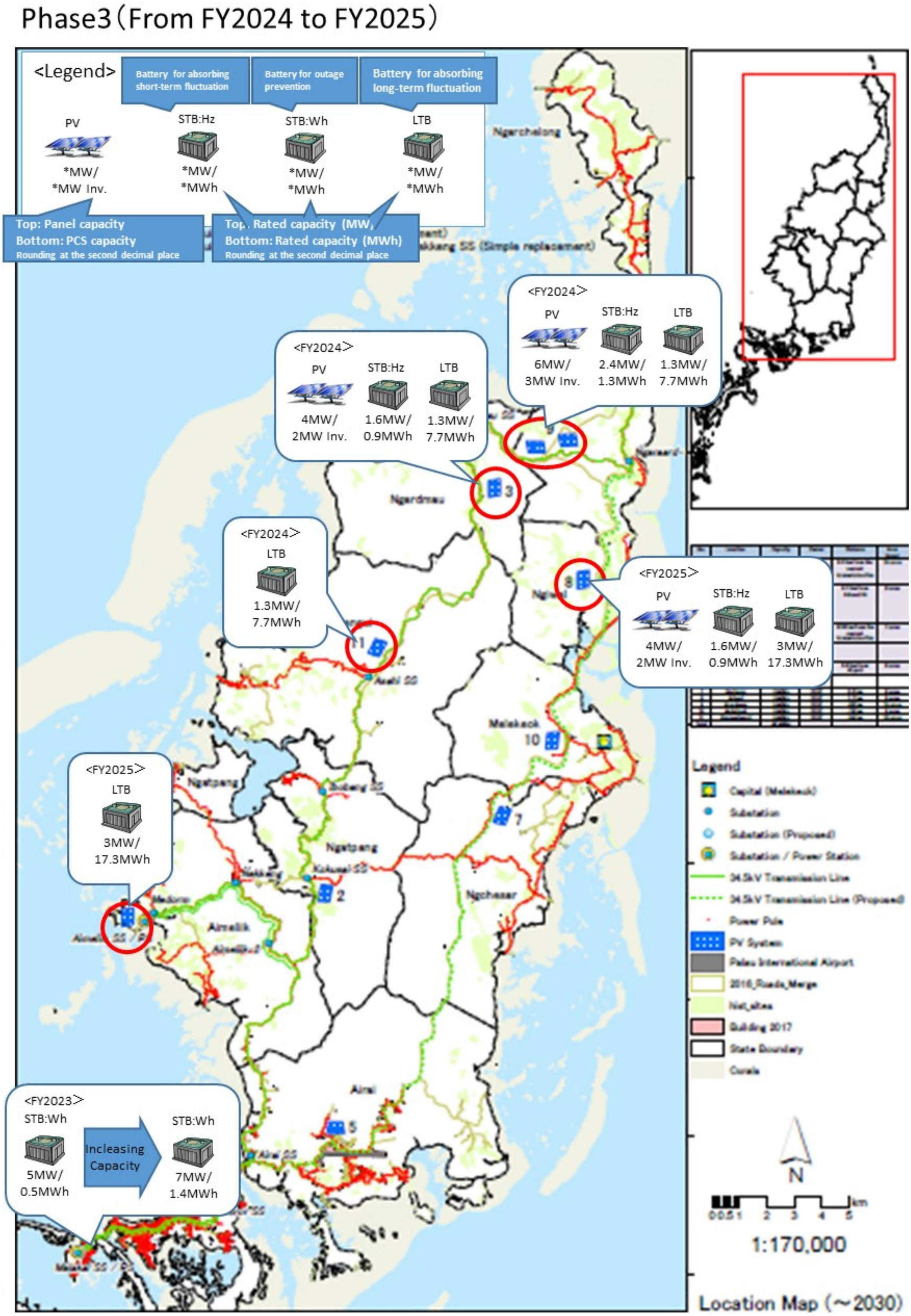
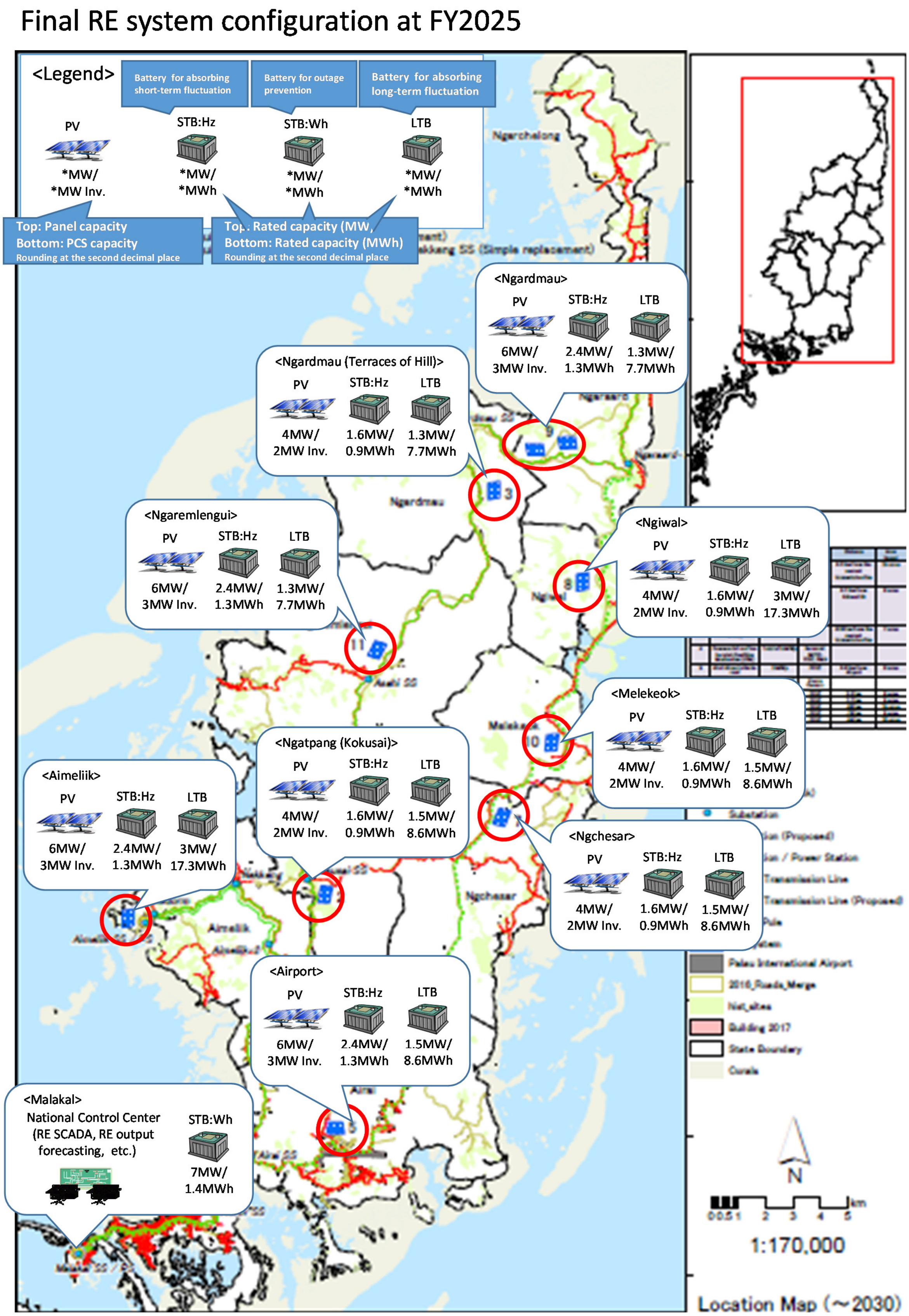



Source: Created by the Survey Team

**Figure 5-2-3-2.3 RE equipment installation steps in Phase 3 (2021–2025)**




Source: Created by the Survey Team

**Figure 5-2-3-2.4 Final form of RE equipment installation as of 2025**

#### 5-2-3-3 RE system introduction cost

The estimated costs of each phase were calculated for the RE system configuration shown in Table 5-2-3-2.1. The unit price is the same as those shown in the "Palau Energy Roadmap Draft for Discussion February 2017" presented to PPUC by IRENA. Each unit price includes all material costs and construction costs necessary for starting power generation, but not the operation and maintenance cost, shipping cost, or cost of land or land acquisition.

For reference, the "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017" from NREL reported that the unit price of PV was 1.34 USD/Wac for a fixed-tilt utility-scale PV system as of 2017. "ELECTRICITY STORAGE AND RENEWABLES: COSTS AND MARKETS TO 2030" from IRENA reported that the unit price for Li-ion batteries was 350 – 420 USD/kWh as of 2016.

**Table 5-2-3-3.1 RE introduction cost by phase**

| | | Unit Price | | Phase1 | Phase2 | Phase3 | Total |
|---|---|---|---|---|---|---|---|
| PV system | Module, PCS, etc… | 1,500 | USD/kW | 24,000,000 | 21,000,000 | 21,000,000 | 66,000,000 |
| (PV station) | T/L to the Grid | 20,000 | USD/site | 60,000 | 60,000 | 60,000 | 180,000 |
| Battery system | Battery | 350 | USD/kWh | | 12,075,000 | 20,125,000 | 32,200,000 |
| (Against long-term fluctuation) | PCS | 150 | USD/kW | | 900,000 | 1,500,000 | 2,400,000 |
| Battery system | Battery | 350 | USD/kWh | 1,225,000 | 2,100,000 | 3,500,000 | 6,825,000 |
| (Against short-term fluctuation) | PCS | 150 | USD/kW | 525,000 | 450,000 | 435,000 | 1,410,000 |
| Battery system | Battery | 350 | USD/kWh | 175,000 | 315,000 | | 490,000 |
| (Against power outate) | PCS | 150 | USD/kW | 75,000 | 135,000 | | 210,000 |
| | | | Total | 26,060,000 | 37,035,000 | 46,620,000 | 109,715,000 |

Source: Created by the Survey Team

The costs of the REMS and RE Power Generation Forecast System necessary for monitoring control of these RE systems are shown in Table 5-2-3-3.2.

**Table 5-2-3-3.2 Costs of REMS and the RE Power Generation Forecast System**

USD

| | | Phase1 (2019-2020) | Phase2 (2021-2023) | Phase3 (2024-2025) | Total | |
|---|---|---|---|---|---|---|
| RE Management System | Master system | 270,000 | 270,000 | 270,000 | 810,000 | Install:270kUSD Additional Slave::90kUSD/Unit |
| | Slave system | 450,000 | 450,000 | 450,000 | 1,350,000 | Install:150USD/Unit |
| | Subtotal | 720,000 | 720,000 | 720,000 | 2,160,000 | |
| RE Forecast | System | 160,000 | 0 | 0 | 160,000 | |
| | O&M (Data maintenance, etc.) | 45,000 | 135,000 | 90,000 | 270,000 | 45kUSD/Year |
| | Subtotal | 205,000 | 135,000 | 90,000 | 430,000 | |
| Total | | 925,000 | 855,000 | 810,000 | 2,590,000 | |

Source: Created by the Survey Team

<Reference> PV-WT system cost for 2025

As stated in Clause 5-2-4-1, PPUC has decided not to introduce WT in this project. However, Table 5-2-3-3.3 and Table 5-2-3-3.4 respectively show the equipment configuration to be adopted and the costs incurred in the case WT is introduced. The number of DEGs for operation and other conditions to review are the same as in the RE system reviews performed so far. The WT conditions are summarized below. In this case:

- ✓ The WT to be introduced in the simulation should be a Vergnet's 275 kW type, a system installed in many island countries.
- ✓ The WT power generation is calculated by limiting the output to 70% of the rated capacity to reduce impact on the wind turbines and then multiplying it by 60% of the actual operation ratio in surrounding island countries.
- ✓ The number of WT units to be introduced is set to a value not requiring short- and long-term batteries, so as to assume a minimum-cost case.

**Table 5-2-3-3.3 PV-WT system configuration for 2025 (reference)**

| | | 2025 |
|---|---|---|
| PV | Module (kW) | 36,000 |
| | Inverter (kW) | 18,000 |
| WT | Turbine(kW) | 8,250 |
| | Inverter (kW) | 5,775 |
| Short-Term Battery against fluctuation | Battery (kW) | 36,000 |
| | Battery (kWh) | 18,000 |
| | Inverter (kW) | 36,000 |
| Short-Term Battery against power outage | Battery (kW) | 5,000 |
| | Battery (kWh) | 2,000 |
| | Inverter (kW) | 5,000 |
| Long-Term Battery | Battery (kW) | 36,000 |
| | Battery (kWh) | 100,000 |
| | Inverter (kW) | 36,000 |

Source: Created by the Survey Team

**Table 5-2-3-3.4 PV-WT system introduction cost for 2025 (reference)**

USD

| | | Total | Unit Price | |
|---|---|---|---|---|
| PV | Module, Inverter, etc...(kW) | 54,000,000 | 1,500 | |
| | T/L to the Grid | 1,800,000 | 200,000 | |
| WT | Tubine, Inverter, etc...(kW) | 22,497,750 | 2,727 | 750kUSD/Unit |
| | T/L to the Grid | 200,000 | 200,000 | |
| Short-term | Battery against fluct. (kWh) | 6,300,000 | 350 | |
| | Inverter against fluct. (kW) | 5,400,000 | 150 | |
| | Battery against outage. (kWh) | 490,000 | 350 | |
| | Inverter against outage (kW) | 1,050,000 | 150 | |
| Long-term | Battery (kWh) | 35,000,000 | 350 | |
| | Inverter (kW) | 5,400,000 | 150 | |
| Total | | 132,137,750 | | |

Source: Created by the Survey Team

### 5-2-3-4 Solutions for reducing the cost of the battery system introduction

The RE systems in this roadmap have been designed to achieve the 45%REtarget@2025 while taking the requirements for stable power supply into account. The systems have also been designed in consideration of PPUC's O&M capacity and manpower. The battery system configuration therefore has some redundancy, and accordingly may be expensive. This section suggests solutions for reducing the cost of the battery system introduction. While there are many solutions for cost reduction, this section focuses on two that could reduce costs drastically. Each of the two solutions has advantages and disadvantages. PPUC should carefully consider which of the solutions (including the system recommended in this roadmap) is good for Palau before introducing the RE system.

**1) Introducing lead-acid batteries**

Lead-acid batteries are popular for industrial application and cheaper than Li-ion batteries. Introducing lead-acid batteries will help reduce the cost of battery introduction. The input/output characteristic of lead-acid batteries is lower than that of Li-ion batteryes, and lead-acid batteries are unsuitable as a countermeasure against short-term fluctuation. The recommended approach is therefore to combine lead-acid batteries with a Li-ion battery system by the method used in the demonstration test of the New Energy and Industrial Technology Development Organization (NEDO) in Izu Oshima Island from 2015 to 2019. Lead-acid batteries need more space compared with Li-ion batteries due to the former's lower energy density.

Table 5-2-3-4.1 shows the case of lead-acid battery introduction as a short- and long-term fluctuation mitigation measure. Table 5-2-3-4.2 shows the case of lead-acid battery introduction as a long-term fluctuation mitigation measure.

As reference, "ELECTRICITY STORAGE AND RENEWABLES: COSTS AND MARKETS TO 2030" from IRENA reported that the unit price of the lead-acid battery was around 147 – 263 USD/kWh as of 2016.

**Table 5-2-3-4.1 Case of lead-acid battery introduction as a short- and long-term fluctuation mitigation measure**

| | | Unit Price | | Phase1 | Phase2 | Phase3 | Total |
|---|---|---|---|---|---|---|---|
| PV system | Module, PCS, etc··· | 1,500 | USD/kW | 24,000,000 | 21,000,000 | 21,000,000 | 66,000,000 |
| (PV station) | T/L to the Grid | 20,000 | USD/site | 60,000 | 60,000 | 60,000 | 180,000 |
| Battery system | Battery | 350 | USD/kWh | | 6,037,500 | 10,062,500 | 16,100,000 |
| (Against long-term fluctuation) | PCS | 150 | USD/kW | | 900,000 | 1,500,000 | 2,400,000 |
| Battery system | Battery | 350 | USD/kWh | 612,500 | 1,050,000 | 1,750,000 | 3,412,500 |
| (Against short-term fluctuation) | PCS | 150 | USD/kW | 525,000 | 450,000 | 435,000 | 1,410,000 |
| Battery system | Battery | 350 | USD/kWh | 87,500 | 157,500 | | 245,000 |
| (Against power outate) | PCS | 150 | USD/kW | 75,000 | 135,000 | | 210,000 |
| | | | Total | 25,360,000 | 29,790,000 | 34,807,500 | 89,957,500 |

**Table 5-2-3-4.2 Case of lead-acid battery introduction as a long-term fluctuation mitigation measure**

| | | Unit Price | | Phase1 | Phase2 | Phase3 | Total |
|---|---|---|---|---|---|---|---|
| PV system | Module, PCS, etc… | 1,500 | USD/kW | 24,000,000 | 21,000,000 | 21,000,000 | 66,000,000 |
| (PV station) | T/L to the Grid | 20,000 | USD/site | 60,000 | 60,000 | 60,000 | 180,000 |
| Battery system | Battery | 350 | USD/kWh | | 6,037,500 | 10,062,500 | 16,100,000 |
| (Against long-term fluctuation) | PCS | 150 | USD/kW | | 900,000 | 1,500,000 | 2,400,000 |
| Battery system | Battery | 350 | USD/kWh | 1,225,000 | 2,100,000 | 3,500,000 | 6,825,000 |
| (Against short-term fluctuation) | PCS | 150 | USD/kW | 525,000 | 450,000 | 435,000 | 1,410,000 |
| Battery system | Battery | 350 | USD/kWh | 175,000 | 315,000 | | 490,000 |
| (Against power outate) | PCS | 150 | USD/kW | 75,000 | 135,000 | | 210,000 |
| | | | Total | 26,060,000 | 30,997,500 | 36,557,500 | 93,615,000 |

### 2) Integration of battery allocation

In this roadmap, the introduction of Li-ion batteries for the short-term and long-term was assumed at each PV site to control the PV output fluctuation. The integration of these batteries into one or several sites will contribute to cost reduction, as the power-switching facilities and battery-control facilities could be shared. Integrating battery allocation also has disadvantages, however, such as deteriorating flexibility of power source operation and the possibility of a large-scale of loss power in the event of a power switching facility breakdown. These disadvantages will be considered.

## 5-2-4 Suggestions

### (1) Operation and maintenance

PPUC could not maintain and operate the RE system shown in Table 5-2-4.1 appropriately. Technology transfer only through training programs is not enough. Operation and maintenance staff should be increased in line with the setting up of the Load Dispatching Center in 2020. The control center operation staff must consist of two persons per team. If the work schedule of the control center is divided into two time shifts per day over a five-day work week, the minimum number of staff required will be 10 persons in total.

**Table 5-2-4.1 Example of a working schedule in a Japanese control center**

Work in shifts,

Shift 1: 08:00 – 17:10

Shift 2: 17:00 – 22:10

Shift 3: 22:00 – 09:10

ref. standard working hour is 08:50 – 17:30

EX. A certain staff's shift work

| | |
|---|---|
| Monday | Shift1 |
| Tuesday | Shift2 + Shift3 |
| Wednesday | |
| Thursday | Shift1 |
| Friday | Shift2 + Shift3 |
| Saturday | |
| Sunday | Day off |
| Monday | Day off |

### (2) Load shifting/creation

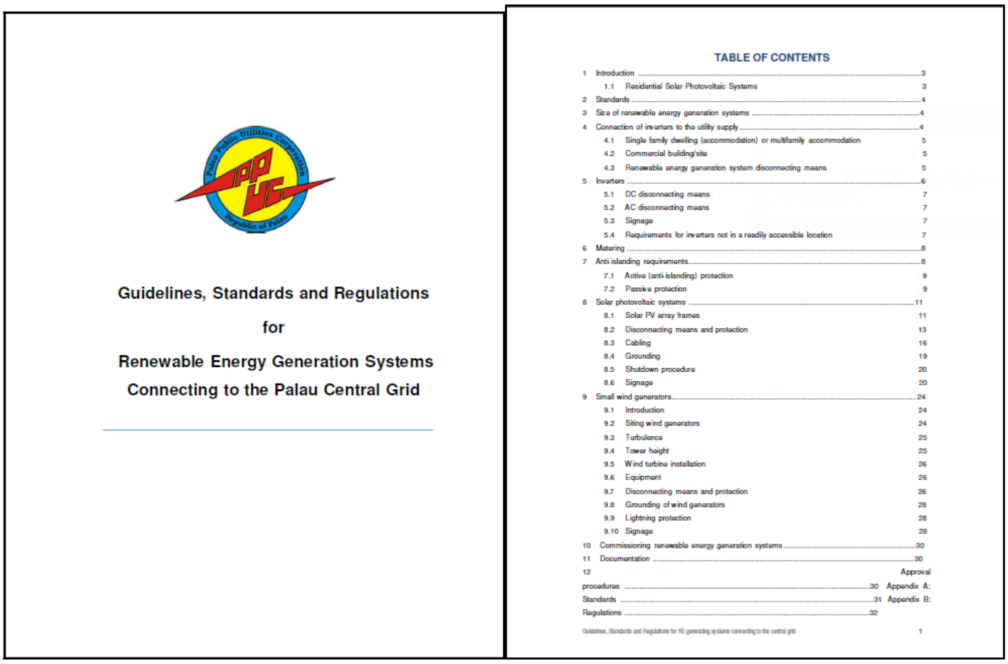
Tourism is the main industry in Palau, and hot water used in hotels and other places is heated with electricity. The greater part of the hot water demand may fall between 18:00 and 21:00. Shifting the load to daytime, or PV power generation time, may reduce the long-term battery capacity requirement. Using a storage-type electric water heater will contribute to demand shifting by storing the hot water in a thermos tank and using the stored hot water at night peak. The Palau government should consider offering incentives to hotels, such as a system to introduce reduced electricity tariffs during off-peak hours. The Palau government is promoting energy-saving measures, including a public relations drive to promote the switchover to LED lights, but they should also proactively work on load shifting and the creation of new load.

### (3) Addition of new / improvement of existing DEG

Considering that power demand will exceed 15 MW after 2023, all four main 5 MW DEGs need to be operated. Therefore, in order as a countermeasure for breakdown or maintenance of a 5 MW DEG during opration, PPUC should closely examine operation rotation by installing more DEGs or using existing DEGs. Given that such a measure, combined with other improvements in system frequency characteristics, etc., could reduce the cost of introducing batteries against short-term fluctuations, DEG rotation with the proactive use of high-speed DEG is recommended for consideration. Improvement of the DEG governor's permanent speed variation or change from a mechanical governor control method to an electrical one can improve system frequency characteristics and thereby reduce the capacity of the batteries against short-term fluctuation. We recommend making these improvements on the existing DEGs in advance of RE system construction and then measuring the system constants by conducting interruption tests to determine the capacity of the batteries against short-term fluctuation.

### (4) Guidelines, Standards, and Regulations for RE Power Sources Connected to the Grid

1) PPUC has a set of "Guidelines, Standards, and Regulations for RE Power Sources Connected to the Grid" (see Figure 5-2-4.1), but the guidelines are only for low-voltage interconnection. PPUC should establish guidelines for high-voltage interconnection immediately. The interconnection of all PV sites in this roadmap is high voltage, and the Palau government has a plan to utilize IPP as a power source.



Guidelines, Standards and Regulations

for

Renewable Energy Generation Systems

Connecting to the Palau Central Grid

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Guidelines, Standards and Regulations for RE generating systems connecting to the central grid 1

**Figure 5-2-4.1 PPUC's Guidelines, Standards, and Regulations for RE Generation Systems Connected to the Palau Central Grid**

In case of the large deployment of PVs and WTs, there will be big impact on the power supply quality if these power source become parallel-off from a system simultaneously when the system voltage drops instantaneously. A fault ride-through function should be applied to the guidelines to prevent RE power sources from becoming parallel-off from a system simultaneously when the system voltage drops instantaneously.

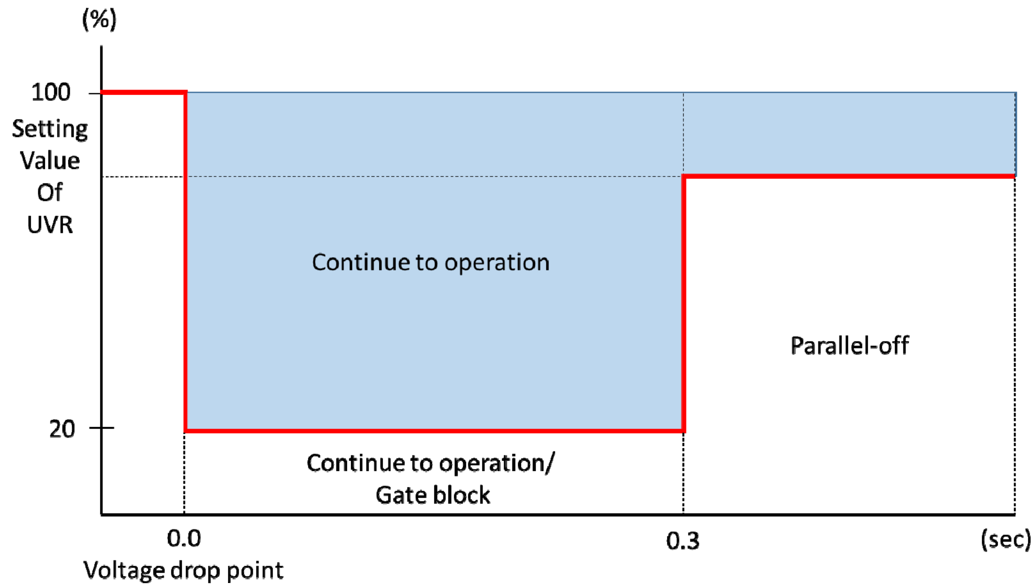



**Figure 5-2-4.2 Fault ride-through regulation for PV (example of voltage-dropping)**

2) Section 5-2-1-4 suggests that the smoothing effect might reduce the fluctuations caused by RE energy source. Therefore, it is recommended to verify and confirm how the amount of the fluctuation can be reduced by the smoothing effect in Palau (see Fig. 5-2-4.3). PPUC should also manage the amount of

PV to be penetrated and consider countermeasures (beyond requiring customers to install a battery, etc.) when the fluctuation exceeds an allowable level.

