8. Solar Power Generation

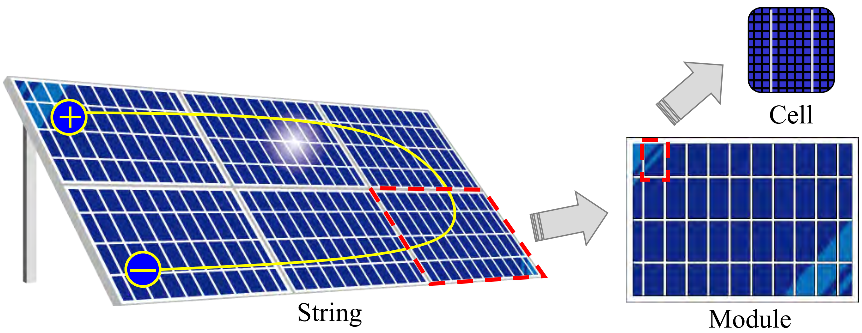
Concerning solar power generation equipment in Cabo Verde, two mega solar power plants were constructed and went into operation in 2010 on Santiago Island and Sal Island respectively utilizing funds from the Government of Portugal. These plants have rated output of 4.28MW and 2.14MW respectively, making them smaller than wind power plants. Since Cabo Verde has hardly any rainfall, even though solar radiation conditions are good, sands and dry soil carried by strong winds off the continent cause the solar panels to become covered in dust; moreover, because the absence of rainfall means that no rain washing effect can be anticipated, generating capacity deteriorates.

Equipment has been installed close to the coast, and corrosion and degradation caused by salt damage can be seen here and there. Because repair costs are not adequately secured, equipment failures tend to be left unaddressed for a long time. SCADA systems have been introduced to monitor the equipment, however, since these aren't functioning due to server failure, they are not utilized for gauging operating conditions or conducting maintenance, etc.

8.1 Solar Power Generation Facilities and Operating Conditions

8.1.1 Power Generation Facilities

First, an outline of the solar power generation systems is given. Figure 8.1-1shows the composition of solar panels. A module comprises multiple cells, which are the basic elements, connected over a panel and protected by glass and so on. Normally, it is such modules that constitute products. Modules are further joined together in series arrangements known as strings. The string voltage is the power generation system DC voltage, and DC current of a certain capacity from strings connected in parallel is inputted to an inverter, where it is converted to AC power and outputted.



Source: JICA Study Team

Figure 8.1-1 Composition of Solar Panels

Based on the above contents, Table 8.1-1 and Table 8.1-2 show lists of the equipment at the two mega solar power plants in Cabo Verde. The manufacturer in both cases is Marifer Solar Co. of Portugal.

Table 8.1-1 Outline of Mega Solar Power Plant Equipment (solar panels)

Island	Modules						Output Power		PV panel
	Manufacturer	Model	Peak power (Wp)	Number	Cell		Peak power (MWp)	Rated power (MW)	inclination (°)
					Type	Efficiency			
Santiago	Martifer Solar	MTS 230P	230	10,944	Polycrystalline Si	14.3%	4.44	4.28	15
		MTS 225P	225	8,568	Polycrystalline Si	14.0%			
Sal	Martifer Solar	MTS 225P	225	9,912	Polycrystalline Si	14.0%	2.23	2.14	15

Source: JICA Study Team based on Information from Electra

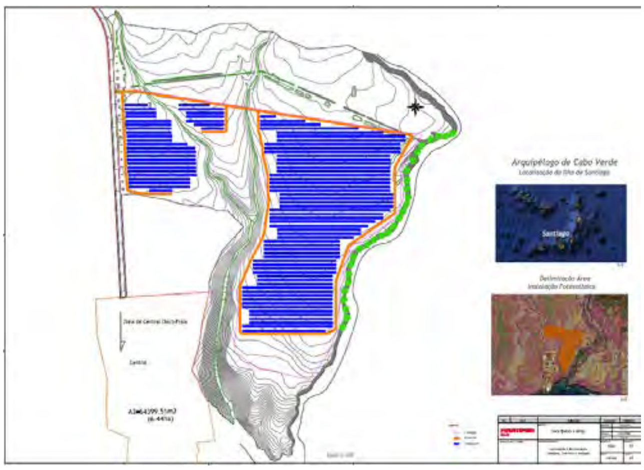
Table 8.1-2 Outline of Mega Solar Power Plant Equipment (inverters, transformers)

Island	Inverter						Transformer		
	Manufacturer	Model	Nominal AC output (kW)	Power factor	Efficiency	Number	Capacity (kVA)	Voltage	Number
Santiago	SMA Solar Technology AG	SC 500HE	500	0.95	98.4%	1	630	315V/20kV	1
		SC 630HE	630	0.95	98.4%	6	630	315V/20kV	6
Sal	SMA Solar Technology AG	SC 250HE	250	0.95	98.4%	1	500	270V/20kV	1
		SC 630HE	630	0.95	98.4%	3	630	315V/20kV	3

Source: JICA Study Team based on Information from Electra

(1) Santiago Island

First, description is given of the solar power generation equipment in Santiago (hereafter referred to as Santiago mega solar). It started operation in September 2010. Figure 8.1-2 shows the equipment layout drawing at the time of planning. Santiago mega solar is installed facing almost due south on land on the north side of Electra Palmarejo Power Station. (See Figure 5.7-1 for the positional relationship between the diesel power station and the mega solar).



Source: Electra

Figure 8.1-2 Layout of Santiago Mega solar

Figure 8.1-3 shows photographs of the Santiago mega solar equipment.

(a) Entire view

(b) Power source connection panel hut (PS)

(c) Inverter, transformer hut PT)

(d) Inverter panel

(e) PT external air suction inlet

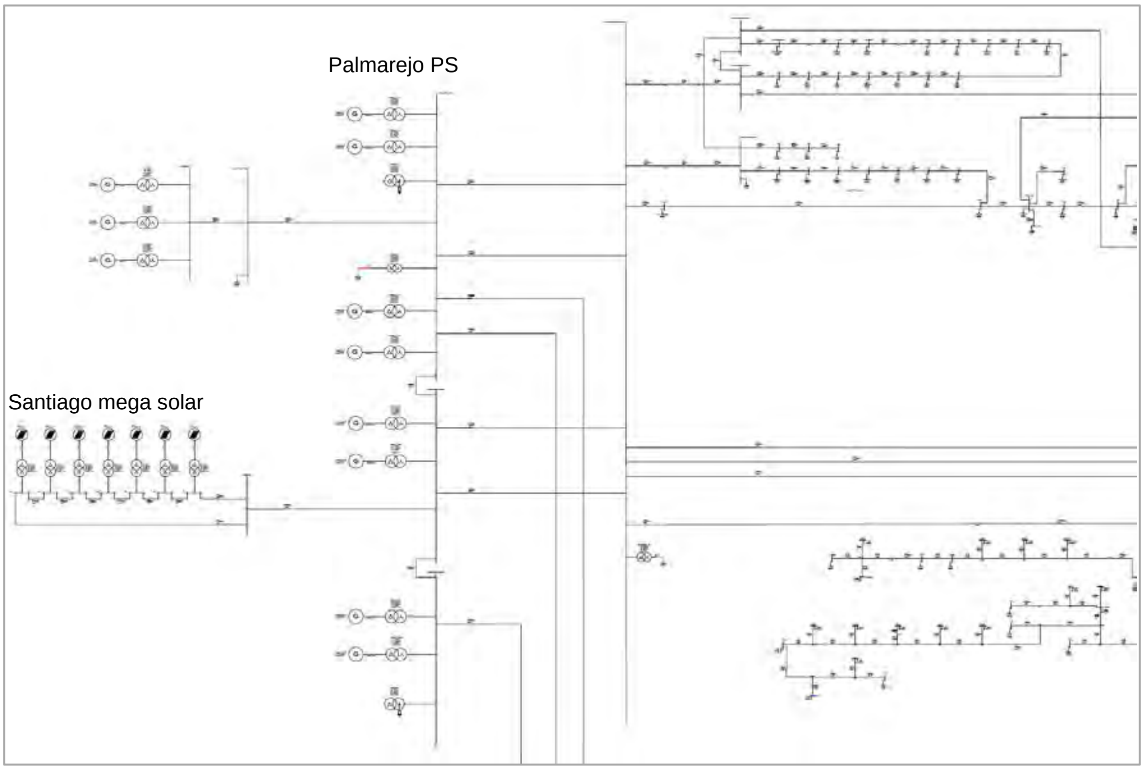
(f) PT exhaust vent

Figure 8.1-3 Santiago mega solar equipment photographs

Since the site is so large, Photograph (a) shows just one part of the solar panels on the left edge of Figure 8.1-2. Santiago mega solar has approximately 20,000 installed modules that generate peak power of 4.44 MW. The inverter rated output is 4.28 MW. Generally speaking, the rated output of solar power generation modules represents generated output under certain conditions, however, under normal conditions of use it is only possible to generate some 90% of such output. Concerning the rated output of inverters, the equipment formation is designed to control the peak rated output, and the mega solar systems in Cabo Verde are no exception. Figure8.1-3, photographs (c) to (f) show views inside and outside of the inverter/transformer hut (PT). The hut is ventilated by fans that introduce outside air, but the kind of air conditioning equipment that is introduced in Japanese solar power generation plants is not used. In recent years, there is a tendency to form airless equipment in Japan too, and this contributes to reducing in-station power and making effective use of the solar generated power. Incidentally, because Santiago mega solar is situated close to the coast, salt damage prevention filters are fitted to the suction inlets (Photograph (e)).

