
H00322	10.8658	10.8658	0	0
H00335	10.8526	10.8526	0	0
H01375	10.7954	10.7954	0	0
T0410	10.7503	10.7503	0	0
H01601	10.7646	10.7646	0	0
H02031-1	10.835	10.835	0	0
T0401	10.8207	10.8207	0	0
H01601-1	10.8295	10.8295	0	0
H00071	10.9813	10.9813	0	0
H00093	10.9505	10.9505	0	0
T0423	10.9351	10.9351	0	0
H03069	10.9065	10.9065	0	0
T0166	10.8603	10.8603	0	0
T0337	10.8933	10.8933	0	0
T0116	10.8812	10.8812	0	0
H00464	10.9659	11.0264	0.0605	1.265
H00336	10.9615	11.0913	0.1298	2.714
H00580	10.8966	10.9571	0.0605	1.265
H01219	10.9802	11.0132	0.033	0.69
H00464	10.9659	11.0264	0.0605	1.265
H00498	10.9296	10.9901	0.0605	1.265
H01015-1	10.7393	10.8009	0.0616	1.288
H00580	10.8966	10.9571	0.0605	1.265
H01015	10.8867	10.9472	0.0605	1.265
T0170	10.8328	10.8933	0.0605	1.265
H77770	10.9648	11.0891	0.1243	2.599

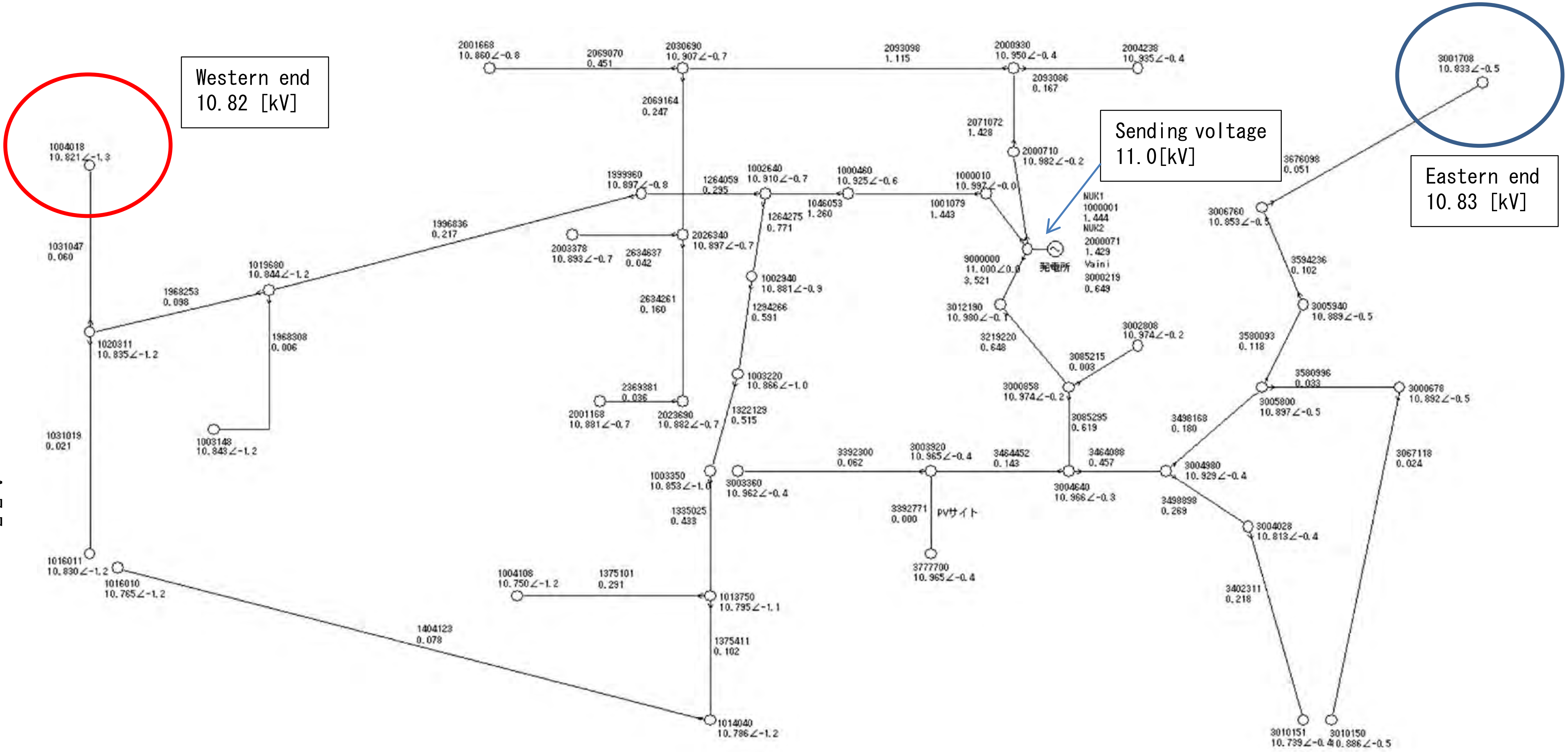
FROM BUS	TO BUS	Active Power Flow Without PV	Active Power Flow With PV
H90000	H01219	649	-348
H01219	H01220	648	-348
H01220	T0085	629	-366
T0085	T0295	619	-376
T0295	T0230	615	-381
T0230	H00464	601	-394
H00464	H00452	143	-852
H00452	H00451	141	-854
H00451	T0380	139	-857
T0380	T0355	135	-861
T0355	H00439	135	-862
H00439	T0084	133	-864
T0084	H00435	128	-869
H00435	H00428	106	-891
H00428	T0377	106	-891
T0377	T0382	99	-899
T0382	H00408	93	-906
H00408	T0376	88	-911
T0376	H00392	82	-918

Case 2 (Connected to NUK1 feeder)

BUS	Without PV Conversion in 11KV	Peak Output Conversion in 11KV	Fluctuation of Voltage Conversion in 11KV	Fluctuation of Voltage Conversion in 230V
GEN	11	11	0	0
H00001	10.9978	10.9989	0.0011	0.023
H00046	10.9373	10.9791	0.0418	0.874
H00264	10.9252	10.9758	0.0506	1.058
H00294	10.8999	10.9802	0.0803	1.679
H00322	10.8867	10.9824	0.0957	2.001
H00335	10.8757	10.9868	0.1111	2.323
H00462	10.8845	11.044	0.1595	3.335
H01375	10.824	10.9351	0.1111	2.323
T0410	10.7833	10.8955	0.1122	2.346
H01601	10.7965	10.9087	0.1122	2.346
H02031-1	10.8603	10.9131	0.0528	1.104
T0401	10.8482	10.901	0.0528	1.104
H01601-1	10.857	10.9087	0.0517	1.081
H00071	10.9813	10.9813	0	0
H00093	10.9505	10.9505	0	0
T0423	10.9351	10.9351	0	0
H03069	10.9065	10.9065	0	0
T0166	10.8603	10.8603	0	0
T0337	10.8933	10.8933	0	0
T0116	10.8812	10.8812	0	0
H00464	10.934	10.934	0	0
H00580	10.8438	10.8438	0	0
H01219	10.9758	10.9758	0	0
H00464	10.934	10.934	0	0
H00498	10.8845	10.8845	0	0
H01015-1	10.6403	10.6403	0	0
H00580	10.8438	10.8438	0	0
H01015	10.8295	10.8295	0	0
T0170	10.7613	10.7613	0	0
H77770	10.8812	11.033	0.1518	3.174

FROM BUS	TO BUS	Active Power Flow Without PV	Active Power Flow With PV
H00046	H00053	1278	278
H00053	T0258	1250	250
T0258	H00058	1208	208
H00058	H00264	1207	208
H00264	H00275	837	-162
H00275	T0274	837	-162
T0274	T0271	823	-176
T0271	H00286	815	-183
H00286	H03093	801	-196
H03093	H00292	787	-210
H00292	H00294	787	-210
H00294	T0266	676	-321
T0266	T0396	669	-328
T0396	T0265	662	-335
T0265	H00322	648	-349
H00322	T0129	607	-390
T0129	H00329	607	-390
H00329	T0135	537	-459
T0135	H00335	533	-463
H00335	H00342	144	-852
H00342	T0426	142	-855
T0426	H00353	126	-871
H00353	H00355	122	-875
H00355	T0131	118	-880
T0131	H00364	107	-891
H00364	T0106	103	-895
T0106	T0074	92	-906
T0074	T0378	93	-906
T0378	T0300	86	-914
T0300	H00392	81	-918

Figure 2.1 Summary of analysis results (for profile at off peak load)

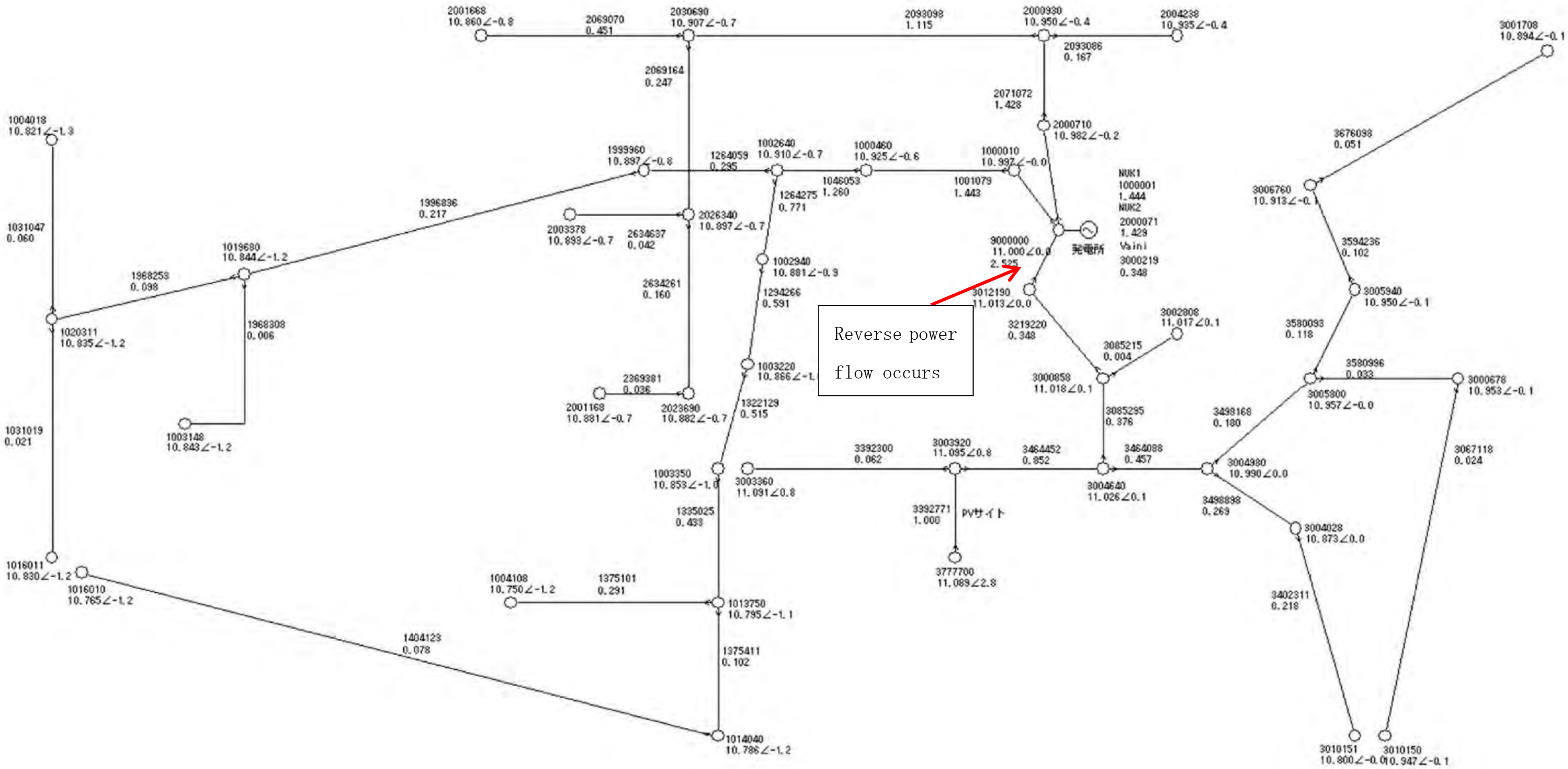


PV Site Connected to Vaini Feeder, without PV

[Profile] 14:00, 15, Jul, 2012

[Load] 3521 [kW]

Figure 2.2 Power flow diagram for V1-Vaini-OP (profile at off peak load, connected to Vaini feeder, without PV)

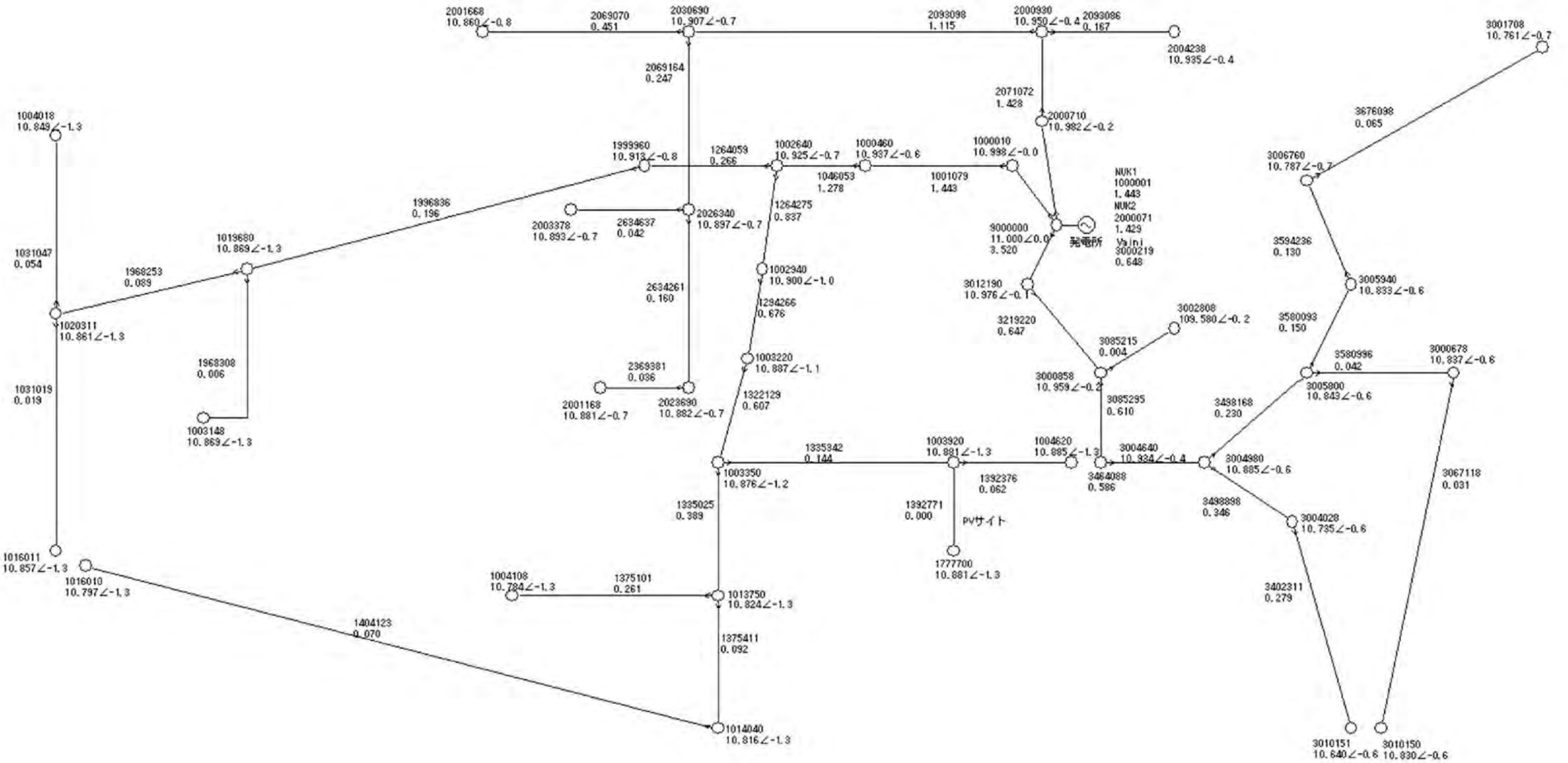


PV Site Connected to Vaini Feeder, Peak Output

[Profile] 14:00, 15, Jul, 2012

[Load] 3521 [kW]