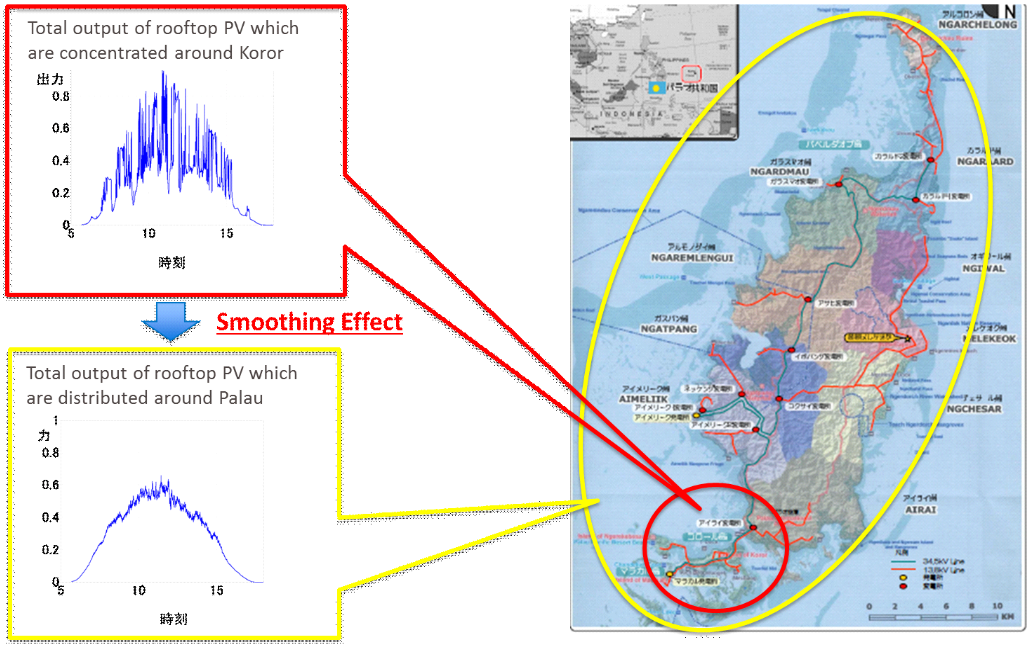



**Figure 5-2-4.3 Image of smoothing-effect in Palau**

### (5) IPP introduction

The Palau government is said to have its sights set on achieving the RE45%target@2025 through IPP introduction. Meanwhile, from the viewpoint of stable power supply, the following items should be considered carefully.

- Clarification of responsibility in power supply (formulation of a supply plan, supply-demand adjustment, cooperation in emergency, etc.)
- Clarification of the cost burden (equipment necessary for power supply, responsibility demarcation point, etc.)
- Establishment of detailed rules for power supply (procedures for connection/parallel-off with power station systems, etc.)

### 5-2-5 Technology transfer

The influence on the power system caused by the penetration of abundant RE sources to the grid and the solar radiation forecasting method have been explained in a technology transfer class. The technical transfer focused on promoting an understanding of the basic method for estimating the capacity of PV and the battery systems neccesary for achieving a 45% RE ratio by 2025, mainly through tasks and exercises.

## 5-3 Formulation of a power system plan

### 5-3-1 Basic policy

In this project, a power system master plan targeting the year 2030 will be formulated in consideration of economic efficiency, adequacy, reliability, etc. The practical and most appropriate power system should be designed in consideration of the following items:

(1) Formulation of a plan integrating power sources and power systems from a long-term point of view
(2) Power supply reliability in conformity with the national development plan
(3) Economic efficiency through cost reduction
(4) Proper use of existing facilities
(5) Efficient use of renewable energy
(6) Natural environmental considerations

### 5-3-2 Flow chart of the plan formulation

Figure 5-3-2.1 shows the flow chart of the power system analysis. The detailed procedures are as follows:

#### (1) Acquisition of PPUC's basic policy on the formulation of the power plan

Before starting the analysis, facility planning criteria will be obtained as the basis for the planning. If no such document exists, the adequate supply reliability will be determined through discussions with PPUC. Accordingly, the allowable current capacity of transmission lines, the rated capacity of transformers, allowable fault current, etc. will be acquired.

#### (2) Acquisition of data on the existing and future system

Data on the existing and future facilities, including generator ratings, substation loads (including power factors), transmission line lengths, conductor types, substation equipment compositions, etc., will be confirmed.

#### (3) Acquisition and preparation of digital data for system analysis

The analysis data obtained from PPUC will be modified if necessary before the construction of the analysis data. If PPUC has not conducted a power system analysis and accordingly lacks data, digital data necessary for the power system analysis will be built up using power system diagrams, facilities lists, power flow diagrams, etc.

**(4) Power flow analysis**

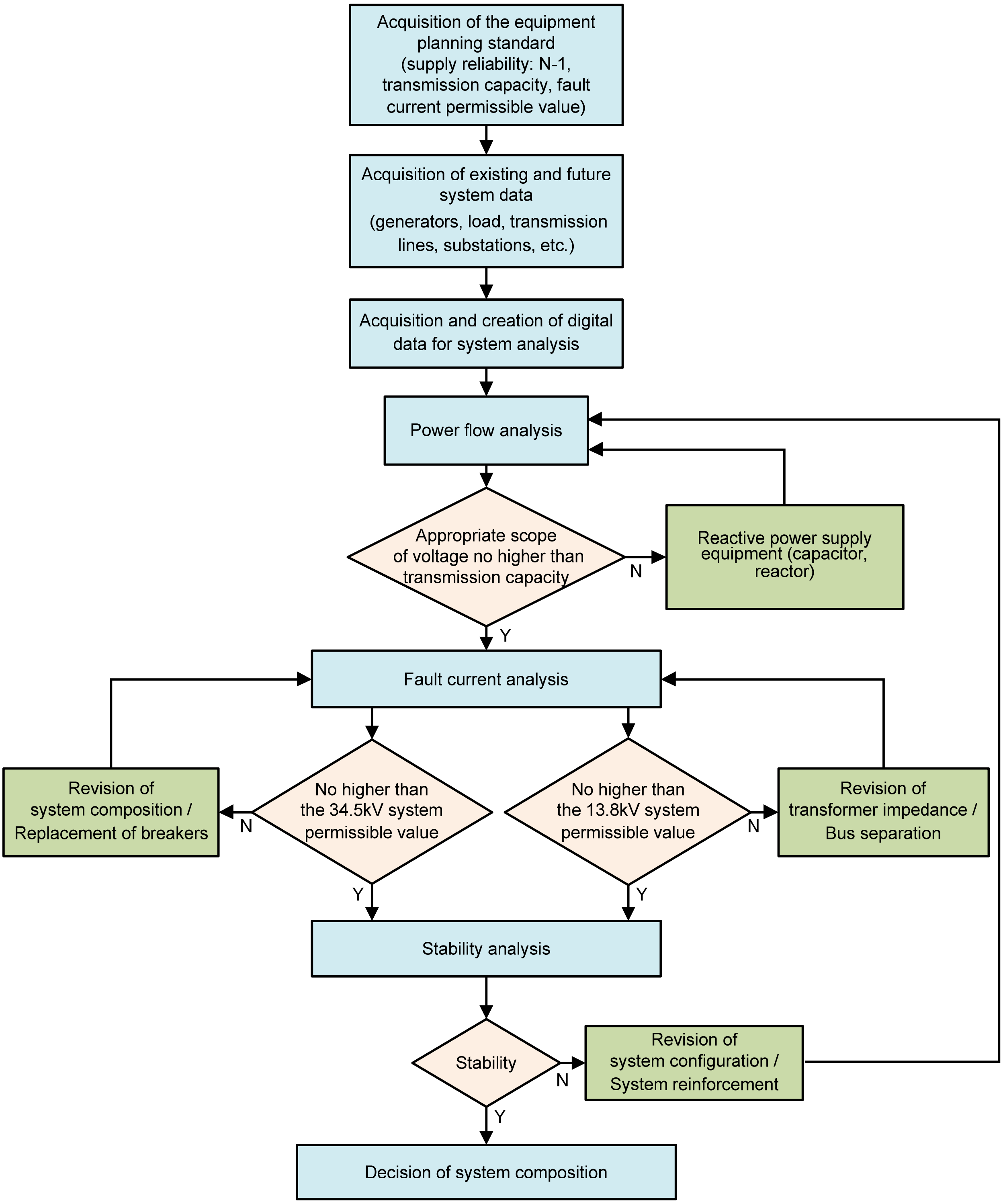
The power flow analysis will be performed with power system analysis software using the data built up for the existing system. The analysis will target two cases: one assuming that all of equipment is in good working condition and one assuming the major equipment is faulty. The analysis will determine whether overload will occur and whether appropriate voltage is sustained in each case. Finally, the status on compliance with power supply reliability and any other newly arising issues will be checked. If overload occurs, changes to the power system configuration and extension of the system will be proposed. If appropriate voltage is not maintained, the installation of reactive power supply equipment (power capacitor, reactor) may be examined, as well.

**(5) Fault current analysis**

A fault current analysis will be performed to confirm that the fault current does not exceed the circuit breaker ratings. If it does exceed the ratings, necessary countermeasures such as changes to the system composition or the replacement of circuit breakers, etc. will be examined.

**(6) Stability analysis**

A stability analysis will be implemented to confirm if the power system stability is maintained in compliance with the power supply reliability standard after the removal of system faults. If the results are shown to be unstable, countermeasures such as extension of the power system and changes to the power system configuration (e.g., a change to larger conductor sizes) will be studied. As the power output of renewable energy fluctuates greatly, the influences on the power system will be analyzed carefully to examine the necessary power output stabilization measures such as the installation of batteries.




Source: JICA Project Team

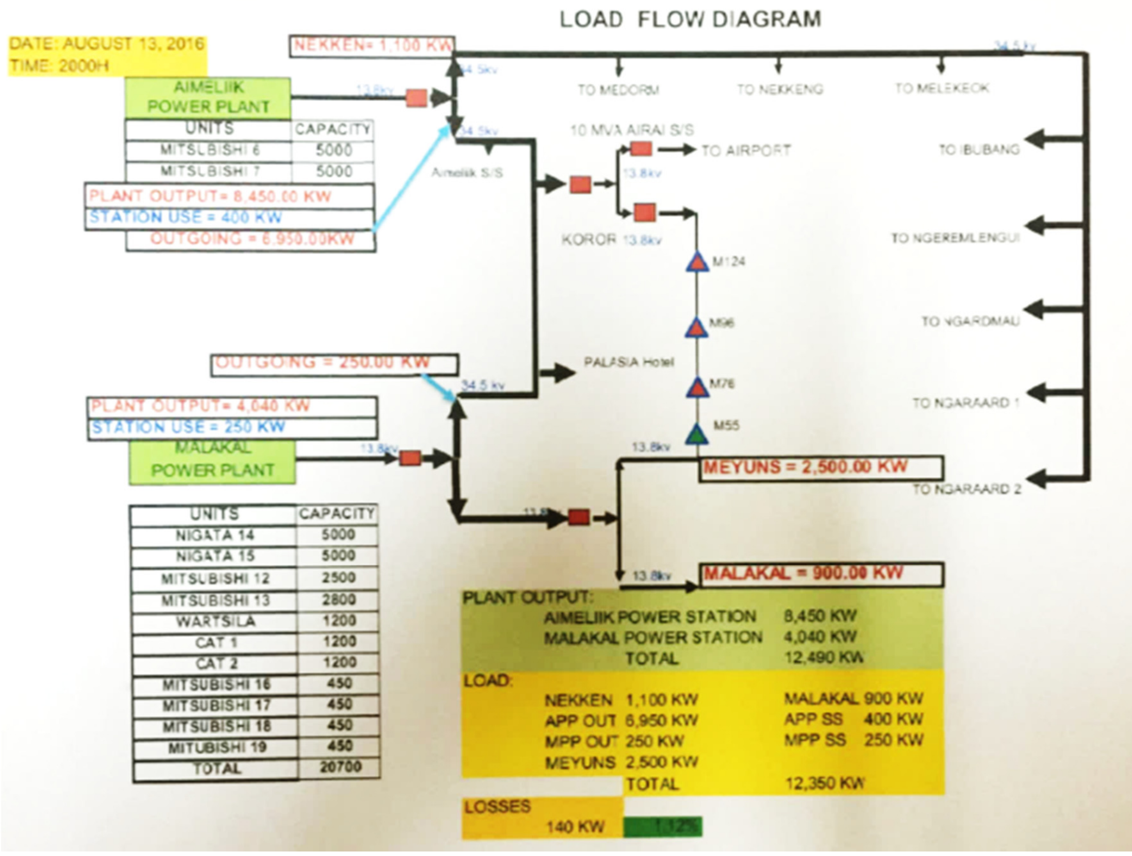
**Figure 5-3-2.1 System analysis flow**

## 5-4 Proposed power system analysis

### 5-4-1 Present power system

#### (1) Voltage and power flow

Figure 5-4-1.1 shows the actual power flow on the 13th of August, 2016, when the system power peak was recorded. The total power demand was 12.35 MW. Aimeliik Power Station supplied 8.45 MW and Malakal Power Station supplied 4.04 MW, accounting for 12.49 MW in total. The transmission loss was 0.14 MW and the loss factor was 1.12%.



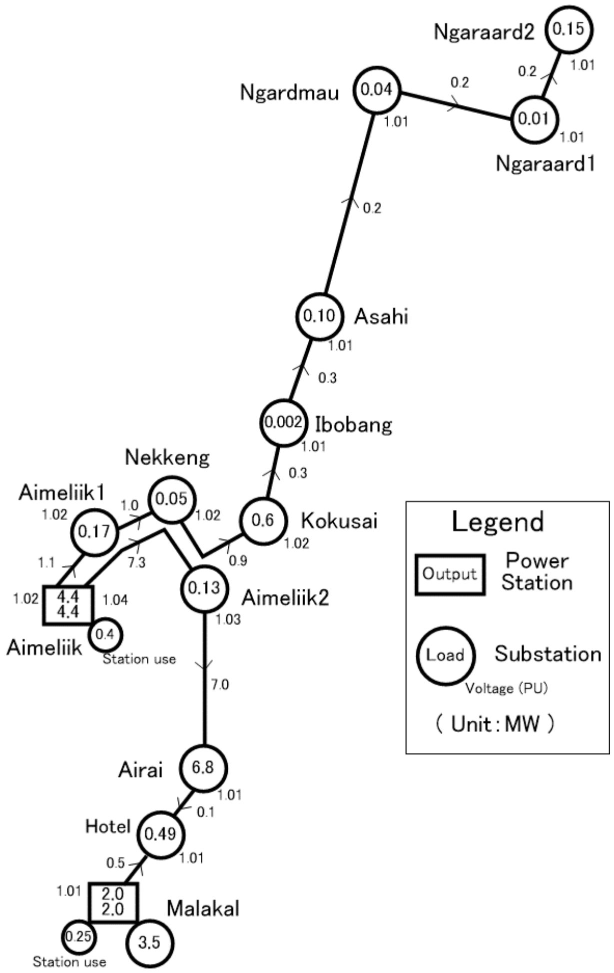

Source: PPUC

**Figure 5-4-1.1 Actual peak power flow on the 13th of August, 2016**

PPUC installed power meters to measure the power flow of transmission lines only to Aimeliik Power Station, Malakal Power Station, and Airai Substation. Thus, the actual transmission line power flow and power load of every substation in the power system are not known. Before starting the power system analysis, the power load of each substation is assumed by dividing the actual power flows measured at the two power stations and Airai Substation by the transformer capacities of the substations connected to each transmission line. The voltage and power flow of the 34.5 kV power system obtained by the analysis is shown in Figure 5-4-1.2. A detailed power flow diagram is also shown in APP-Figure 5-1 to APP-Figure 5-4.

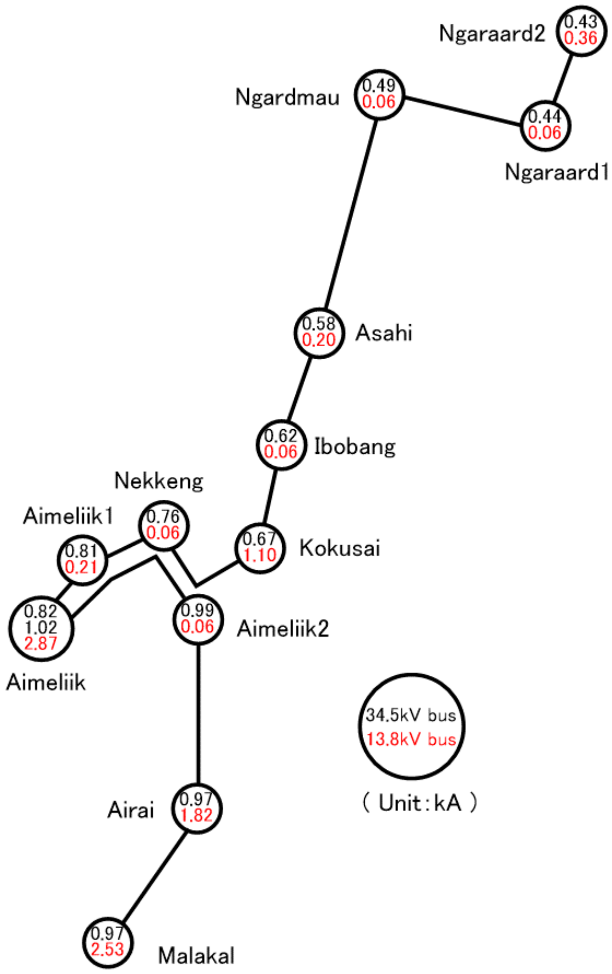
The maximum power flow is 7.3 MW, on the transmission line between Aimeliik Power Station and

Aimeliik 2 Substation. Since the transmission capacity is 21.5 MW, a level considered sufficient-to-large compared to the maximum flow, no possibility of overload is foreseen. Regarding the voltage status of the 34.5 kV transmission network, the highest voltage is 1.04 PU, at Aimeliik Power Station and the lowest is 1.01 PU, at Asahi Substation and the other substations. As the voltages range, the voltages are sustained appropriately from 0.95 PU to 1.05 PU throughout the power system.




Source: JICA Project Team

**Figure 5-4-1.2 Voltage and power flow result**




Source: JICA Project Team

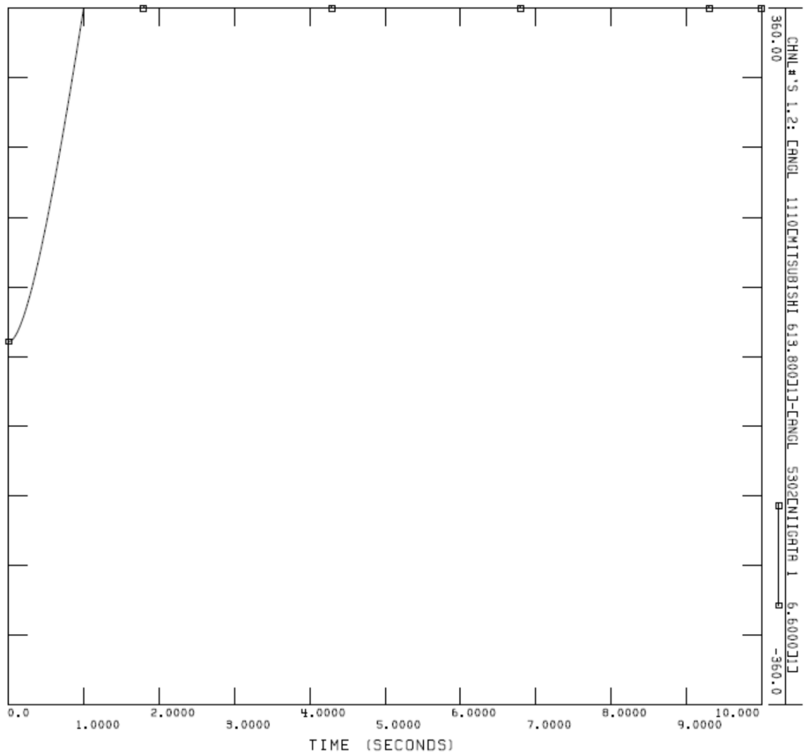
**Figure 5-4-1.3 Fault current result**

### (2) Fault current

Figure 5-4-1.3 shows the results of the fault current analysis. Since the power system is small in scale and every transmission line consists of only one circuit, the resulting network configuration is simple and the maximum three-phase short circuit of the 34.5 kV transmission line is 1.02 kA at Aimeliik Substation (whilst the fault current of the 13.8 kV feeder at this substation is also as small as 2.87 kA). These figures are sufficiently small compared to 12.5 kA, the value of the rated circuit breaking current. No problems have been identified.

### (3) Stability

Based on the actual circuit breaking time of the 34.5 kV circuit breaker determined by PPUC, the following conditions were decided for the stability analysis: after the occurrence of a three-phase short circuit fault at a transmission line, the faulty section will be isolated by the activation of circuit breakers in 300 ms. Because a fault occurring at a transmission line with a large power flow poses serious risks to stability, a stability analysis was conducted at the outgoing point of Aimeliik Power Station on the transmission line from this station to Aimeliik2 Substation. The results are shown in Figure 5-4-1.4.




Source: JICA Project Team

**Figure 5-4-1.4 Generator internal voltage angle fluctuation**

A stoppage of power transmission by a fault disrupts the balance between the mechanical input from the diesel engine and the electrical output, resulting in an acceleration of the generator. Even after isolation of the faulty section, the power sway will not be converged and will accordingly lose the synchronism. The power system will thus become unstable and unsustainable. Since only one circuit is installed on the transmission line between Aimeliik Power Station and Malakal Power Station, the separation of each system resulting from a fault will eliminate the interconnections between both power sources.

The survey on power outages revealed that no whole system blackouts occurred even when the Aimeliik Power Station system and Malakal Power Station system were separated due to faults on the transmission line interconnecting the two stations. The power demand and supply at each system after separation were kept almost balanced by chance. Power generation operation and load conditions vary every time, and the stability must be maintained under various system operation conditions according to the power supply reliability criteria. Therefore, even if the power system stabilizes under a certain system condition by chance, the system will be considered unstable as long as it is unstable under the other conditions.

### 5-4-2 Problems and countermeasures of the power system of Palau

The first problem identified by the power system analysis on the present grid is that stable operation is not realized when the power system is separated into two systems: one is from Aimeliik Power Station and the other is from Malakal Power Station, when the existing one circuit on the 34.5 kV transmission line between these two power stations is open. In addition, since the circuit breakers are installed only at Aimeliik Power Station and Malakal Power Station, regardless of the actual locations of faults somewhere along the 28 km total length of this transmission line, all sections of this line will have to be open and the power outage will continue until power transmission is resumed after the fault is cleared.

Secondly, although the Koror area, the important area in Palau, accounts for 85% of the total power demand in this country, the aging 34.5/13.8 kV Airai Substation constructed in 1985 actually serves more than half of the power supply to this area. Finally, to enhance the power supply reliability to Melekeok area (where power is transmitted through 14 km of only one 13.8 kV feeder) and Koror International Airport (where power is supplied through one feeder) will also have to be improved.

Countermeasures against the above issues are studied based on the utilization of renewable energy.

### 5-4-3 Power system planning

Based on the agreement with PPUC, photovoltaic (PV) was selected as a renewable energy (RE) source. Additionally, a stability analysis with PV and wind turbine (WT) was conducted as a reference case.

#### 5-4-3-1 Voltage class interconnecting to renewable energy

A small-scale rooftop PV system will be connected to distribution feeders, in principle. However, mega-solar systems have an output capacity ranging from 4 to 6 MW. The most appropriate interconnecting voltage was examined from the viewpoint of voltage drop. The results are shown in Table 5-4-3-1.1.

When the interconnecting voltage is 13.8 kV (distribution feeders) under the condition whereby the distance is 5 km and the power factor is 90 %, the voltage drops in the cases of 4 MW and 6 MW of PV output are 3.7 % and 5.6 %, respectively. When the transmission distance reaches 10 km, the voltage drops of 4 MW and 6 MW PV output will reach 7.4 % and 11.0 %, respectively.

Since most of candidate sites of RE are located in the northern and eastern parts of Babeldaob Island, most of the distances of the distribution line to be connected to the mega solar system are expected to be beyond 10 km. Thus, the voltage drop is assumed to be more than 10 %. Based on this discussion, it is concluded that the mega-solar system will be connected to 34.5 kV transmission lines.

**Table 5-4-3-1.1 Voltage drop in the case where a mega-solar system is connected to the distribution lines**

| PV Output | PV Power Factor | PV Terminal Sending Voltage | Distribution Line Length | Receiving Voltage | Voltage Drop |
|---|---|---|---|---|---|
| 4 MW | 90 % | 100 % | 5 km | 96.3 % | 3.7 % |
| 6 MW | | | | 94.4 % | 5.6 % |
| 4 MW | | | 10 km | 92.6 % | 7.4 % |
| 6 MW | | | | 89.0 % | 11.0 % |

Source: JICA Project Team

### 5-4-3-2 Power system network configuration

#### (1) Draft power system network configuration

The following need to be considered with respect to the power system configuration.

- 9 locations of mega-solar system are interconnected to the grid.
- Interconnection among Malakal Power Station and Aimeliik Power Station is maintained during faults on the transmission lines.
- A new substation is constructed as a countermeasure against the aging Airai Substation.
- Melekeok Substation is newly constructed in order to relocate the Parliament Office and other governmental offices.

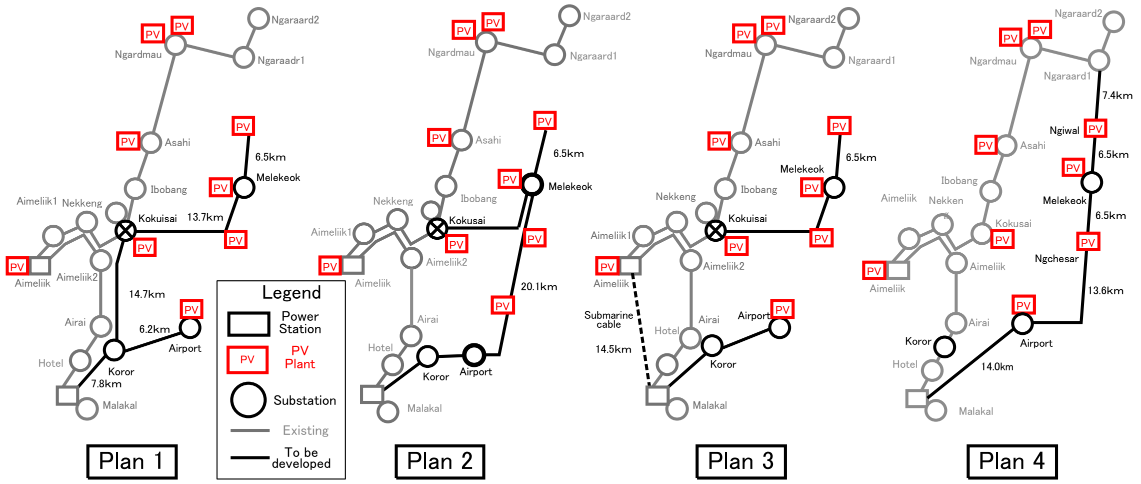
Drafts of the power system network are shown in Figure 5-4-3-2.1. The main components of each plan are as follows:

Plan 1: A new 34.5 kV transmission line is constructed along with the existing transmission line from Malakal Power Station to Kokusai Substation. In addition, two 34.5 kV transmission line circuits are newly constructed to connect Melekeok Substation (New) and Airport Substation (New).