The modules are connected in strings comprising 24 units connected in series. This generates DC voltage of approximately 800V. This is converted to 270V or 315V AC voltage by inverter, and then stepped up to 20kV by transformer for connection to the grid.

Figure 8.1-4 shows the system diagram for Santiago Island. The mega solar power plant is indicated on the left side, and the cable from the mega solar power source connection panel (PS) is directly connected to the bus line of Palmarejo.



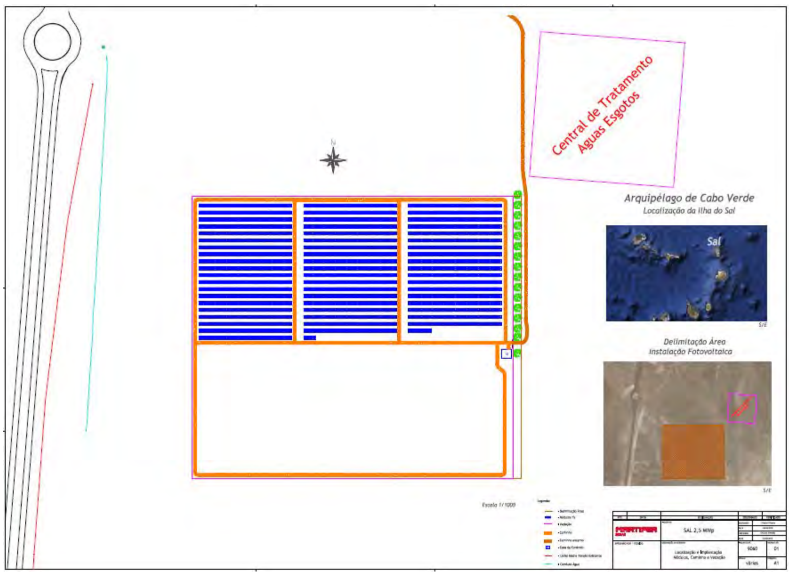
Source: Electra

Figure 8.1-4 Santiago Island System Diagram (excerpt)

(2) Sal Island

The solar power generation equipment in Sal (hereafter referred to as Sal mega solar) has the same basic configuration as in Santiago. Sal mega solar underwent test operation in September 2010 and started operation in October that year.

Figure 8.1-5 shows the equipment layout drawing at the time of planning. Sal mega solar is installed facing almost due south, approximately 20 kilometers south from Sal's main power station at Palmeira. (See Figure 5.4-1 for the positional relationship between the diesel power station and the mega solar).



Source: Electra

Figure 8.1-5 Layout of Sal Mega Solar

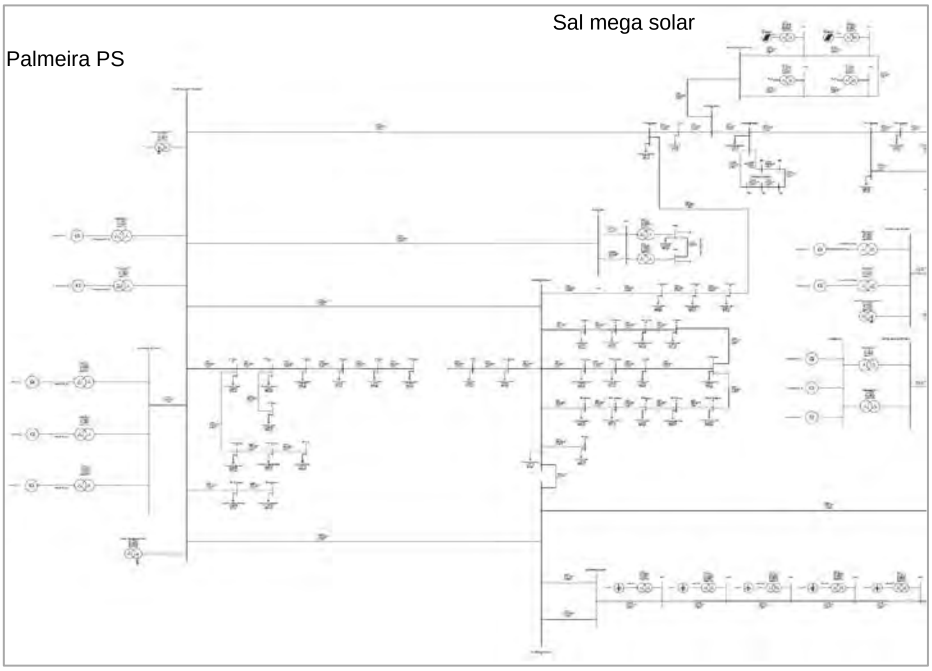
Figure 8.1-6 shows photographs of the Sal mega solar equipment.

(a) Entire view (b) Power source connection panel (PS)

Figure 8.1-6 Sal mega solar equipment photographs

Sal mega solar has approximately 10,000 installed modules that generate peak power of 2.23 MW. The inverter rated output is 2.14 MW, roughly half that of Santiago mega solar. As is also the case with Santiago mega solar, because Sal mega solar is situated close to the coast, salt damage prevention filters are fitted to the suction inlets.

Figure 8.1-7 shows the system diagram for Sal Island. Unlike Santiago mega solar, since the plant is installed a long way from the main power station, Sal mega solar is inter-connected to the grid. Accordingly, output from the mega solar system cannot be directly measured at the main power station.



Source: Electra

Figure 8.1-7 Sal Island System Diagram (excerpt)

As was mentioned earlier, the mega solar facilities in Cabo Verde were constructed by the Government of Cabo Verde utilizing funds from the Government of Portugal. The systems were initially planned for 5 MW on Santiago Island and 2.5 MW on Sal Island, and it was intended for 10% of the equipment to be constructed using funds from Electra, however, because Electra was unable to raise its share of the funds, the systems in Santiago and Sal were both constructed with around 10% less capacity than planned. Specifically, in Santiago, no equipment was installed beyond the No.2 inverter (500 kW), and the number of inverters was revised to one 500 kW unit and six 630 kW units. In Sal, the number of solar panels connected to the 500 kW inverter was reduced, and the inverter capacity was reduced to 250 kW in line with this.

Mega solar power generation equipment is owned by the Government of Cabo Verde, which has concluded a concession agreement with Electra giving utilization and development rights to Electra. In line with this, Electra pays concession fees for each system and transmission lines, etc.

8.1.2 O&M (Power Generation Performance)

(1) Santiago Island

Figure 8.1-8 shows photographs of weather data observation equipment in a mega solar system. The data measured by such equipment, i.e. solar radiation, wind velocity, air temperature, rainfall, and also solar power generation data regarding voltage, current and frequency, are stored in a SCADA system. However, in Santiago mega solar, due to failure of the current server, it was not possible to acquire current and past data. Even so, since the solar power generation is directly connected to Palmarejo Power Station, where it is possible to grasp the solar power generation output in real time, the daily operating report records the amount of generated electrical energy based on the hourly output and routine watt hour meter readings.

Figure 8.1-8 Weather Data Observation Equipment (Santiago)

Table 8.1-3 shows the amount of generated energy at Santiago mega solar in 2015 based on the daily operation reports. The lower row of the table shows the equipment capacity factor. The annual equipment capacity factor is 10.7%, which is lower than the general equipment capacity factor in Japan of 12~14%. Looking at the monthly figures, the equipment capacity factor dips greatly between July and November.