Figure 2.3 Power flow diagram for V2-Vaini-OP-PV (profile at off peak load, connected to Vaini feeder, Peak Output)

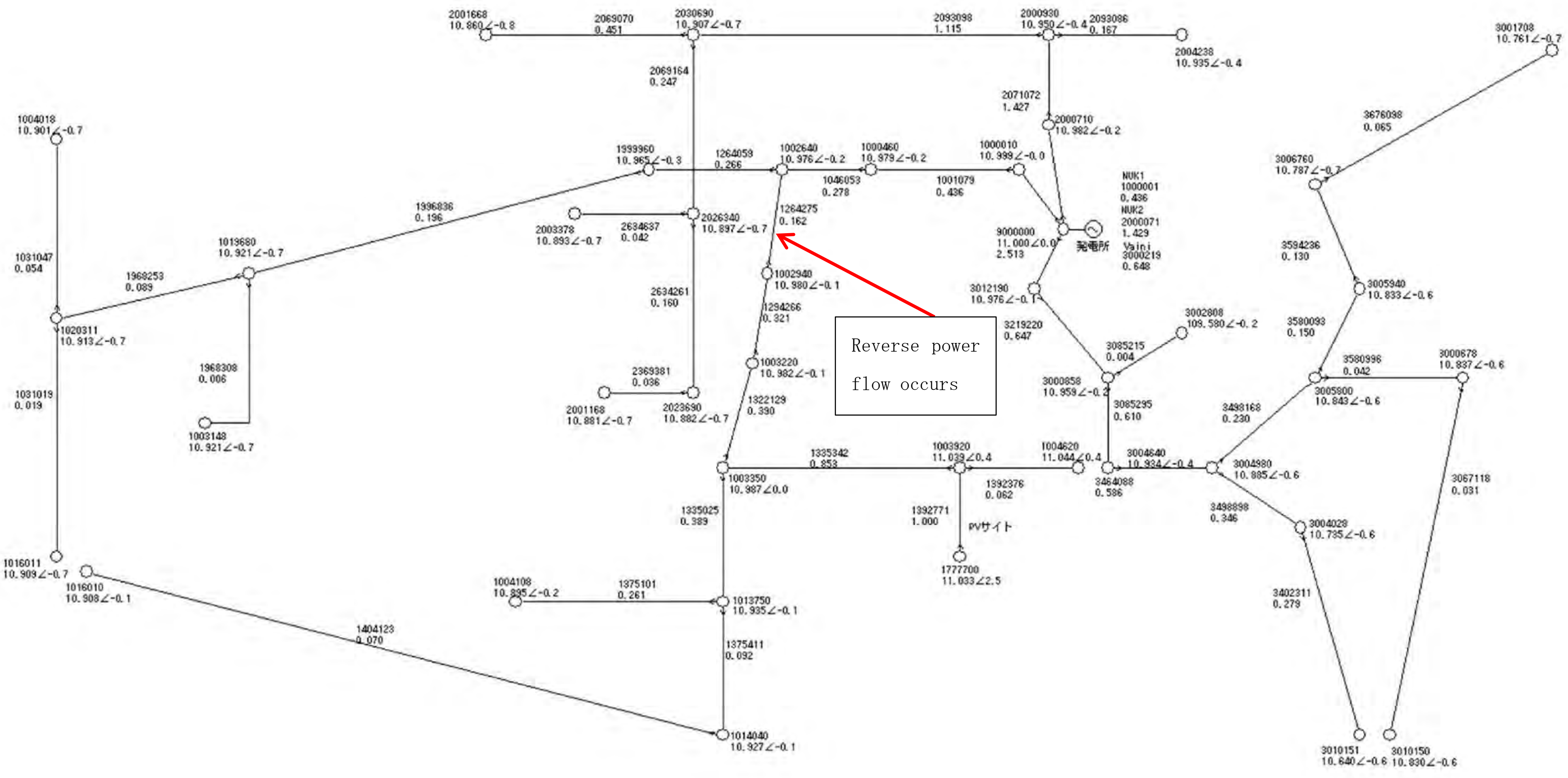


PV Site Connected to NUK1 Feeder, without PV

[Profile] 14:00, 15, Jul, 2012

[Load] 3521 [kW]

Figure 2.4 Power flow diagram for V3-NUK1-OP (profile at off peak load, connected to NUK1 feeder, without PV)



PV Site Connected to NUK1 Feeder, Peak Output

[Profile] 14:00, 15, Jul, 2012

[Load] 3521 [kW]

Figure 2.5 Power flow diagram for V4-NUK1-OP-PV (profile at off peak load, connected to NUK1 feeder, Peak Output)

Power flow analysis result of Tongatapu Island (profile at peak load)

[Profile] 14:15, 18, Jan, 2012
[Load] 6983 [KW]
[Sending Power Flow]

NUK1[KW]	NUK2[KW]	Vaini[KW]
2487	3604	892

[Sending Voltage] 11 [KV]
[Newly Placed PV Site] 1000 [KW]
[Voltage Evaluation Standar 230±10 [V]

Case 1 (Connected to Vaini feeder)

BUS	Without PV	Peak Output	Fluctuation of Voltage	
	Conversion in 11KV	Conversion in 11KV	Conversion in 11KV	Conversion in 230V
GEN	11	11	0	0
H00001	10.9934	10.9934	0	0
H00046	10.8493	10.8493	0	0
H00264	10.8196	10.8196	0	0
H00294	10.7646	10.7646	0	0
H00322	10.7371	10.7371	0	0
H00335	10.7151	10.7151	0	0
H01375	10.6139	10.6139	0	0
T0410	10.5358	10.5358	0	0
H01601	10.5622	10.5622	0	0
H02031-1	10.6524	10.6524	0	0
T0401	10.6293	10.6293	0	0
H01601-1	10.6447	10.6447	0	0
H00071	10.945	10.945	0	0
H00093	10.857	10.857	0	0
T0423	10.8196	10.8196	0	0
H03069	10.7327	10.7327	0	0
T0166	10.6139	10.6139	0	0
T0337	10.6975	10.6975	0	0
T0116	10.6656	10.6656	0	0
H00464	10.945	11.0055	0.0605	1.265
H00336	10.9329	11.0638	0.1309	2.737
H00580	10.8471	10.9076	0.0605	1.265
H01219	10.9692	11.0033	0.0341	0.713
H00464	10.945	11.0055	0.0605	1.265
H00498	10.8911	10.9527	0.0616	1.288
H01015-1	10.6282	10.6909	0.0627	1.311
H00580	10.8471	10.9076	0.0605	1.265
H01015	10.8328	10.8933	0.0605	1.265
T0170	10.7591	10.8207	0.0616	1.288
H77770	10.9384	11.0627	0.1243	2.599

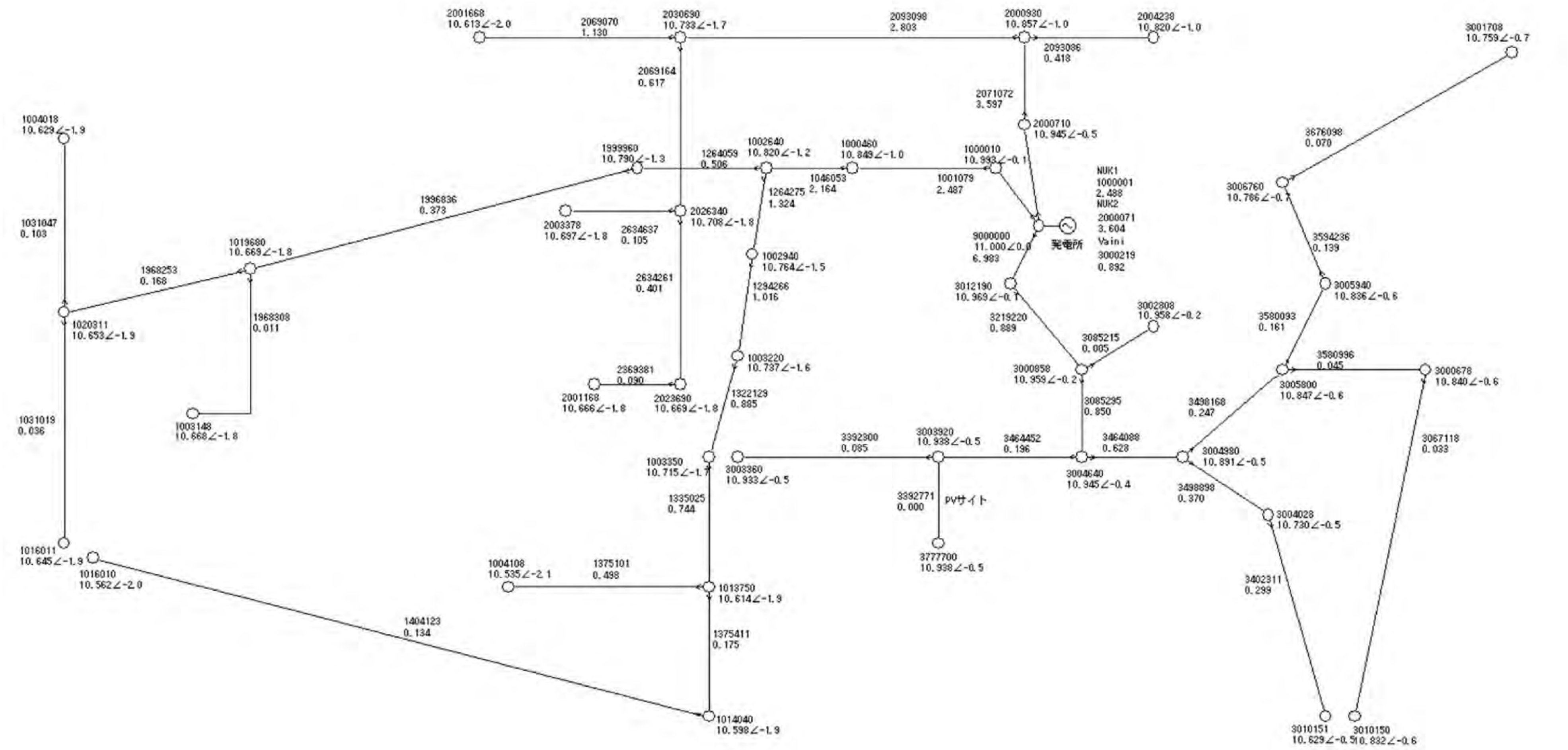
FROM BUS	TO BUS	Active Power Flow	
		Without PV	With PV
H90000	H01219	892	-108
H01219	H01220	889	-108
H01220	T0085	864	-133
T0085	T0295	850	-147
T0295	T0230	844	-152
T0230	H00464	824	-171
H00464	H00452	196	-800
H00452	H00451	193	-803
H00451	T0380	190	-806
T0380	T0355	184	-812
T0355	H00439	184	-812
H00439	T0084	181	-816
T0084	H00435	176	-822
H00435	H00428	145	-852
H00428	T0377	145	-852
T0377	T0382	136	-862
T0382	H00408	127	-872
H00408	T0376	121	-878
T0376	H00392	112	-888

Case 2 (Connected to NUK1 feeder)

BUS	Without PV	Peak Output	Fluctuation of Voltage	
	Conversion in 11KV	Conversion in 11KV	Conversion in 11KV	Conversion in 230V
GEN	11	11	0	0
H00001	10.9945	10.9956	0.0011	0.023
H00046	10.8614	10.9065	0.0451	0.943
H00264	10.8339	10.8889	0.055	1.15
H00294	10.78	10.8647	0.0847	1.771
H00322	10.7536	10.8537	0.1001	2.093
H00335	10.7316	10.8471	0.1155	2.415
H00462	10.7316	10.8955	0.1639	3.427
H01375	10.6414	10.758	0.1166	2.438
T0410	10.571	10.6876	0.1166	2.438
H01601	10.5941	10.7118	0.1177	2.461
H02031-1	10.6887	10.7448	0.0561	1.173
T0401	10.6678	10.7239	0.0561	1.173
H01601-1	10.6821	10.7382	0.0561	1.173
H00071	10.945	10.945	0	0
H00093	10.857	10.857	0	0
T0423	10.8196	10.8196	0	0
H03069	10.7327	10.7327	0	0
T0166	10.6139	10.6139	0	0
T0337	10.6975	10.6975	0	0
T0116	10.6656	10.6656	0	0
H00464	10.9021	10.9021	0	0
H00580	10.7734	10.7734	0	0
H01219	10.9659	10.9659	0	0
H00464	10.9021	10.9021	0	0
H00498	10.8306	10.8306	0	0
H01015-1	10.4918	10.4918	0	0
H00580	10.7734	10.7734	0	0
H01015	10.7547	10.7547	0	0
T0170	10.6601	10.6601	0	0
H77770	10.7294	10.8878	0.1584	3.312

FROM BUS	TO BUS	Active Power Flow	
		Without PV	With PV
H00046	H00053	2195	1186
H00053	T0258	2146	1138
T0258	H00058	2073	1067
H00058	H00264	2072	1066
H00264	H00275	1439	433
H00275	T0274	1438	433
T0274	T0271	1413	409
T0271	H00286	1400	397
H00286	H03093	1376	373
H03093	H00292	1352	350
H00292	H00294	1351	350
H00294	T0266	1160	160
T0266	T0396	1148	148
T0396	T0265	1135	136
T0265	H00322	1111	112
H00322	T0129	1042	43
T0129	H00329	1041	43
H00329	T0135	922	-76
T0135	H00335	915	-83
H00335	H00342	246	-751
H00342	T0426	242	-755
T0426	H00353	215	-782
H00353	H00355	208	-790
H00355	T0131	201	-797
T0131	H00364	183	-815
H00364	T0106	176	-822
T0106	T0074	158	-841
T0074	T0378	158	-841
T0378	T0300	146	-853
T0300	H00392	139	-861

Figure 2.6 Summary of analysis results (for profile at peak load)