Plan 2: A new 34.5 kV transmission line is constructed halfway around the southern part of Babeldaob Island for interconnection to the new Melekeok Substation.

Plan 3: Malakal Power Station and Aimeliik Power Station are directly connected by submarine cables. In addition, two circuits on 34.5 kV transmission lines are newly constructed: one to connect Melekeok Substation (New) from Kokusai Substation and one to connect New Koror Substation and Airport Substation (New) from Malakal Power Station.

Plan 4: A new 34.5 kV transmission line is constructed to form one round of transmission network loop through Babeldaob Island, where the new mega solar PV stations (nine locations), Melekeok Substation, and Airport Substation are connected.



Source: JICA Project Team

**Figure 5-4-3-2.1 Drafts of the power system network**

### (2) Comparison of the draft power system network configurations

Table 5-4-3-2.1 shows the results of a comparison of the proposed power system network configurations.

Among Plan 1, Plan 2, and Plan 4, approximately 50 km of overhead transmission lines are newly constructed, meaning there are no big differences among these plans. Although Plan 3 requires the least new construction of overhead transmission lines, it requires the construction of 14.5 km of new submarine cables. Accordingly, the construction cost of Plan 3 rises above that of the other plans, making it inferior from an economic viewpoint.

The number of substations that will undergo power outages due to faults of single sections of transmission lines is highest in Plan 3 (11 substations). In Plan 4, in contrast, only one substation will undergo such outages, namely, Ngaraard 2 Substation located at the northern end.

Considering the environmental impact, Plan 3 requires the excavation of approximately 14.5 km of coral reef, which can be predicted to result in massive damage to the environment.

In conclusion, Plan 4, which forms one round of 34.5 kV transmission line throughout Babeldaob Island, is superior to the other plans.

**Table 5-4-3-2.1 Comparison of drafts of the power system network**

| | Plan 1 | Plan 2 | Plan 3 | Plan 4 |
|---|---|---|---|---|
| Distance of new overhead line | 48.9 km | 54.3 km | 34.2 km | 48.0 km |
| Distance of submarine cable | - | - | 14.5 km | - |
| Cost for transmission line work | 1.47 billion Japanese yen | 1.63 billion Japanese yen | 2.64 billion Japanese yen | 1.44 billion Japanese yen |
| Power supply reliability (substations that undergo power outages due to the transmission line faults) | Low (7 substations) | Medium (5 substations) | Low (11 substations) | High (1 substation) |
| Environmental impact | Low | Low | High Excavation to coral reefs | Low |
| Overall evaluation rank | 3 | 2 | 4 | 1 |

Source: JICA Project Team

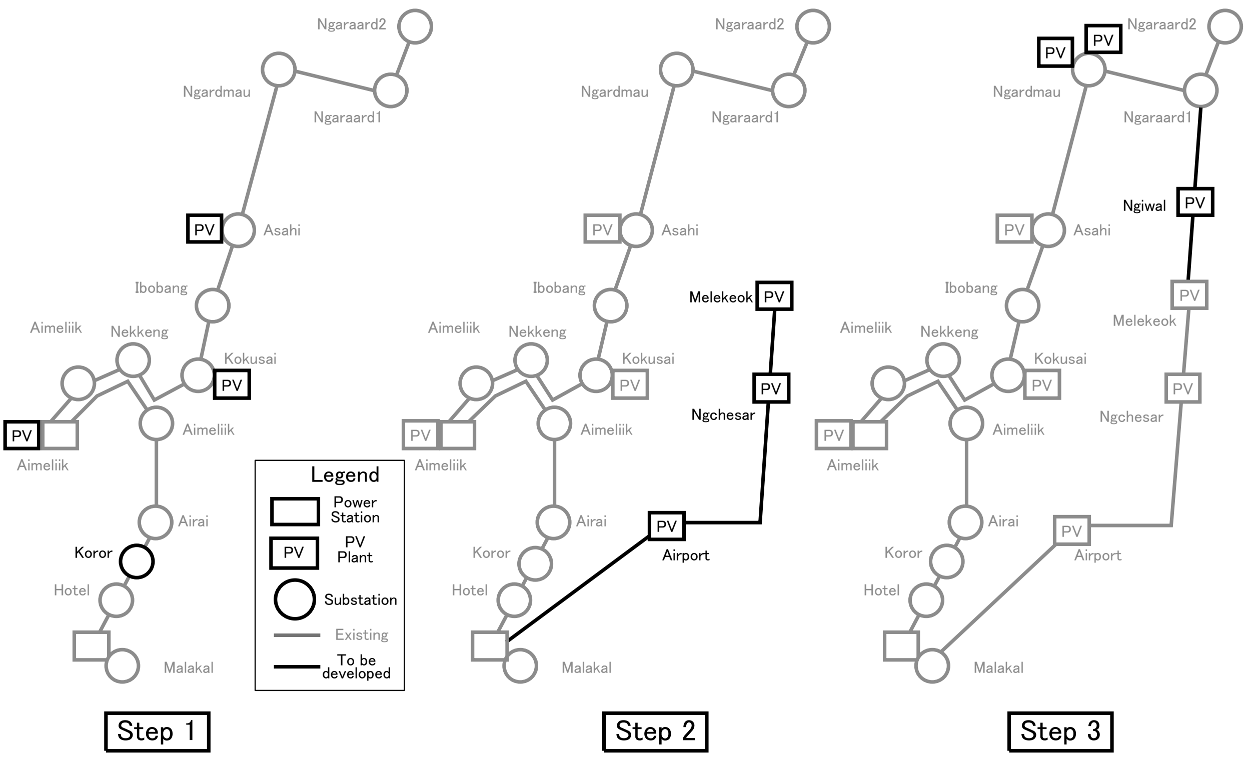
### (3) Power system developing step

Figure 5-4-3-2.2 shows the power system development steps. Within the short period remaining between now and 2025, the mega solar PV system and new Koror Substation will be constructed at 9 locations to replace the aging Airai Substation. Considering the economic and power supply reliability, the following steps are identified. Note, however, that Airport Substation and Melekeok Substation will be constructed at times determined to be appropriate vis-à-vis the power demand increase and progress of regional development.

Step 1: Koror Substation will be newly constructed and connected to the existing 34.5 kV transmission line as a countermeasure against the aging Airai Substation. In parallel, PV stations at Aimeliik, Kokusai, and Asahi will be constructed and connected to the existing 34.5 kV transmission line.

Step 2: PV stations at Melekeok, Ngchesar, and Airport will be constructed. In parallel, a 34.5 kV transmission line from Malakal Power Station to Melekeok will be constructed in order to interconnect the PV stations.

Step 3: With a total power output capacity reaching 10 MW PV station at Ngardmau and at Ngiwal will be constructed. In parallel, a new 34.5 kV transmission line will be constructed between Ngaraard 1 and Melekeok, forming one round of 34.5 kV transmission line loop.




Source: JICA Project Team

**Figure 5-4-3-2.2 Steps to augment the power system**

### 5-4-4 Results of the power system analysis

The power system analysis was conducted for the following cases: in 2020, an intermediate year when Step 1 will have been completed, in 2023, an intermediate year when Step 2 will have been completed, and in 2025, the final target year. The peak demand each year is forecasted to take place at around 19:00, when no RE power is generated. For the evaluation of the system stability when RE is used, the stability analysis is conducted under a daytime condition when the minimum number of units, that is, two diesel engine generators, run with 50% of output with the application of the highest load (refer to chapter 5-2-3-2), so as to assume the most severe condition. The precise times are 14:00 in August, 2020, 11:00 in August, 2023, and 11:00 in August, 2025.

#### 5-4-4-1 Power system in 2020

##### (1) System overview

The peak demand in 2020 is 14.1 MW at 19:00 on weekdays in August. The highest demand that satisfies the two criteria, namely, (i) daytime and (ii) only 2 operational diesel engine generators, is forecasted to be 13.5 MW on 14:00 in August.

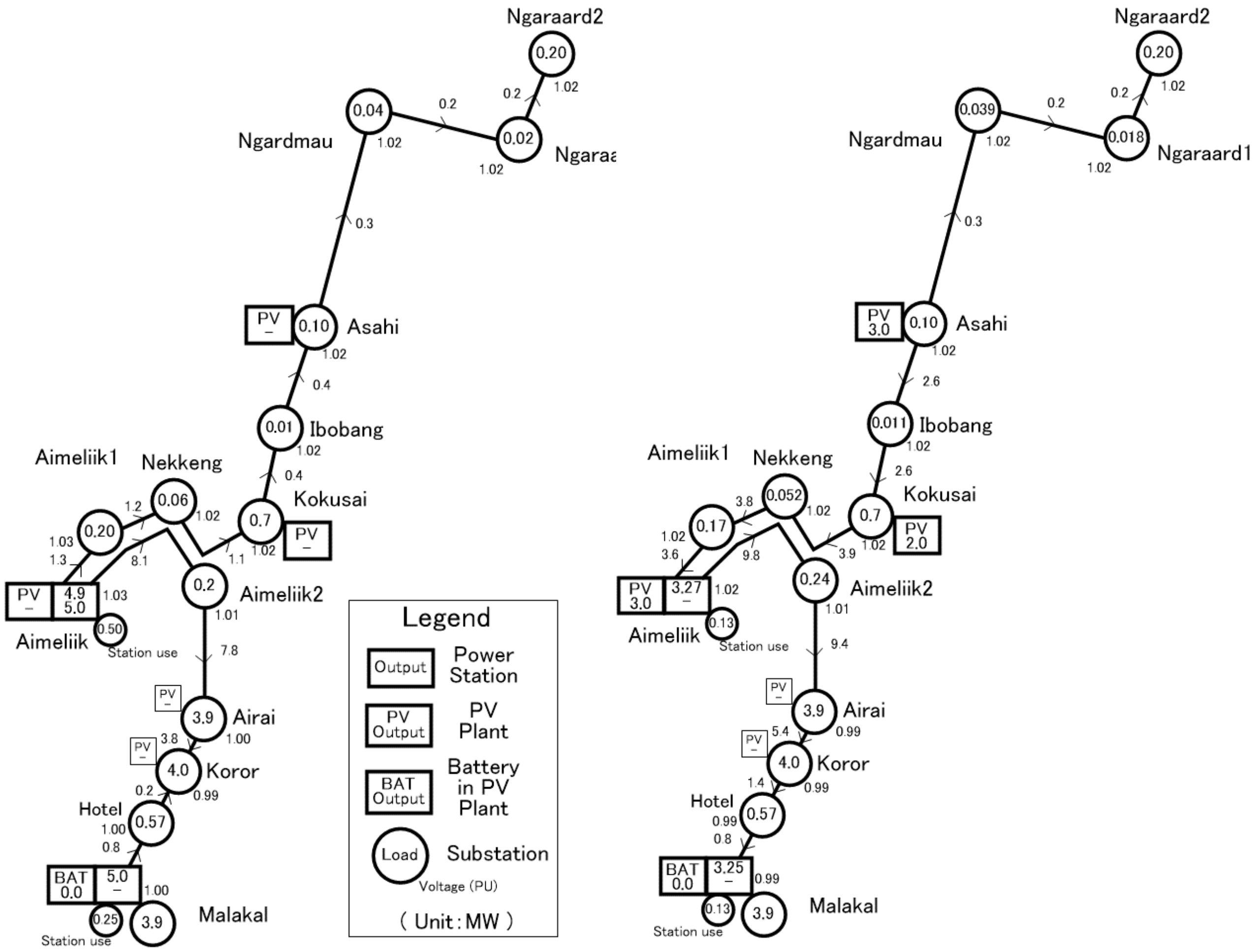
Power generation to be supplied to loads is set as shown below in order to assume severe conditions for the system.

Peak demand: Peak demand emerges at around 19:00. Given that no PV power is generated in the evening and that the power outputs from short-term batteries are zero, DEGs will supply power to all the loads. In this situation, three DEGs will be operational in accordance with Figure 5-2-3-2.6. It is assumed that one DEG at Malakal Power Station and two DEGs at Aimeliik Power Station, which is located rather remotely from load center, are in operation, respectively.

The highest power output from PV: Because it is daytime, the PVs located at Aimeliik, Kokusai, and Asahi are assumed to generate the maximum output of the inverters installed in PV sites, and the DEGs at the existing power stations are assumed to generate approx. 3.25 MW

##### (2) Voltage and power flow

Figure 5-4-4-1.1 shows the results of the voltage and power flow analysis. The highest power flows are 8.1 MW for the Peak-demand case and 9.8 MW for the Highest-power-output-from-PV case on the transmission line between Aimeliik Power Station and Aimeliik-2 substation. These values are both less than the transmission capacity, 21.5MW, so no overloading is forecasted. The voltage ranges from 99 to 103% and 99 to 102% percent, respectively, which is deemed to be appropriate.




Peak demand case Highest-output-from-PV case

Source: JICA Project Team

**Figure 5-4-4-1.1 Results of the voltage and power flow analysis (2020)**

**(3) Stability**

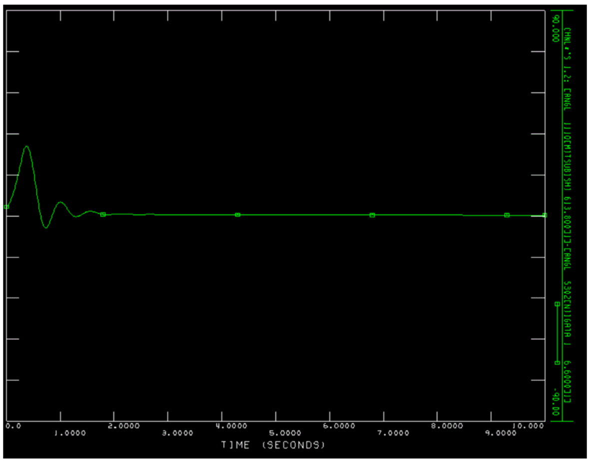
A stability analysis for a power system that includes RE will be carried out for the case where the power output from RE fluctuates. In this project, where the proportion of energy to be generated by RE is as high as 45%, the power output fluctuation will need to be compensated by short-term and long-term batteries. Furthermore, the central control system will control PV and batteries located throughout the system to minimize the influence. System faults such as three-phase short circuits, meanwhile, are difficult to predict, and the voltage drop to zero at the fault point trips the circuit to disconnect the fault. As such, the stability analysis was conducted for cases with system faults.

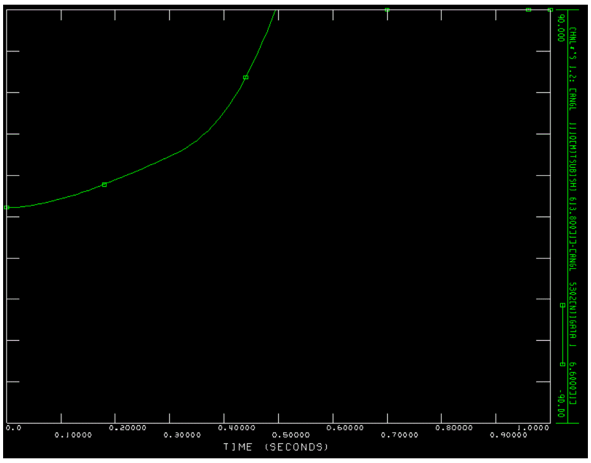
When the power output from the RE is the highest in 2020, two DEGs will be operational and PV will generate the highest output. The system will therefore be in a more severe condition compared to the case where three DEGs are operational. Therefore, the case with the highest output from RE is considered for the stability analysis. The fault conditions are set as shown below. In both cases, the time for clearing the faults is set as 300 ms.

➢ A three-phase short circuit occurs on the line between Aimeliik Power Station and Aimeliik-1 Substation at the nearest point from the busbar of Aimeliik Power Station, and the line is tripped. The PVs at Kokusai and Asahi (power outputs: 2 MW and 3 MW, respectively) are disconnected, as well.

➢ A three-phase short circuit occurs on the line between Aimeliik Power Station and Aimeliik-2 Substation at the nearest point from the busbar of Aimeliik Power Station, where the highest power flow is observed, and the line is tripped.

Figure 5-4-4-1.2 shows the difference in the generator internal voltage angle between Aimeliik Power Station and Malakal Power Station. When the fault occurs on the line between Aimeliik Power Station and Aimeliik 1 Substation, the fluctuation converges and finally stabilizes. When the fault occurs on the line between Aimeliik Power Station and Aimeliik 2 Substation, however, the fluctuation is unstable due to the loss of interconnection between the two power stations.




Aimeliik Power Station – Aimeliik 1 Substation Aimeliik Power Station – Aimeliik 2 Substation

Source: JICA Project Team

**Figure 5-4-4-1.2 Results of the stability analysis (generator internal voltage angles) for 2020**

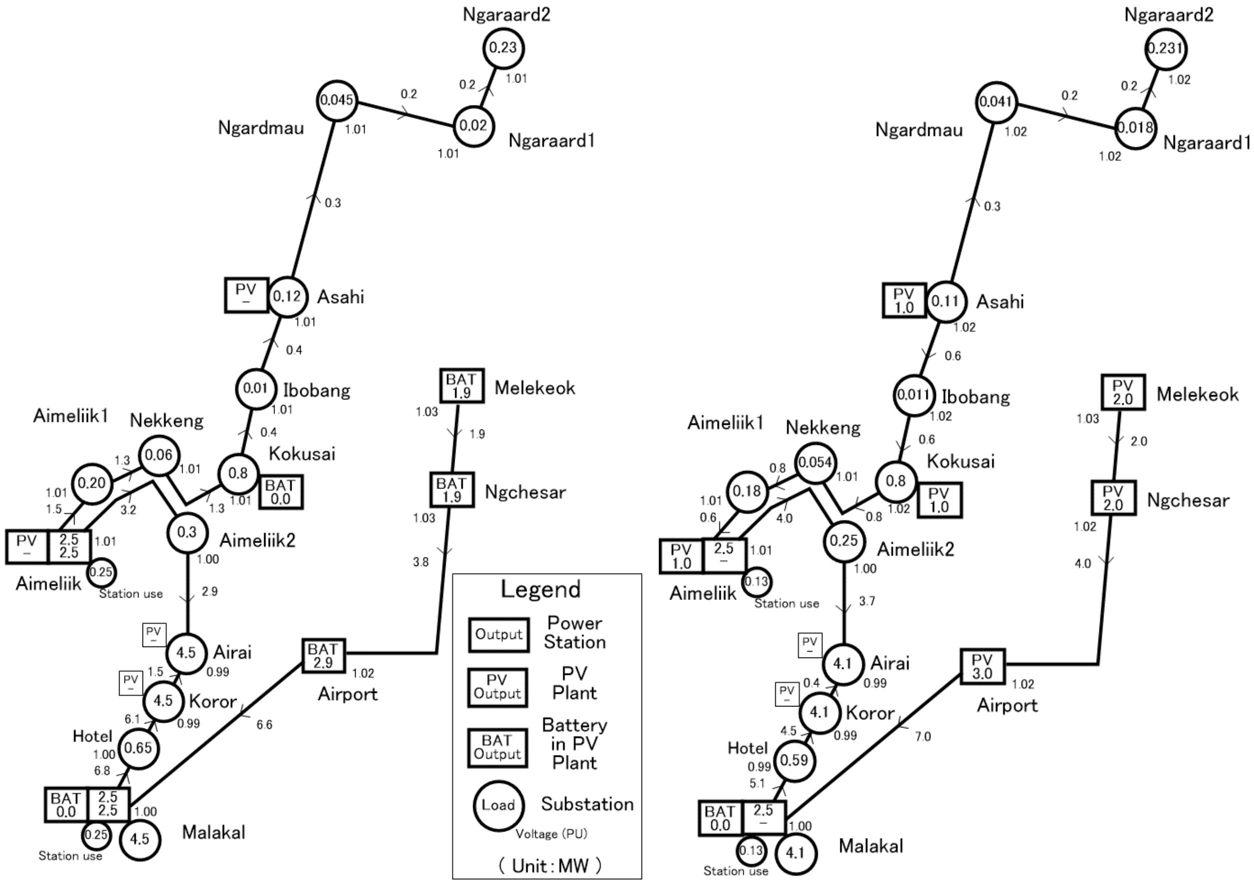
### 5-4-4-2 Power system in 2023

#### (1) System overview

The Malakal-Melekeok line will be constructed in 2023 and PV stations to be constructed near the Airport in Ngchesar and Melekeok will be interconnected. The peak demand is assumed to be 16.5 MW at 19:00 in August. The power will be supplied from DEGs at Malakal Power Station and Aimeliik Power Station and long-term batteries charged in daytime. At the time of the highest power output from PV, the peak demand under the condition where two DEGs are operational is 14.9 MW at 11:00 in August. Airport, Ngchesar, and Melekeok are assumed to generate the highest PV output to set the most severe case for the system.

#### (2) Voltage and power flow

Figure 5-4-4-2.1 shows the results of the voltage and power flow analysis. The highest power flow for the Peak-demand case is 6.8 MW, recorded on the line between the Malakal Power Station and Hotel, and that for the Highest-output-from-PV case is 7.0 MW, on the line between Malakal Power Station and the Airport. The power will be far less than the transmission capacity, 21.5 MW, in both cases, so no overloading is forecasted. The voltage ranges from 99 to 103% in both cases, which is deemed to be an appropriate level.




Peak demand case    Highest-output-from-PV case

Source: JICA Project Team

**Figure 5-4-4-2.1 Results of the voltage and power flow analysis (2023)**

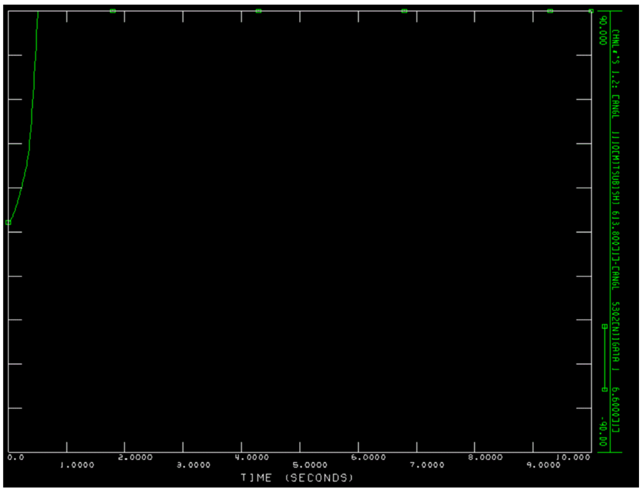
### (3) Stability

The highest output from RE case, which provides the more severe situation than the peak demand case, is selected for the stability analysis. The fault condition is set as shown below. In both cases, the fault clearing time is set as 300 ms.

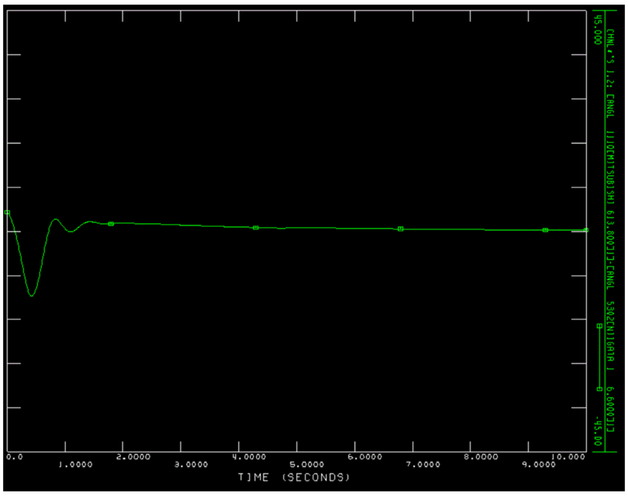
- A three-phase short circuit occurs on the line between Aimeliik Power Station and Aimeliik-2 Substation at the nearest point from the busbar of Aimeliik Power Station, and the line is tripped.
- A three-phase short circuit occurs on the line between Malakal Power Station and Airport Substation at the nearest point from the busbar of Malakal Power Station, where the highest power flow is observed, and the line is tripped. Accordingly, the PV stations at the Airport, Ngchesar, and Melekeok, with a total output of 7 MW, are disconnected.

The difference in the generator internal voltage angle between Aimeliik Power Station and Malakal Power Station is shown in Figure 5-4-4-2.2. When the fault occurs on the line between Malakal Power

Station and the Airport, fluctuation is damped and finally stabilizes. When the fault occurs on the line between Aimeliik Power Station and Aimeliik 2 Substation, the fluctuation is unstable due to the loss of interconnection between the two power stations.



Fault on the Aimeliik Power Station – Aimeliik 2



Fault on the Malakal Power Station – Airport line

Source: JICA Project Team

**Figure 5-4-4-2.2 Results of stability analysis**

### 5-4-4-3 Power system in 2025

#### (1) System overview

The peak demand case is assumed as shown below. The peak demand in 2025 will be 18.1 MW at 19:00 on weekdays in August. Four DEGs (rated output: 5 MW) will be operated with 50% output (total output: 10 MW). The shortage of power output will be supplied from long-term batteries that have been charged by PV output at daytime. The output from the long-term batteries is assumed to be proportional to the rated capacity of each battery. Rooftop PV is assumed to supply no power, as no batteries are installed in the system.

A case with the highest output from RE has also been assumed, as shown below. The peak demand under the condition where two DEGs are operational is 14.9 MW at 11:00 in August. The PV output from the PV stations at Asahi, Ngardmau, and Ngiwal located in the northern part, the area most remote from the center of power demand, are determined to generate the highest output, so as to assume the most severe case for the system.