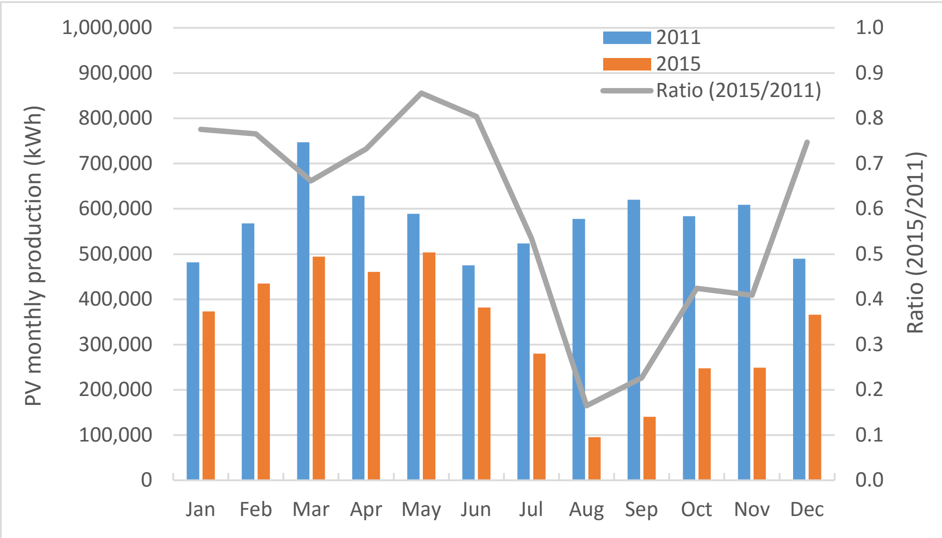
Table 8.1-3 Monthly Solar Power Generated Energy (Santiago, 2015)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Production (kWh)	373,601	434,733	494,132	460,819	503,852	382,056	279,851	95,268	140,232	247,869	249,207	365,867	4,027,487
Capacity facter	11.7%	15.1%	15.5%	15.0%	15.8%	12.4%	8.8%	3.0%	4.6%	7.8%	8.1%	11.5%	10.7%

Source: JICA Study Team based on Information from Electra

Figure 8.1-9 shows a graph giving a comparison with the past amount of generated energy. In 2015, compared with 2011, which was the next year following the start of operation, the amount of generated energy declined greatly between July and November. It is thought that generation during this period was impacted by a lot of cloud cover as well as major equipment failure, etc., although this cannot be confirmed at the present time. Concerning the period from December to June, the amount of generated energy was roughly 20% lower in 2015 than it was in 2011. It is guessed that this was due to reduced generating efficiency caused by degradation of the cells over time as well as partial equipment failure and so on.

The annual equipment capacity factor for 2011 was 18.4%, which was fairly high compared even to the aforementioned equipment capacity factor in Japan, and this is thought to demonstrate the good quality of sunlight conditions in Cabo Verde.



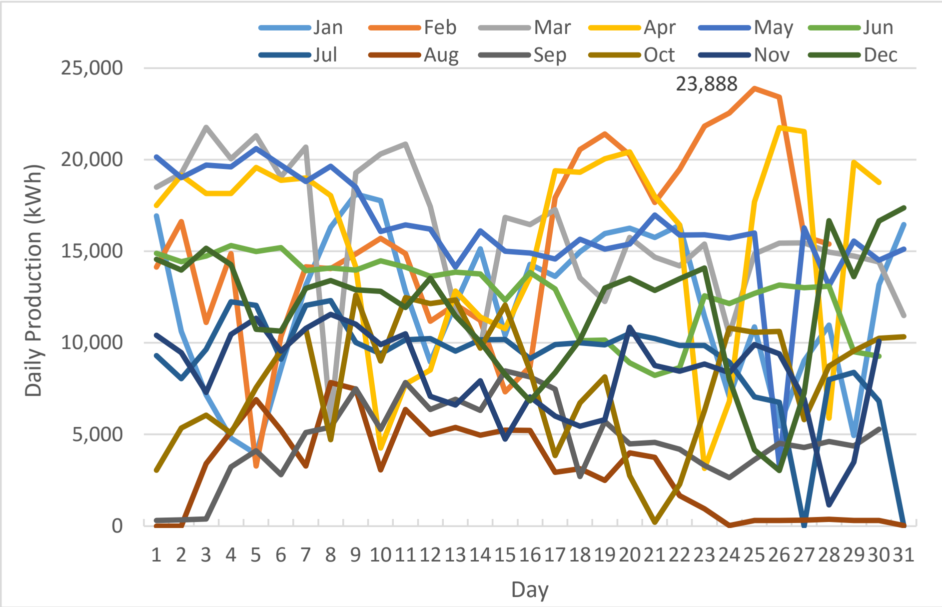
Source: JICA Study Team based on Information from

2011 data: Information Collection and Confirmation Survey Report in the Cabo Verde Climate Change Countermeasures Sector, JICA, August 2012

2015 data: Electra

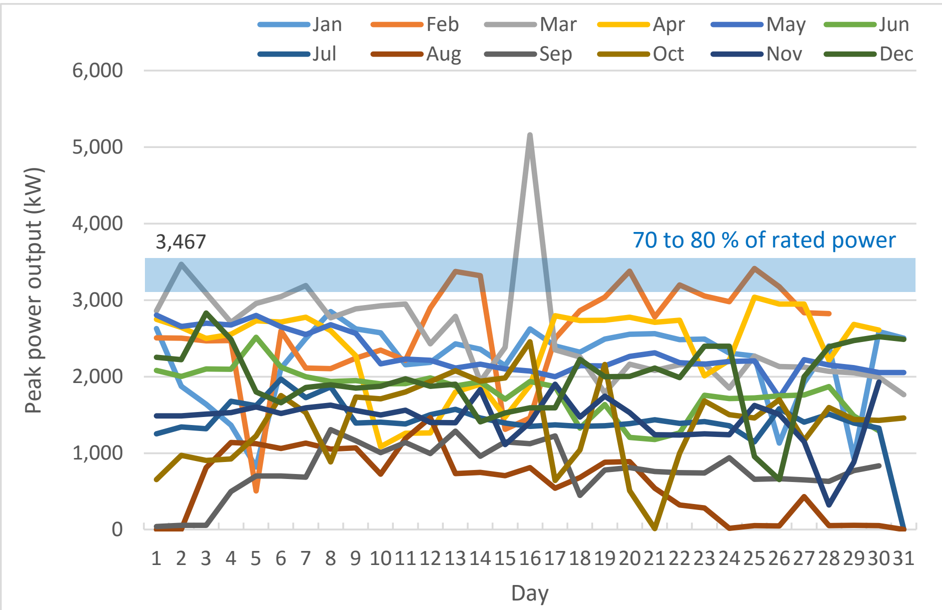
Figure 8.1-9 Monthly Solar Power Generated Energy (Santiago 2011, 2015)

Figure 8.1-10 and Figure 8.1-11 respectively show the daily amount of solar generated energy and peak power output throughout 2015.



Source: JICA Study Team based on Information from Electra

Figure 8.1-10 Daily Solar Power Generated Energy (Santiago, 2015)

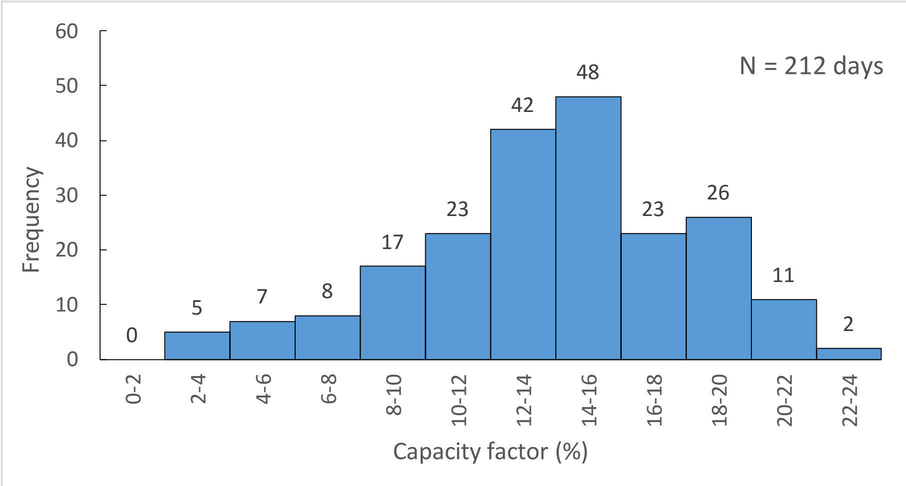


Source: JICA Study Team based on Information from Electra

Figure 8.1-11 Daily Solar Peak Power Output (Santiago, 2015)

Concerning August, when the generated energy was low, the peak power output overall was around 1/4 of rated output, while hardly any energy was generated from the latter part of August to the start of September, indicating the possibility that partial equipment failure occurred and power generation maybe had to be suspended to deal with this.