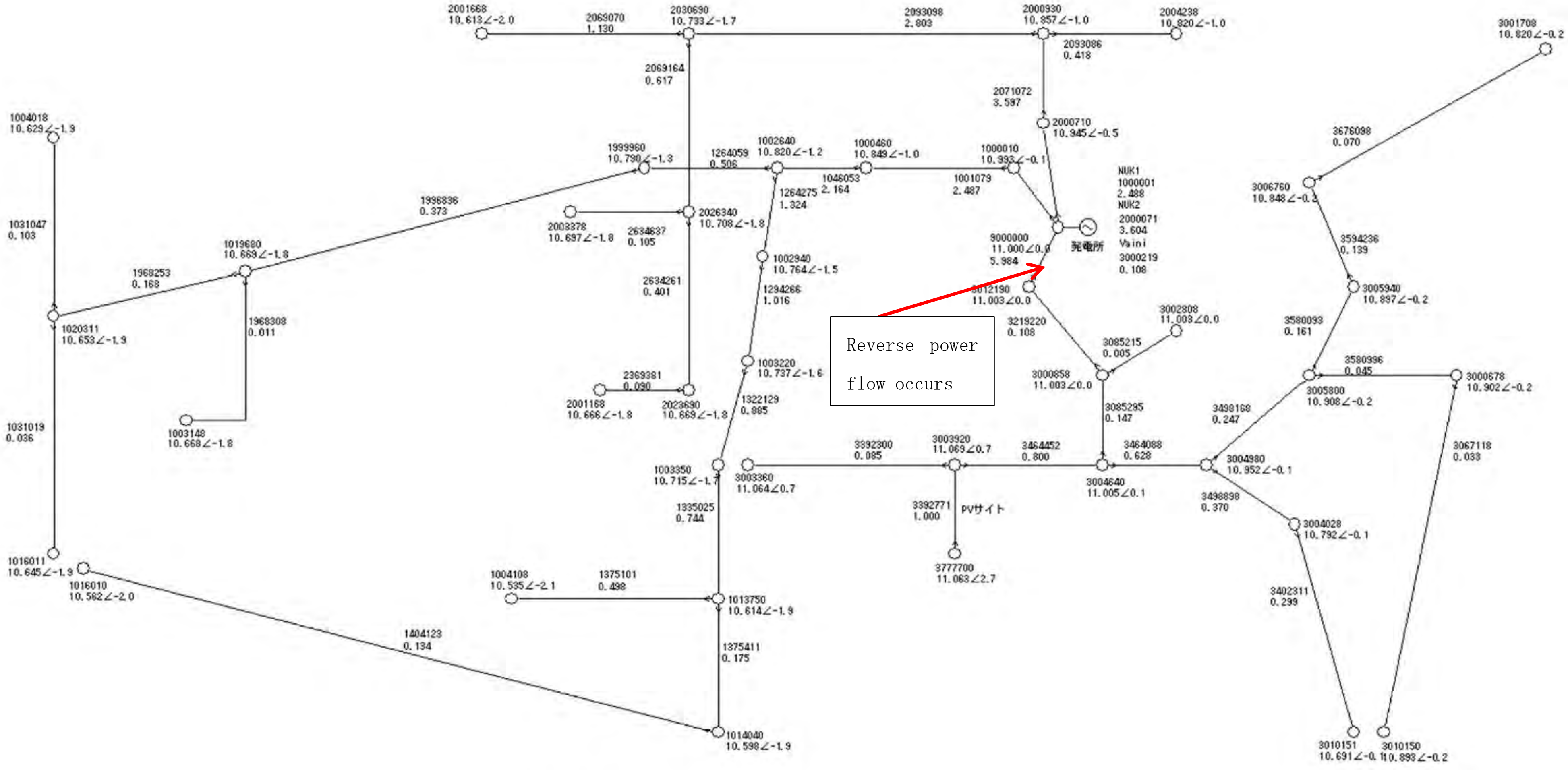


PV Site Connected to Vaini Feeder, Without PV

[Profile] 14:15, 18, Jan, 2012

[Load] 6983 [kW]

Figure 2.7 Power flow diagram for V5-Vaini-P (profile at peak load, connected to Vaini feeder, Without PV)

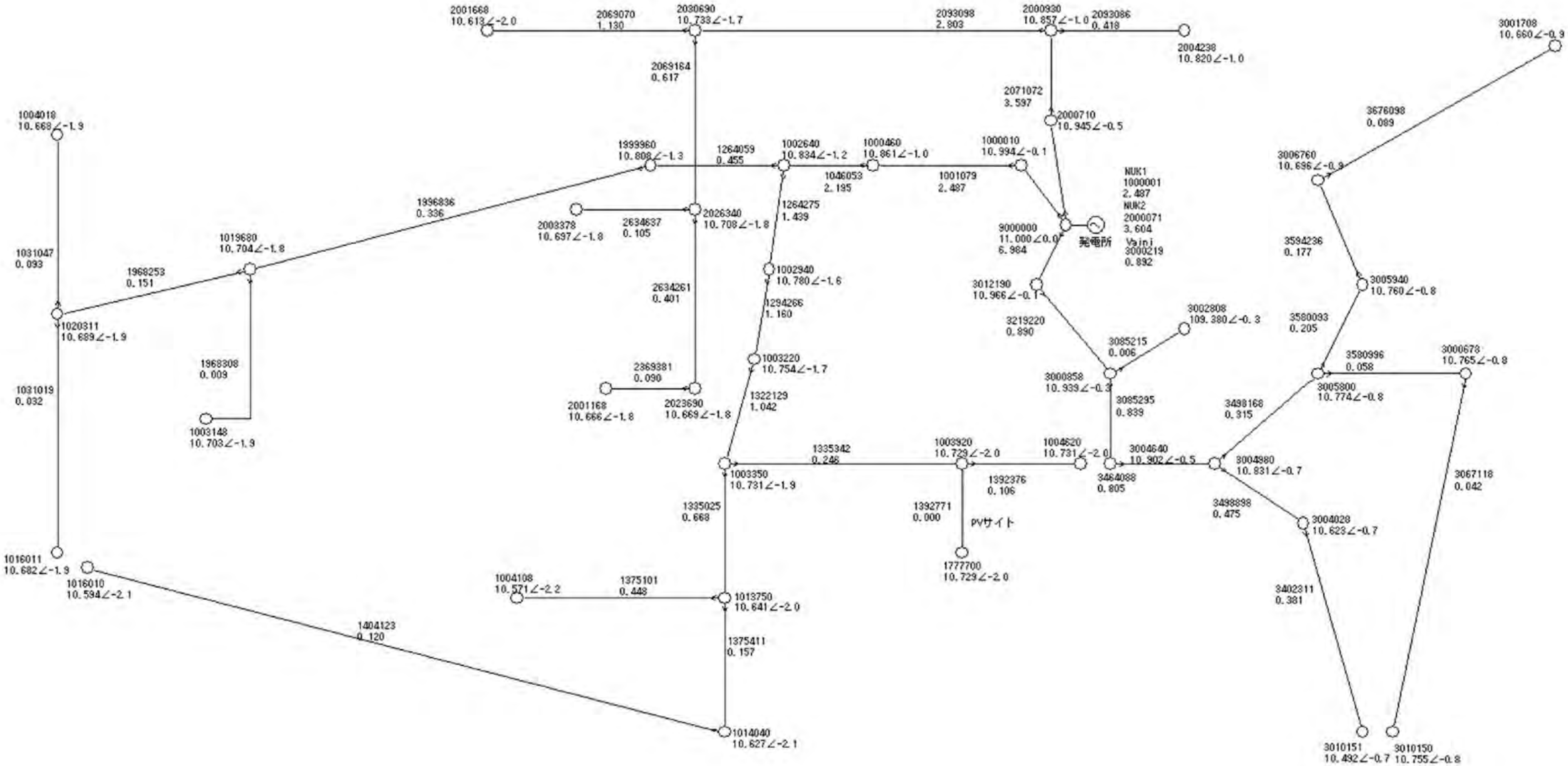


PV Site Connected to Vaini Feeder, Peak Output

[Profile] 14:15, 18, Jan, 2012

[Load] 6983 [kW]

Figure 2.8 Powerflow diagram for V6-Vaini-P-PV (profile at peak load, connected to Vaini feeder, Peak Output)

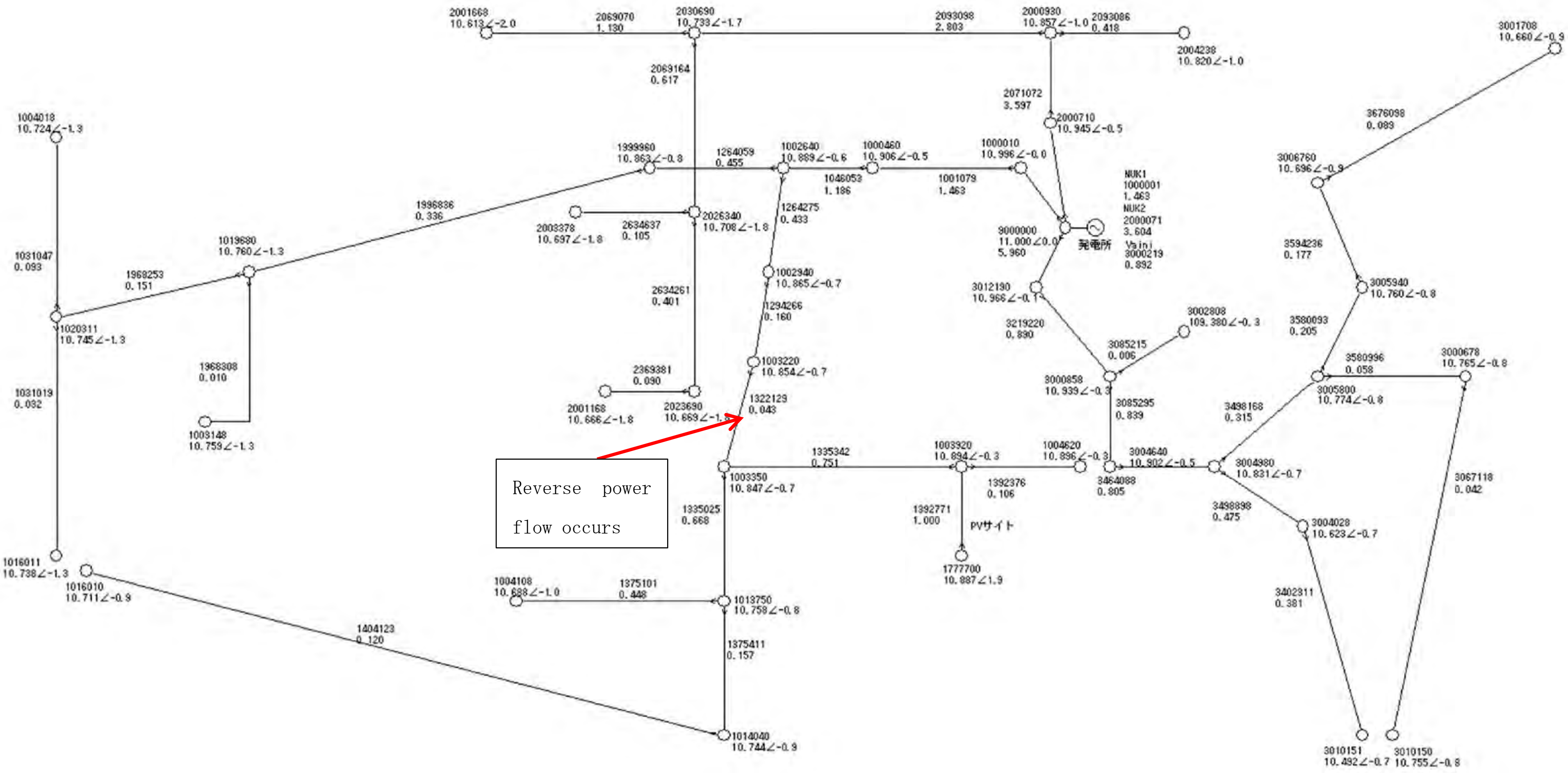


PV Site Connected to NUK1 Feeder, Without PV

[Profile] 14:15, 18, Jan, 2012

[Load] 6983 [kW]

Figure 2.9 Powerflow diagram for V7-NUK1-P (profile at peak load, connected to NUK1 feeder, Without PV)



PV Site Connected to NUK1 Feeder, Peak Output

[Profile] 14:15, 18, Jan, 2012

[Load] 6983 [kW]

Figure 2.10 Power flow diagram for V8-NUK1-P (profile at peak load, connected to NUK1 feeder, Peak Output)

３．Evaluation of fluctuation of frequency

３．１　Fluctuation of PV output

(1)　Outline of Analysis

The fluctuation of frequency, when PV output decreases suddenly, is evaluated by conducting transient analysis. Influence of the converter capacity of storage battery is also evaluated. Analysis conditions and evaluation methods are described in ①～③.

①　Parameter

・PV Output（decrease suddenly）

/Amount of Change : 50%（Newly Placed PV＋ Existing PV＝1150kW）, 80%（1840kW）

/varying time：5 sec,　10 sec

・Converter Capacity of Storage Battery

/250kW for each site(total sum, 500kW),　500kW(1000kW),　750kW(1500kW)

②　Models

Each model and points to consider to formulate models are listed below.

〇Distribution System

・The static stability analysis model described in Chap. ２.is used as the base profile, since the amount of fluctuation of frequency is largely detected in the static stability analysis.

・Three power generators CAT G2, G3, G6 as the load following generators are connected in parallel, as in the case of base profile as is the real situation.

〇Power Generator Model

・Initial output：407[kW]（unified value among G2, G3, G6, either in Vaini case and NUK1 case）

〇AVR Model

〇GOV Model

〇Power Storage System

〇PV Model

・PV output changes as ramp function (amount of change for newly placed PV is different from that of existing PV, since, the same change rates [%/sec] are adopted regardless of the capacity.)

③　Evaluation Method

・The capacity of storage battery that falls in the management range (frequency +0.2Hz～－0.1Hz) shall be confirmed.

(2) Analysis Cases

Following 16 analysis cases were conducted according to the condition (1). The case that PV output suddenly decrease by 50%/10sec, is adopted as base case.