#### (2) Voltage and power flow

The 5-4-4-3.1 shows the results of the voltage and power flow analysis. The detailed results on power flow are shown in APP-Figures 5-2 and 5-3.

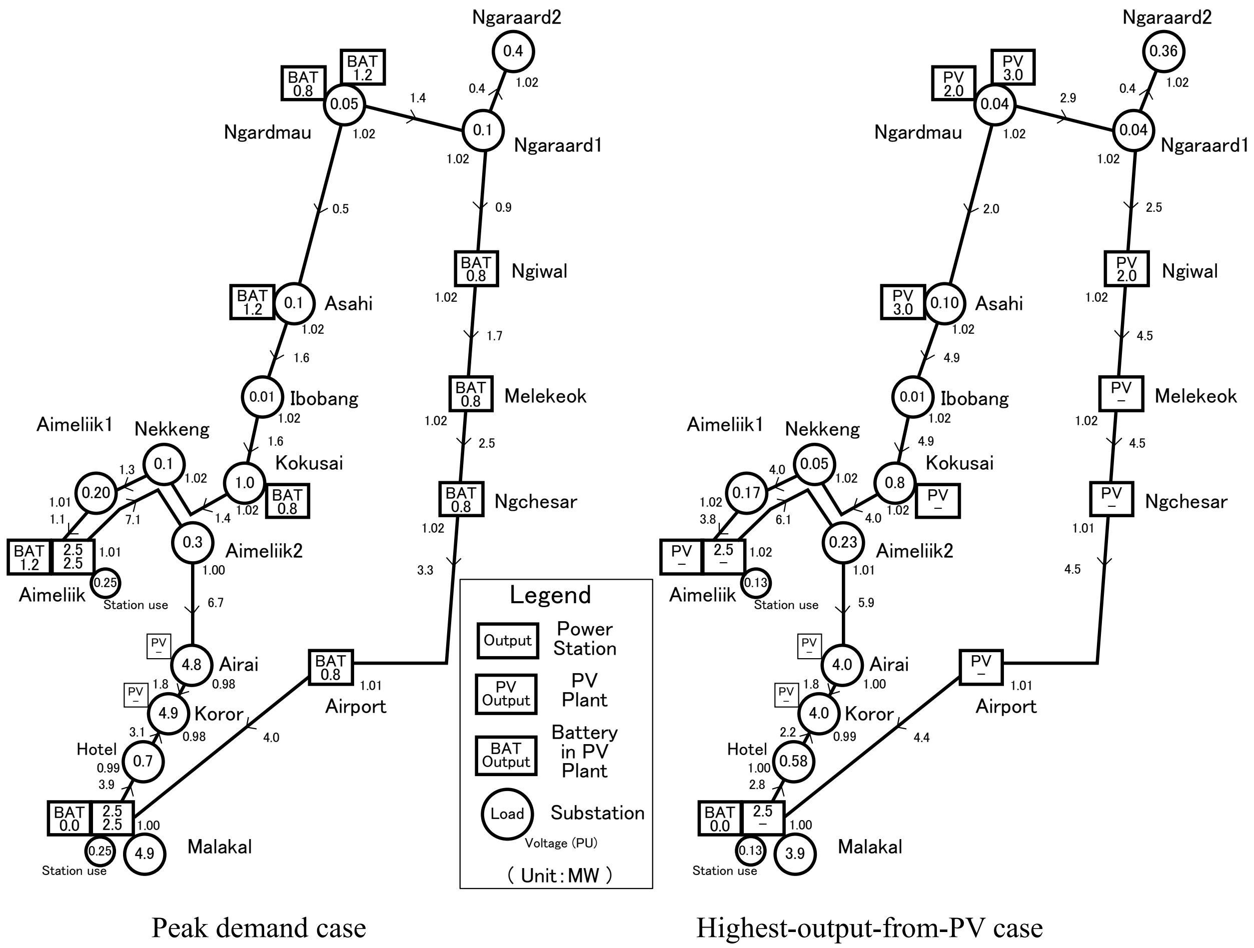
The results for the peak demand case are as follows:

- Because the voltages of the inverters of the long-term batteries can be maintained, the voltages of the 13.8 kV and 34.5 kV systems will be maintained at between 98 % and 102 % at all points.

- The highest power flow will be 7.1 MW, in the section between Aimeliik Power Station and Aimeliik 2 Substation. This value is far smaller than the 21.5 MW transmission capacity, hence no overload will result even if this section trips and the power flow is diverted to the other transmission line routes.
- Through the completion of the 34.5 kV loop network, the balance of the power flows in the eastern and western routes will be sustained.

The results of the highest-output-from-RE case are as follows:

- The northern part of the network is far from diesel power generation, hence the voltage condition in the northern system is relatively severe. The PV inverters, however, will maintain the voltages, so the voltages will be maintained at between 99 % and 102 % at all points.
- The highest power flow will be 6.1 MW in the section between Aimeliik Power Station and Aimeliik-2 Substation. No overloads will occur under any condition (normal condition, contingency condition, etc.).



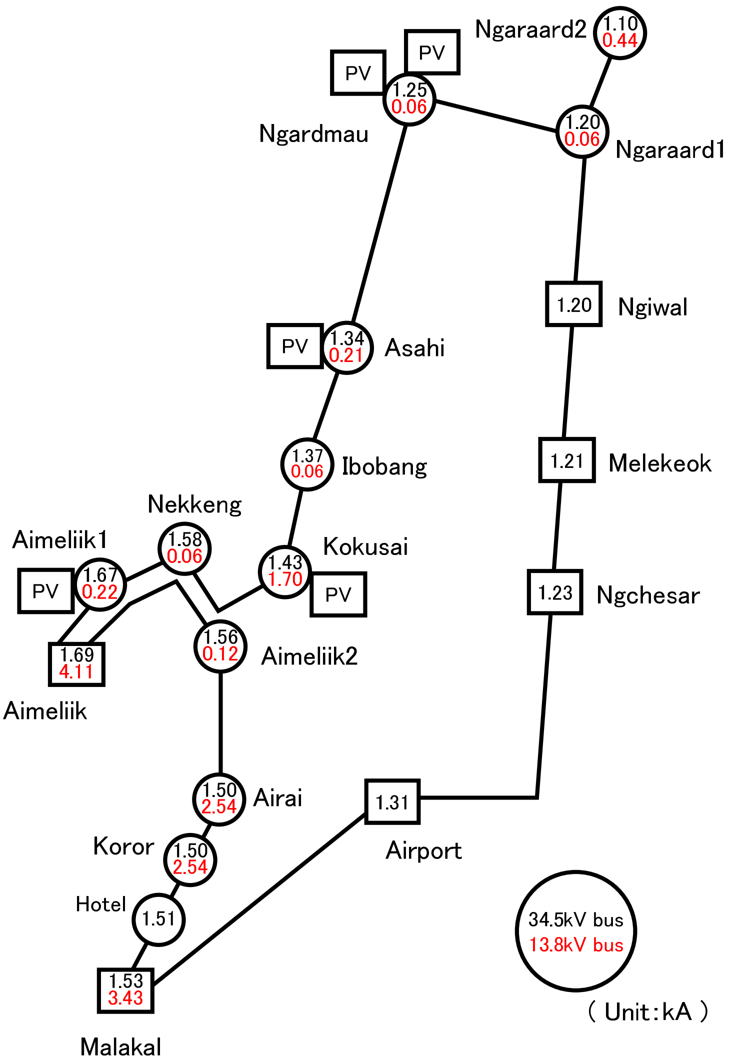

Peak demand case Highest-output-from-PV case

Source: JICA Project Team

**Figure 5-4-4-3.1 Results of the voltage and power flow analysis**

### (3) Fault current

Figure 5-4-4-3.2 shows the results of the fault current analysis. This analysis was conducted on the condition that 4 DEGs at Aimeliik Power Station and Malakal Power Station will be in operation, in order to set the highest fault current among the various operation conditions. The results are as follows:




Source: JICA Project Team

**Figure 5-4-4-3.2 Results of the fault current analysis**

- The highest value for a three-phase short circuit in the 34.5 kV system is 1.69 kA, at Aimeliik Power Station, and that in the 13.8 kV system is 4.11 kA, also at Aimeliik Power Station. These values are far smaller than 12.5 kA, the rated breaking current of the existing circuit breakers. Thus, there are no problems.

- The PV inverters at each PV station can maintain the voltage and therefore provide fault currents. The value, however, is approximately 0.09 kA per PV station, so the overall fault current dispersion will not be affected.

**(4) Stability**

The case where 2 DEGs are operational and 2/3 of the load is supplied from RE is assumed for the stability analysis so as to set a severe system condition. The following three conditions are also set for the fault condition.

Fault case 1:

A three-phase short circuit fault occurs on the line between Aimeliik power station and Aimeliik 2 Substation at the nearest point from the 34.5 kV busbar at Aimeliik Power Station, where the highest power flow emerges. The circuit breakers are activated in 300 ms and the transmission line from Aimeliik Power Station to Koror Substation via Aimeliik-2 Substation and Airai Substation is opened. As no circuit breakers are installed at the Aimeliik-2 Substation and Airai Substation, the entire section mentioned above will be tripped and power outages will accordingly occur at Aimeliik 2 Substation and Airai Substation.

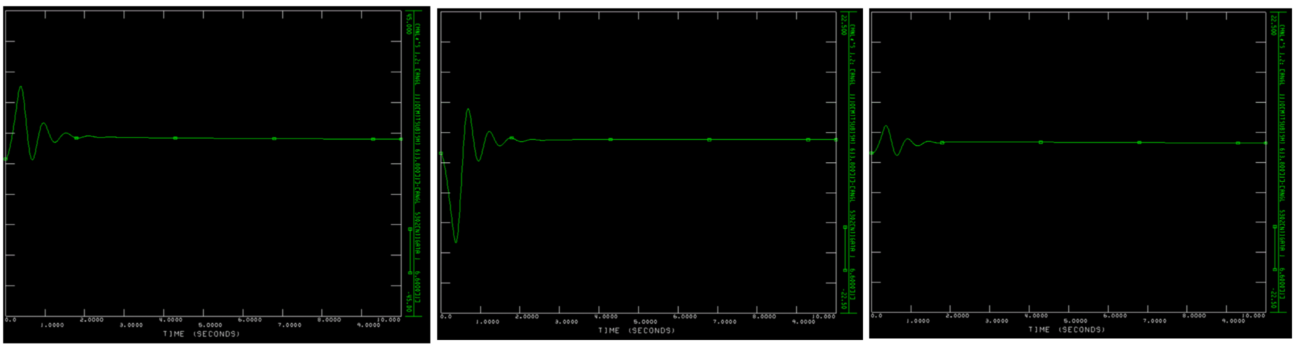
Fault case 2:

A three-phase short circuit fault occurs on the line between Malakal power station and Airport Substation at the nearest point from the 34.5 kV busbar at Malakal Power Station. The circuit breakers are activated in 300 ms and the transmission line from Malakal Power Station to Airport is tripped.

Fault case 3:

A three-phase fault occurs on the line between Ngardmau and Ngaraard at the nearest point from the 34.5 kV busbar at Ngardmau, the facility connected to the highest total PV station capacity. The circuit breakers are activated in 300 ms and the line between Ngardmau and Ngaraard is opened.

The difference in the generator internal voltage angle between Aimeliik Power Station and Malakal Power Station is shown in Figure 5-4-4-3.3. The loop system of the 34.5 kV transmission line will make it possible to maintain the interconnection between the two power stations during the tripping of the transmission lines caused by the fault. Therefore, the power generation fluctuation will be damped in any case. The results show that the system stability is maintained regardless of the extent of the faults that occur.



Fault case 1 Fault case 2 Fault case 3

Source: JICA Project Team

**Figure 5-4-4-3.3 Results of the stability analysis**

### 5-4-5 The case of wind turbine introduction

**(1) Conditions for the system analysis**

The conditions assumed for the system analysis for wind turbine (WT) are as follows:

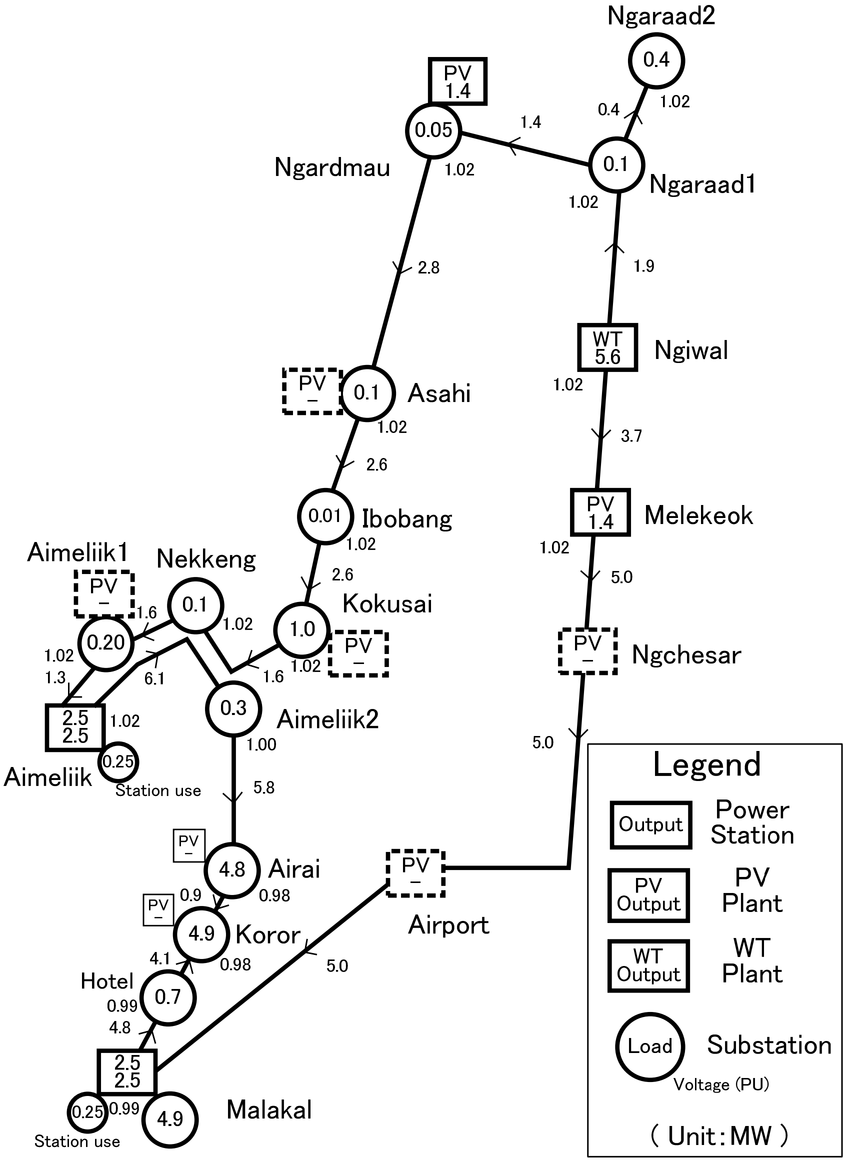
- Interconnection points: According to the Results of the wind condition survey, the appropriate location for the WT is the eastern area of Babeldaob Island. The location is therefore set as Ngiwal.
- Power output capacity: Considering the economic efficiency stated in Chapter 5-2-3-3, a total power output of 8.25 MW consisting of 30 units of 275 kW without battery systems (neither short-term nor long-term) is assumed. The maximum output is limited to 5.6 MW (70 % of the facility capacity) in consideration of the limits in the influence on the wind turbine. The induction generator is assumed to be an alternator type (the least-cost and generally applied mechanism for WT).
- Targeted system: The peak demand case in 2025 is identified. Also, PV stations producing a total output equivalent to 5.6 MW are assumed not to be developed. The PV stations located around the Koror area are set to zero output while the PV stations located in remote areas continue generating power. The transmission distance thus increases, making the conditions severe.

**(2) Voltage and power flow**

Figure 5-4-5.1 shows the results of the voltage and power flow analysis. APP-Figure 5-4 shows the detailed power flow diagram.

The results are summarized below:

- Since the WT consists of an induction generator, it is incapable of maintaining the voltage. The voltage-maintaining capability in the northern area is low because the area is remote from diesel engine generators. The PV inverters can maintain the voltage, however, so the voltages throughout the system, including the northern area, will be maintained within a range from 99 % to 102 %.
- The largest power flow is 6.1 MW from Aimeliik Power Station to Aimeliik-2 Substation. The second largest power flow is identified as 5.0 MW in the Melekeok-Malakal line located nearby the WT and PV stations. In these cases, the power flows are far smaller than the 21.5 MW transmission capacity. Even if the line is tripped during a fault and the power flow is diverted to the other lines, no overloading will occur.



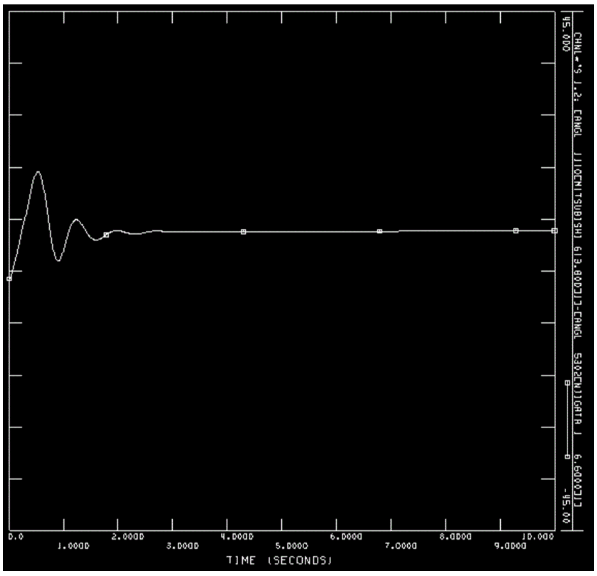

Source: JICA Project Team

**Figure 5-4-5.1 Results of the voltage and power flow analysis**

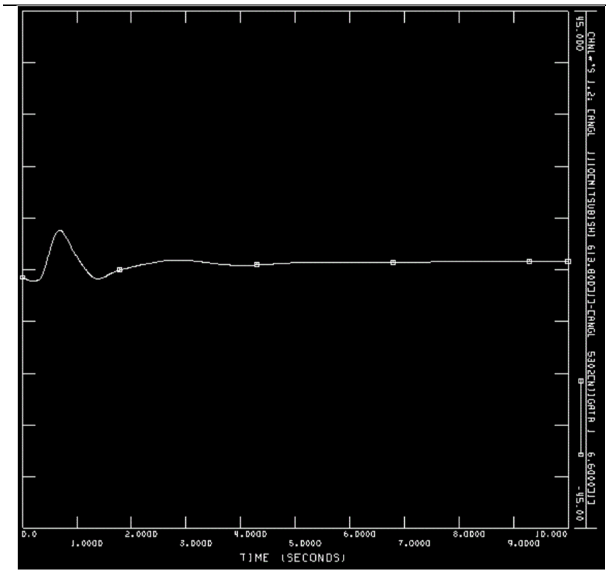
### (3) Stability

The stability analysis condition is assumed to be the same as the PV case shown in chapter 5-4-4. The fault condition analyzed in the Ngiwal-Melekeok line (Ngiwal end) was selected to verify the influence of the introduction of WT, in addition to the fault condition in the line between Aimeliik Power Station and Aimeliik-2 Substation, where the largest amount of power flows.

Figure 5-4-5.2 shows the difference in the generator internal voltage angle between Aimeliik Power Station and Malakal Power Station. Through the construction of the one round of 34.5 kV transmission line, the interconnection between these two power stations will be maintained even when the line is tripped during a system fault. Therefore, even if the large-scale WT station is introduced, the fluctuation of generators will be damped as time passes and the system stability will be maintained even if a severe fault occurs.



Aimeliik P.S.-Aimeliik-2 Substation line fault



Ngiwal-Melekeok line fault

Source: JICA Project Team

**Figure 5-4-5.2 Results of the stability analysis**

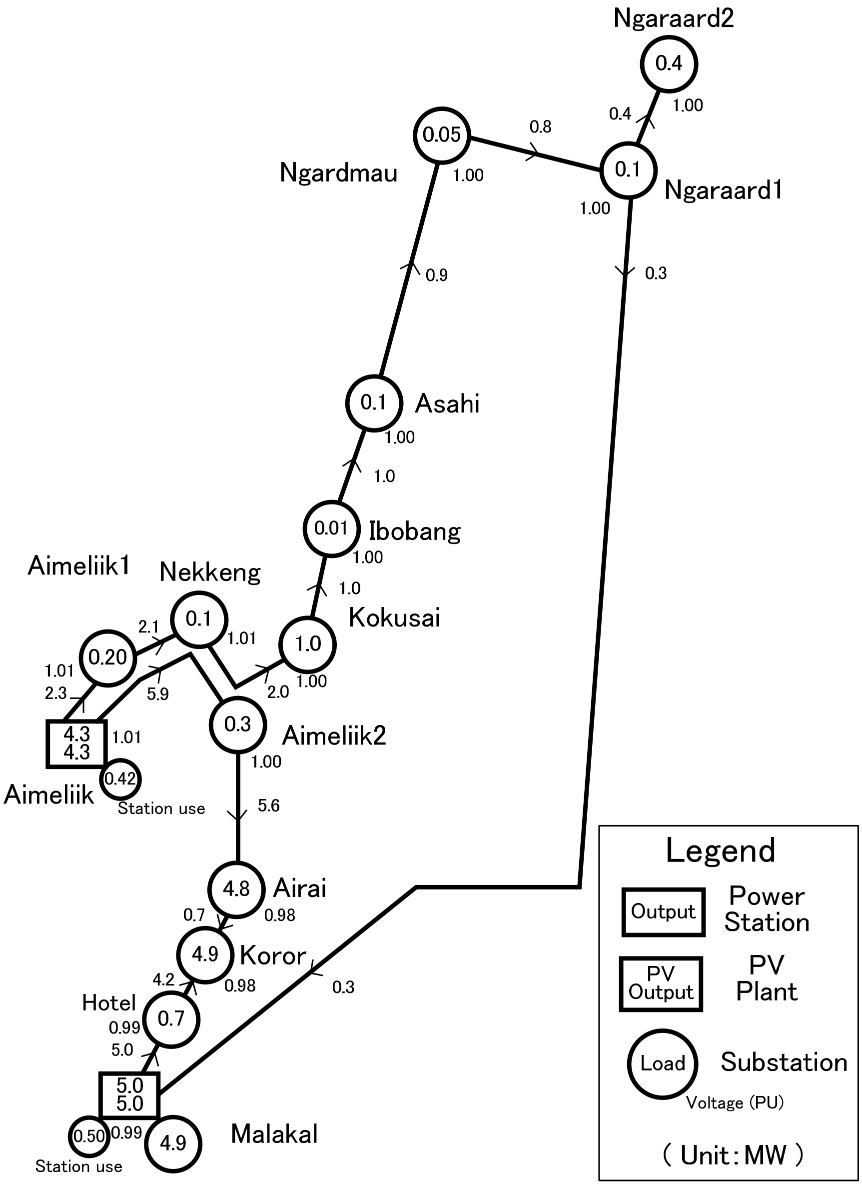
### 5-4-6 Case without the renewable energy

The power system analysis was conducted based on the looping system in 2025 with diesel engine generators only (renewable energy sources such as solar photovoltaic and wind turbine are not considered). This case is equivalent to the condition where power generation from PV is zero, all batteries (both short-term and long-term) are in a zero-charge state, and no solar irradiation is generated for a long period. The results are shown in the following sections.

#### (1) Voltage and power flow

Figure 5-4-6.1 shows the results of the voltage and power flow analysis. The findings are summarized below:

- Due to the looping system, the voltage will be maintained at between 98 % and 101 % at all points throughout Babeldaob Island, including the northern part where the voltage tends to be weak due to its remote location from Aimeliik Power Station and Malakal Power Station.
- The highest power flow will be 5.9 MW, in the section between Aimeliik Power Station and Aimeliik 2 Substation, followed by 5.0 MW, in the section between Malakal Power Station and Palaisia Hotel, the section through which power is supplied to Koror Substation nearby the load center. These power flows are much smaller than the 21.5 MW transmission line capacity, hence no overload will occur regardless of the tripped sections.



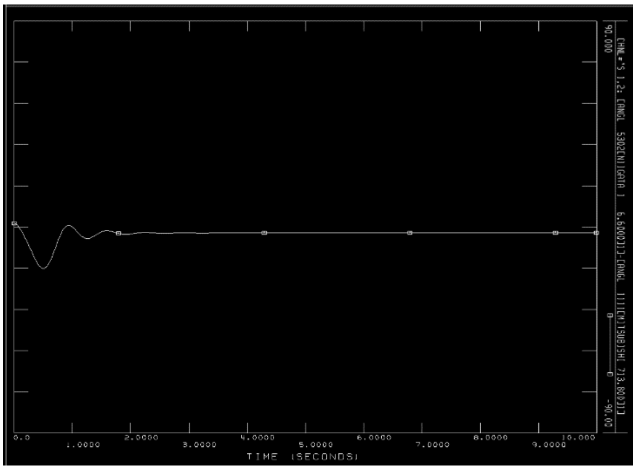

Source: JICA Project Team

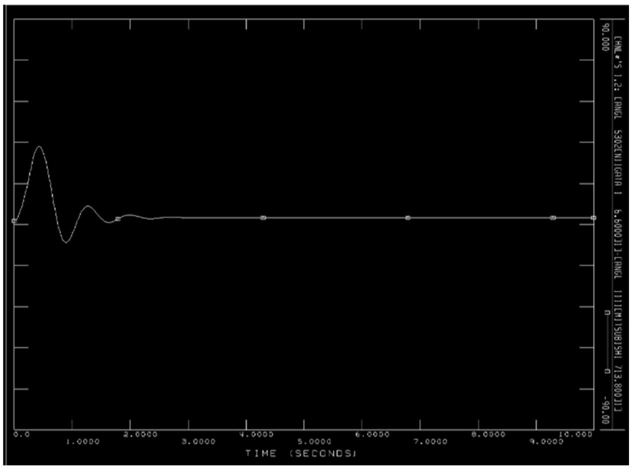
**Figure 5-4-6.1 Results of the voltage and power flow analysis**

**(2) Stability**

Faults were set in the section between Aimeliik Power Station and Aimeliik 2 Substation and the section between Malakal Power Station and Palasia Hotel, respectively, as the assumed fault conditions. The faults in both cases are assumed to be severe faults, as the power flow will be heavily changed due to the power flow diversion along with the loop system caused by the tripping of transmission line.