Figure 8.1-12 shows a histogram of the equipment capacity factor in terms of daily amount of generated energy over seven months not including the period from July to November, when generated energy declined for some reason or other. The equipment capacity factor over this period was 13.8%.



Source: JICA Study Team based on Information from Electra

Figure 8.1-12 Histogram of Equipment Capacity Factor in Solar Power Generation (Santiago)

Since the local climate has little rainfall, there are few days when the generated energy and equipment capacity factor are low, so the overall power generation performance is stable.

Concerning the peak power shown in Figure 8.1-11, since the figure for March 16 is thought to be the result of mistaken entry in the daily report, if this is omitted, the peak power is 3,467 kW on February 2 and the ratio with respect to the module rated output of 4,440 kW is 78.1%. Generally speaking, compared to the rated output of the solar power modules, since output on the inverter AC side is said to decline to around 70~80% due to the actual values under the aforementioned normal conditions of use and conversion loss in the inverter and so on, this figure is generally assumed to be valid output.

(2) Sal Island

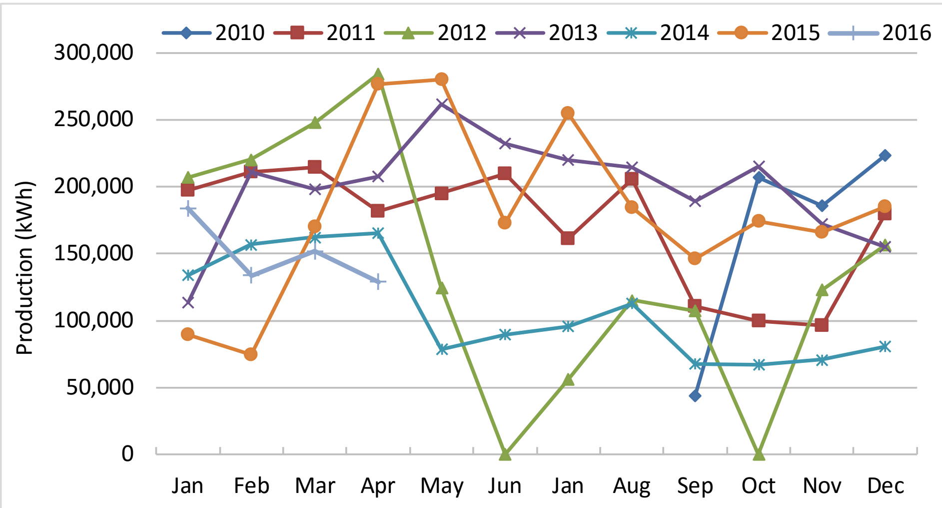
Table 8.1-4 shows the monthly amount of generated energy at Sal mega solar from September 2010 when it started operation. The lower row of the table shows the equipment capacity factor.

Table 8.1-4 Monthly Solar Power Generated Energy (Sal, 2010~2016)

	2010	2011	2012	2013	2014	2015	2016
Jan		197,449	206,606	113,205	133,727	89,376	184,019
Feb		210,963	220,194	210,984	156,763	74,352	133,666
Mar		214,346	247,777	198,196	162,151	170,262	151,759
Apr		181,711	283,844	207,326	165,375	276,656	128,816
May		194,948	124,294	261,452	78,308	279,698	
Jun		209,390	0	232,066	89,213	172,946	
Jan		161,156	55,736	220,078	95,594	254,439	
Aug		205,296	115,064	214,565	112,411	184,215	
Sep	43,861	110,929	107,357	188,882	67,547	146,409	
Oct	206,673	99,960	0	214,819	67,142	174,214	
Nov	185,850	96,350	122,940	172,042	70,733	165,820	
Dec	223,096	179,601	156,415	154,718	80,565	185,088	
Total	659,480	2,062,099	1,640,227	2,388,333	1,279,529	2,173,475	598,260
Capacity Factor*	13.0%	11.0%	10.5%	12.7%	6.8%	11.6%	9.6%
Remarks	*From Oct to Dec		*Except for Jun and Oct				*From Jan to Apr

Source: Electra

The annual equipment capacity factor was 13% in 2010 following the start of operation, however, after that it fluctuated around the relatively low level of 11% every year. Based on this table, Figure 8.1-13 shows the graph of changes in the monthly amount of generated energy.



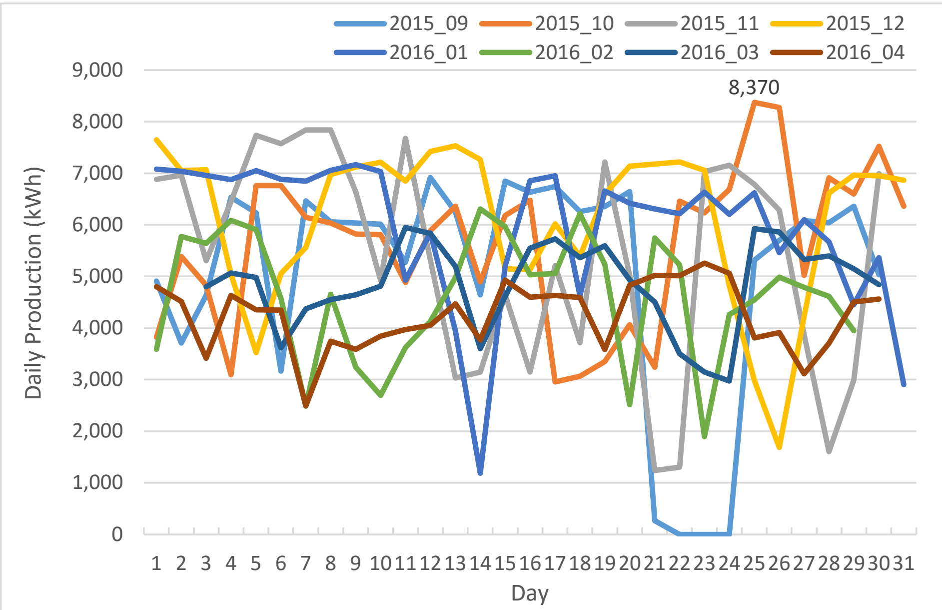
Source: Electra

Figure 8.1-13 Monthly Solar Power Generated Energy (Sal, 2010~2016)

The amount of generated energy declined greatly between September and November 2011, between May 2012 and January 2013, and from May 2014 to March 2015. According to Electra, the reasons for this were as follows.

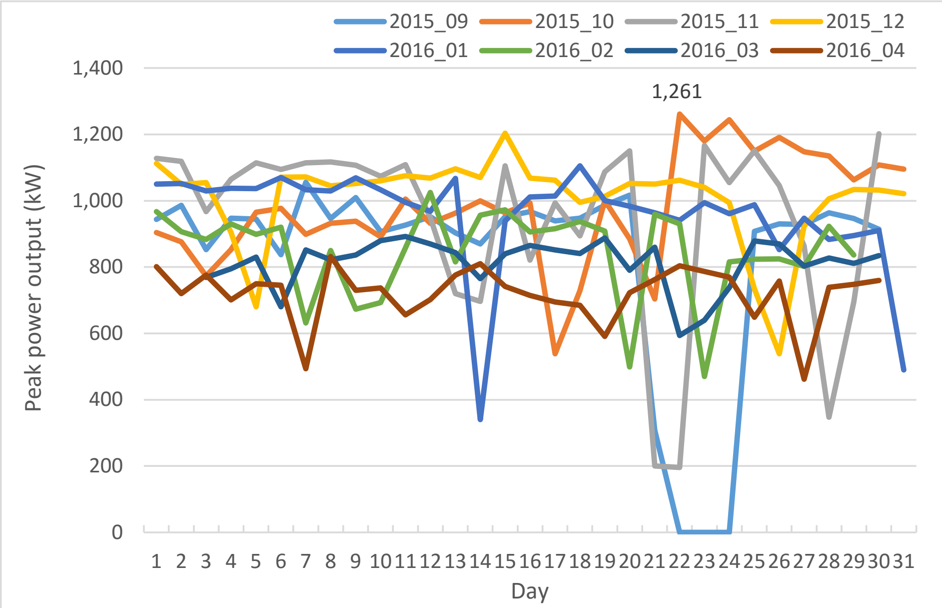
Concerning the period from 2011 to 2012, because a maintenance problem in the CATERPILLAR diesel generator stopped it from following up large load fluctuations, this limited the solar power generation output. In 2014, many of the connectors (MC4 connectors) connecting the solar panels in series were burned, however, due to the difficulty in procuring connector parts, it was not possible to conduct repairs and so power generation declined. In February 2015, power generation increased again following maintenance work to replace the connectors. In 2016, power generation has declined because there hasn't been enough budget to adequately clean the solar panels.