（Maximum magnitude of PV output decrease, 558kW/10s(120902.xlsx)⇒43%/10s, are figured out from measured data excel file：120829.xlsx，120830.xlsx，120831.xlsx，120901.xlsx，120902.xlsx）

Table 3.1 Evaluation of fluctuation of frequency : analysis cases

Cases	Cases (Power Flow Profile)	PV Output (Newly Placed + Existing)	Capacity of Storage battery	Remarks
F1-V2-Vaini-OP-PV-50P10S-D500	V2-Vaini-OP-PV	50%/10sec ⇒ 1.15MW down	500kW	Base
F2-V2-Vaini-OP-PV-50P5S-D500		50%/5sec⇒1.15MW down		
F3-V2-Vaini-OP-PV-50P10S-D250		50%/10sec ⇒ 1.15MW down	250kW	
F4-V2-Vaini-OP-PV-50P10S-D750		50%/10sec ⇒ 1.15MW down	750kW	
F5-V2-Vaini-OP-PV-80P10S-D500		80%/10sec ⇒ 1.84MW down	500kW	Reference
F6-V2-Vaini-OP-PV-80P5S-D500		80%/5sec⇒1.84MW down		
F7-V2-Vaini-OP-PV-80P10S-D250		80%/10sec ⇒ 1.84MW down	250kW	
F8-V2-Vaini-OP-PV-80P10S-D750		80%/10sec ⇒ 1.84MW down	750kW	
F9-V4-NUK1-OP-PV-50P10S-D500	V4-NUK1-OP-PV	50%/10sec ⇒ 1.15MW down	500kW	Base
F10-V4-NUK1-OP-PV-50P5S-D500		50%/5sec⇒1.15MW down		
F11-V4-NUK1-OP-PV-50P10S-D250		50%/10sec ⇒ 1.15MW down	250kW	
F12-V4-NUk1-OP-PV-50P10S-D750		50%/10sec ⇒ 1.15MW down	750kW	
F13-V4-NUK1-OP-PV-80P10S-D500		80%/10sec ⇒ 1.84MW down	500kW	Reference
F14-V4-NUK1-OP-PV-80P5S-D500		80%/5sec⇒1.84MW down		
F15-V4-NUK1-OP-PV-80P10S-D250		80%/10sec ⇒ 1.84MW down	250kW	
F16-V4-NUK1-OP-PV-80P10S-D750		80%/10sec ⇒ 1.84MW down	750kW	

(3) Analysis result and Evaluation

Connected to Vaini feeder：

Table 3.2 shows the bottom frequency values for each case. Figure 3.1 show time variation of frequency in case F1q,F2···F2case F1qFigure 3.2 shows time variation of frequency in case F1e,F3···F3cas

In the case of 500kW for the capacity of converters, as shown in bottom frequency value and wave form for base case F1···ottom frequedeviates the management range by 0.03Hz. In more rapid decrease cases 80%/10S(F5%/, 80%/5S(F6gement range by 0.03Hz. In more rais seen. In the case of 50%/5S(F2(F2. In the case of 50%/.03Hz.Hz. These cases shall be used as reference since these situations rarely occurs. In the case of storage battery capacity dependence, 50%/10s is adopted as base case.

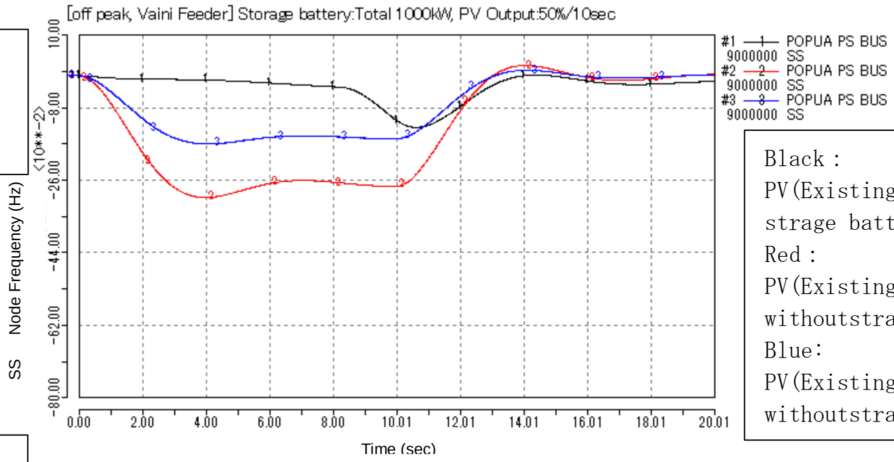
There is little decrease of frequency in 750kW storage battery case. In 500kW case, frequency deviates the management range by 0.03Hz. In 250kW case, storage battery reaches peak output in a few seconds, accompanied by increase of diesel machine output and decrease of frequency. From the results, it is valid to adopt the 500kW or more of the capacity for power storage system.

Decrease of frequency was obvious in a few seconds, since after output of power storage system reaches the rated output, DGs cover the shortage while reaction speed of DGs is a little slower than the speed of power storage device.

Table 3.2 Bottom frequency value for Vaini case

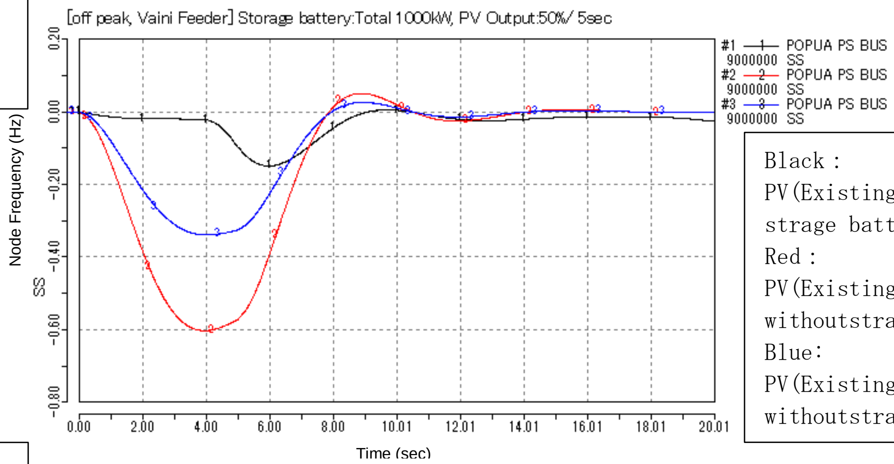
Cases	Bottom frequency value [Hz]	Time [sec]
F1-V2-Vaini-OP-PV-50P10S-D500	-0.12920	10.62
F2-V2-Vaini-OP-PV-50P5S-D500	-0.14953	5.97
F3-V2-Vaini-OP-PV-50P10S-D250	-0.29417	8.69
F4-V2-Vaini-OP-PV-50P10S-D750	-0.04070	14.44
F5-V2-Vaini-OP-PV-80P10S-D500	-0.46198	9.98
F6-V2-Vaini-OP-PV-80P5S-D500	-0.73203	5.48

PV output suddenly decrease 50%/10sec



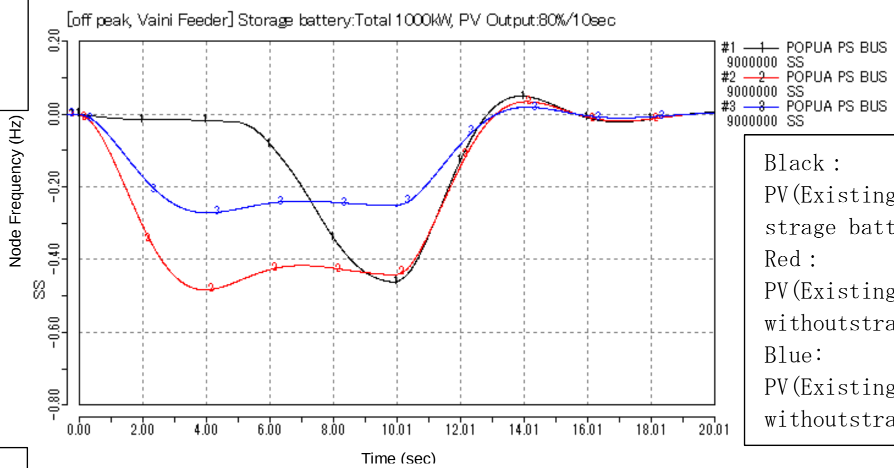
Black :
PV(Existing+Newly Placed)
strage battery 500kW×2
Red :
PV(Existing+Newly Placed)
withoutstrage battery
Blue:
PV(Existing)
withoutstrage battery

PV output suddenly decrease 50%/5sec



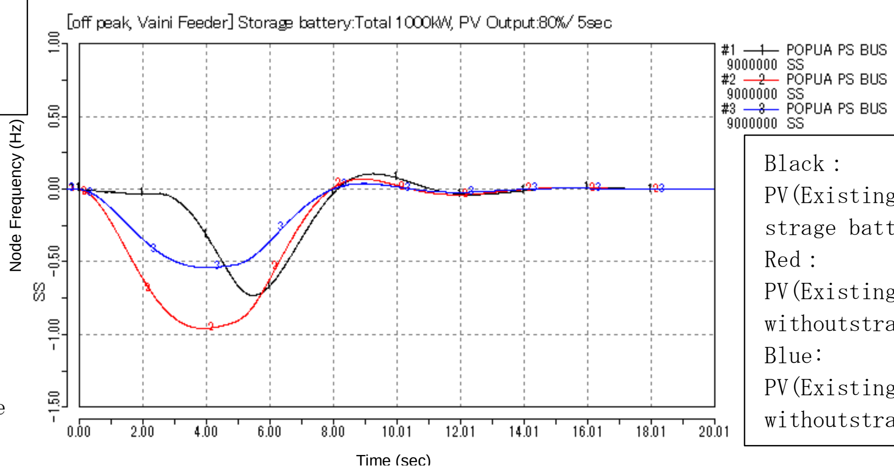
Black :
PV(Existing+Newly Placed)
strage battery 500kW×2
Red :
PV(Existing+Newly Placed)
withoutstrage battery
Blue:
PV(Existing)
withoutstrage battery

PV output suddenly decrease 80%/10sec



Black :
PV(Existing+Newly Placed)
strage battery 500kW×2
Red :
PV(Existing+Newly Placed)
withoutstrage battery
Blue:
PV(Existing)
withoutstrage battery

PV output suddenly decrease 80%/5sec



A note:Range

Black :
PV(Existing+Newly Placed)
strage battery 500kW×2
Red :
PV(Existing+Newly Placed)
withoutstrage battery
Blue:
PV(Existing)
withoutstrage battery

Figure 3.1 Comparison of frequency among cases F1, F2, F5, F6【Storage Battery：500kW】

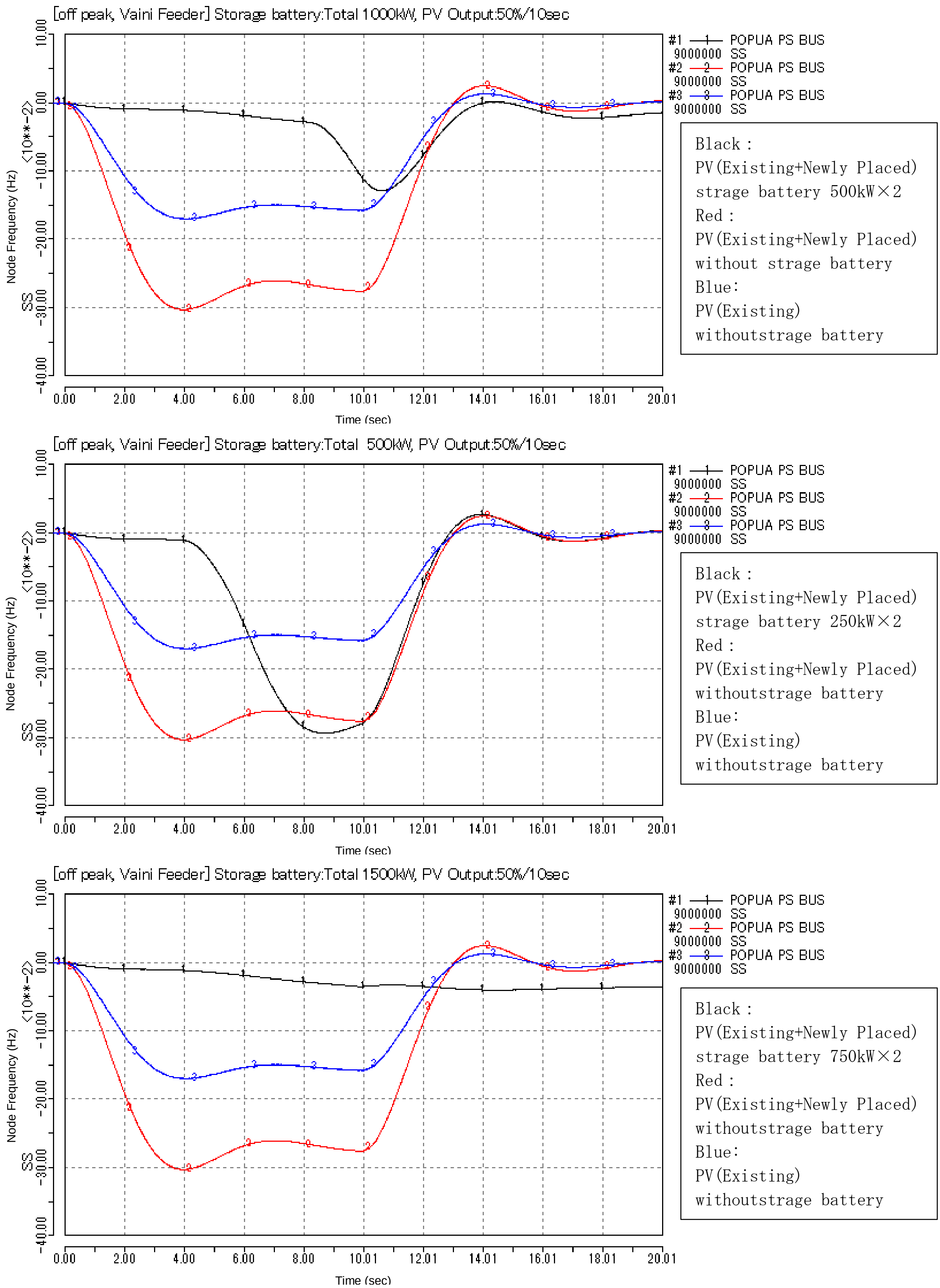


Figure 3.2 Comparison of frequency among cases F1…,F3…,F4…

【Storage Battery : 500kW,250kW,750kW】

Connected to NUK1 feeder：

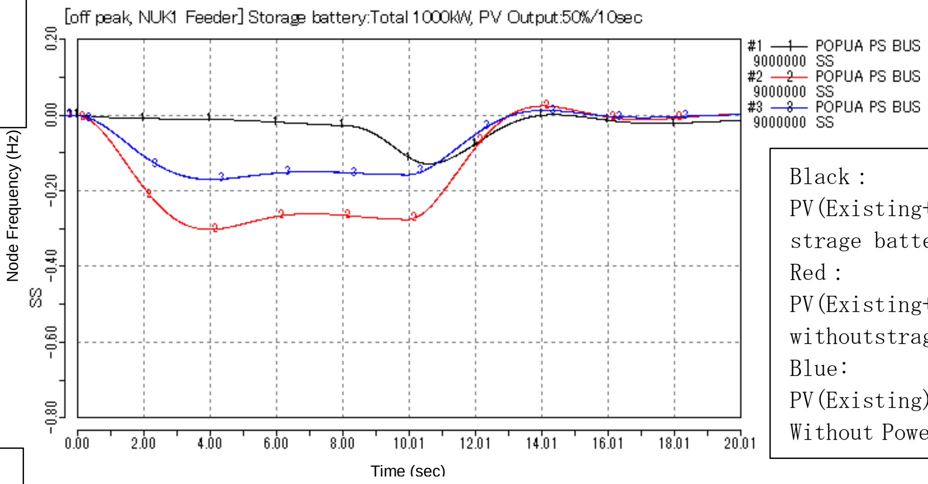
Table 3.3 shows the bottom frequency values for each case. Figure 3.3 shows time variation of frequency in caseF9me variation of frFigure 3.4 shows time variation of frequency in case F9e variation

There are only few difference in analysis results from the case of Vaini.