Figure 5-4-6.2 shows the results of the stability analysis. The loop system of the 34.5 kV transmission line will make it possible to maintain the interconnection between the two power stations when the transmission line is tripped by the fault. The power generation fluctuation will therefore be damped. The results show that the stability will be maintained even during severe faults.





Aimeliik Power Station – Aimeliik 2 Substation fault        Malakal Power Station- Palaisia Hotel line fault

Source: JICA Project Team

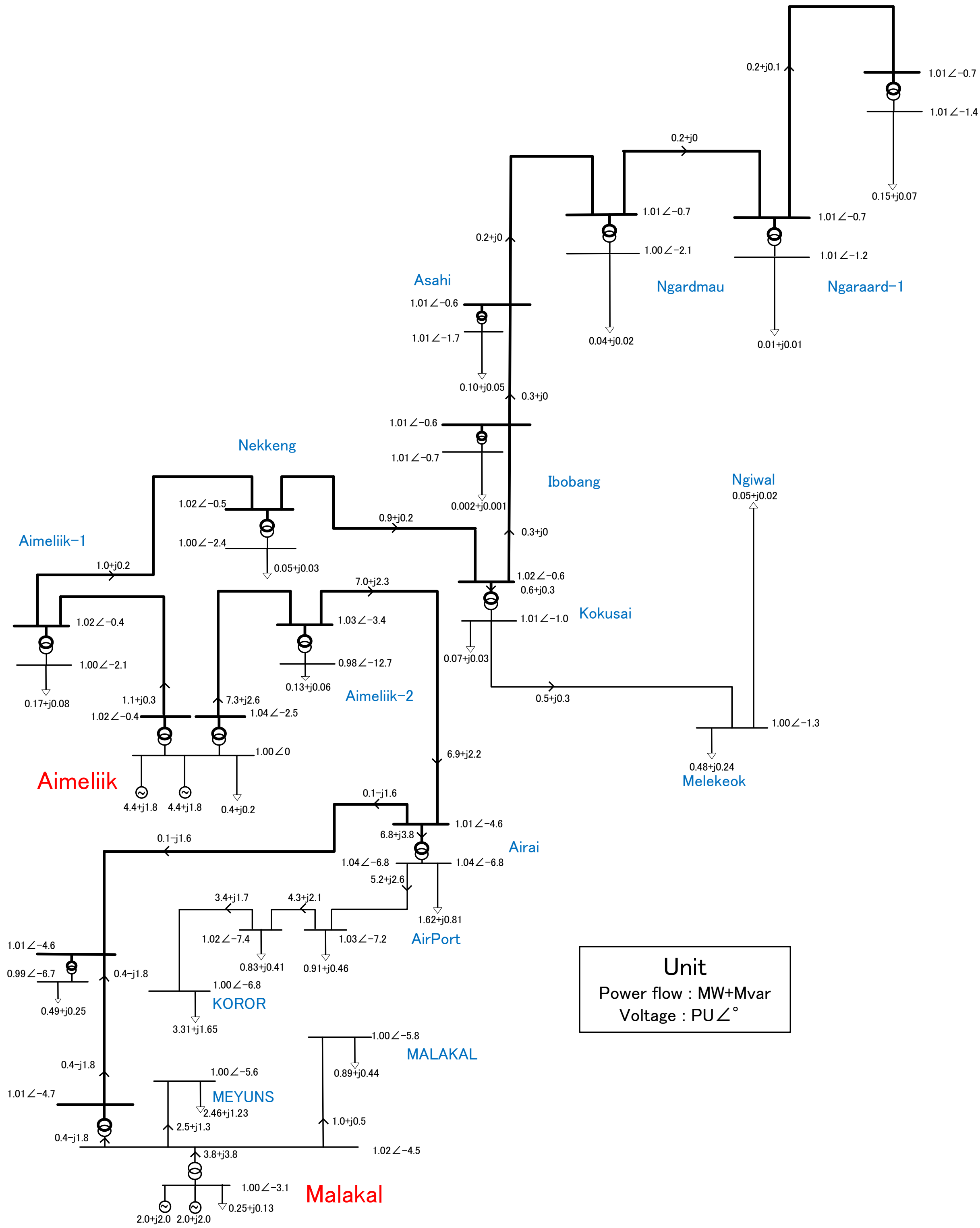
**Figure 5-4-6.2    Results of the stability analysis**

### 5-4-7 Conclusion

The results of the analyses for the existing system, intermediate systems, and final system in 2025 demonstrate no observable problems with respect to the voltage, power flow, and fault current.

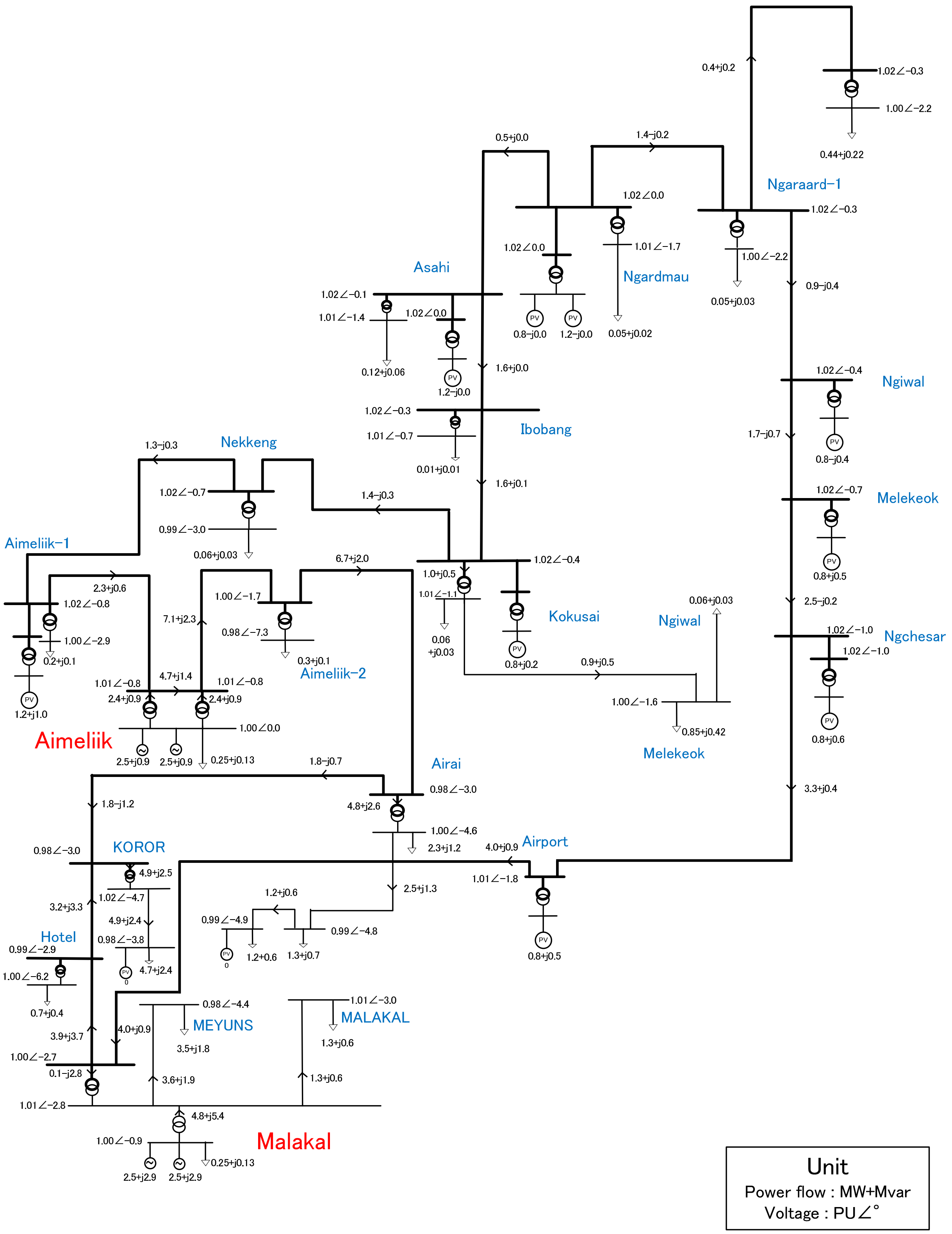
From the viewpoint of stability, the existing and intermediate systems become unstable because the existence of only one circuit leads to a loss of interconnection between the two power stations. In year 2025, with the completion of the loop transmission network, however, the interconnection between Aimeliik Power Station and Malakal Power Station will be maintained in the event of a transmission line fault at any location, and the system will remain stable. In addition, since most of the substations will be connected to the loop circuit, the power supply to the substations in the Koror-Babeldaob network will be maintained even during transmission line faults, which will remarkably improve the reliability of the power supply.

The system stability, however, depends on the magnitude of the synchronization force provided by the rotating generators, in principle. When the generators provide a smaller proportion of power, the system stability declines in parallel. Further, the synchronization force is derived from the physical characteristics by nature, and hence will not depend on artificial control. On the other hand, the power output, voltage, etc. in an RE system needs to be controlled through RE inverters artificially. This control will also require knowledge of the theory and methodology for control coordination among all inverters located throughout the power system. Furthermore, the system analysis software still seems to be immature and in need of further development. There are still plenty of challenges to solve for the analysis of a power system made up of a large portion of RE output compared to rotating generators. We must say that the introduction of a 45% ratio of energy generated by RE under the JICA master plan is a tremendously challenging project of a type the world has never experienced. A deeper examination of the unknowns and deeper analyses from diverse views will be required.



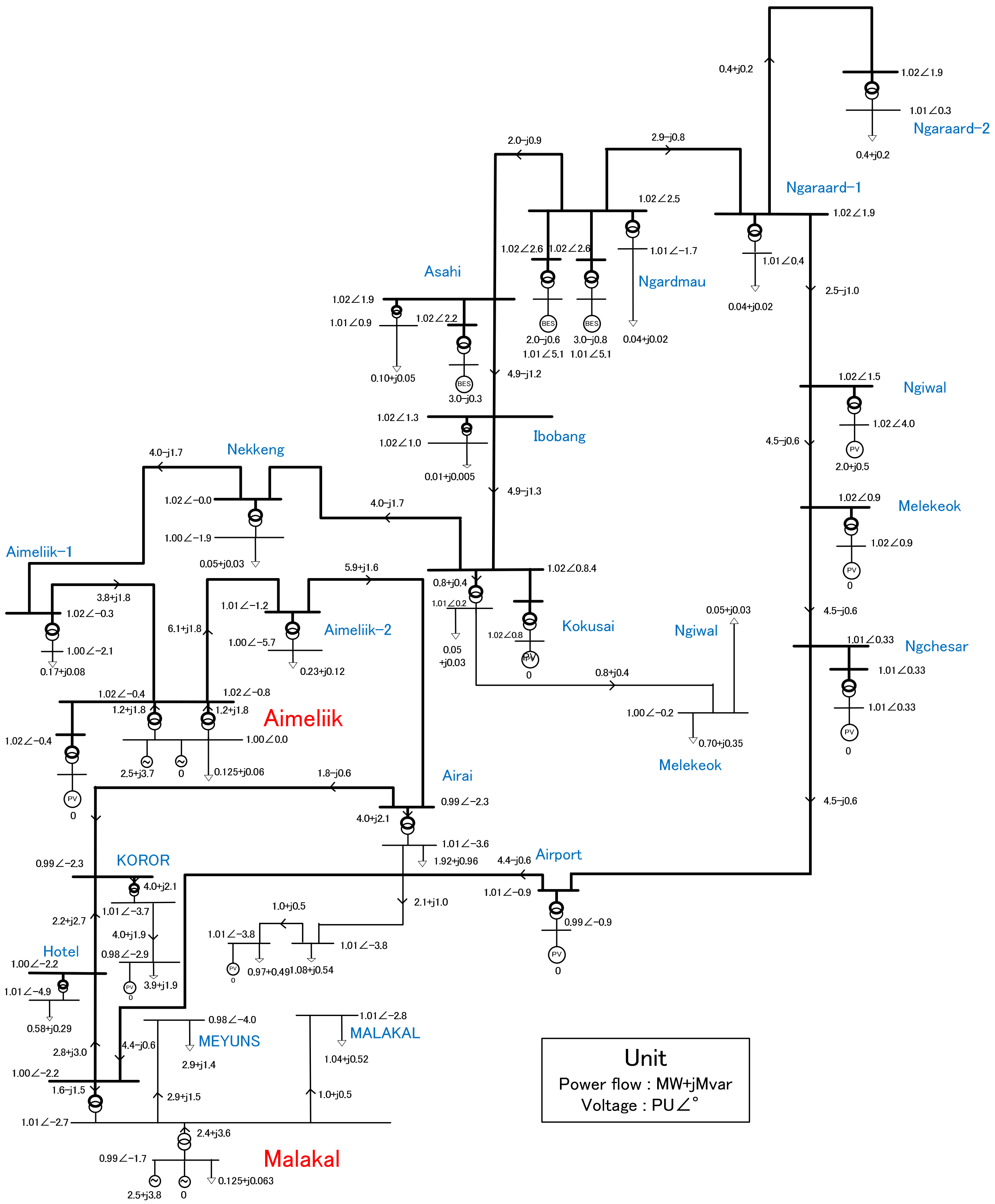

Source: JICA Project Team

**APP-Figure 5-1 Power flow diagram (peak demand time in 2016)**



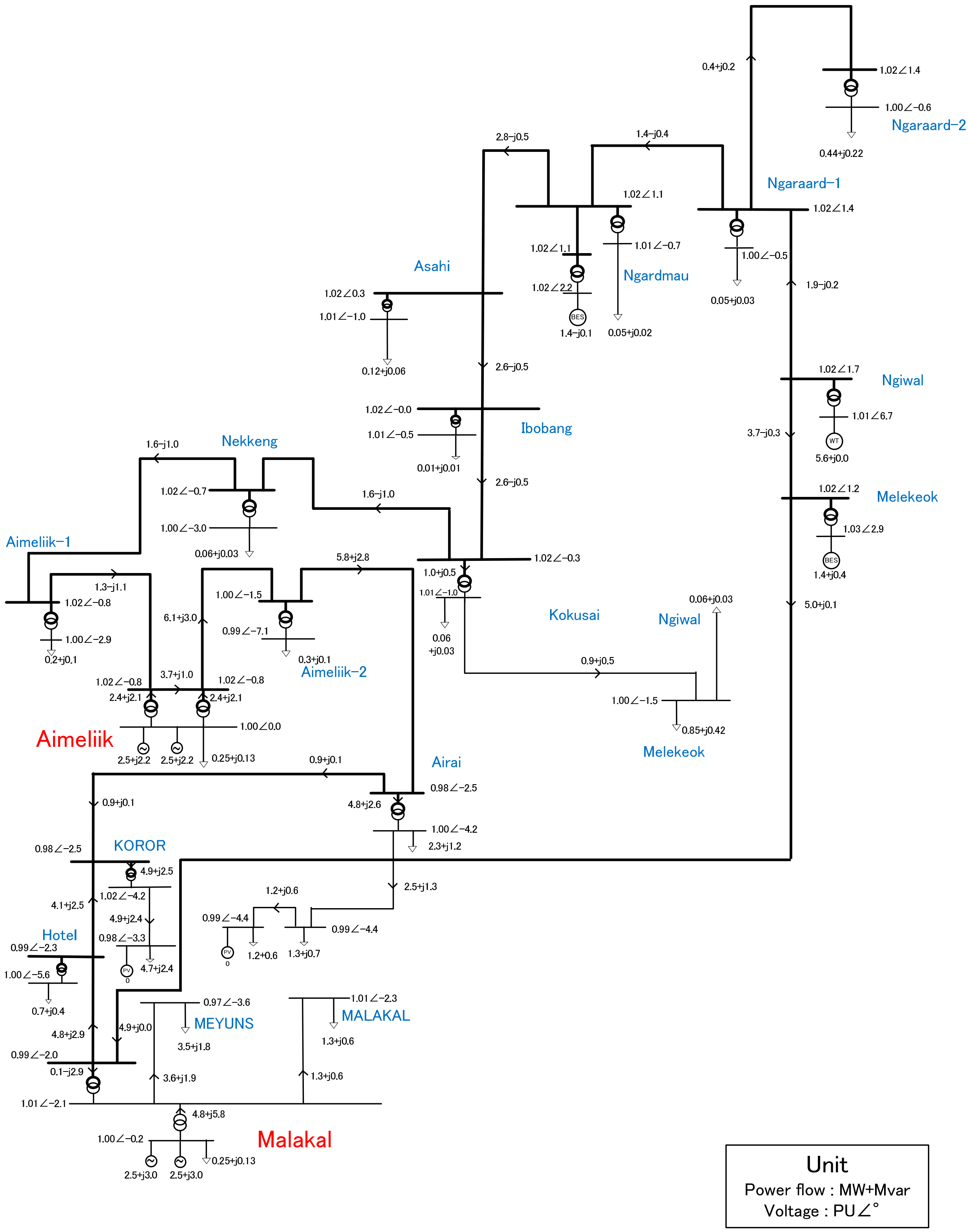

Source: JICA Project Team

**APP-Figure 5-2 Power flow diagram (peak demand time in 2025)**




Source: JICA Project Team

**APP-Figure 5-3 Power flow diagram (highest RE output time in 2025)**




Source: JICA Project Team

**APP-Figure 5-4 Power flow diagram with WT and PV (peak demand time in 2025)**

# CHAPTER 6 Planning of Power Transmission, Distribution, and Substations

# Chapter 6 Planning of Power Transmission, Distribution, and Substations

## 6-1 Present State of the Equipment

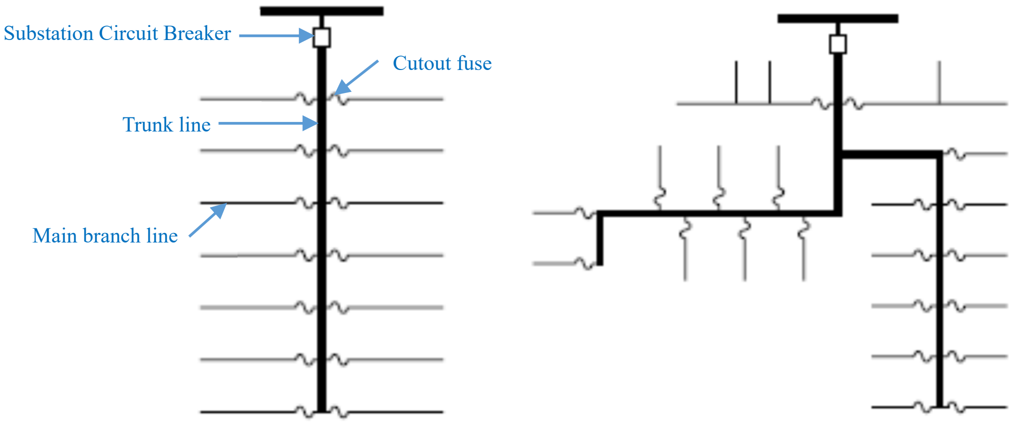
### 6-1-1 Transmission and Distribution System

#### 6-1-1-1 Type and configuration of the system

About 98% of Palau's power facilities are installed in the area covered under this project. The power system in this area consists of a 34.5 kV transmission system, 13.8 kV Medium-Voltage (MV) distribution system, and 240/120 V Low-Voltage (LV) distribution system.

The MV distribution system is a neutral point, direct grounding, three-phase, three-wire system. As shown in Figure 6-1-1-1.1, the system takes the basic form of a trunk line (mainline) with main branch lines connected to it with cutouts. The trunk line is protected by relays and circuit breakers at the substations and the branch line is protected by cutout fuses.

The simple basic structure of the MV trunk makes it difficult to secure interconnection points to link to adjacent systems. The lack of interconnection points, in turn, makes it difficult to secure flexible load switching in the event of faults.




(a) Single mainline (b) Balanced mainline

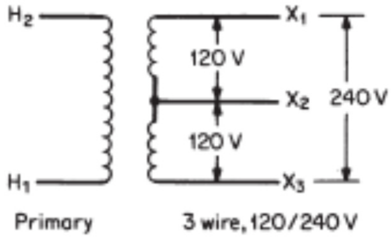
Source: Electric Power Distribution Handbook, CRC PRESS, 2004

**Figure 6-1-1-1.1 Basic forms of the MV system**

The LV distribution system supplies power to single-phase loads and three-phase loads via a combination of single-phase transformers.

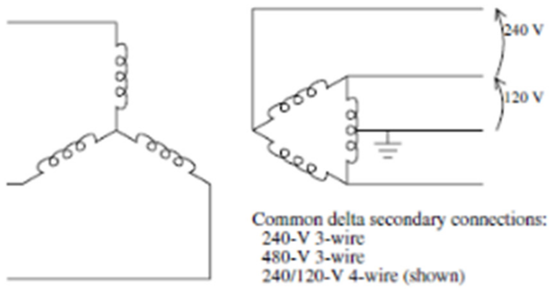
As shown in Figure 6-1-1-1.2, a single-phase, three-wire transformer is used when supplying only to a single-phase load. One of the terminals on the primary side is connected to the ground to form a single wire earth return circuit. The transformation ratio of this transformer is 7.96 kV: 240/120 V.

As shown in Figure 6-1-1-1.3, three single-phase transformers are connected to form the bank configuration when supplying to three-phase loads. One of the transformers is used as a single-phase, three-wire transformer by drawing a neutral wire to form a three-phase, four-wire system that supplies power from a bank to three-phase loads and single-phase loads.




Source: Electrical Distribution Engineering, CRC PRESS

**Figure 6-1-1-1.2 Transformer connection for single-phase load supply**




Source: Electric Power Distribution Handbook, CRC PRESS, 2004

**Figure 6-1-1-1.3 Transformer connection for a three-phase, four-wire system**

### 6-1-1-2 Outline of the MV system

Malakal Island and Babeldaob Island have two transmission systems (34.5 kV) and twelve distribution systems (13.8 kV) drawn from substations, as summarized in Table 6-1-1-2.1.

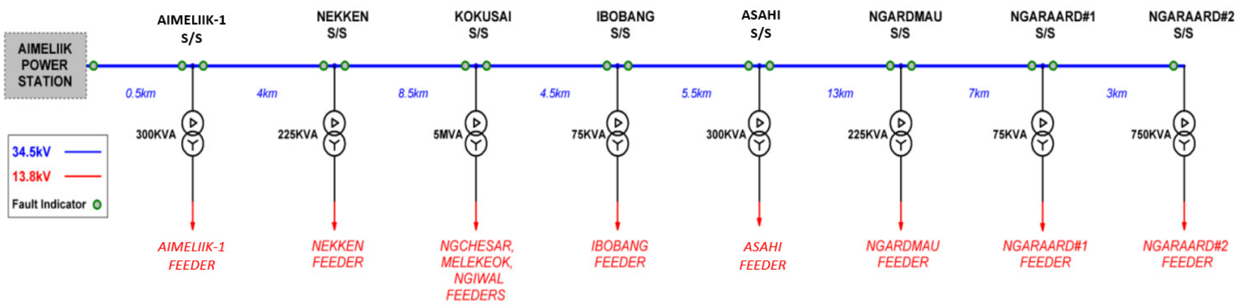
**Table 6-1-1-2.1 Main transmission and distribution systems (34.5 kV and 13.8 kV)**

| System (voltage) | Power source | Name | note |
|---|---|---|---|
| Transmission (34.5 kV) | Aimeliik P/S | Nekken | |
| | Aimeliik P/S・Malakal P/S | Aimeliik – Malakal | P/S parallel operated |
| Distribution (13.8 kV) | Airai S/S | Airai –Airport | |
| | | Airai - Koror | |
| | Malakal P/S | Meyuns feeder | |
| | | Malakal feeder | |
| | Aimeliik -1 S/S | (name of area, etc.) | Distribution lines under the Nekken transmission line |
| | Aimeliik -2 S/S | | |
| | Nekken S/S | | |
| | Kokusai S/S | | |
| | Ibobang S/S | | |
| | Asahi S/S | | |
| | Ngardmau S/S | | |
| | Ngaraard -1 S/S | | |
| | Ngaraard -2 S/S | | |

Source: study team

Aimeliik power plant and Malakal power station are usually connected by 34.5 kV transmission lines and operated in parallel.

Eight small substations (see Figure 6-1-1-2.1 (from Aimeliik-1 to Ngaraard-2)) are connected on the Nekken transmission line drawn from Aimeliik power station, with 8 feeders (13.8 kV) drawn in total. A single line diagram of the Nekken transmission line is shown in Figure 6-1-1-2.1. Since these 8 feeders (13.8 kV) are small-capacity feeders in depopulated areas, they form a radial network with no interconnection with other feeders. These substation are basically configured as pole-mounted transformers (see Figure 6-1-1-2.2), with all system protections handled with cutout fuses.