Unlike Santiago mega solar, Sal mega solar is inter-connected to the grid. Accordingly, since it isn't possible to grasp output at the diesel power station, data concerning solar power generation is incorporated into the local server. Currently only the data from September 2015 to April 2016 is available. In this data, the generated output is recorded as 15-minute values. Figure 8.1-14 and Figure 8.1-15 respectively show the daily amount of solar generated energy and peak power output over this period



Source: JICA Study Team based on Information from Electra

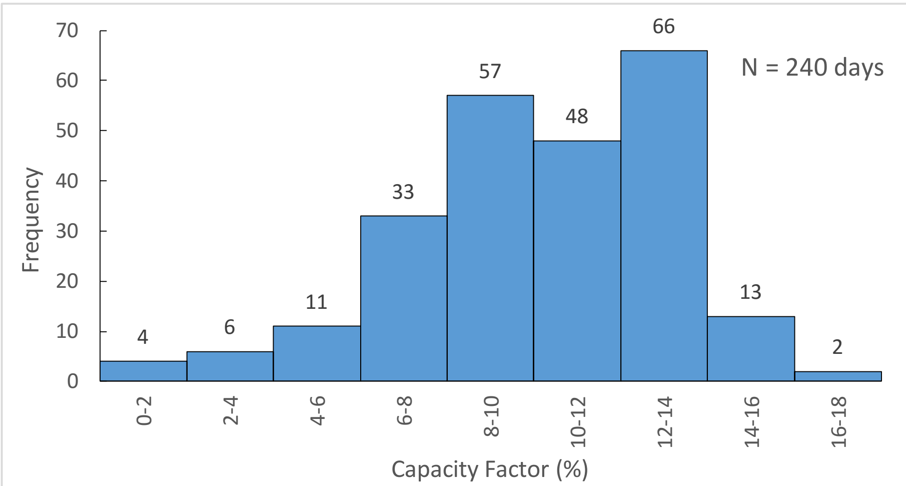
Figure 8.1-14 Daily Solar Power Generated Energy (Sal, September 2015~April 2016)



Source: JICA Study Team based on Information from Electra

Figure 8.1-15 Daily Solar Peak Power Output (Sal, September 2015~April 2016)

Judging from Figure 8.1-14, the generated amount of generated energy is generally stable at 3,000 kWh －7,000 kWh. As is also the case in Santiago, a histogram of the amount of generated energy is shown in Figure 8.1-16. The equipment capacity factor over this period was 10.7%.



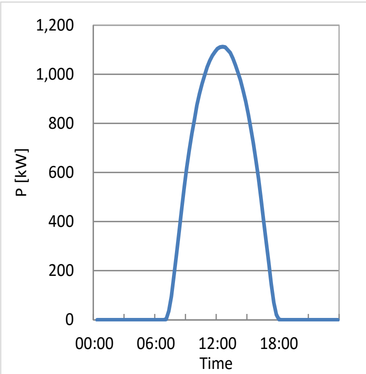
Source: JICA Study Team based on Information from Electra

Figure 8.1-16 Histogram of Equipment Capacity Factor in Solar Power Generation (Sal)

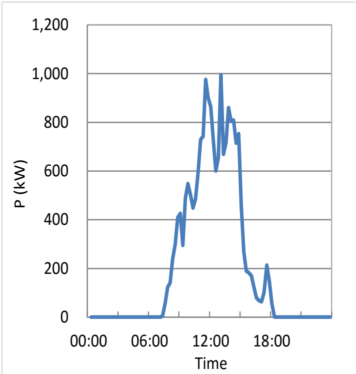
Compared to Santiago mega solar indicated in Figure 8.1-12, there are very few days of high energy generation when the daily equipment capacity factor is 14% or higher.

The peak power shown in Figure 8.1-15 is highest at 1,261 kW on October 22, when the ratio compared to module rated output is 2,230 kW. This is a fairly low value compared to the aforementioned figure of 70~80%, which is given as the general ratio of inverter AC output relative to the rated output of the solar power modules. Judging from Figure 8.1-13, the generally low level of power generation is thought to be caused by problems or issues in the actual equipment, rather than changes over time. This issue is also described in section 8.2.

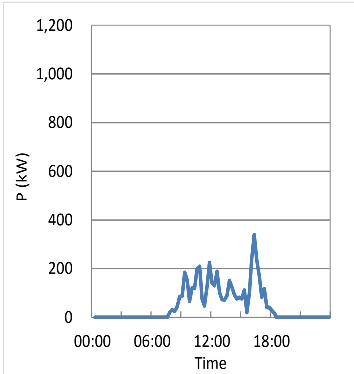
Figure 8.1-17 shows typical output patterns for Sal mega solar.



(a) December 1



(b) January 11



(c) January 14

Source: Electra

Figure 8.1-17 Typical Output Patterns for Sal Mega Solar

Figure (a) shows a sharply defined sine wave output curve depicting output on a clear day. Since this was winter, there was a slight decline in the solar radiation and the peak output is still limited to around 1,100 kW even on days of good solar radiation conditions. Figure (b) shows the output curve for a medium output day when approximately 5,000 kWh was generated. Since the data sampling time interval is 15 minutes, there are no fluctuations in output due to cloud cover, however, fluctuation of around 700 kW can be recognized over 15 minutes. Figure (c) shows the output curve on a day when hardly any energy could be generated.

8.1.3 O&M (Maintenance)

Electra implements the maintenance of the mega solar systems. Two maintenance staff members are assigned to each site. However, it is difficult to secure funds to conduct repairs, meaning that failures cannot be immediately addressed when they occur.

(1) Santiago Island

Power transformation equipment undergoes preventive maintenance six times per year. Specifically, this comprises internal cleaning of the PT, PS, inverters and transformers; moreover, tightening and so on is implemented on the transformers, frame joints and inverters two times per year. Concerning the solar panels, if sufficient budget can be acquired, cleaning is implemented a maximum of four times between February and June at an annual cost of CVE 660,000. In 2014 and 2015, a repair budget of approximately CVE 770,0000 was secured, however, this wasn't enough to acquire all the necessary materials due to the need for consumable parts and maintenance.

A problem with equipment means that decline in the insulation resistance of solar power generation equipment at times of rainfall leads to persistent occurrence of the PID phenomenon described later, burning of connectors (MC4 connectors) between modules (this occurs with high frequency during the rainy season) and power loss due to inverter tripping. Concerning the burning of MC4 connectors, the dust and water resistance performance that is stipulated in the IEC's (International Electrotechnical Commission's) IEC144 and IEC529 standards has been addressed through replacing IP65 connectors with IP68 connectors, which offer greater water resistance.

Concerning detection of system abnormalities, SCADA was used to check the condition of fuses installed along each string as well as measure voltage, etc., however, now that this system is broken, maintenance staff members check for abnormalities and measure values using measuring instruments in the junction box (Figure 8.1-18).

Initially 50 replacement modules were provided, and 12 of these have already been used due to failures. Moreover, the ventilation fans in the PT and PS huts have also broken down.

Figure 8.1-18 Junction Box (Santiago)

(2) Sal Island

Concerning Sal Island, the ratio of solar power generation relative to renewable energy overall is small; moreover, because there is also an issue concerning the compulsory requirement to receive energy from Cabeolica wind power plant, even if problems arise in the solar power generation, the order of priority for repairs is low and its takes a long time to resolve the issue.

Since Sal mega solar is located far from the main diesel power station at Palmeira, the site can only be visited for inspection once every one or two months.