Table 3.3 Bottom frequency value for NUK1 case

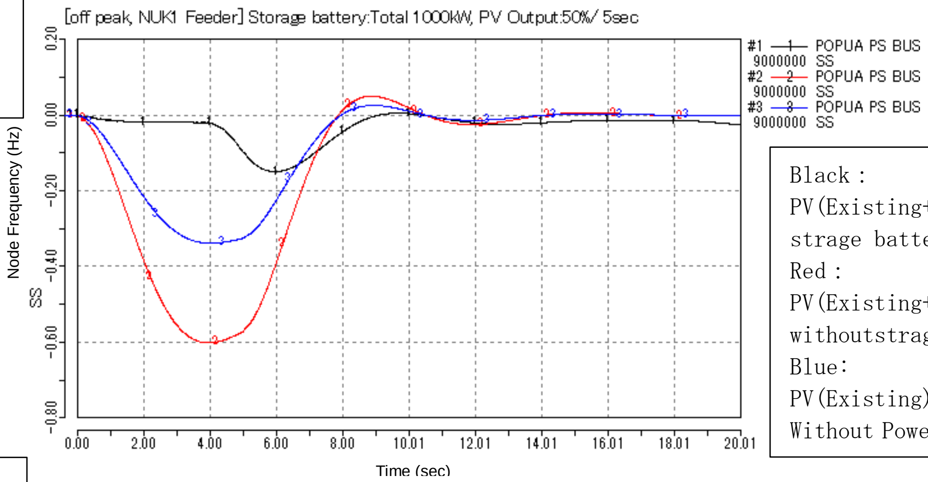
Cases	Bottom frequency value [Hz]	Time [sec]
F9-V4-NUK1-OP-PV-50P10S-D500	-0.12913	10.59
F10-V4-NUK1-OP-PV-50P5S-D500	-0.14975	5.96
F11-V4-NUK1-OP-PV-50P10S-D250	-0.29372	8.7
F12-V4-NUk1-OP-PV-50P10S-D750	-0.04060	14.53
F13-V4-NUK1-OP-PV-80P10S-D500	-0.46117	9.67
F14-V4-NUK1-OP-PV-80P5S-D500	-0.73057	5.48

PV output suddenly decrease 50%/10sec



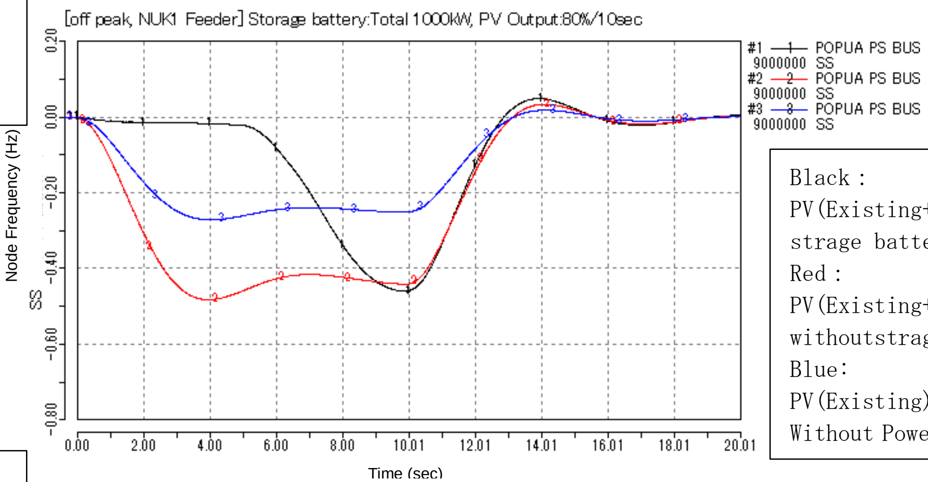
Black :
PV(Existing+Newly Placed)
strage battery 500kW×2
Red :
PV(Existing+Newly Placed)
withoutstrage battery
Blue:
PV(Existing)
Without Power storage system

PV output suddenly decrease 50%/5sec



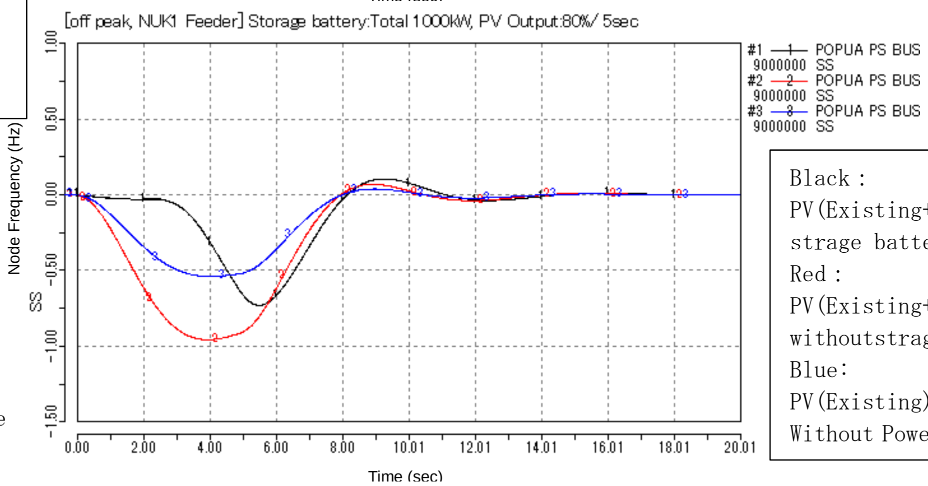
Black :
PV(Existing+Newly Placed)
strage battery 500kW×2
Red :
PV(Existing+Newly Placed)
withoutstrage battery
Blue:
PV(Existing)
Without Power storage system

PV output suddenly decrease 80%/10sec



Black :
PV(Existing+Newly Placed)
strage battery 500kW×2
Red :
PV(Existing+Newly Placed)
withoutstrage battery
Blue:
PV(Existing)
Without Power storage system

PV output suddenly decrease 80%/5sec



A note:Range

Black :
PV(Existing+Newly Placed)
strage battery 500kW×2
Red :
PV(Existing+Newly Placed)
withoutstrage battery
Blue:
PV(Existing)
Without Power storage system

Figure 3.3Comparison of frequency among casesF9,F10,F13,F14【Storage Battery : 500kW】

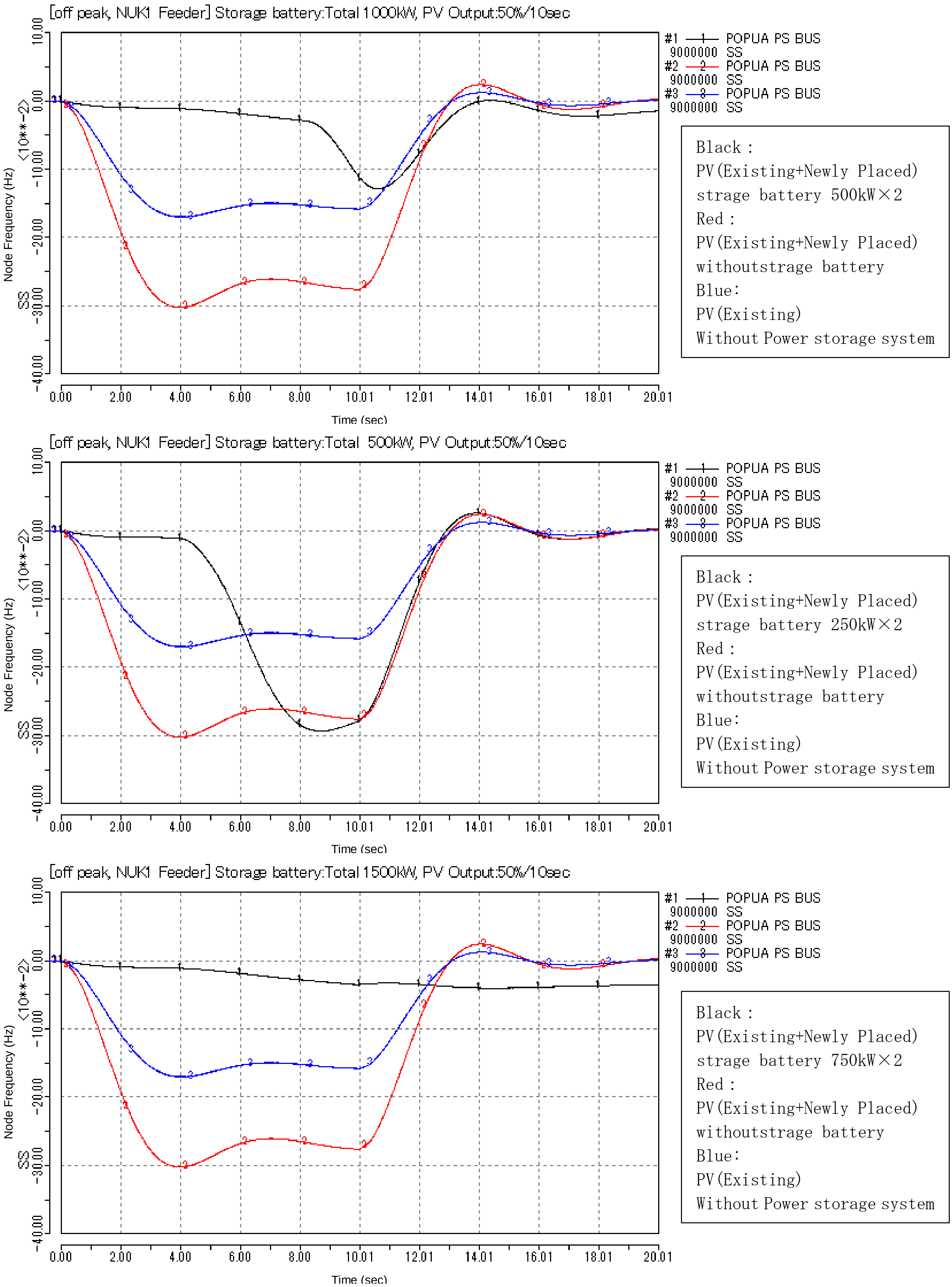


Figure 3.4 Comparison of frequency among cases F9…, F11…, F12…

【Storage Battery : 500kW, 250kW, 750kW】

(4) Conclusion

Conclusion of this analysis is summarized as follows.

○Result of analysis

No difference was observed about the evaluation result of analysis of voltage subject to the connection of Vaini feeder or NUK1 feeder

・Fluctuation of voltage was observed to be in the range of 230 range, the standard of evaluation.

・Amount of fluctuation of frequency was observed to be approximately in the operational range of +0.2Hz to -0.1Hz, from the analysis assuming rapid change of PV output caused by change of irradiation, with power storage system of the capacity of 500kW or more. The adopted operational value was more severe than ±he adopthe value of Japanese island area.

○Points to remember on the analysis for evaluation of the amount of fluctuation of voltage

・Than the end-voltage distribution lines BUS voltage and east-west lines of the current state of Tongatapu Island power plant, it is necessary to check the validity of the resulting voltage decline trend power flow analysis (see Figure 2.2 power flow diagram).

○Points to remember on the analysis for evaluation of the amount of fluctuation of frequency

・The maximum magnitude of PV output decrease is uncertain in analysis of frequency fluctuation. From the measured data of 2012/08/29～2012/09/02, the maximum value of 558kW/10s (approximately 43%/10s) are figured out.

・Because we adjust it with a sampling level about the speed properties of the governor for ten seconds, it is thought that the flattery for the rapid decrease appears in the good direction if the sensitivity of the actual machine is better than a calculated value. In order to improve the accuracy of analysis, measured value of 1 second sampling and the response property of governor (ex. Measured waveforms of load rejection test) are needed.

・In the base case of frequency fluctuation analysis, 3 power generators are connected. In the case of 2 generators, frequency becomes more unstable. In contrast, frequency becomes more stable as for the case of 4 generators.

Charge capacity and maximum output of parallel number of DGs shall be considered carefully on operation after installation of new PV modules.

・Because the converter capacity only considered for the battery is the battery capacity is equivalent to infinity. In the case of using a capacitor, it should be noted charge capacity.

・Not considered in this analysis PV sites smoothing effect is expected.

３．２ Confirmation of load following capability of existing diesel generators

(1) Outline of Analysis

Evaluation of fluctuation of frequency was conducted again by applying change rate limiter of existing diesel engine generator (DG) to governor model. The condition of the analysis and the methodology for the evaluation are as follows.

① Change in governor model

・Change rate limiter of 5%/sec was installed

② Parameter

・PV output (rapid decrease)

/Amount of change: 50%（Newly placed PV + Existing PV = 1150kW）

/Duration: 10msec, 5sec, 10sec

・Capacitor of invertor for power storage system

/Each site 500kW(Total 1000kW), 750kW(Total 1500kW)

⇒Capacitor of power storage system was determined to be 500kW for each site for the analysis, since in case of 250kW for each site, fluctuation of frequency exceeded operation range by a large extent and in case of 750kW for each site, the fluctuation shall be less than in case of 500kW, taking account of results of the previous analysis.

③ Model

・This section is the same as the previous analysis and shall be omitted (Refer to the previous document for the detail)

④ Methodology for evaluation

・Capacitor of power storage system appropriate for management range (frequency + 0.2Hz~ -0.1Hz) shall be determined.

Frequency shall be evaluated whether it is appropriate for management range even though there is a change for governor model, since 500kW is applied as the capacity of power storage system based on the result of previous results.

(2) Cases of analysis

Based on conditions described in (1), following 8 analysis cases were conducted.

The most fluctuated (50%/10msec) case is analyzed for the case that capacitor of power storage device of 750kW. And to compare this case with the existing grid, the case of rapid decrease by 50 % of existing PV (1.3MW) was analyzed and the case without power storage system was also analyzed.

Table 3.4 Evaluation of fluctuation of frequency: analysis cases

Cases	Cases (Power Flow Profile)	PV output (Newly Placed + Existing)	Capacity of converter for power storage system
F21-V2-Vaini-OP-PV-50P10MS-D500	V2-Vaini-OP-PV	50%/10msec⇒1.15MW down	500kW
F22-V2-Vaini-OP-PV-50P5S-D500		50%/5sec⇒1.15MW down	
F23-V2-Vaini-OP-PV-50P10S-D500		50%/10sec⇒1.15MW down	
F24-V2-Vaini-OP-PV-50P10MS-D750		50%/10msec⇒1.15MW down	750kW
F25-V4-NUK1-OP-PV-50P10MS-D500	V4-NUK1-OP-PV	50%/10msec⇒1.15MW down	500kW
F26-V4-NUK1-OP-PV-50P5S-D500		50%/5sec⇒1.15MW down	
F27-V4-NUK1-OP-PV-50P10S-D500		50%/10sec⇒1.15MW down	
F28-V4-NUK1-OP-PV-50P10MS-D750		50%/10msec⇒1.15MW down	750kW

(3) Result of analysis and evaluation

○Vaini Feeder：

Figure3.5 shows figures of frequency from F21… to F24. (Blue line stands for current situation for comparison)

In case of 500kW of capacity of converter, the bottom frequency value became 0.2Hz in F21 frequenPV output fluctuates in step function. The bottom frequency value became approximately 0.15Hz in case of F22… and F23… where, based on the real situation, PV output fluctuates in ramp function. The same results were obtained as the result before the improvement of GOV model, since change rate of the ramp function is less than or equal to the limit of GOV change rate.