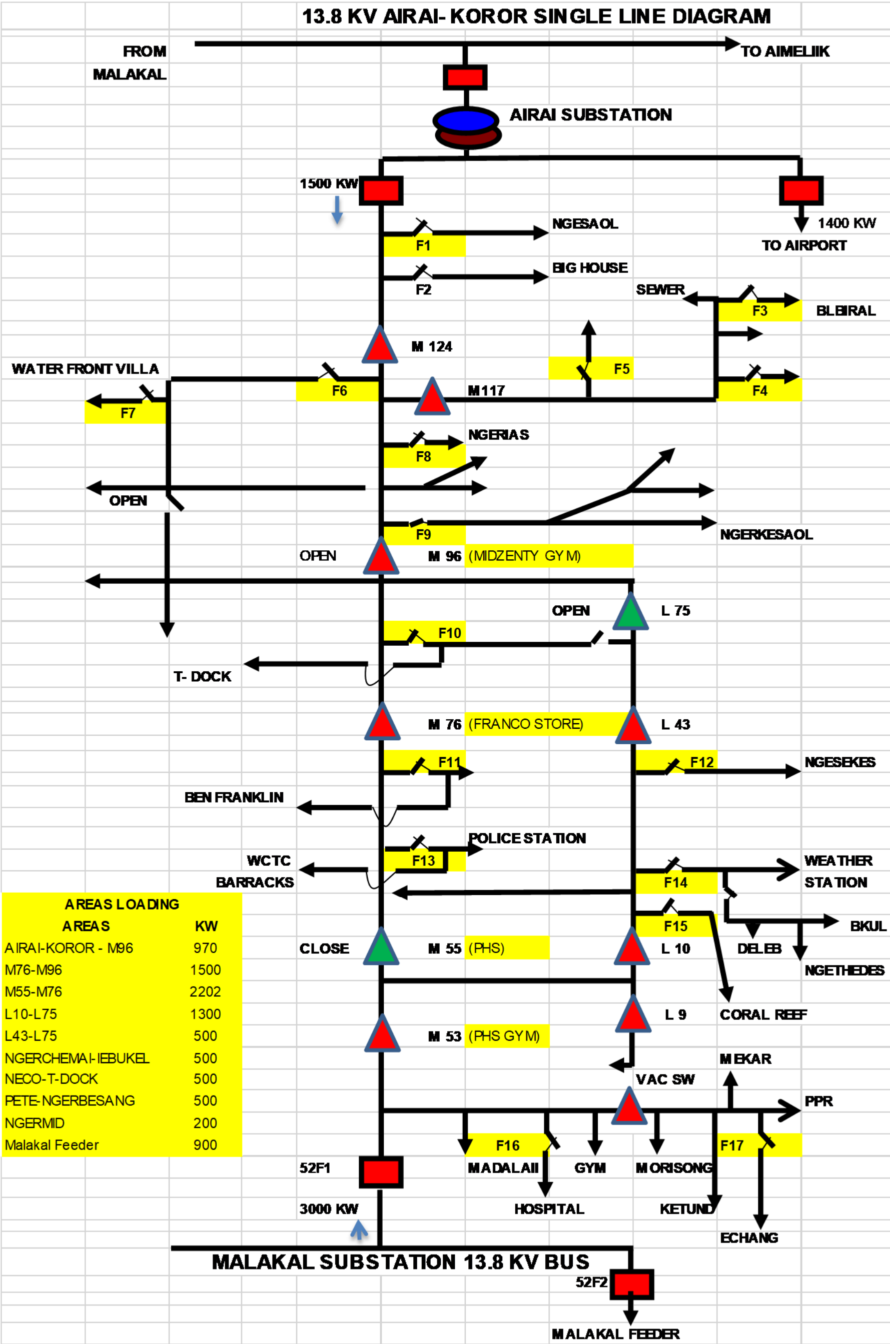

Source: Evaluation of the PPUC Power Transmission & Distribution System due to Unknown Tripping Events, Jan.28, 2017

**Figure 6-1-1-2.1 Single line diagram of the Nekken transmission line**

**Figure 6-1-1-2.2 Example of pole-mounted substation equipment (Asahi Substation)**

Figure 6-1-1-2.3 shows a single line diagram of the distribution system drawn from Airai Substation and Malakal Power Station, facilities that supply to the center of demand. Two feeders are drawn out from Airai Substation and another two are drawn out from Malakal Power Station. Among these four feeders, only the Airai - Koror Feeder and Meyuns feeder are interconnected to form a system configuration that allows load switching when faults occur. The basic configurations of the Airai-Koror feeder and Meyuns feeder, however, are Single mainline (Figure 6-1-1-1.1 (a)) and Balanced mainline (Figure 6-1-1-1.1 (b)), respectively, so the two feeders substantially have only one interconnection point each.

Moreover, a phase lag exists between the voltages of Airai Substation and Malakal Power Station, as the transformer connection of the former is Δ-Y whereas that of the latter is Y-Y. Therefore, uninterruptible switching between the Airai - Koror Feeder and Meyuns feeder cannot be carried out.




Source: PPUC

**Figure 6-1-1-2.3 Single line diagram of the Airai substation system and Malakal power plant system**

### 6-1-1-3 Transmission and distribution equipment amounts

#### (1) Power transmission equipment

A breakdown of the 34.5 kV power transmission equipment is shown in Table 6-1-1-3.1. The transmission line conductors are unified to AAC (336 MCM).

**Table 6-1-1-3.1 Breakdown of the 34.5 kV transmission equipment**

| No. | Name | Linear Length (m) | Conductor | |
|---|---|---|---|---|
| | | | Type | size（MCM） |
| 1 | Aimeliik～Nekken | 4,287.5 | AAC | 336 |
| 2 | Nekken～Kokusai | 8,849.7 | AAC | 336 |
| 3 | Kokusai～Ngaraard | 38,774.8 | AAC | 336 |
| 4 | Nekken～Airai S/S | 14,266.7 | AAC | 336 |
| 5 | Malakal～Airai S/S | 9,184.9 | AAC | 336 |
| | Total | 75,367.2 | | |

Source: Data Handbook for PPUC, PPA, Nov 22,2010

**(2) Distribution lines**

A breakdown of the 13.8 kV distribution lines is shown in Table 6-1-1-3.2. AAC (336 MCM) conductors are applied to the trunk lines (feeders) and CU (2, etc.) conductors are mainly applied to the branch lines and small-capacity lines.

**Table 6-1-1-3.2 Breakdown of the 13.8 kV distribution lines**

| No. | Feeder | Line name | Linear Length (m) | Conductor (type and size) |
|---|---|---|---|---|
| 1 | Airai-Airport | Airai to Ngerikiil pumping station | 9,714.8 | AAC 336MCM |
| 2 | | Airai to Pole (AA195) | 5,339.3 | AAC 336MCM |
| 3 | Airai-Koror | Ngermid | 2,737.6 | AAC 336MCM |
| 4 | | Ngesaol | 1,258.4 | CU. 2 |
| 5 | | Iyebukel and Ngerchemai | 2,787.1 | AAC 336MCM |
| 6 | | Ngerkeseuaol | 1,340.3 | CU. 4 |
| 7 | | T-Dock | 830.5 | AAC 336MCM |
| 8 | | Dngeronger | 595.2 | AAC 336MCM |
| 9 | Malakal feeder | Idid-Ikelau | 2,048.4 | AAC 336MCM |
| 10 | | Ngerbeched | 4,248.4 | AAC 336MCM |
| 11 | | Medalaii | 2,100.6 | AAC 336MCM |
| 12 | | Meyuns | 5,111.2 | AAC 336MCM |
| 13 | MMDC feeder | Malakal | 1,763.0 | AAC 336MCM |
| 14 | Aimeliik Feeder | Aimeliik | 8,588.3 | AAC 336MCM |
| 15 | 13.8 kV feeder | Ngatpang | 8,168.7 | AAC 336MCM |
| 16 | | Ibobang | 2,913.6 | CU. 2 |
| 17 | | Ngardmau | 3,038.2 | AAC 336MCM |
| 18 | | Capitol to Ngiwal | 10,839.5 | CU. 2 |
| 19 | | Kokusai to Capitol | 21,152.1 | AAC 336MCM |
| 20 | | Malakal to Airai (Main Road) | 9,184.9 | AAC 336MCM |
| 21 | | Ngchesar | 21,411.0 | CU. 2 |
| 22 | | Ngaraard | 26,150.6 | CU. 2 |
| 23 | | Ngerchelong | 10,357.4 | CU. 2 |
| 24 | | Ngaremlengui-3phase line | 17,783.6 | AAC 336MCM |
| 25 | | Ngaremlengui-1phase line | 2,250.2 | CU. 2 |
| Total | | | 181,712.6 | |

Source: Data Handbook for PPUC, PPA, Nov 22, 2010

### 6-1-1-4 Status of power outages in the power transmission and distribution system

Table 6-1-1-4.1 shows the status of power outages in the 34.5 kV transmission lines (T/L) and 13.8 kV distribution lines (D/L) in the nearest year (from 2016/10 to 2017/9). The table was generated from data extracted from the power outage list kept by SCD based on the operation records of the substations relays. The relays are installed at the withdrawal sections for the transmission lines and distribution lines in the major three substations: Aimeliik, Malakal, and Airai. The incidence and levels of the power outages in the PPUC power system can be grasped from this record.

**Table 6-1-1-4.1 Power outages in 34.5 kV T/L and 13.8 kV D/L**
**(Analysis of the outage records kept by SCD (2016/10 - 2017/9))**

| Name of the facility | ①Number of outage (times/y) * | ②Total outage duration (min/y) | ③Total outage kWh (kWh/y) ** | (%) | ④Average outage Duration ②/① (min/outage) | ⑤Average outage Power ③/(①*④/60) (MW/outage) | ⑥total Length of the line | ⑦Number of outage per line length ①／⑥ (times/km) |
|---|---|---|---|---|---|---|---|---|
| Aimeriik－Malakal T/L | 19 | 331 | 39,507 | 46% | 17.4 | 7.17 | 28km | 0.68 |
| Nekken T/L | 47 | 1169 | 17,968 | 21% | 24.8 | 0.92 | 49km | 0.96 |
| 34.5kV T/L (Subtotal) | 66 | 1,500 | 57,475 | 67% | | | | |
| AIRAI-AIRPORT | 5 | 169 | 4,140 | 4.8% | 34 | 1.47 | 15 km | 0.33 |
| AIRAI – KOROR | 6 | 61 | 2,382 | 2.8% | 10 | 2.34 | 9.4 km | 0.63 |
| MALAKAL | 5 | 25 | 324 | 0.4% | 5 | 0.78 | 1.7 km | 2.94 |
| MEYUNS FDR | 15 | 478 | 15,588 | 18.1% | 32 | 1.96 | 13.5 km | 1.11 |
| 13.8kV D/L (Subtotal) | 31 | 733 | 22,433 | 26% | | | | |
| Power station | 2 | 253 | 6,334 | 7% | | | | |
| Total | 99 | | 86,242 | 100% | | | | |

Note: (1) Number of fault occurred simultaneously in 34.5kV systems and 13.8kV systems is counted as one
(2) Outage kWh of connected 13.8kV D/L is included in the data of 34.5kV T/L
Source: JICA Study Team

### (1) Status of power outages in the power transmission system

As shown in Table 6-1-1-4.1, the annual power outage kWh of the Aimeliik - Malakal line is 39 MWh. This accounts for 46% of the total outage kWh, or slightly more than double the annual outage kWh of the Nekken T/L (21%). While the Nekken T/L has a relatively small average power outage range of 0.92 MW / time, the total number and total duration of power outages of the Nekken T/L are larger than those of Aimeliik - Malakal line.

Table 6-1-1-4.2 shows the causes of the power outages in the transmission lines, as tabulated from the same outage records. While the expressions used in the outage cause column vary, the data serve adequately to show the typical outage causes in the transmission lines at present. When divided roughly, ① Transient outages are the most frequent type listed in the table. A transient outage is an outage of unspecified cause that is recovered by trial recharging. In most cases, the cause is assumed to be caused by other objects coming into contact with the electric wires. Contact with trees ② and strong winds ③ also cause power outages.

As the lines are mostly installed close to trees, contact with trees is estimated to be the main cause of these outages.

**Table 6-1-1-4.2 Status of power outage in the transmission lines by cause (Analysis of outage data of 2016/10 to 2017/9 by SCD)**

Total number / year (Total kWh / year)

| Cause | Transient | Big tree on the line | Wind faults | Line Fault | Total |
|---|---|---|---|---|---|
| See the above notes on outage causes. | Outages of unspecified causes recovered by trial recharging | Outages caused by contact with tree(s) | Outages caused by strong winds (duration of 12 hours or longer) | Details unclear | |
| Aimeliik-Malakal T/L | 18<br>(39,005) | 0<br>(0) | 0<br>(0) | 1<br>(502) | 19<br>(39,507) |
| Nekken T/L | 43<br>(1,094) | 2<br>(2,147) | 1<br>(10,800) | 1<br>(3,927) | 47<br>(17,968) |
| Total | 61<br>(40,099) | 2<br>(2,147) | 1<br>(10,800) | 2<br>(4,429) | 66<br>(57,475) |

Source: JICA Study Team

Although the system reliability of the transmission lines is low at present, the incidence of outages can be decreased when the double routes of the transmission system are constructed into the final form of the master plan in the future. Once the final form is attained, it will be possible to separate the fault section and minimize the outage by recharging the sound sections using SCADA remote control. The reliability of the transmission lines is therefore expected to be improved in the long term. It will be desirable, however, to improve the reliability of the 34.5 kV lines in each phase of the network (Phase 1, Phase 2) until the final form is attained (Phase 3), given the importance of these lines for transmitting RE power and power supply for load.

**(2) Status of power outages in the distribution system**

Regarding the outages of the 13.8 kV distribution line, the total outage time of the Meyuns distribution lines is prominent, accounting for 18% of the total (see Table 6-1-1-4.1). Table 6-1-1-4.3 shows the outage record for the Meyuns line. On the worst day of outages for this line, February 8, 2017, five intermittent power outages (total 5,288 kWh) occurred in approximately 6 hours (18:20 to 24:10 of the next day) under strong wind conditions. While detailed information on the places and causes of the faults has yet to be confirmed, because of insufficient equipment maintenance is a very likely factor.

**Table 6-1-1-4.3 Power outage record for the Meyuns distribution line (Extract)**

| date | trip | close | duration (min) | causes | (kW) | (kWh) |
|---|---|---|---|---|---|---|
| 10/12 | 2337 | 0119 | 102 | OVERCURRENT PH C, 2027 AMP | 2200 | 3,740 |
| 11/12 | 1313 | 1316 | 3 | OVERCURRENT PH B, 1390 AMP | 3200 | 160 |
| 12/6 | 0311 | 0313 | 2 | OVER CURRENT "C" 1232 AMP | 2050 | 68 |
| 12/9 | 0011 | 0100 | 49 | CUT OFF NEUTRAL LINE | 1950 | 1,593 |
| 1/4 | 2335 | 2446 | 71 | CROSS ARM FAILURE | 2300 | 2,722 |
| 2/8 | 1820 | 1825 | 5 | STRONG WINDS | 2600 | 217 |
| 2/8 | 2018 | 2020 | 2 | STRONG WINDS | 2100 | 70 |
| 2/8 | 2040 | 2128 | 48 | STRONG WINDS | 1600 | 1,280 |
| 2/8 | 2130 | 2205 | 35 | STRONG WINDS | 1500 | 875 |
| 2/8 | 2210 | 2305 | 55 | STRONG WINDS | 1450 | 1,329 |
| 2/8 | 2310 | 2410 | 60 | STRONG WINDS | 1300 | 1,300 |
| 2/11 | 1820 | 1825 | 5 | TRANSIENT LINE FAULT | 2600 | 217 |
| 7/22 | 0935 | 1002 | 27 | OVERCURRENT | 2900 | 1,305 |
| 8/29 | 2055 | 2105 | 10 | LINE FAULT | 3400 | 567 |
| 8/31 | 0230 | 0234 | 4 | TRANSIENT LINE FAULT | 2200 | 147 |
| Total | 15 times | | | | | 15,588 |

Source: JICA Study Team

In addition to the above outage records kept by SCD, PDD has reported data on 13.8 kV line power outages restored. This report includes details on restored outages caused by mishaps such as cutout fuse blowouts, a rather small type of outage compared to the types handled by SCD. Table 6-1-1-4.4 shows a representative power outage list summarized from a report by the IS system. In the technical transfer phase, it will be necessary to observe the present status of the work processes and plan out how to give advice on more effective ways of accumulating and analyzing outage data.

**Table 6-1-1-4.4 Summary of distribution line power outages**
**(List of outages restored by PDD crews (2016/1/17 to 7/1))**

SUMMARY OF POWER INTERRUPTIONS

| DATE | TIME OFF | TIME ON | PHASE | FUSE SIZE | AREA | CAUSES | CATEGORIES | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | TREES | HARDWARES | UNKNOWN | ANIMAL |
| 1/07/2016 | 0100 | 0230 | C | 8 | MONGAMI | UNKNOWN | | | 1 | |
| 30/06/2016 | 0200 | 0330 | B | | NGESAOL | TREE BRANCH ON THE LINE | 1 | | | |
| 30/06/2016 | 2000 | 2200 | B | 8 | NGCHESAR | UNKNOWN | | | 2 | |
| 28/06/2016 | 0500 | 0630 | A,B,C | | NGERBECHED | BETEL NUT LEAVES ON THE LINE | 2 | | | |
| 26/06/2016 | 1130 | 1400 | B | | NGIWAL | COCONUT LEAVES ON THE LINE | 3 | | | |
| 25/06/2016 | 0630 | 0930 | B | | NGURANG | UNKNOWN | | | 6 | |
| 25/06/2016 | 2030 | 2230 | B | | NGCHESAR | UNKNOWN | | | 5 | |
| 24/06/2016 | 2100 | 2400 | A | | NGURANG | UNKNOWN | | | 4 | |
| 24/06/2016 | 0530 | 0730 | C | | NGIWAL | UNKNOWN | | | 3 | |
| 23/06/2016 | 2100 | 0030 | B,C | | ULIMANG SS | TREE BRANCH ON THE LINE | 4 | | | |
| 17/06/2016 | 0945 | 1000 | A,B,C | | WHOLE WEST COAST | BIG TREE FALL | 5 | | | |
| 17/06/2016 | 1630 | 1830 | B | | NGERKEBESANG | UNKNOWN | | | 7 | |
| 17/06/2016 | 1900 | 2200 | B | | NGCHESAR | UNKNOWN | | | 8 | |
| 10/06/2016 | 0230 | 0500 | A | | NGERSUUL (NGCHESAR) | BIG RAT | | | | 1 |
| 31/05/2016 | 0130 | 0630 | C | | CHOLL TO NGARCHELONG | BROKEN U BAND | | 1 | | |
| 28/05/2016 | 1830 | 2000 | A | | KESEBELAU | UNKNOWN | | | 11 | |

Source: IS system, report #13808

### 6-1-1-5 Current status of the transmission lines

#### (1) Outline of the route survey

The current status of the transmission lines was assessed in the route survey. Two transmission lines were selected as investigation targets:

- Aimeliik - Malakal transmission line
- Nekken transmission line

The routes of these lines are shown in Figure 6-1-1-5.1. Both transmission lines are drawn out from the Aimeliik power station. In the section up to Nekken substation (section No.: AM-1, N-1), two transmission line circuits are installed per pole (double-circuit section). In the section (AM-2, N-2) up to COMPACT road (three-way junction), the line circuits are laid on both sides of a road. Along COMPACT road from the three-way junction, the Nekken transmission line runs northward up to the Ngaraard 2 substation at the end. From the same three-way junction running southward, the Aimeliik - Malakal transmission line runs to the Malakal power station via Airai substation and KB Bridge.

The results of the route survey are shown in Table 6-1-1-5.1. Problems in the maintenance of these transmission lines were apparent. Sections (2) and (3) below describe the problems found in the double-circuit section and old road section along COMPACT road.

**Table 6-1-1-5.1 Results of the transmission line route survey**

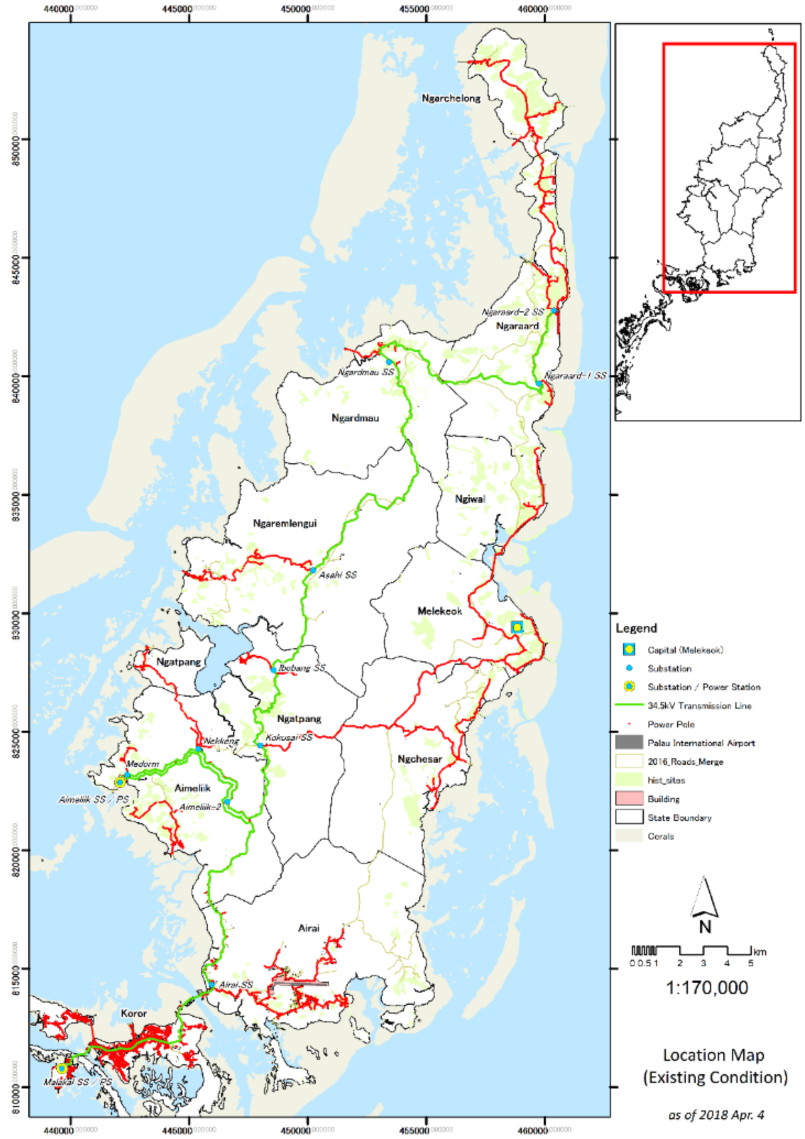
**(1) Aimeliik - Malakal transmission line**

| Section No. | Section (From -) | Outline of site conditions where transmission lines are installed | Length of section (km) |
|---|---|---|---|
| AM-1 | Aimeliik power station - | - Mountain area (roadside installation)<br>- Two transmission line circuits are installed per pole (double-circuit section) | 4.3 |
| AM-2 | Nekken substation - | Mountain area (roadside installation) | 5.2 |
| AM-3 | COMPACT road (starting point towards the south) - | · Mountain area (roadside installation; Some of the poles in this section are installed at difficult-to-maintenance sections of the old road) | 9.0 |
| AM-4 | Airai substation - | · Town area and coast area (roadside installation)<br>· Inside the KB bridge structure | 2.5 |
| AM-5 | Koror Island entrance - | Mountain area (roadside installation) | 1.5 |
| AM-6 | Koror downtown entrance - Malakal Power Station | Town area (roadside installation) | 5.2 |
| | Total | | 27.8 |

**(2) Nekken transmission line**

| Section No. | Section (From -) | Outline of site conditions where transmission lines are installed | Length of section (km) |
|---|---|---|---|
| N-1 | Aimeliik power station - | - Mountain area (roadside installation)<br>- Two transmission line circuits are installed per pole (double-circuit section) | 4.3 |
| N-2 | Nekken substation - | Mountain area (roadside installation) | 5.2 |
| N-3 | COMPACT road (starting point toward the north) - | · Mountain area (roadside installation; Some of the poles in this section are installed at difficult-to-maintenance sections of the old road) | 3.7 |
| N-4 | Kokusai S/S - | - Mountain area (roadside installation; Most of the poles in this section are installed at difficult-to-maintenance sections of the old road.)<br>- Land slippage is observed in parts of the old road. | 5.3 |
| N-5 | Ibobang S/S - | - Mountain area (roadside installation; Most of the poles in this section are installed at difficult-to-maintenance sections of the old road.) | 5.7 |
| N-6 | Asahi S/S - | - Mountain area (roadside installation; Most of the poles in this section are installed at difficult-to-maintenance sections of the old road.) | 14.2 |
| N-7 | Ngardmau S/S - | - Mountain area (Most of the poles in this section are installed at difficult-to-maintenance sections of the old road.)<br>- Town area (The area is easy to go through. The line runs a distance of about 3 km through this area.) | 10.2 |
| N-8 | Ngaraard 1 S/S – Ngaraard 2 S/S | - Mountain area (roadside installation; Most of the poles in this section are installed at difficult-to-maintenance sections of the old road.) | 3.6 |
| | Total | | 52.2 |

Source: Study Teem




Source: Study Teem

**Figure 6-1-1-5.1 Routes of existing transmission lines**

### (2) Status of double-circuit sections (AM-1, N-1)

Two transmission line circuits are mounted per pole in the section running from the Aimeliik Power Station to the Nekken Substation. This condition is causing the following weaknesses in facility maintenance.

- Risk of equipment damage: both lines could black out at the same time if a pole breaks.
- Restrictions on facility maintenance: simultaneous blackout of both lines is required to ensure safety during work on a pole.

When simultaneous blackouts occur in two circuits in this section, the whole power supply from the Aimeliik power station cuts off, causing large impacts on the power supply in the whole of Palau. The integrity of this important section in the power system should be improved by constructing a new pole route to enable conversion from the existing double-circuit into two separate-circuits.

**Figure. 6-1-1-5.2 Status of transmission line mounting on poles in the double-circuit section (Between Aimeliik power station and Nekken substation)**

### (3) Status of the old road section along COMPACT road (N-3 to N-8, AM-3)

Table 6-1-1-5.2 summarizes the installation conditions of the transmission line poles in the section along COMPACT road. The transmission lines run a total length of 52 km mounted on 909 poles. About a quarter of the total, 224 poles, are installed on or near COMPACT road. Most of the other 685 poles run along the decommissioned old road. A very small number of poles run through an approximately 3-km-long village section of the Ngardmau substation area.

Some parts of the old road route section where vehicles could enter were surveyed directly, while other routes inaccessible by vehicles were surveyed by remote visual observation from COMPACT road.

Most of the old road runs through mountainous or damp ground and are poorly maintained. Some parts of the road in this section have been lost by landslide, which makes it difficult to maintain the equipment nearby. Trees close to the lines are currently trimmed to prevent contact and secure passages for maintenance. If the old road is not maintained in the future, the tree trimming work can be expected to become more difficult and less safe to perform. There is a pressing need to address this problem by relocating the existing transmission line along the old road.

COMPACT road is generally well maintained, so the route along the road is a candidate alternative route for relocation. Nearby trees also grow along some parts of COMPACT road, but they would be easier and safer to trim than the trees along the old road. The relocation of the existing line to the side of COMPACT road could be an effective measure to improve the safety of maintenance work and reduce the risk of power outages caused by contact with trees.