The washing of solar panels is outsourced three or four times per year. Each washing cycle lasts one or two weeks but differs according to the contractor. It requires roughly 10 tons of water to conduct washing, however, since an underground washing water tank with capacity of 100 tons has been installed, examination is being conducted with a view to effectively utilizing this in order to reduce costs.

Similar to the situation at Santiago mega solar, the SCADA monitoring system is broken and out of order. When it was in working order, this system could grasp the condition of all breakers and fuses, however, since this area is not even within range of mobile phones, the loss of such data is considered to be a major problem. However, repairing the system would incur a major investment and is not currently feasible.

Concerning equipment problems on Sal Island, salt damage is a major concern and this has caused a lot of corrosion to frames, connectors, etc. Moreover, a lot of corrosion was observed on building ventilation fan filters, which are subjected to frequent washing (Figure 8.1-19).

Initially 40 replacement modules were provided, and only one of these has been used.

(a) Frame and connector (b) Building ventilation fan filter

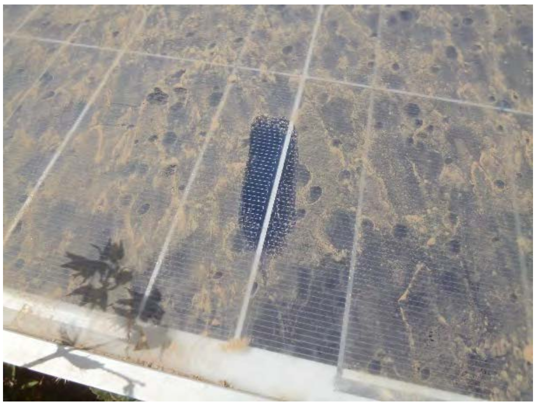
Figure 8.1-19 Equipment Corrosion caused by Salt Damage (Sal)

8.2 Issues in Solar Power Generation

According to hearings with local people, the issues that face solar power generation are reduced output caused by dust and the PID phenomenon. The following sections mainly discuss these issues.

8.2.1 Dust

Since Cabo Verde has an arid climate, the soil is dry and dusty. Moreover, strong winds blowing off the continent carry sand and dust that cover the solar panels. Since there is hardly any rainfall throughout the year, no rain washing effect can be anticipated. Figure 8.2-1 shows pictures of the solar panels that were taken onsite. The dust that has accumulated on the panels sticks due to the moisture of condensation and it cannot be easily removed.



(a) Santiago mega solar

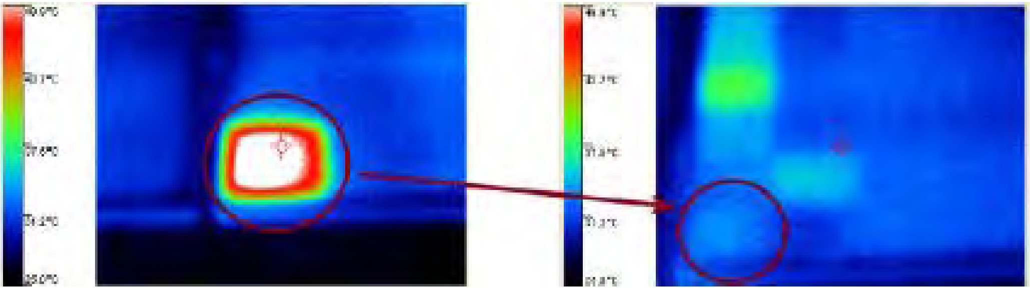
(b) Sal mega solar

Figure 8.2-1 Dust Cover on Solar Panels

This issue is also mentioned in the report of testing conducted by ITC (Institute Tecnológico de Canarias) in March 2011, six months following construction and the start of operation of the mega solar plant (Informe técnico. Ensayo de recepción de las Instalaciones fotovoltaicas de Santiago y Sal, May 2011).

According to the report, particularly at Sal mega solar, because the solar power generation plant is situated to the south of an unpaved road that is used by large vehicles and northerly winds are prevalent in the local area, there is continuous accumulation of dust. At the time of the site survey too, JICA Study Team confirmed that the plant is surrounded by fine dirt that imparts extreme impacts.

The main impacts of dust are pointed out as follows: (1) reduction of generated energy due to obstruction of solar radiation, and (2) shortening of service life in long-term use. Concerning (1), the report states that the total mean loss over the test period was approximately 5%. Concerning (2), degradation is caused by the emergence of hot spots arising from uneven staining that occurs in areas of extreme dirt. Hot spots occur in cases of highly conspicuous differences in cell staining within modules, when badly stained cells are activated with reverse bias and become resistors, and they heat up instead of generating energy. Over the long term, such a situation accelerates the degradation of elements in the form of deteriorated insulation performance and energy generating capacity, and this can result in shortening of the module service life. As an example observed at Sal mega solar, Figure 8.2-2 indicates temperature increase of a solar power generation module caused by accumulated dirt in the bottom left part of the module. In this case, the temperature reached 51.2℃. The right figure shows the same area following the washing away of dust. Here, the temperature has fallen to 33.4℃.



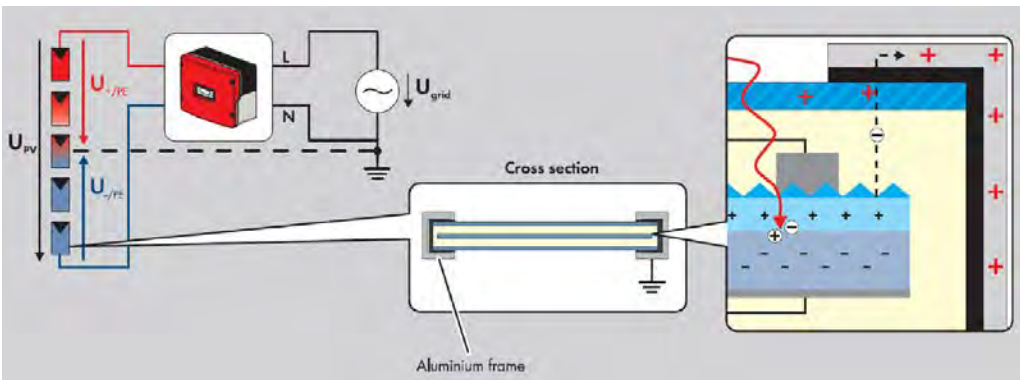
Source: Informe técnico. Ensayo de recepción de las Instalaciones fotovoltaicas de Santiago y Sal., Instituto Tecnológico de Canarias, 16/5/2011

Figure 8.2-2 Thermography Images of an Area of Dust Buildup

In addition to the above impacts, dust infiltration has been confirmed inside equipment and there have been reports of deteriorated insulation resistance and decline of generated power arising from leaking currents.

8.2.2 PID Phenomenon

The phenomenon of PID (Potential Induced Degradation) became widely recognized as a result of tests published by the Fraunhofer Society of Germany in 2012, although it had been raised as an issue previously. In the PID phenomenon, when high voltage is exerted on silicon crystal modules, depending on the environmental conditions, leakage current flows from the metal frames to the cells causing output to decline, and this is greatly affected by external factors such as high temperatures and high humidity and salt content (see Figure 8.2-3). It has been numerously reported in mega solar systems in which DC high voltage of almost 1,000 V was generated. It is said to be caused by the ionization of sodium in module surface glass due to high voltage, although the detailed mechanism of occurrence has not yet been clarified. In the above tests, the PID phenomenon did not occur in modules made by only four out of 13 international manufacturers, and there were modules where output declined by a maximum of 90%.



Source: CABO VERDE POTENCIAL INDUCED DEGRADATION (PID), MARTIFER SOLER, 9/2011

Figure 8.2-3 Schematic Diagram of the PID Phenomenon

Information concerning the PID phenomenon in mega solar systems in Cabo Verde was compiled in the PID report published in September 2011 by MARTIFER SOLAR Co., which constructed the power plants. According to this, partial voltage decline was detected in strings monitored by automatic measuring system in February 2011, five months after installation. Accordingly, modular voltage was measured on a sample basis in a number of strings where voltage was found to be declining. As a result, since voltage declined a lot on the negative electrode side of series connections, it was presumed that this had been caused by the PID phenomenon. Moreover, in the aforementioned testing conducted by ITC in March 2011, modular output tests were implemented and the results of these also pointed to occurrence of the PID phenomenon.