In case of capacity of 750kW of converter for power storage device, the fluctuation of frequency was confirmed to be in the range of operation frequency of -0.1Hz since the bottom frequency value became 0.08Hz.

○NUK 1 Feeder：

Table 3.5 shows the bottom function of each case from F25… to F28…. Figure 3.6 shows figures of frequency of the case from F25… to F28. (Blue line is for comparison)

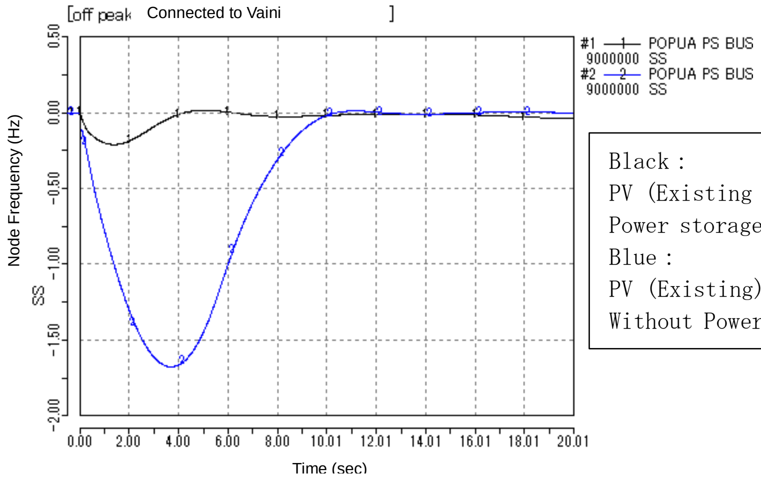
Based on the figures of frequency and the bottom frequency values, the behavior was the same as the case of Vaini feeder connection.

Table 3.5 The bottom frequency values in each case

Cases	Bottom frequency value [Hz]	Time [sec]
F21-V2-Vaini-OP-PV-50P10MS-D500	-0.21	1.37
F22-V2-Vaini-OP-PV-50P5S-D500	-0.15	5.96
F23-V2-Vaini-OP-PV-50P10S-D500	-0.13	10.61
F24-V2-Vaini-OP-PV-50P10MS-D750	-0.08	0.41
F25-V4-NUK1-OP-PV-50P10MS-D500	-0.21	1.43
F26-V4-NUK1-OP-PV-50P5S-D500	-0.15	5.95
F27-V4-NUK1-OP-PV-50P10S-D500	-0.13	10.60
F28-V4-NUK1-OP-PV-50P10MS-D750	-0.08	0.40

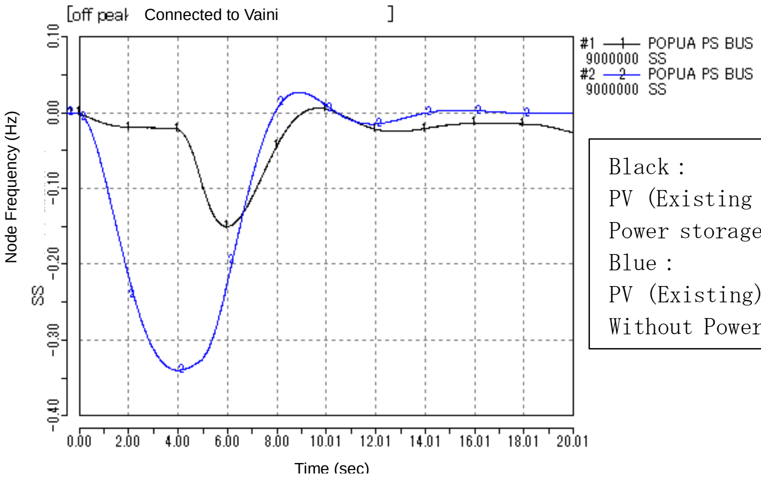
From above mentioned, while in the most severe case fluctuation of frequency exceeds the operation value of -0.1Hz by 0.11Hz, the fluctuation of frequency exceeds by 0.05Hz in the cases based on the real situation of both Vaini connection and NUK1 connection. When the allowable frequency deviation of Japanese islands of ±eviation of Japan there seemed to be no problem since operation value adopted to the analysis was severe on the bases of the allowable frequency.

PV output
Rapid decrease
50%/10msec



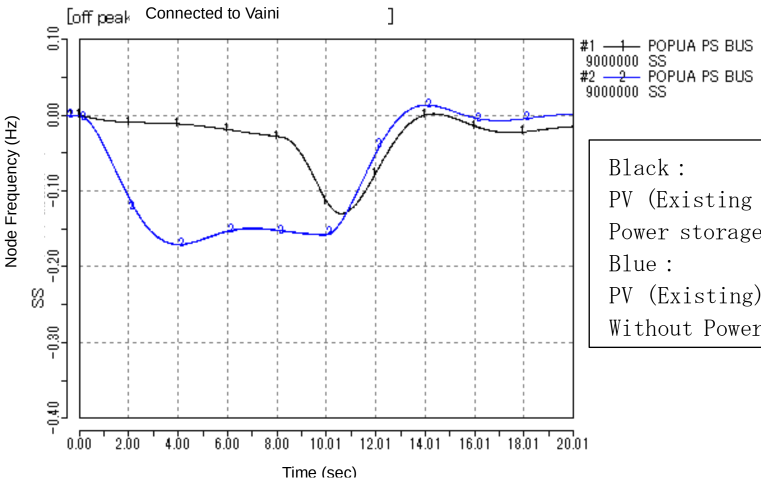
Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Blue :
PV (Existing)
Without Power storage system

PV output
Rapid decrease
50%/5sec



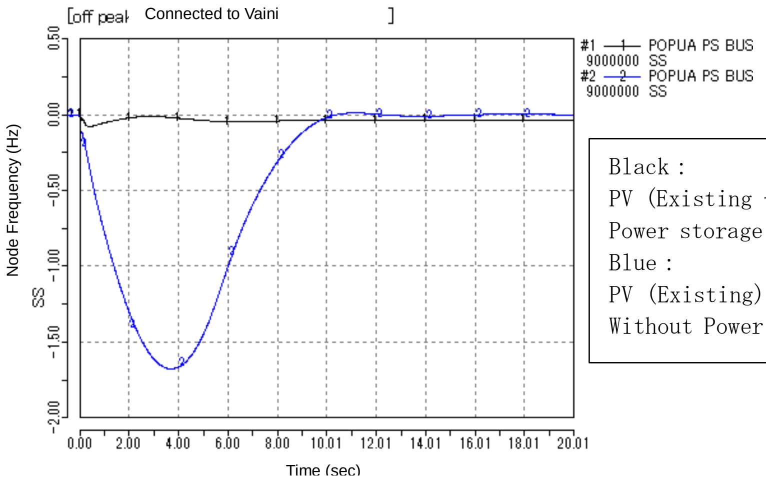
Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Blue :
PV (Existing)
Without Power storage system

PV output
Rapid decrease
50%/10sec



Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Blue :
PV (Existing)
Without Power storage system

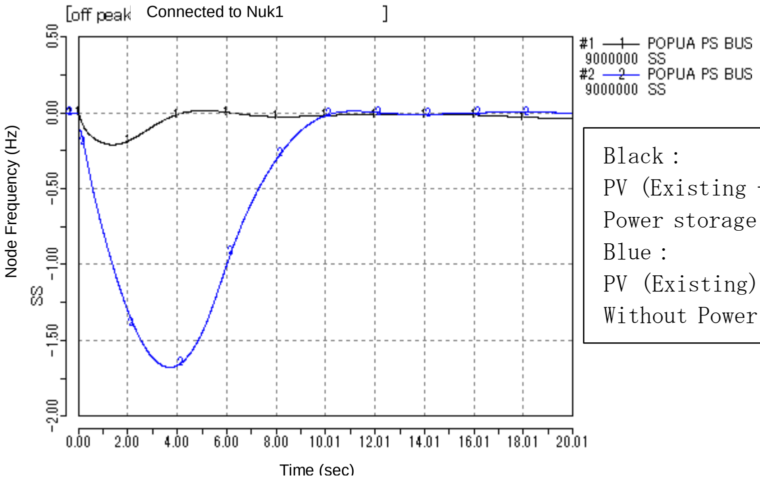
PV output
Rapid decrease
50%/10msec



Black :
PV (Existing + Newly placed)
Power storage device750kW×2
Blue :
PV (Existing)
Without Power storage system

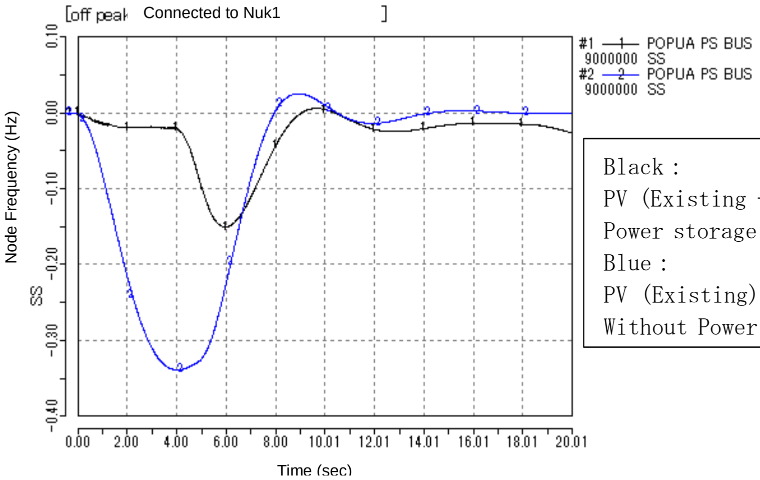
Figure 3.5 Result of comparison in frequency according to the difference of range of change in case of 50% of PV output
(Power storage system 500kW, 750 kW/ Connected to Vaini)

PV output
Rapid decrease
50%/10msec



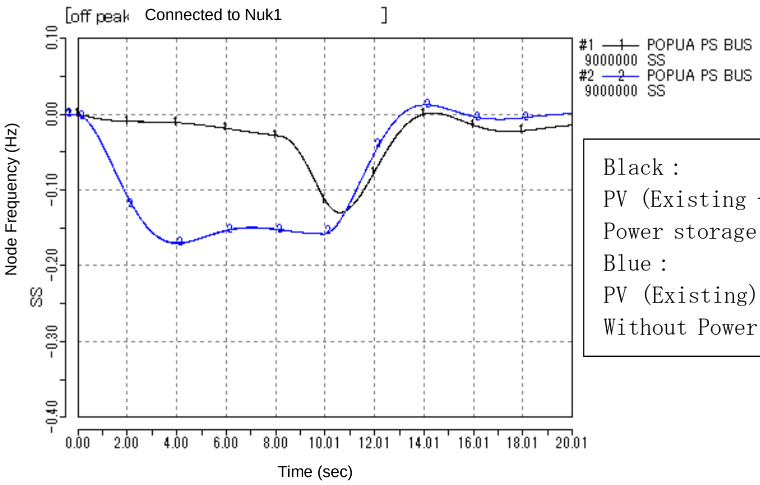
Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Blue :
PV (Existing)
Without Power storage system

PV output
Rapid decrease
50%/5sec



Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Blue :
PV (Existing)
Without Power storage system

PV output
Rapid decrease
50%/10sec



Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Blue :
PV (Existing)
Without Power storage system

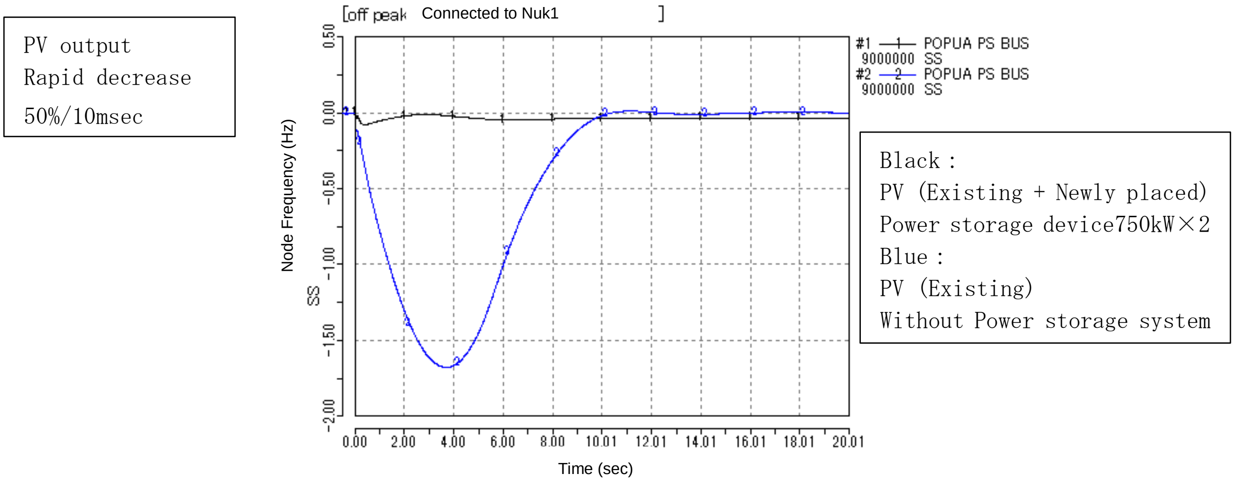


Figure 3.6 Result of comparison in frequency according to the difference of range of change in case of 50% of PV output

(Power storage system 500kW, 750 kW/ Connected to NUK 1)

3．3 Evaluation of requisite Capacity of Power Storage System

(1) Outline of analysis

Grid model was formulated considering capacity of power storage system so as to conduct hourly evaluation of the capacity of power storage system. 60 sec was assumed as time constant for the first order lag for compensation (variable time constant control) for 500kW rated output of power storage system in the previous model. However three cases of 40 sec, 20 sec, 10 sec are added to the output characteristic for more detailed analysis.

① Generator, Governor model

・CAT (High speed diesel engine generator) 3 units (parallel)

・GOV ：Limitation model of change rate at 5%/sec

② PV output (rapid decrease)

/Amount of change: 50%（Newly placed PV + Existing PV＝1150[kW]）

/Duration: 10msec

③ Model for power storage system

・Capacity of converter for power storage system

/Each site 500[kW]（Total 1000[kW]）

・Characteristic of variable time constant control for 500kW rated output of power storage system are as follows.