**Table 6-1-1-5.2 Summary of the installation conditions of the poles in the section along COMPACT road**

| Section No. | Section (from -) | Length of existing line (km) | Number of poles (A) | On COMPACT road (B) | Not on COMPACT road (C) | (C)/(A) |
|---|---|---|---|---|---|---|
| AM-3 | COMPACT road (starting point towards south) – Airai substation | 9.0 | 155 | 86 | 69 | 45% |
| N-3 | COMPACT road (starting point towards north) - | 3.7 | 68 | 16 | 52 | 76% |
| N-4 | Kokusai S/S - | 5.3 | 88 | 7 | 81 | 92% |
| N-5 | Ibobang S/S - | 5.7 | 99 | 23 | 76 | 77% |
| N-6 | Asahi S/S - | 14.2 | 246 | 43 | 203 | 83% |
| N-7 | Ngardmau S/S - | 10.2 | 177 | 39 | 138 | 78% |
| N-8 | Ngaraard 1 S/S – Ngaraard 2 S/S | 3.6 | 76 | 10 | 66 | 87% |
| Total | | 51.7 | 909 | 224 | 685 | 75% |

Landslide along the old road　　line running over the trees　　line running on the hills

**Figure 6-1-1-5.3 Status of the transmission line route on the old road**

**(4) Directions to take for addressing the maintenance challenges of the existing transmission lines**

A more reliable transmission network will be required to introduce large-scale renewable energy to Palau in the future. A certain level of reliability can be secured with the existing transmission equipment by cutting trees and repairing broken parts. But as the facilities age and the old road continues to deteriorate in the future, the reliability of the facilities concerned will be more difficult to maintain. To address the above challenges expected to emerge, plans will be made to improve the existing transmission line while constructing a new transmission line to secure adequate maintenance and power supply reliability.

### 6-1-2 Substation Facilities

#### 6-1-2-1 Overview of substation facilities

There are 12 substations (see Table 6-1-2-1.1), including substation facilities in power stations, in the Project Sites.

Koror Island, the center of demand in Palau, accounts for 80% of the demand for the whole of the country. Malakal power station on Malakal Island and Aimeliik power station on Babeldaob Island supply diesel-generated power to Koror via Airai Substation.

Airai Substation also supplies power to Palau International Airport.

Two 10 MVA transformers boost the voltage from 13.8 kV to 34.5 kV at Aimeliik Substation located within Aimeliik power station. The other substations are outfitted with only one transformer each. Since there is no redundancy of equipment, the N-1 criteria are not satisfied and inspections cannot be performed by conducting planned outages.

**Table 6-1-2-1.1 List of Substations**

| No. | Name | First Year of Operation | Transformer Ratio (kV) | Main Transformer | Total Capacity (kVA) | Connection |
|---|---|---|---|---|---|---|
| 1 | Malakal | 1995 | 13.8/34.5 | Three-Phase 10 MVA×1 | 10,000 | Y-Y |
| 2 | Airai | 1986 | 34.5/13.8 | Three-Phase 10 MVA×1 | 10,000 | Y-Y |
| 3 | Aimeliik | 1986 | 13.8/34.5 | Three-Phase 10 MVA×2 | 20,000 | Δ-Y |
| 4 | Aimeliik-1 | 1986 | 34.5/13.8 | Three-Phase 1000 kVA×1 | 1,000 | Δ-Y |
| 5 | Aimeliik-2 | 1986 | 34.5/13.8 | Single-Phase 75 kVA×3 | 225 | Δ-Y |
| 6 | Nekken | 1986 | 34.5/13.8 | Single-Phase 75 kVA×3 | 225 | Δ-Y |
| 7 | Kokusai | 1995 | 34.5/13.8 | Three-Phase 5 MVA×1 | 5,000 | Δ-Y |
| 8 | Ibobang | 1995 | 34.5/13.8 | Single-Phase 75 kVA×3 | 225 | Δ-Y |
| 9 | Asahi | 1996 | 34.5/13.8 | Three-Phase 300 kVA×1 | 300 | Δ-Y |
| 10 | Ngardmau | 1999 | 34.5/13.8 | Single-Phase 75 kVA×3 | 225 | Δ-Y |
| 11 | Ngaraard-1 | 1999 | 34.5/13.8 | Single-Phase 25 kVA×3 | 75 | Δ-Y |
| 12 | Ngaraard-2 | 1999 | 34.5/13.8 | Three-Phase 750 kVA×1 | 750 | Δ-Y |

Three of the substations listed in Table 6-1-2-1.1, namely, Aimeliik, Malakal, and Airai, are equipped with circuit breakers for the protection of the transmission and distribution lines. The other substations are equipped with simple combinations of smaller-capacity distribution transformers with load break switches and power fuses. Due to the single-circuit arrangement for lines and transformer bays, continuous power cannot be supplied during a power failure or maintenance work on the facilities.

Appendix A-4 (SS-01 - SS-12) shows a single line diagram for substation facilities and the configurations of each substation confirmed by field surveys and documents received from PPUC.

**6-1-2-2 Condition of substation facilities**

The conditions of each substation are shown in Appendix A-5 “Field Survey Report (Substation Facilities)”. Because the facilities are aged and improperly maintained, there have been frequent troubles and power failures overall. Most notably, non-functional load break switches in various substations make it impossible to minimize the area affected by interrupted power supply during recovery drills. It will therefore be helpful to secure 38 kV LBS in necessary quantities for spare parts.

Most of the moisture absorbers for the main transformers are discolored and have to be better maintained and periodically replaced. It would also be helpful to secure the necessary quantities of silica.

The substations were constructed in 1986 and continue to age. Improvement plans with equipment replacements are considered for the substations shown in Table 6-1-2-2.1.

Table 6-1-2-2.1 List of candidate substations requiring countermeasures against age

| No. | Name | First Year of Operation | Transformer Ratio (kV) | Main Transformer | Total Capacity (kVA) | Connection |
|---|---|---|---|---|---|---|
| 1 | Airai | 1986 | 34.5/13.8 | Three-Phase 10 MVA×1 | 10,000 | Y-Y-Δ |
| 2 | Aimeliik | 1986 | 13.8/34.5 | Three-Phase 10 MVA×2 | 20,000 | Δ-Y |
| 3 | Aimeliik-1 | 1986 | 34.5/13.8 | Three-Phase 1000 kVA×1 | 1,000 | Δ-Y |
| 4 | Aimeliik-2 | 1986 | 34.5/13.8 | Single-Phase 75 kVA×3 | 225 | Δ-Y |
| 5 | Nekken | 1986 | 34.5/13.8 | Single-Phase 75 kVA×3 | 225 | Δ-Y |

## 6-2 Equipment Plan for a 34.5 kV Transmission Line

### 6-2-1 Construction of a New Transmission Lines under the Master Plan

With respect to the transmission system of PPUC, a transmission line and substations are to be constructed with the aim of establishing a master plan network that addresses the demand increment and the planned RE introduction by the year of 2025. The route of the new transmission line is to start from Ngaraard1 Substation, run onward to COMPACT road via the areas near the capital and near the airport, cross KB Bridge, run through the downtown area of Koror Island, and end at Malakal Power Station (Figure 6-2-1.1).


**Figure 6-2-1.1 Route of the new transmission line (blue line)**

COMPACT Road    Existing cable-pulling pole near KB Bridge    Downtown Koror

**Figure 6-2-1.2 Status of the installation sites along the new construction route**

### 6-2-2 Power Transmission Capacity and Reinforcements Measures

As shown in the results of the system analysis, the conductors in the existing transmission lines in PPUC are already large enough in size to achieve the required capacity from the viewpoint of allowable current and voltage drops up to the year 2030. Capacity reinforcements are thus unnecessary.

### 6-2-3 Improvement Plan for Existing Transmission Line

As described in 6-1-1-5, the existing transmission line is to be improved to secure adequate maintenance and power supply reliability through the following steps.

- Relocation of the transmission line (section along COMPACT road)
- Separation of the double-circuit in the transmission line (section from Aimeliik power station to Nekken substation)

Figure 6-2-3.1 shows the route of the existing transmission line to be improved under the plan.

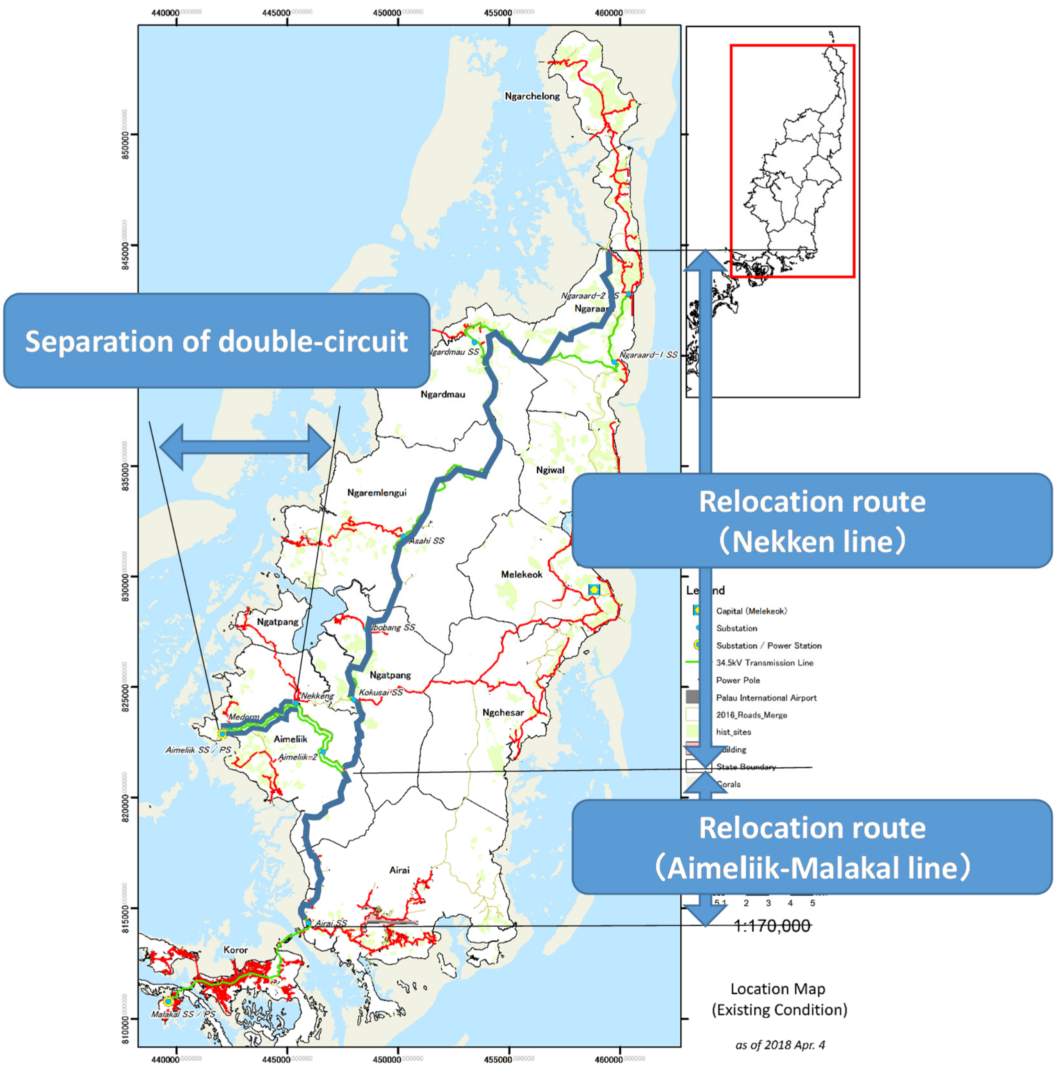



**Figure 6-2-3.1 Route of the existing transmission line to be improved under the plan**

### 6-2-3-1 Relocation of transmission lines

#### (1) Relocation policy

The plan for relocating the transmission line was established by considering the following policy.

##### 1) Relocation of transmission lines

The existing transmission lines on sections of the old road where equipment is difficult to maintain are to be relocated to a new route constructed easily accessible by vehicles along COMPACT road. Insulated wire will be applied for the 34.5 kV line conductors. In the section along COMPACT road, existing poles will be diverted and deteriorated equipment such as wires and arms will be replaced. The decommissioned transmission line on the old road is assumed to be left as is, with no plans for removal.

##### 2) Relocation of substations

Along with the above 1), the substations at Asahi, Ngardmau, Ngaraard 1 and Ngaraard 2 will be relocated to near the side of COMPACT road.

##### 3) Securing connection lines to the existing 13.8 kV distribution lines

Along with the above 2), that 13.8 kV distribution lines that connect the section between the relocated substations and existing substations are to be secured by constructing new 13.8 kV routes, by diverting the existing 34.5 kV lines to 13.8 kV lines, and so on.

#### (2) Outline of replacement plan of transmission line

The map in Fig. 6-2-3-1.1 outlines the replacement plan in the section from around Ngardmau S/S toward the end, a plan based on the policy described above.

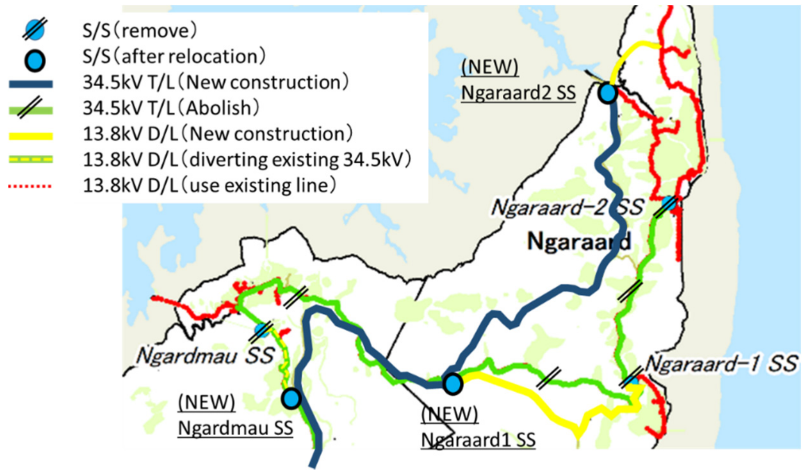



**Figure 6-2-3-1.1 Map outlining the replacement plan in the section from around Ngardmau S/S toward the end**

The plan for the transmission line replacement work is outlined in Table 6-2-3-1.1.

Because Ngaraard1 substation is placed at the end of the section in the plan for the construction of new transmission lines, the result has to be reflected in the plan when this replacement work is to be done in advance.

**Table 6-2-3-1.1 Outline of the work plan for relocating the transmission lines**

| Class | Work planned | Supplementary note |
|---|---|---|
| Transmission | Replacement (construction length) 45.2 km<br>- Nekken line: 36.2 km<br>- A-M line: 9.0 km | The existing transmission line (section length: 51.7 km) related to the replaced section shall be treated as follows.<br>1) Existing poles on COMPACT road are to be used in the existing position (Nekken line 2.8 km, A-M line 4.9 km)<br>2) Diversion to the 13.8 kV line (near Ngardmau substation) (1.5 km)<br>3) Left as is (no removal planned) (47.4 km) |
| Distribution | New line construction 6.0 km<br>·- Near Ngaraard1 substation : 4.6 km<br>·- Near Ngaraard2 substation : 1.4 km | |

### 6-2-3-2 Separation of double-circuit of transmission lines

#### (1) Policy for separation

Because there are no other roads available for this target section, one route of poles is to be added to the existing route and the existing two transmission circuits are to be separated to opposite sides of the road. In the first step, both circuits will remain on the side of the road where most of the existing poles are installed, in order to secure the same transmission capacity as the lines. Next, one more circuit will be constructed on the other side of the road. While the existing poles are to be used in this separation work, deteriorated equipment on the pole such as wires and arms will be replaced. Insulated wires will serve as the conductor wires.

#### (2) Outline of the plan for separating the double-circuit

The work plan for separating the double-circuit of transmission line is outlined in Table 6-2-3-2.1.

**Table 6-2-3-2.1 Outline of the work plan for separating the double-circuit**

| Class | Work planned | Supplementary note |
|---|---|---|
| Transmission | Replacement (construction length) 8.6 km<br>- Nekken line: 4.3 km<br>- A-M line: 4.3 km | Separate the equipment in the existing double-circuit transmission line section (section length: 4,3 km) |

## 6-3 Equipment Planning for the 13.8 kV Distribution Lines

### 6-3-1 System Planning for the 13.8 kV Distribution Lines

The master plan for the 13.8 kV distribution has been examined based on the construction and improvement plan for the transmission. The following individual plans for the transmission lines and substations for the 13.8 kV lines need to be addressed.

1) Relocation of substations accompanying the relocation of the Nekken T/L
2) Construction of a new Koror S/S

The relocation of the Nekken T/L is already outlined in the previous section. As for the others, new distribution lines are to be formed by switching and diverting the existing lines as described below.

### 6-3-1-1 Addressing the construction of the new Koror S/S

The distribution lines around the new Koror S/S are planned according to the following policy. The transition step are outlined in Fig. 6-3-1-1.1.

#### (1) Load switching from the Airai S/S to Koror S/S

Switching the load on the existing Airai Koror line to a new feeder from the Koror S/S (in around 2020).

Switching the load on the existing Airai Airport line to a new feeder from the Koror S/S. (Because the Airai S/S is located near the load demand area (airport), it will supply power for as long as it exists. Later, when the Airai S/S is decommissioned the load will be switched to the Koror S/S.)

#### (2) Construction of a new feeder for the center of Koror Island

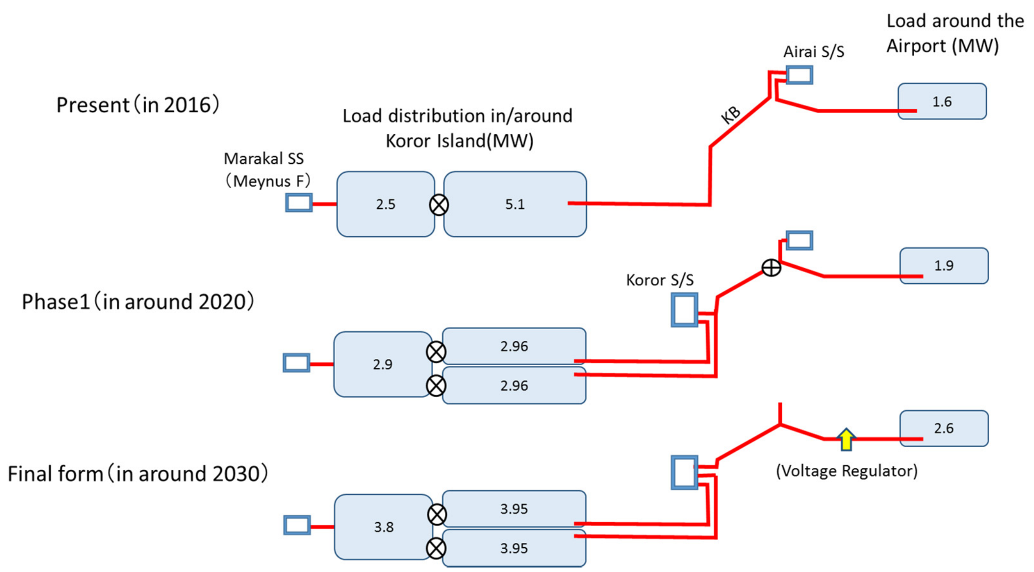
The following 2 feeders are currently supplying power to Koror Island.

- Airai Koror line (Airai substation)
- Meyuns Line (Malakal Substation)

Each feeder has the capacity to back up the other line if one line is stopped. However, as described in 6-3-2-2 (1), the capacity for backup will be insufficient when the load increases in the future. The construction of a new feeder from the Koror substation is therefore planned. About half of the load on the existing Airai Koror line is to be transferred to the new feeder.

#### (3) Construction of a new feeder for the area around the airport

A new feeder from the Koror S/S to the area around the airport will be constructed to separate the distribution network toward the center of Koror Island. The reliability of the two divided feeders will be improved by shutting down the effects of faults on each.




Source: JICA Study Team

**Figure 6-3-1-1.1 Diagram outlining the transition of the 13.8 kV distribution system in relation to the construction of the Koror S/S**

### 6-3-2 Plan for the Reinforcement of the 13.8 kV Distribution Lines

The need for distribution line reinforcement has been examined by checking whether the current capacity and voltage drops in the 13.8 kV lines exceed the reference values under the estimated demand conditions up to 2030. The lines will be reinforced by adding new feeders or by upgrading the size of the trunk line conductors.

The forms of the existing network the final network in 2030 have both been examined.

#### 6-3-2-1 Evaluation of the need to reinforce the form of the existing distribution network

Table 6-3-2-1.1 shows the capacity of the existing PPUC distribution lines.

**Table 6-3-2-1.1 Capacity of major PPUC distribution lines**

| Voltage | Conductor | transmission capacity (MW) |
|---|---|---|
| 13.8 kV | ACSR336MCM | 9.1 |
| | CU2 | 5.7 |

Source: PPUC

The following section examines the need for reinforcement of each 13.8 kV distribution line in the existing network form under the assumed demand conditions (without taking RE in consideration). The results are shown in Table 6-3-2-1.2.

**Table 6-3-2-1.2 Results of the evaluation of distribution line reinforcement (13.8 kV)**
**(Assumptions: current network form, predicted demand in 2030, RE not considered)**

| Distribution line | | | | Current capacity | | Voltage drop | | | Notes |
|---|---|---|---|---|---|---|---|---|---|
| Power source | Name of 13.8 kV line | Trunk line conductor | Feeder current capacity (MW) | Assumed load (MW) | Result | Assumed length of trunk line (km) | Voltage drop rate | Result | |
| Airai S/S | Airai –Airport | AAC336 | 9.1 | 2.6 | ○ | 9.6 | 5.5% | × | |
| | Airai - Koror | AAC336 | 9.1 | 7.9 | ○ | 6.8 | 5.5% | × | |
| Malakal P/S | Meyuns feeder | AAC336 | 9.1 | 3.8 | ○ | 4.6 | 3.9% | ○ | |
| | Malakal feeder | AAC336 | 9.1 | 1.4 | ○ | 1.5 | 0.5% | ○ | |
| Aimeliik - Malakal T/L | Aimeliik -2 S/S | AAC336 | 9.1 | 0.3 | ○ | 5 | 0.3% | ○ | |
| Nekken T/L | Aimeliik -1 S/S | AAC336 | 9.1 | 0.2 | ○ | 1.5 | 0.1% | ○ | |
| | Nekken S/S | AAC336 | 9.1 | 0.1 | ○ | 5.9 | 0.1% | ○ | |
| | Kokusai S/S | AAC336 | 9.1 | 1.2 | ○ | 26.5 | 5.4% | × | |
| | Ibobang S/S | Cu.2 | 5.7 | 0.01 | ○ | 1.8 | 0.0% | ○ | |
| | Asahi S/S | AAC336 | 9.1 | 0.1 | ○ | 6.8 | 0.2% | ○ | |
| | Ngardmau S/S | AAC336 | 9.1 | 0.1 | ○ | 1.6 | 0.0% | ○ | |
| | Ngarraard-1 S/S | Cu.2 | 5.7 | 0.1 | ○ | 1.5 | 0.0% | ○ | |
| | Ngarraard-2 S/S | AAC336 | 9.1 | 0.6 | ○ | 14.4 | 2.0% | ○ | |

Legend: Voltage drop for criteria value ○ : Not exceeded × : Exceeded
Source: JICA Study Team

**(1) Excess of current capacity (in existing feeders)**

Each existing feeder was confirmed to have sufficient current capacity to supply the estimated load up to 2030.

The Meyuns feeder and Airai-Koror feeder have mutual interconnection switches, so a backup load can be obtained by one from the other when an outage occurs in either. The combined load of both distribution lines, however, will be 7.9 MW + 3.8 MW = 11.7 MW in 2030, a level that exceeds the allowable capacity of each distribution line (9.1 MW). A new feeder from the Koror S/S for the center of Koror Island is therefore added in the master plan, as described in 6-3-1-2.

**(2) Excess voltage drop (in existing feeders)**

The voltage drop was evaluated with the criteria set as +/- 5%. The results showed that the value will be exceeded in two lines from the Airai S/S and in one line from the Kokusai S/S in the existing system. The following section shows the evaluation result for the case where the final form of the 13.8 kV master plan line is adopted.

### 6-3-2-2 Evaluation of the need for reinforcement in the final system form under the master plan

Following is an examination of the need for reinforcement for each 13.8 kV distribution line in the final network form in the master plan under the assumed demand conditions (without considering RE). The results are shown in Table 6-3-2-2.1. The 13.8 kV distribution lines that change in form due to S/S construction or relocation are indicated in yellow.

**Table 6-3-2-2.1 Examination of the need to reinforce the 13.8 kV distribution system (Assumptions: final network form, predicted demand in 2030, without RE)**

| Distribution line | | | | Current capacity | | Voltage drop | | | Notes |
|---|---|---|---|---|---|---|---|---|---|
| Power source | Name of 13.8 kV line | Trunk line conductor | Feeder current capacity (MW) | Assumed load (MW) | Result | Assumed length of trunk line (km) | Voltage drop rate | Result | |
| New Koror S/S (substitution for Airai S/S) | New Koror S/S -Airport | AAC336 | 9.1 | 2.6 | ○ | 13.5 | **7.7%** | × | To North of airport |
| | New Koror S/S -Koror feeder A | AAC336 | 9.1 | 3.95 | ○ | 2.9 | 2.5% | ○ | (The existing load is equally divided between feeders A and B.) |
| | New Koror S/S -Koror feeder B | AAC336 | 9.1 | 3.95 | ○ | 2.9 | 2.5% | ○ | |
| Malakal P/S | Meyuns feeder | AAC336 | 9.1 | 3.8 | ○ | 4.6 | 3.9% | ○ | to L75 |
| | Malakal feeder | AAC336 | 9.1 | 1.4 | ○ | 1.5 | 0.5% | ○ | |
| Aimeliik-Malakal T/L | Aimeliik -2 S/S | AAC336 | 9.1 | 0.3 | ○ | 5 | 0.3% | ○ | |
| Nekken T/L | Aimeliik -1 S/S | AAC336 | 9.1 | 0.2 | ○ | 1.5 | 0.1% | ○ | |
| | Nekken S/S | AAC336 | 9.1 | 0.1 | ○ | 5.9 | 0.1% | ○ | |
| | Kokusai S/S | AAC336 | 9.1 | 1.2 | ○ | 26.5 | 5.43% | ○ | |
| | Ibobang S/S | Cu.2 | 5.7 | 0.01 | ○ | 1.8 | 0.0% | ○ | |
| | Asahi S/S | AAC336 | 9.1 | 0.1 | ○ | 6.8 | 0.2% | ○ | |
| | New Ngardmau S/S | AAC336 | 9.1 | 0.1 | ○ | 3.1 | 0.0% | ○ | |
| | New Ngarraard-1 S/S | Cu.2 | 5.7 | 0.1 | ○ | 5.0 | 0.1% | ○ | |
| | New Ngarraard-2 S/S | AAC336 | 9.1 | 0.6 | ○ | 15.8 | 2.2% | ○ | |

Legend: Current capacity / Voltage drop for criteria value ○ : Not exceeded × : Exceeded
Source: JICA Study Team

**(1) Excess of current capacity**

Each existing feeder was confirmed to have sufficient current capacity to supply the estimated load up to 2030. As described above, along with the construction of the Koror S/S, one new feeder towards the center of Koror Island is to be added to secure two feeders in total, with the load of the existing distribution feeder divided into two. With this system reinforcement, load backup can be provided by the Meyuns line in the event of a fault.