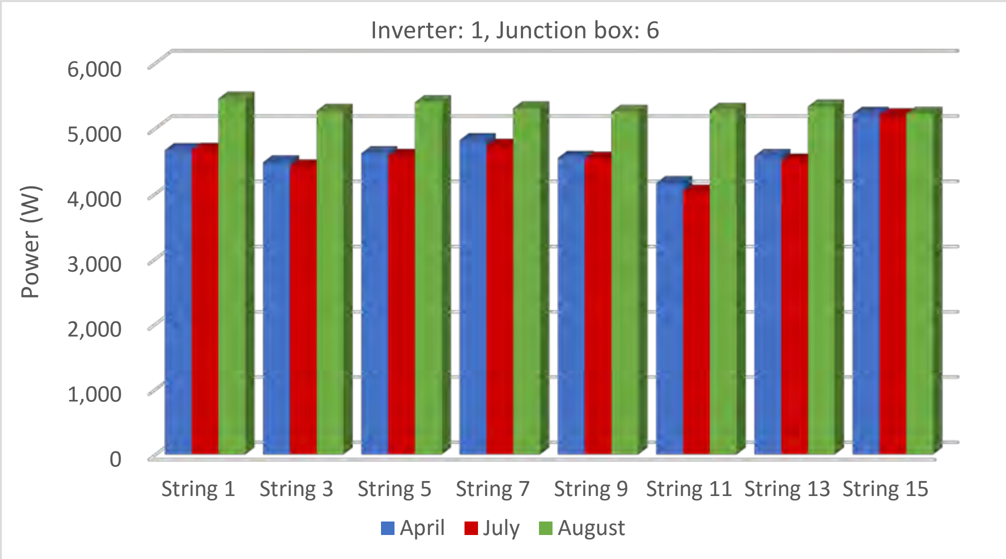
In order to demonstrate this, MARTIFER SOLAR consigned testing to TÜV Rheinland, which is a highly skilled inspection and certification service agency in Germany. In the testing, it was confirmed that output declines in modules on the negative electrode side; moreover, because PID is an irreversible phenomenon, testing was conducted up to the regeneration of modular output when implementing countermeasures.

Table 8.2-1 and Figure 8.2-4 show the generated energy measured in oddly numbered strings connected to the sixth junction box that is inputted to inverter 1.

Table 8.2-1 Output in Each String (Santiago, junction box 1.6)

Power measured by I-V curve (W)					
Inverter Junction Box	String	April	July	August	⊿P (%) (Apr-Aug)
1.6	1	4,662.95	4,667.13	5,451.34	16.91%
	3	4,477.00	4,412.31	5,265.29	17.61%
	5	4,615.63	4,575.64	5,395.64	16.90%
	7	4,816.04	4,729.43	5,304.14	10.13%
	9	4,543.71	4,532.10	5,250.16	15.55%
	11	4,158.06	4,028.56	5,279.42	26.97%
	13	4,573.22	4,503.44	5,331.28	16.58%
	15	5,218.83	5,197.39	5,220.97	0.04%

Source: CABO VERDE POTENCIAL INDUCED DEGRADATION (PID), MARTIFER SOLAR, 9/2011



Source: CABO VERDE POTENCIAL INDUCED DEGRADATION (PID), MARTIFER SOLER, 9/2011

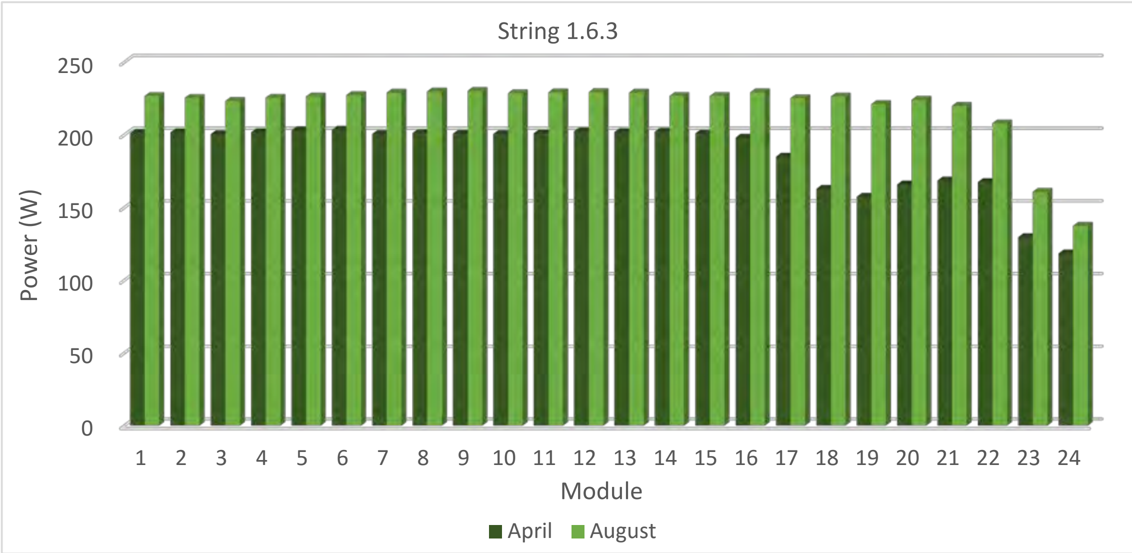
Figure 8.2-4 Output in Each String (Santiago, junction box 1.6)

Measurements in July indicated decline in output compared to the measurements conducted in April, suggesting that degradation caused by the PID phenomenon was progressing. Following the measurements in July, the following two measures were implemented:

(1) Connection of inverter negative electrodes (PT1, PT8)

(2) Repositioning of modules through changing the series connections.

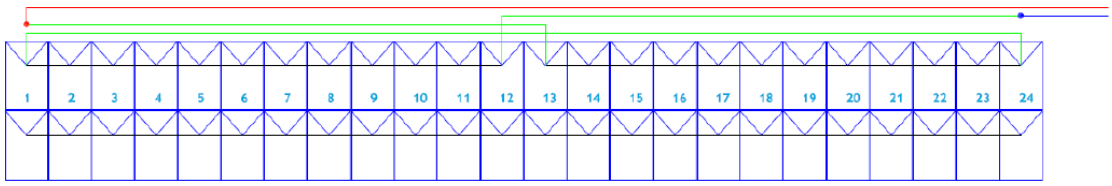
In the measurements conducted in August three weeks after implementation of the measures, output had been restored. Figure 8.2-5 shows output from modules in string 3 (1.6.3). Overall, output was more or less restored to 230 W, however, in string 1.6.3, where only the first countermeasure was implemented, output did not adequately recover in the modules (23, 24, etc.) close to the negative electrode.



Source: CABO VERDE POTENCIAL INDUCED DEGRADATION (PID), MARTIFER SOLER, 9/2011

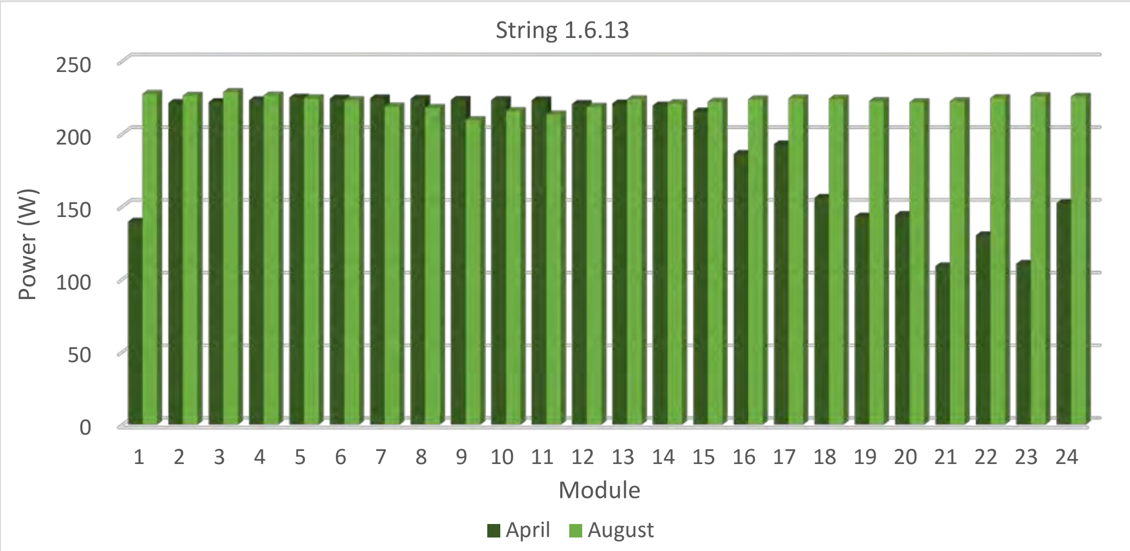
Figure 8.2-5 Modular Output (Santiago, string 1.6.3)

Figure 8.2-7 shows the results of measuring output in string 1.6.13, in which the second countermeasure of changing the connections was implemented as shown in Figure 8.2-6. Whereas output recovered greatly in modules 20~24 situated far from the negative electrode, it declined in modules 5~12 situated close to the negative electrode.