/500[kW]/60sec, 40sec, 20sec, 10sec (4 patterns in total)

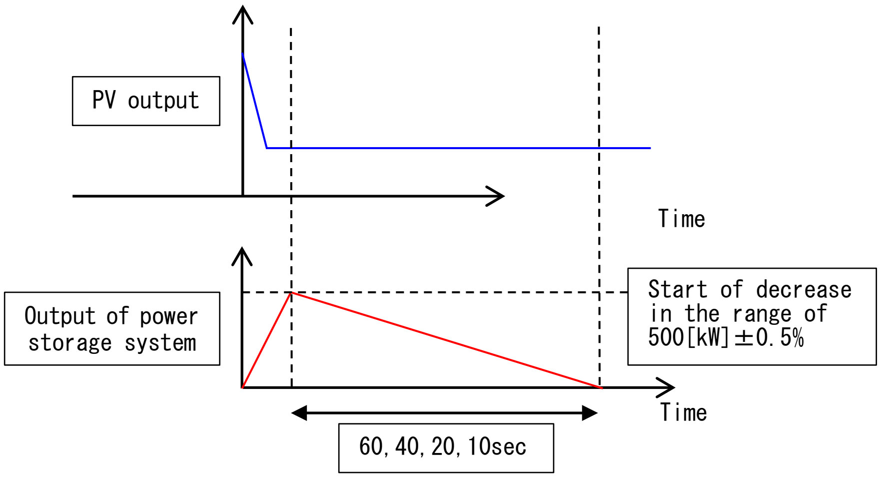


Figure 3.7 Performance of PV output and output of power storage system

(2) Cases of analysis

Profile at off peak load is adopted as base profile as is the case with the previous analysis. Nuk1 feeder shall be the objective of analysis since there is no difference between Nuk 1 connection and Vaini connection in terms of fluctuation of frequency.

Cases of analysis based on the condition described in (1) are 4 cases as follows.

Table 3.6 Cases of analysis for the amount of fluctuation of frequency

Cases	PV output (Newly placed + Existing)	Capacity of converter for power storage system	Change speed 500[kW]/xxx
F31-V4-NUK1-OP-PV-50P10MS-D500-60S	50%/10msec⇒1.15MW Rapid decrease	500kW	60sec
F32-V4-NUK1-OP-PV-50P10MS-D500-40S			40sec
F33-V4-NUK1-OP-PV-50P10MS-D500-20S			20sec
F34-V4-NUK1-OP-PV-50P10MS-D500-10S			10sec

(3) Results of analysis and evaluation

The bottom value of frequency and convergence value of the frequency in each case are listed in Table 3.7. Wave profile in each case (F31… ~ F34…) are shown in Figure 3.8. In addition, comparisons with the latest case are shown in Figure 3.9. (Blue line: Wave profile of the latest case)

○Result of analysis with change speed at 500[kW]/60sec(8.33[kW]/sec) in case of low output of power storage device

The bottom value of frequency became -0.22[Hz] caused by decrease of PV output. Fluctuation of frequency became approximately -0.04[Hz] in 10 sec since variation width of output of power storage system became the same as variation width of DG output. Frequency started to fluctuate again in 60 sec since output of power storage system becomes 0.0 [kW] and governor follows again. The variations of the output of power storage system and the DG output became the same again after the fluctuation and frequency became the same. And fluctuation of frequency became approximately 0.0 [Hz].

○Result of analysis with change speed at 500[kW]/40sec(12.50[kW]/sec) in case of low output of power storage device

Following speed of DG became slower than in case of 500 [kW]/60sec and the bottom frequency value became -0.01 [Hz] lower since change speed became approximately 4 [kW]/sec faster than in case of 500 [kW]/60sec. Fluctuation of frequency became approximately -0.06[Hz], in the same way, after variation width of output of power storage system became the same as variation width of DG output. Behavior afterward tended to be the same as in case of 500 [kW]/60sec.

○Result of analysis with change speed at 500 [kW]/20 sec (25.00 [kW]/sec), 500 [kW]/10 sec (50.00 [kW]/sec) in case of low output of power storage device

In case of 20 sec and 10 sec, the behavior tented to be the same and the bottom frequency value and displacement of convergence value after fluctuation of frequency became larger.

Table 3.7 Bottom frequency value and convergence value after fluctuation of frequency for each case

Cases	Bottom frequency value [Hz]	Time [sec]	Convergence value after fluctuation of frequency [Hz]
F31-V4-NUK1-OP-PV-50P10MS-D500-60S	-0.22	1.46	-0.04
F32-V4-NUK1-OP-PV-50P10MS-D500-40S	-0.23	1.53	-0.06
F33-V4-NUK1-OP-PV-50P10MS-D500-20S	-0.26	1.77	-0.12
F34-V4-NUK1-OP-PV-50P10MS-D500-10S	-0.35	2.41	-0.24

From the table above, bottom frequency value in the immediate aftermath of frequency decrease exceeded the operational range of -0.1 [Hz], in the most harsh case where PV output continued to decrease by 50%. There seems to be no problem other than F34 if Japanese islands' case where permissible deviation of frequency is ±0.3 [Hz], is taken into account. There seems to be no problem in case of F31… and F32… except for the case of F 33… or F34… where the frequency exceeds operational range of -0.1 [Hz], in terms of convergence value.

Thus capacity of power storage system and following capability seems to be well balanced when model with control characteristics of changeable time constant of 500 [kW]/60sec or 500 [kW]/40 sec are assumed.

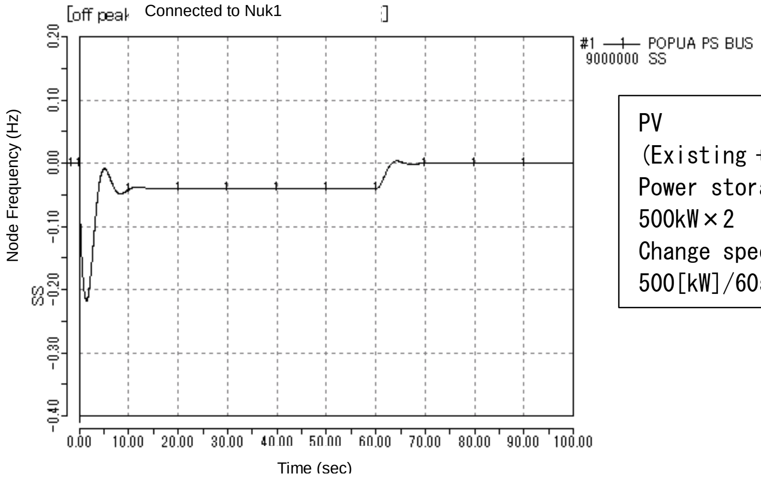
Hourly evaluation shall be described as follows

Consumption energy of power storage system in each case is listed in table 3.8. Half capacity of power storage system since total capacity of power storage system is 11 [kWh]. There seems to be no problem in terms of sufficiency of capacity, in each case even if half of the capacity is adopted for the analysis.

Table 3.8 Consumption electrical energy of power storage system in each case

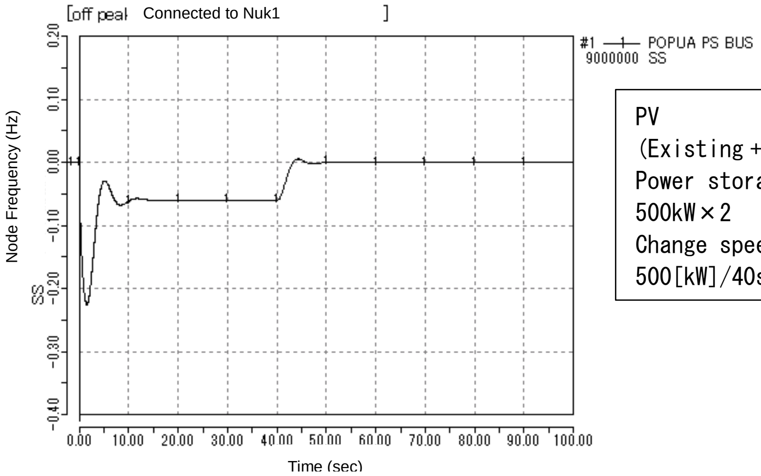
Cases	Consumption electrical energy of power storage system [kWh]
F31-V4-NUK1-OP-PV-50P10MS-D500-60S	4.167
F32-V4-NUK1-OP-PV-50P10MS-D500-40S	2.778
F33-V4-NUK1-OP-PV-50P10MS-D500-20S	1.389
F34-V4-NUK1-OP-PV-50P10MS-D500-10S	0.694

PV Rapid decrease
50%/10msec



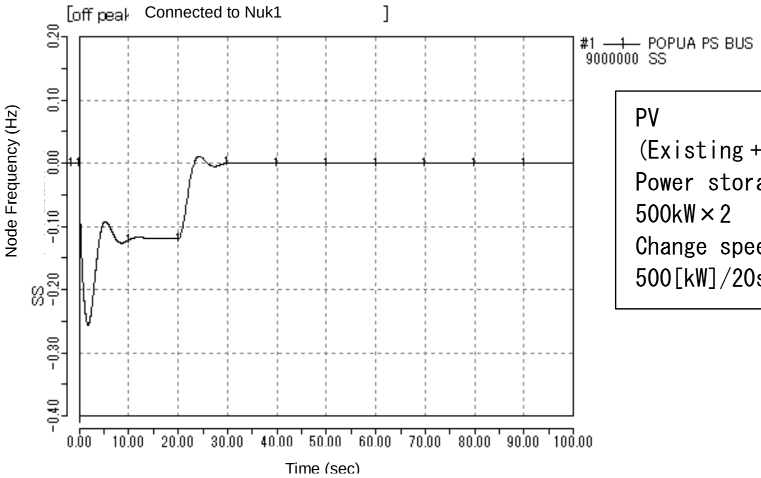
PV
(Existing + Newly Placed)
Power storage system
500kW×2
Change speed
500[kW]/60sec

PV Rapid decrease
50%/10msec



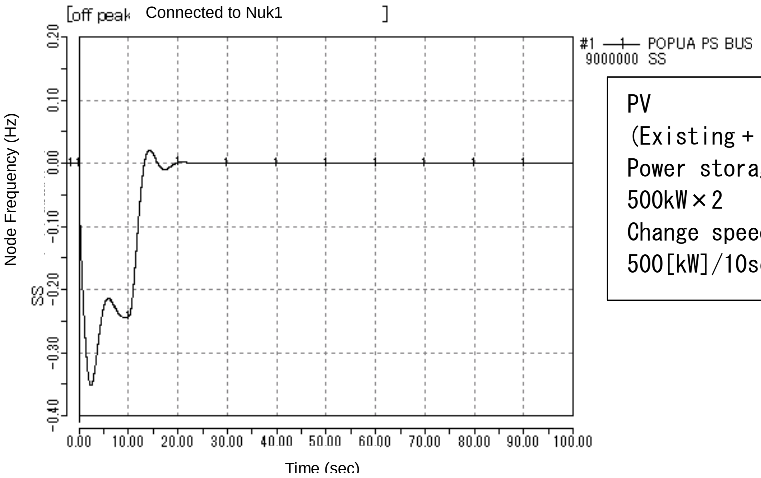
PV
(Existing + Newly Placed)
Power storage system
500kW×2
Change speed
500[kW]/40sec

PV Rapid decrease
50%/10msec



PV
(Existing + Newly Placed)
Power storage system
500kW×2
Change speed
500[kW]/20sec

PV Rapid decrease
50%/10msec

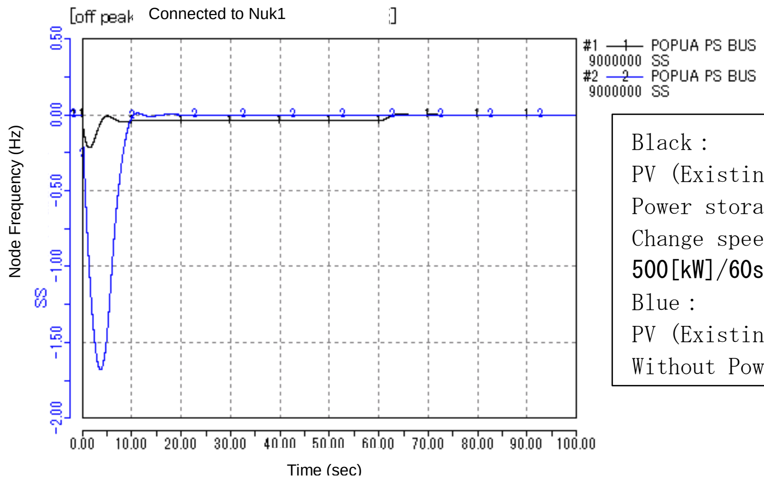


PV
(Existing + Newly Placed)
Power storage system
500kW×2
Change speed
500[kW]/10sec

Figure 3.8 Results of comparison of frequency subjected to change speed in case of little output from Power storage system
【PV Output 50%/10mse / Power storage system 500kW×2 / NUK1】

PV Rapid decrease

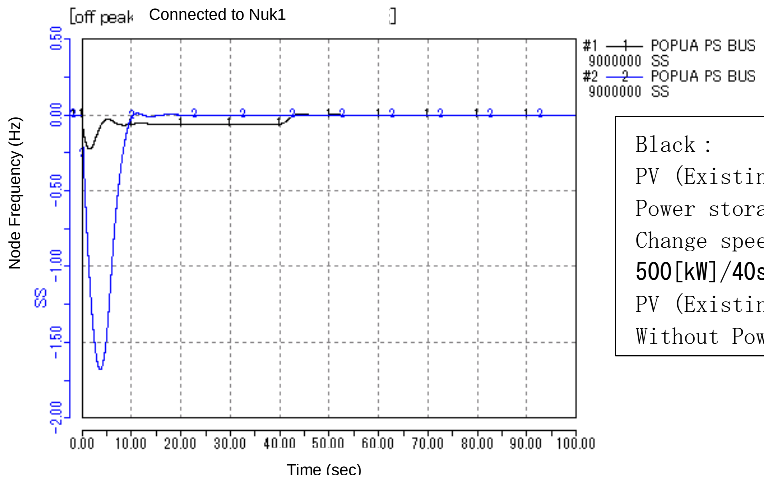
50%/10msec



Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Change speed
500[kW]/60sec
Blue :
PV (Existing)
Without Power storage system

PV Rapid decrease

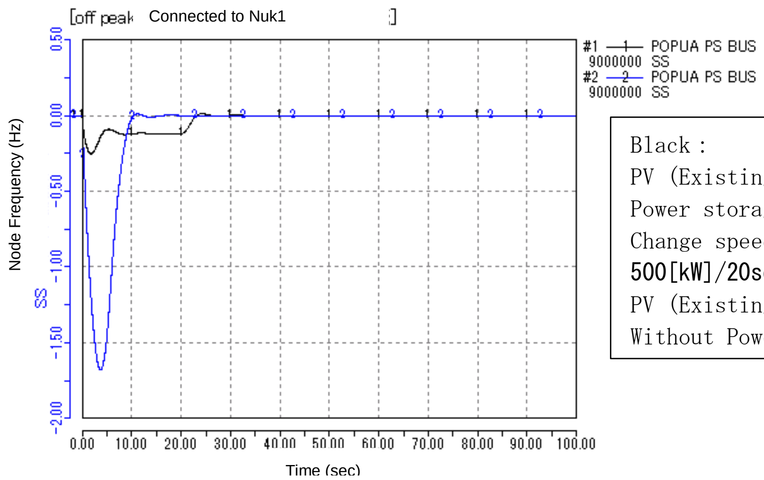
50%/10msec



Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Change speed
500[kW]/40sec
PV (Existing)
Without Power storage system

PV Rapid decrease

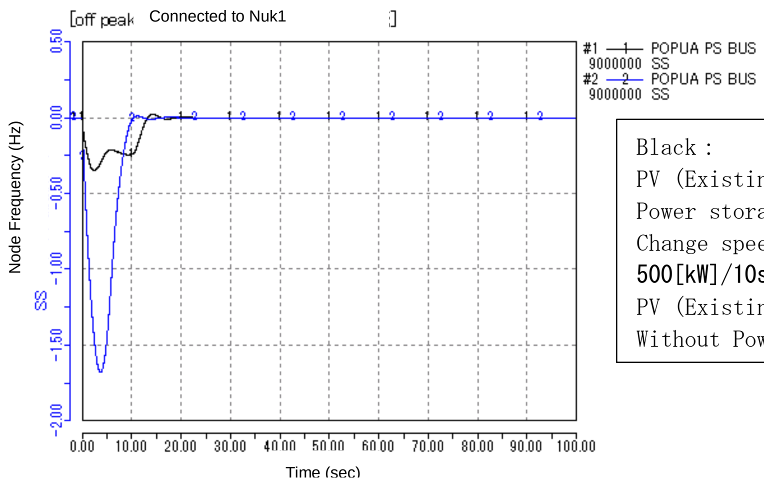
50%/10msec



Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Change speed
500[kW]/20sec
PV (Existing)
Without Power storage system

PV Rapid decrease

50%/10msec



Black :
PV (Existing + Newly placed)
Power storage device500kW×2
Change speed
500[kW]/10sec
PV (Existing)
Without Power storage system

Figure 3.9 Results of comparison of frequency subjected to change speed in case of little output from Power storage system (Together with comparison to Current parameter)
【PV Output 50%/10mse / Power storage system 500kW×2 / NUK1 Feeder】

3．4　Evaluation of the following capability in case of middle-speed diesel engine instead of high-speed diesel engine

(1)　Outline of Analysis

Replacement of DG from high-speed engine to middle-speed scheduled in 2013 was taken into account for the analysis.