**(2) Excess voltage drop**

The voltage drop was evaluated with the criterion set as +/- 5%.

Since the feeder for the airport area is switched from the Airai S/S to the new Koror S/S in the master plan, the feeder length is extended and the voltage drop is increased. These changes will be addressed in the construction stage by carrying out a detailed voltage drop evaluation with the individual load distribution factored in, and equipment for voltage regulation such as line SVRs (step voltage regulators) will be installed as needed.

The voltage drop in the distribution line from Koror S/S to Koror Island can be reduced to 5% or less by adding one feeder to divide the load.

The voltage drop in the existing feeder from the Kokusai S/S can be kept within the criterion value by switching the supply feeder for the load around the capital area from the Kokusai S/S to the new Melekeok S/S.

### 6-3-3 Impact of Introducing RE into the 13.8 kV Distribution Lines

Based on the Palau government's goal of generating 45% of its energy from RE sources by 2025, the master plan for the power system was examined with the assumption that RE will mainly be introduced through the establishment of large-scale PV power plants. As described in Chapter 5, PPUC expects the RE power plants to be as large as 3 to 6 MW, that is, of a capacity sufficient to connect to the transmission lines.

There can also be cases, however, of grid interconnection of medium-sized RE of around 1 MW to 13.8 kV distribution lines. Those cases should be examined individually, case by case, to consider the interconnection position and RE power source output. The influences of RE on current capacity and voltage drops when connected to 13.8 kV distribution lines were examined for reference. For the calculation of typical model cases, interconnection of an RE power source of around 1 MW at the end of the trunk line is assumed.

[Assumed model cases]

1) RE generation output: 0.5 MW / 1 MW / 2 MW
2) Line current: same as the expected RE generation output (the load current is set to 0 as the maximum case)
3) Interconnection position of RE: at the end of the trunk line (to maximize the influence on voltage)

Regarding the capacity of the line, existing lines have at least 5.7 MW, so the current from RE will not exceed the line capacity in the assumed model cases.

The results on voltage in the existing system and the final system in the master plan are shown in Table 6-3-3.1 and Table 6-3-3.2, respectively. The voltage rise exceeded 5% in the following cases of RE interconnection.

· Existing system:

Connection of 1 MW to the end of the Kokusai S/S feeder (Ngiwal)

Connection of 2 MW to the end of the Ngaraard 2 S/S feeder (Ollei)

· Final system:

Connection of 2 MW to the end of the new Koror - airport line (around the north side of the airport)

Connection of 2 MW to the end of the new Melekeok S/S feeder (Ngiwal)

Connection of 2 MW to the end of the new NGARAARD 2 S/S feeder (Ollei)

As described above with respect to the 13.8 kV distribution lines, the examinations showed that some degree of RE interconnection is possible in terms of the current capacity and voltage drops.

The distribution substation equipment in Palau, however, are generally small in capacity and have only simple protection by fuses. The state of the equipment makes it necessary to examine the influence of reverse flow into the power transmission system when planning the interconnection of large RE sources. The decision of whether or not to interconnect RE should be examined for each practical case while considering the need for the following measures in the power system.

· Securing the capacity of the substation transformers

· Installation of protection systems for fault detections and circuit breaks

**Table 6-3-3.1 Voltage rise in 13.8 kV distributions line in the model case of RE interconnection (Assumptions: existing system form, no load current, RE interconnected)**

| Distribution line | | | | Voltage drop | | | | Note (end of route) |
|---|---|---|---|---|---|---|---|---|
| Power source | Name of 13.8 kV line | Trunk line conductor | Feeder current capacity (MW) | Assumed length of trunk line (km) | 0.5 MW | 1 MW | 2 MW | |
| Airai S/S | Airai –Airport | AAC336 | 9.1 | 9.6 | 1.1% | 2.1% | 4.2% | North of airport |
| | Airai - Koror | AAC336 | 9.1 | 6.8 | 0.3% | 0.6% | 1.2% | |
| Malakal P/S | Meyuns feeder | AAC336 | 9.1 | 4.6 | 0.5% | 1.0% | 2.0% | |
| | Malakal feeder | AAC336 | 9.1 | 1.5 | 0.2% | 0.3% | 0.7% | |
| Aimeliik -Malakal T/L | Aimeliik -2 S/S | AAC336 | 9.1 | 5 | 0.6% | 1.1% | 2.2% | |
| Nekken T/L | Aimeliik -1 S/S | AAC336 | 9.1 | 1.5 | 0.2% | 0.3% | 0.7% | |
| | Nekken S/S | AAC336 | 9.1 | 5.9 | 0.7% | 1.3% | 2.6% | |
| | Kokusai S/S | AAC336 | 9.1 | 26.5 | 3.4% | 6.8% | 13.6% | Ngiwal |
| | Ibobang S/S | Cu.2 | 5.7 | 1.8 | 0.3% | 0.7% | 1.3% | |
| | Asahi S/S | AAC336 | 9.1 | 6.8 | 0.8% | 1.5% | 3.0% | |
| | Ngardmau S/S | AAC336 | 9.1 | 1.6 | 0.2% | 0.4% | 0.7% | |
| | Ngarraard-1 S/S | Cu.2 | 5.7 | 1.5 | 0.3% | 0.6% | 1.1% | |
| | Ngarraard-2 S/S | AAC336 | 9.1 | 14.4 | 1.6% | 3.2% | 6.3% | Ollei |

Legend: Criterion set for excess voltage drop 〇：Not exceeded ×：Exceeded

Source: JICA Study Team

**Table 6-3-3.2 Voltage rise in 13.8 kV distribution lines in the model case of RE interconnection (Assumptions: final system form, no load current, RE interconnected)**

| Distribution line | | | | Voltage drop | | | | Note (end of route) |
|---|---|---|---|---|---|---|---|---|
| Power source | Name of 13.8 kV line | Trunk line conductor | Feeder current capacity (MW) | Assumed length of trunk line (km) | 0.5 MW | 1 MW | 2 MW | |
| New Koror S/S (substitution for Airai S/S) | New Koror S/S -Airport | AAC336 | 9.1 | 13.5 | 1.5% | 3.0% | 5.9% | north of airport |
| | New Koror S/S -Koror feeder A | AAC336 | 9.1 | 2.9 | 0.3% | 0.6% | 1.3% | (Existing load is equally divided on feeder A and B) |
| | New Koror S/S -Koror feeder B | AAC336 | 9.1 | 2.9 | 0.3% | 0.6% | 1.3% | |
| Malakal P/S | Meyuns feeder | AAC336 | 9.1 | 4.6 | 0.5% | 1.0% | 2.0% | |
| | Malakal feeder | AAC336 | 9.1 | 1.5 | 0.2% | 0.3% | 0.7% | |
| Aimeliik-Malakal T/L | Aimeliik -2 S/S | AAC336 | 9.1 | 5 | 0.6% | 1.1% | 2.2% | |
| Nekken T/L | Aimeliik -1 S/S | AAC336 | 9.1 | 1.5 | 0.2% | 0.3% | 0.7% | |
| | Nekken S/S | AAC336 | 9.1 | 5.9 | 0.7% | 1.3% | 2.6% | |
| | Kokusai S/S | AAC336 | 9.1 | 26.5 | 3.4% | 5.8% | 13.6% | |
| | Ibobang S/S | Cu.2 | 5.7 | 1.8 | 0.3% | 0.7% | 1.3 % | |
| | Asahi S/S | AAC336 | 9.1 | 6.8 | 0.8% | 1.5% | 3.0% | |
| | New Ngardmau S/S | AAC336 | 9.1 | 3.1 | 0.3% | 0.7% | 1.4% | |
| | New Ngarraard-1 S/S | Cu.2 | 5.7 | 5.0 | 0.9% | 1.9% | 3.7% | |
| | New Ngarraard-2 S/S | AAC336 | 9.1 | 15.8 | 1.7% | 3.5% | 6.9% | Ollei |

Legend: Criterion set for excess voltage drop ○ : Not exceeded × : Exceeded
Source: JICA Study Team

## 6-4 Substation Facility Planning

### 6-4-1 Concept for Substation Facility Planning

The basic concept for substation facility planning is as follows:

- **Countermeasures against the results of power demand forecasts**
  - A power flow analysis for the years 2020, 2023, and 2025 has been conducted by allocating the load demand for each substation. The method used is explained in Chapter 5 "Power system plan & Power system analysis" based on the result of the power demand forecasts in Chapter 4 "Power Demand Forecasts." The basis for the expansion or extension is set when the load reaches 100% of the capacity, as the actual demand may shift with a higher growth rate. The results show, however, that there is no need to reinforce the substation capacity, as none of the cases reach 100% capacity.
  - Reinforcement at some point after 2025 will be recommended unless any of the facilities are very likely to exceed the 100% capacity soon after that year.
- **Countermeasures against the aging of substation facilities**
  - There is no urgent need to replace the equipment, though visual inspections at the beginning of the project identified some facilities that will require maintenance. The target schedule for the replacement of the substation facilities will be set at 40 years after the commencement of operation, but none of the facilities require countermeasures within the period of the master plan (2025).
  - Replacement at some point after 2025 will be recommended for the facilities unless facilities are

to reach the 40 year point immediately after that year.

- **Improving power supply reliability**

  - The future role of the substation in supplying power to the load center will be considered in the facility configuration at Koror substation.
  - The grid connection of the solar power generation and looping transmission line operation will be considered in the configuration of the transmission line system.

- **Improving the manageability of maintenance**

Basically, maintenance or replacement of single transformer bank should be enabled. Furthermore, second transformer bank at main substations after 2025 will be introduced in order to meet the future demand.
The superannuated condition of the substations built in 1986 calls for improvements. The improvement or replacement of the substations shown in Table 6-4-1.1 is therefore being considered.

**Table 6-4-1.1 List of candidate substations requiring countermeasures against aging**

| No. | Name | First Year of Operation | Transformer Ratio (kV) | Main Transformer | Total Capacity (kVA) | Connection |
|---|---|---|---|---|---|---|
| 1 | Airai | 1986 | 34.5/13.8 | Three-Phase 10 MVA×1 | 10,000 | Y-Y |
| 2 | Aimeliik | 1986 | 13.8/34.5 | Three-Phase 10 MVA×2 | 20,000 | Δ-Y |
| 3 | Aimeliik-1 | 1986 | 34.5/13.8 | Three-Phase 1000 kVA×1 | 1,000 | Δ-Y |
| 4 | Aimeliik-2 | 1986 | 34.5/13.8 | Single-Phase 75 kVA×3 | 225 | Δ-Y |
| 5 | Nekken | 1986 | 34.5/13.8 | Single-Phase 75 kVA×3 | 225 | Δ-Y |

The insulators at the Airai substation are subject to harsh pollution due to the substation's location near the shore. In the plans for equipment replacement, the 34.5 kV switch equipment is therefore the cubicle type rather than the air-insulated type. A bushing type is not used for the transformer, and the overhead line will be changed to a CV power cable, a type preferable from the viewpoint of substation maintenance efficiency and minimized space.

The Aimeliik substation serves a function equally important to that of the Malakal substation for PPUC. High-quality supply reliability will accordingly be required. If a transformer or oil circuit breaker leaks oil due to progressive aging, the equipment will have to be replaced before it begins to drip oil.

### 6-4-2 Countermeasures to Attain a More Reliable Power Supply

The Study Team has considered three types of countermeasures for power supply more reliable than that from the aging Airai substation. The countermeasures are summarized below (a more detailed explanation can be found in the table below). In conclusion, the "Plan-C Construction of a New Koror Substation" is highly evaluated and recommended.

#### Plan-A Improvement of the Existing Airai Substation (Evaluation: Low)

This is a plan to secure additional land surrounding the existing Airai substation in Airai State. This plan is evaluated as low for two reasons: additional land (private) would be difficult to acquire and the additional site preparations on slopes and frequent power outages for installation and changeover works would have high cost impacts.

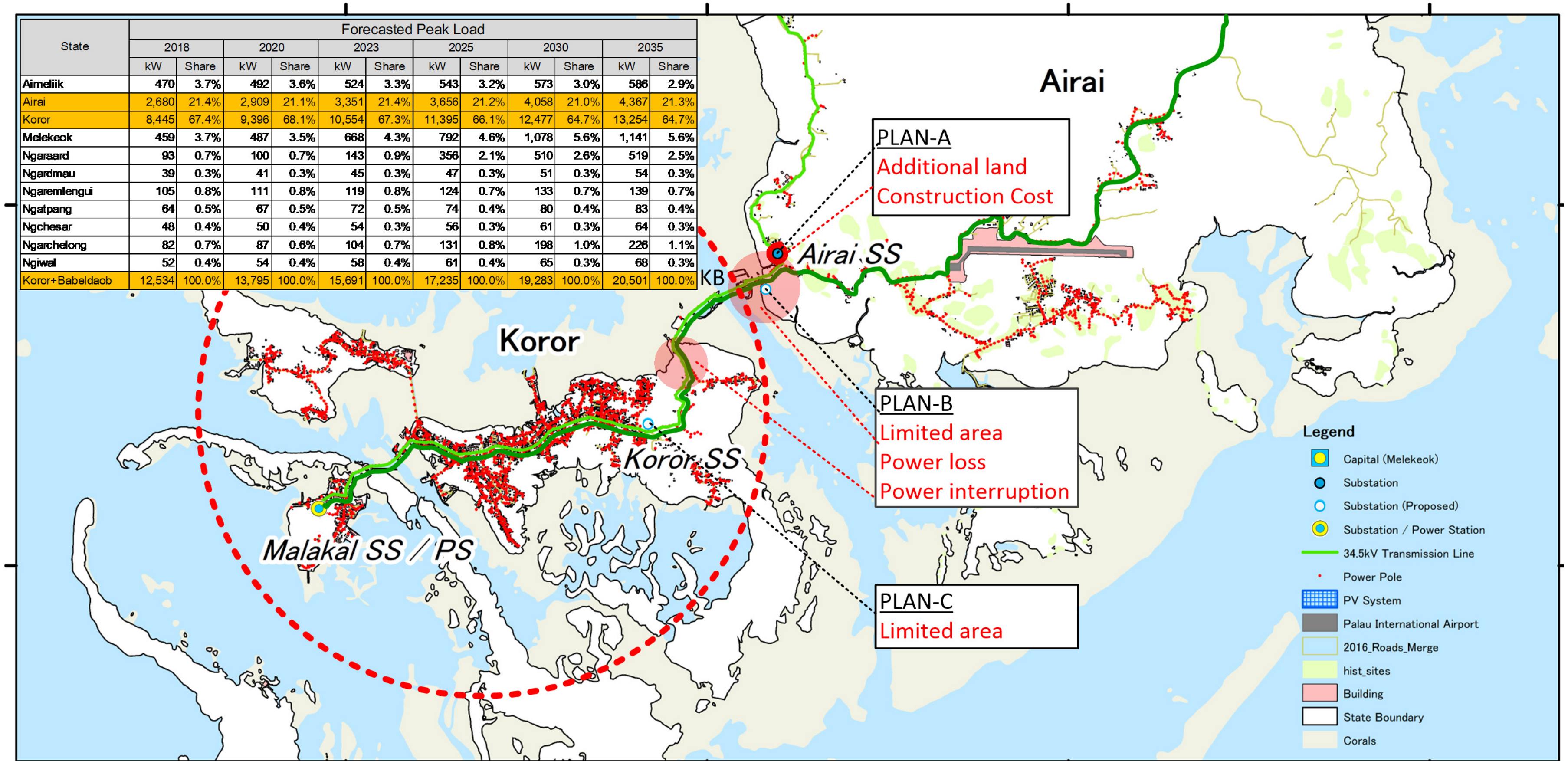
**Plan-B Renewal of the Airai Substation (Evaluation: Medium)**

This is a plan to secure land for a new substation somewhere in Airai state. The evaluation would be high if based solely on the installation conditions, implementation period, and cost impact from the free acquisition of government-owned land. The location, however, could be closer to the load-center in Koror state. When evaluated in terms of reliable power supply to the load-center in Koror state, this plan is compromised by power loss and a risk of power interruption due to the placement of the line route along with the bushes falling off the cliff.

**Plan-C Construction of a New Koror Substation (Evaluation: High)**

Although land acquisition of the substation land might be difficult, this plan receives the highest evaluation, provided that the land is available and there are no substantial environmental or social concerns. The plan offers greater advantages for all of the evaluation items, including improved power supply reliability for the load-center Koror state.

| State | Forecasted Peak Load 2018 | | 2020 | | 2023 | | 2025 | | 2030 | | 2035 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kW | Share | kW | Share | kW | Share | kW | Share | kW | Share | kW | Share |
| Aimeliik | 470 | 3.7% | 492 | 3.6% | 524 | 3.3% | 543 | 3.2% | 573 | 3.0% | 586 | 2.9% |
| Airai | 2,680 | 21.4% | 2,909 | 21.1% | 3,351 | 21.4% | 3,656 | 21.2% | 4,058 | 21.0% | 4,367 | 21.3% |
| Koror | 8,445 | 67.4% | 9,396 | 68.1% | 10,554 | 67.3% | 11,395 | 66.1% | 12,477 | 64.7% | 13,254 | 64.7% |
| Melekeok | 459 | 3.7% | 487 | 3.5% | 668 | 4.3% | 792 | 4.6% | 1,078 | 5.6% | 1,141 | 5.6% |
| Ngaraard | 93 | 0.7% | 100 | 0.7% | 143 | 0.9% | 356 | 2.1% | 510 | 2.6% | 519 | 2.5% |
| Ngardmau | 39 | 0.3% | 41 | 0.3% | 45 | 0.3% | 47 | 0.3% | 51 | 0.3% | 54 | 0.3% |
| Ngaremlengui | 105 | 0.8% | 111 | 0.8% | 119 | 0.8% | 124 | 0.7% | 133 | 0.7% | 139 | 0.7% |
| Ngatpang | 64 | 0.5% | 67 | 0.5% | 72 | 0.5% | 74 | 0.4% | 80 | 0.4% | 83 | 0.4% |
| Ngchesar | 48 | 0.4% | 50 | 0.4% | 54 | 0.3% | 56 | 0.3% | 61 | 0.3% | 64 | 0.3% |
| Ngarchelong | 82 | 0.7% | 87 | 0.6% | 104 | 0.7% | 131 | 0.8% | 198 | 1.0% | 226 | 1.1% |
| Ngiwal | 52 | 0.4% | 54 | 0.4% | 58 | 0.4% | 61 | 0.4% | 65 | 0.3% | 68 | 0.3% |
| Koror+Babeldaob | 12,534 | 100.0% | 13,795 | 100.0% | 15,691 | 100.0% | 17,235 | 100.0% | 19,283 | 100.0% | 20,501 | 100.0% |




| PLAN-A Improvement of existing Airai substation | PLAN-B Renewal of the Airai substation | PLAN-C Construction of New Koror substation |
|---|---|---|
| (0.14acre→ approx.0.21acre)<br>(Evaluation: Low)<br>--- Advantage---<br>• Utilization of secured land<br>• No involuntary resettlement<br>--- Disadvantage---<br>• Additional land (private) acquisition<br>• Additional site preparation on the slope<br>• Power outage for installation and changeover works. | (approx.0.12acre)<br>(Evaluation: Medium)<br>---Advantage---<br>• Free-land acquisition<br>• Construction cost<br>• Construction Period<br>---Disadvantage---<br>• Limited area closer to the Load-center<br>• Power loss (approx.: 5km)<br>• Risk of power interruption | (approx.0.12acre)<br>(Evaluation: High)<br>---Advantage---<br>• Free-land acquisition<br>• Construction cost<br>• Construction Period<br>• Power supply reliability for Koror<br>---Disadvantage---<br>• Limited area closer to the Load-center |

Source: Developed by JICA Study Team

**Figure 6-4-3.1 Countermeasures against the aging of Airai substation**

## 6-5 Summary of Power Transmission, Distribution and Substation Planning

The plans for facility expansion and upgrades have been formulated as shown in the Table 6-5.1, based on the Scenario Settings of the Renewable Energy Road Map, field surveys to confirm the condition of the existing facilities, and SEA results.

**Table 6-5.1 Improvement of transmission, distribution and substation facilities (by step)**

| Step | Year to be commissioned | Renewable Energy Road Map | Expansion/Upgrading of Facilities | Remarks |
|---|---|---|---|---|
| 1 | ～2020 | Phase1 | -Relocation of the 34.5 kV transmission line<br>-Relocation of substation facilities<br>-New construction of a substation | (High Urgency)<br>Necessary for adequate maintenance and improved power supply reliability |
| 2 | 2021～2023 | Phase2 | -New transmission line construction | (Looping)<br>Improved power supply reliability along with construction of a PV system |
| 3 | 2024～2025 | Phase3 | -New transmission line construction | (Complete Looping)<br>Improved power supply reliability along with construction of a PV system |
| Recommendation | ～2030 | ― | -Replacement of substation facilities<br>-Decommissioning of Airai substation | (Recommendation)<br>Simple replacement of substation equipment upon reaching a service life 40 years |

Table 6-5.3 shows the Transmission, Distribution and Substation Facility Plan and Tentative Rough Cost Estimation. Figures 6-5.1 to Figure 6-5.8 show the expansion plan for each development step and the Network Diagrams in Koror and Babeldaob.

**Table 6-5.2 Recommended countermeasures (for reference after 2025 )**

| Countermeasure | Target | Content | Remark |
|---|---|---|---|
| Countermeasures against the aging of substation facilities | Aimeliik substation | Simple facility replacement | Though visual inspections, periodical checks, and adequate maintenance are expected to lengthen the service life of the facilities, deterioration should be analyzed (analyze for gas-in-oil or test the insulation oil characteristics) before the transformers reach the 40-year point, in order to determine the target facilities for replacement. |
| | Aimeliik-1 substation | Simple facility replacement | Ditto |
| | Nekken substation | Simple facility replacement | Ditto |
| | Aimeliik-2 substation | Simple facility replacement | Ditto |
| | Airai substation | Decommission | Koror substation will be able to supply power for both Koror and Airai states after the load allocation is switched over from Airai substation. |
| Future Power Demand and Improvement of maintenance manageability | Koror substation | 2-bank transformers | One of the two transformers can be shut down for maintenance while the other supplies power without power interruption. |
| | Malakal substation | 2-bank transformers | Ditto |

**Table 6-5.3 Summary of the Transmission, Distribution, and Substation Facility Plan**

| Step | Period | RE roadmap | ID | Year | Facility | Main Objective | Outline | Remark | Rough Cost (Million USD) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | by 2020 | Phase1 | 1-1 | 2020 | T&D | More manageable maintenance | ■ Relocation of existing 34.5 kV transmission line<br>・ Transmission line (41.8 km) Airai – Aimeliik - Ngaraard 2<br>・ Distribution line (4.6 km) Ngaraard 1<br>・ Countermeasures against power outages | – | 12.7 |
| | | | 1-2 | 2020 | SS | More manageable maintenance | ■ Relocation of existing substations<br>・ Ngardmau<br>・ Ngaraard 1<br>・ Ngaraard 2 | – | 1.1 |
| | | | 1-3 | 2020 | SS | Improved of power supply reliability | ■ Construction of Koror substation<br>・ 34.5/13.8 kV 1 bank x 10MVA | – | 1.9 |
| | | | 1-4 | 2020 | D | More reliable power supply | ■ Construction of 13.8 kV distribution line<br>・ 1 feeder (2 km) x 13.8 kV distribution line | – | 0.4 |
| | | | 1-5 | Within the period | SS | For grid protection and maintenance | ■ Installation of circuit breaker panel<br>・ Grid-connected PV system (Aimeliik) | Upon construction of grid-connected PV system | 0.2 |
| | | | 1-6 | Within the period | SS | For grid protection and maintenance | ■ Installation of pole-mounted switches<br>・ Grid-connected PV system (Ngatpang (Kokusai))<br>・ Grid-connected PV system (Ngaremlengui) | Upon construction of grid-connected PV system | 1.8 |
| 2 | 2021 - 2023 | Phase2 | 2-1 | 2023 | T | For a grid-connected PV system and more reliable power supply | ■ Construction of 34.5 kV transmission line<br>・ Transmission line (33.5 km) Malakal – Melekeok PV site<br>・ Cabling (0.6 km at KB bridge) | – | 8.4 |
| | | | 2-2 | 2023 | SS | More manageable maintenance | ■ Expansion of Malakal substation<br>・ Expansion of Malakal outgoing feeder bay | Option | 0.4 |
| | | | 2-3 | Within the period | SS | For grid protection and maintenance | ■ Installation of Pole-mounted Switches<br>・ Grid connected PV system (Airai Airport)<br>・ Grid connected PV system (Ngchesar)<br>・ Grid connected PV system (Mlelekeok) | Upon Construction of grid-connected PV system | 2.6 |
| 3 | 2024 - 2025 | Phase3 | 3-1 | 2025 | T&D | For a grid-connected PV system and more reliable power supply | ■ Construction of 34.5 kV transmission line<br>・ Transmission line (13.9km) Melekeok PVsite - Ngaraard 1<br>・ Expansion of outgoing feeder at Ngaraard 1 | – | 3.3 |
| | | | 3-2 | Within the period | SS | For grid protection and maintenance | ■ Installation of Pole-mounted Switches<br>・ Grid connected PV system (Ngiwal)<br>・ Grid connected PV system (Ngardmau (Terraces of Hill))<br>・ Grid connected PV system (Ngardmau) | Upon Construction of grid connected PV system | 2.2 |
| | | | | | | | | **Total** | **35.0** |

Remarks: T&D, transmission and distribution facilities; T, transmission facilities; D, distribution facilities; SS, substation facilities