① Profile of supply and demand

・Profile at off peak：load 3.521[MW]

・Connected to NUK1 feeder

② Generator model

・Generator model is listed in Table 3.9. High speed DG is also in the Table 3.9 for comparison.

Table 3.9　Generator model

Name	Mak	CAT
Rotation type	middle-speedDG	high-speed DG
Rated MVA	3.456	1.750
Rated MW	2.765	1.400
Parallel	2 units	3 units
inertial constant [sec]	3.94*1	7.00*2

*1 Results of survey are adopted for constant of synchronous generator of a few hundred kVA to a few MW.

*2 Calculated from Tongatapu Power Station Protection Coordination Review

③ Governor model

・Governor block：Refer to Figure 3.10 Governor block diagram

・GOV following speed (on load control) [parameter on load control obtained from field survey]

：increasing 1.8%/sec（standard parameter 3.6%/sec）,　decreasing 3.6%/sec

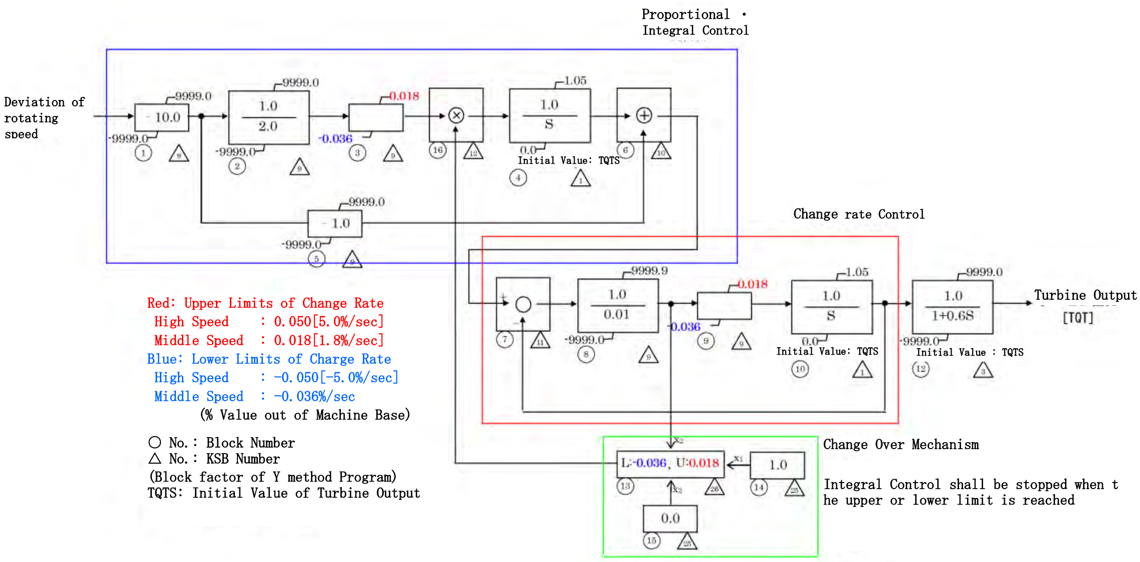


Figure3.10　Governor control block diagram of the established diesel generators

④ PV output (rapid decrease))

・Amount of change：50%（Newly placed ＋existing PV＝1150[kW]）

・Duration：10msec

⑤ Model for power storage system

・Capacity of converter for power storage system：Each Site 500 [kW]（Total 1000[kW]）

・Control characteristics of variable time constant after output of 500[kW]

：500[kW]/60sec,40sec,20sec　Total 3 pattern

(2) Analysis Cases

Analysis was conducted in 3 cases based on the condition (1) (the case of variable time constant with 10 sec was eliminated in the analysis, since it is difficult not only for middle speed DG for the analysis but also for high speed DG)

Table 3.10 Analysis cases for amount of fluctuation of frequency①

Cases	PV Output (Newly placed + existing)	Capacity for Converter	Variable time constant
F41-V4-NUK1-OP-MAKG-PV-50P10MS-D500-60S	50%/10msec ⇒1.15MW Rapid decrease	500kW	60sec
F42-V4-NUK1-OP-MAKG-PV-50P10MS-D500-40S			40sec
F43-V4-NUK1-OP-MAKG-PV-50P10MS-D500-20S			20sec

In addition to the cases above, following speed of DG was changed from 1.8%/sec to 3.6%/sec for referential analysis case.

Table 3.11 Analysis cases for amount of fluctuation of frequency①

Cases	PV Output (Newly placed + existing)	Capacity for Converter	Variable time constant
F44-V4-NUK1-OP-MAKG-PV-50P10MS-D500-GOVC36-60S	50%/10msec ⇒1.15MW Rapid decrease	500kW	60sec

(3) Results of analysis

Read values of frequency are plotted in Figure 3.11.

Table 3.12 shows bottom frequency value and convergence value after fluctuation for each case, Figure 3.12 and 3.13 shows figures of frequency for each case.

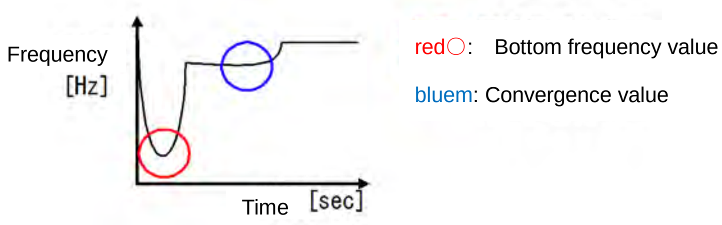


Figure 3.11 Read values for frequency

Table 3.12 Bottom frequency value and convergence value after fluctuation for each case

Cases	Bottom Frequency Value [Hz]	Time [sec]	Convergence value after fluctuation of frequency [Hz]
F41-V4-NUK1-OP-MAKG-PV-50P10MS-D500-60S	-0.47(-0.22)	2.50	-0.03(-0.04)
F42-V4-NUK1-OP-MAKG-PV-50P10MS-D500-40S	-0.51(-0.23)	2.74	-0.05(-0.06)
F43-V4-NUK1-OP-MAKG-PV-50P10MS-D500-20S	-0.73(-0.26)	4.02	-0.09(-0.12)
F44-V4-NUK1-OP-MAKG-PV-50P10MS-D500-GOVC36-60S	-0.30	1.41	-0.03

*In () is the case with high speed-DG in the same condition

○Results of control of variable time constant 500[kW]/60sec(8.33[kW]/sec)

The bottom frequency becomes -0.47[Hz] because of decrease of PV output. Fluctuation of frequency becomes approximately -0.03[Hz] in 10 sec since range of power storage system and range of DG output becomes well balanced. Frequency fluctuates because the governor follows again in 60 seconds, since output of power storage system runs out. And frequency becomes approximately 0.00[Hz] again after range of output becomes the same.

Difference in the result of analysis between high speed DG and middle speed DG is described as follows.

7 seconds are adopted as inertial constant in case of High speed DG and 3.94 are adopted in case of middle speed DG. In case of rapid decrease of PV output, the bottom frequency is largely influenced by inertia constant or parallel number. Thus, the bottom frequency becomes less in case of middle speed DG where inertia is large and parallel number is less. Concerning to the convergence frequency, the range of fluctuation of output of power storage system and the range of fluctuation of output of governor shall be balanced when fluctuation of frequency becomes stabled, since 100[kW]/sec (1.8%/sec for 2 parallels), the following speed of middle speed DG is slow compared to 210[kW]/sec (5%/sec for 3 parallels), the following speed of high speed DG, and

middle speed DG follows slowly. Thus, less frequency decreases in case of middle speed DG than in case of high speed DG.

〇Results of the analysis of variable time constant control　500[kW]/40sec(12.5[kW]/sec),
Variable time constant control　500[kW]/20sec(25.0[kW]/sec)
Behaviors in case of 40 sec and for 20 sec are the same as in case of 60 sec.

(4)　Conclusion

〇Results of analysis

・In the most severe case, where PV output decrease at the rate of 50 %, the frequency exceeded allowable frequency deviation of island area, ±3%[Hz] in case of middle speed DG. However, severe case of 1.8%/sec was adopted for the analysis and the bottom frequency became -0.3 [Hz] with the standard parameter of 3.6%/sec (referential case).

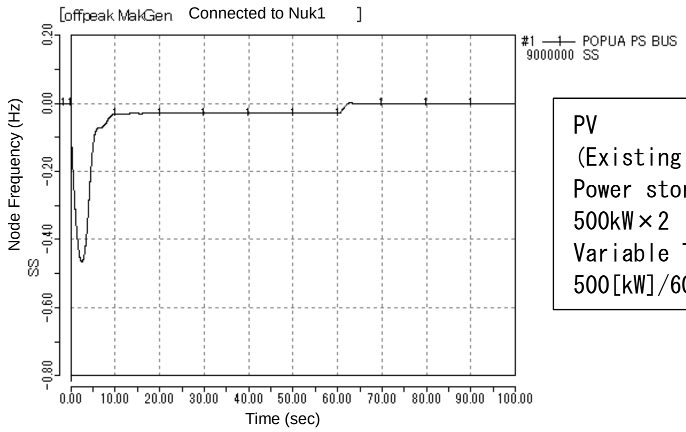
・It is assumed that the frequency shall be valid when the following speed of governor of constant rotation speed control shall be adopted, since, in the analysis, the following speed of governor of constant rotation was adopted for middle speed DG. Any case is assumed and measurement value of field test such as load dump test shall be used for simulation for both middle speed DG and high speed DG.

・The bottom value of frequency can be improved by increasing parallel number of generators, the sum of rated output. It shall be kept in mind that reserved capacity from parallel numbers compensates not only effective electric power but also frequency.

〇Hourly evaluation of middle speed DG

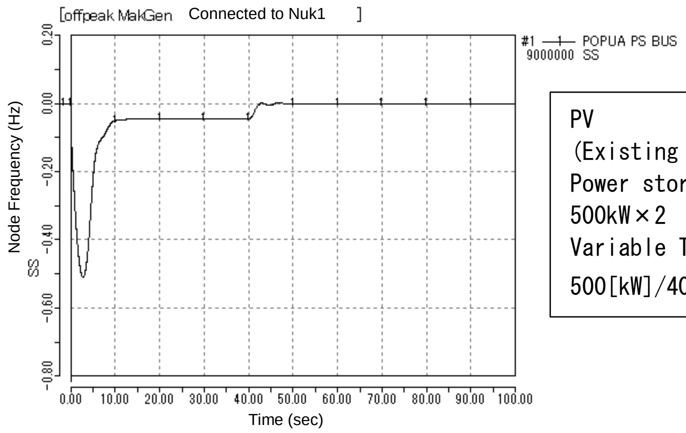
・It is deemed that enough capacity can be saved in each case since variable time constant control are the same for high speed DG and for model for power storage system. (They are calculated from integrated value without loss value.)

PV output
Rapid decrease
50%/10msec



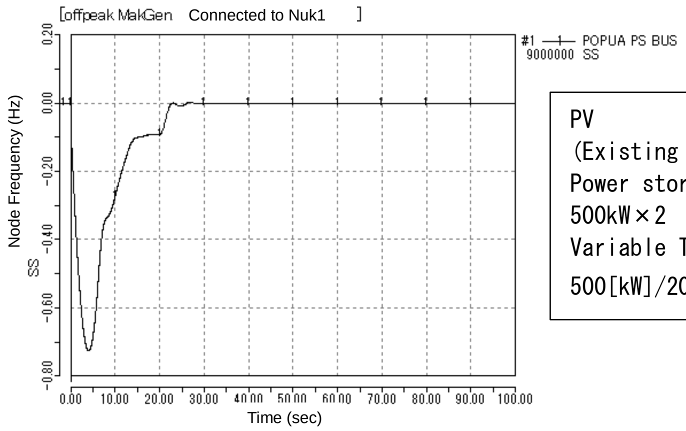
PV
(Existing + Newly Placed)
Power storage system
500kW×2
Variable Time Constant
500[kW]/60sec

PV output
Rapid decrease
50%/10msec



PV
(Existing + Newly Placed)
Power storage system
500kW×2
Variable Time Constant
500[kW]/40sec

PV output
Rapid decrease
50%/10msec

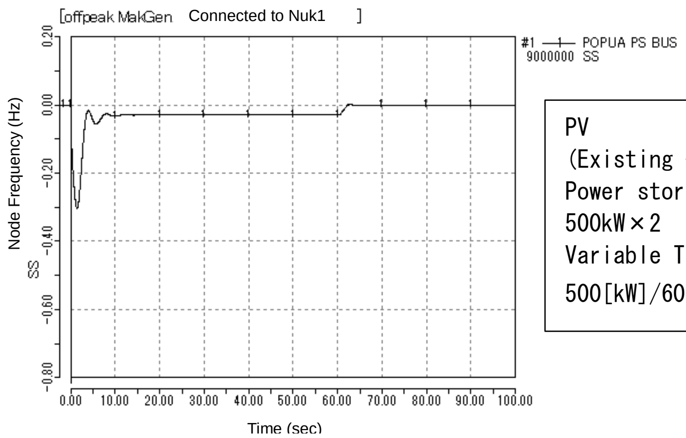


PV
(Existing + Newly Placed)
Power storage system
500kW×2
Variable Time Constant
500[kW]/20sec

Figure 3.12 Results of comparison of frequency in case of little output from Power storage system

【PV Output 50%/10msec / Power storage system500kW×2 / NUK1 Feeder / Mak 2 parallel】

PV output
Rapid decrease
50%/10msec



PV
(Existing + Newly Placed)
Power storage system
500kW×2
Variable Time Constant
500[kW]/60sec

Figure 3.13 Referential case

【PV Output 50%/10mse/Power storage system 500kW×2/NUK1 Feeder/Mak 2 parallel/Limit of change rate in rising:3.6%/sec】