Source: CABO VERDE POTENCIAL INDUCED DEGRADATION (PID), MARTIFER SOLER, 9/2011

Figure 8.2-6 Rearrangement of Module Wiring Connections



Source: CABO VERDE POTENCIAL INDUCED DEGRADATION (PID), MARTIFER SOLER, 9/2011

Figure 8.2-7 Modular Output (Santiago, string 1.6.3)

From the above test results it was confirmed that the decline in output in the mega solar systems in Cabo Verde was caused by the PID phenomenon, and the effectiveness of countermeasures was also confirmed.

In light of these results, it is currently unclear how countermeasures are being implemented and how far the effects of PID are still there. Currently, manufacturers of solar panels implement ample testing and PID countermeasures, and it is thought that PID-resistant panels will be selected and adequate PID countermeasures such as installation of earth, etc. will be adopted when solar power generation systems are newly installed in the future.

8.2.3 Comparison with Wind Power Generation

Wind power generates a lot of energy mainly in the winter months when the wind conditions are favorable, however, winds drop significantly during the summer, meaning that there are large seasonal fluctuations over the course of a year. On the other hand, solar power generation is stable throughout the year and entails relatively little seasonal fluctuation. Accordingly, there is room to consider adoption of solar power generation when introducing renewable energy. Here, solar power and wind power are compared primarily from the viewpoint of cost, which is an important element in introduction.

Table 8.2-2 shows the main items in the comparison of wind power and solar power generation.

Table 8.2-2 Comparison of Wind Power Generation and Solar Power Generation

Item		Wind Power Generation	Solar Power Generation
Equipment unit cost		2,279 EURO/kW (Japan[*1]) 2,279 EURO/kW (CV performance)	1,906 EURO/kW (Japan[*1]) 1,223 EURO/kW (Europe[*2])
Equipment capacity factor (2015 performance)		Santiago: 39.5% Sal: 28.6% São Vicente: 37.3% Boa Vista: 35.0%	Santiago: 10.7% Sal: 11.6%
owner generation unit cost[*3] [Calculation criteria]		5.8 EURO Ct./kWh	14.9 EURO Ct./kWh (Japan) 9.2 EURO Ct./kWh (Europe)
	Equipment unit cost	2,279 EURO/kW	Unit cost in ( ) area
	Decommissioning costs	5% of the construction costs	5% of the construction costs
	Operation maintenance costs	46.6 EURO/kW/year	28.1 EURO/kW/year
	Equipment capacity factor	40 %[*4]	14 %[*5]
	Interest rate	3 %	3 %
	Running period	20 years	20 years
Construction period		Approx. 2 years (850kW×30 units)	Santiago: 8 months (4.28MW) Sal: 7 months (2.14MW)

*1: "Opinion concerning FY2016 procurement Prices and procurement Periods (procurement Prices, etc. Calculation Committee, Japan, February 2016)"
*2: Calculated based on TRENDS 2015 IN PHOTOVOLTAIC APPLICATIONS (IEA PVPS) (Average value of European countries 105.24 JPY/US$)
*3: Calculation of capital cost (Initial costs, Decommissioning costs) + operation and maintenance cost based on "Report on Verification of Generating Cost, etc. for the Long-term Energy Supply and Demand Prospects Committee (Power Generation Cost Verification Working Group, Japan, May 2015)"
*4: Capacity factor in Santiago, where output limitation is not implemented, is applied.
*5: Capacity factor is applied from the months in 2015 when no decline in output could be recognized in Santiago (see 8.1.2)
(Note) Exchange rate of JPY/EUR on End of FY2015: 131.66
Source: JICA Study Team information in annotation

Since the equipment capacity factor in wind power generation is high thanks to the favorable wind conditions, the power generation unit cost is fairly low compared to Japan and elsewhere. On the other hand, since there are uncertain fluctuating elements when calculating the unit cost of solar power generation, these will be taken into account when calculating the unit cost. For the equipment capacity factor, the performance in the year after the start of operation of Santiago mega solar is adopted, and the capacity factor during the period when generated energy declined during 2015 in excluded. Equipment unit rates are based on unit rates in Europe, and these are multiplied by a factor of 1.5 or 2 to reflect higher costs for transportation, etc. Table 8.2–3 shows the solar power generation unit costs calculated under these conditions.

Table 8.2-3 Results of Calculating Solar Power Generation Unit Costs

Capacity factor / Equipment unit rate	14% (2015)	18.4% (2011 performance)
1,223 EURO/kW (Europe)	9.2 EURO Ct./kWh	7.0 EURO Ct./kWh
×1.5 times [1,838 EURO/kW]	12.6 EURO Ct./kWh	9.6 EURO Ct./kWh
×2.0 times [2,446 EURO/kW]	16.0 EURO Ct./kWh	12.2 EURO Ct./kWh

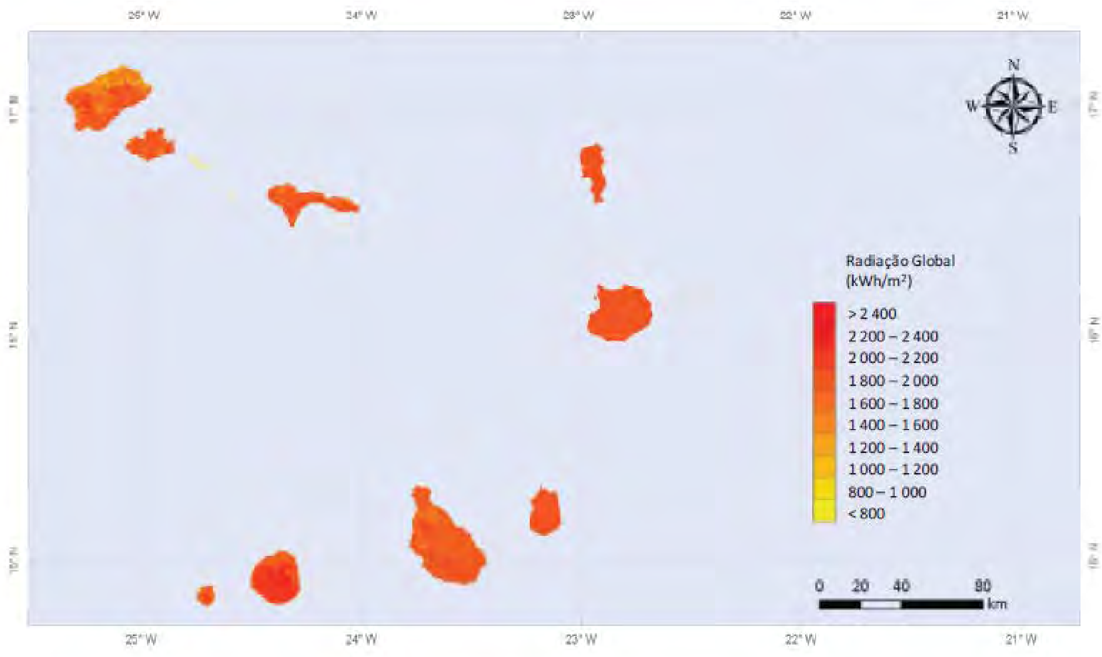
(Note) Exchange rate of JPY/EUR on End of FY2015: 131.66

Source: JICA Study Team based on information in annotation of Table 8.2-2

If good power generation can be achieved without abnormalities in the generating equipment and the equipment can be constructed at a cheap cost, similar costs to wind power generation can be anticipated, however, currently it is likely that solar power generation will be more expensive than wind power due to the transportation cost, etc.

8.3 Examination of Solar Potential

According to the Cabo Verde Official Gazette No. 7/2012, the government has approved the renewable energy strategic plan that specifies the renewable energy development zones (ZDER). As is also the case with wind power generation, the official gazette states the ZDER selection method, potential, etc. for solar power generation, and the validity of those contents are assessed here.
Figure 8.3-1 shows the map of global solar radiation in Cabo Verde.

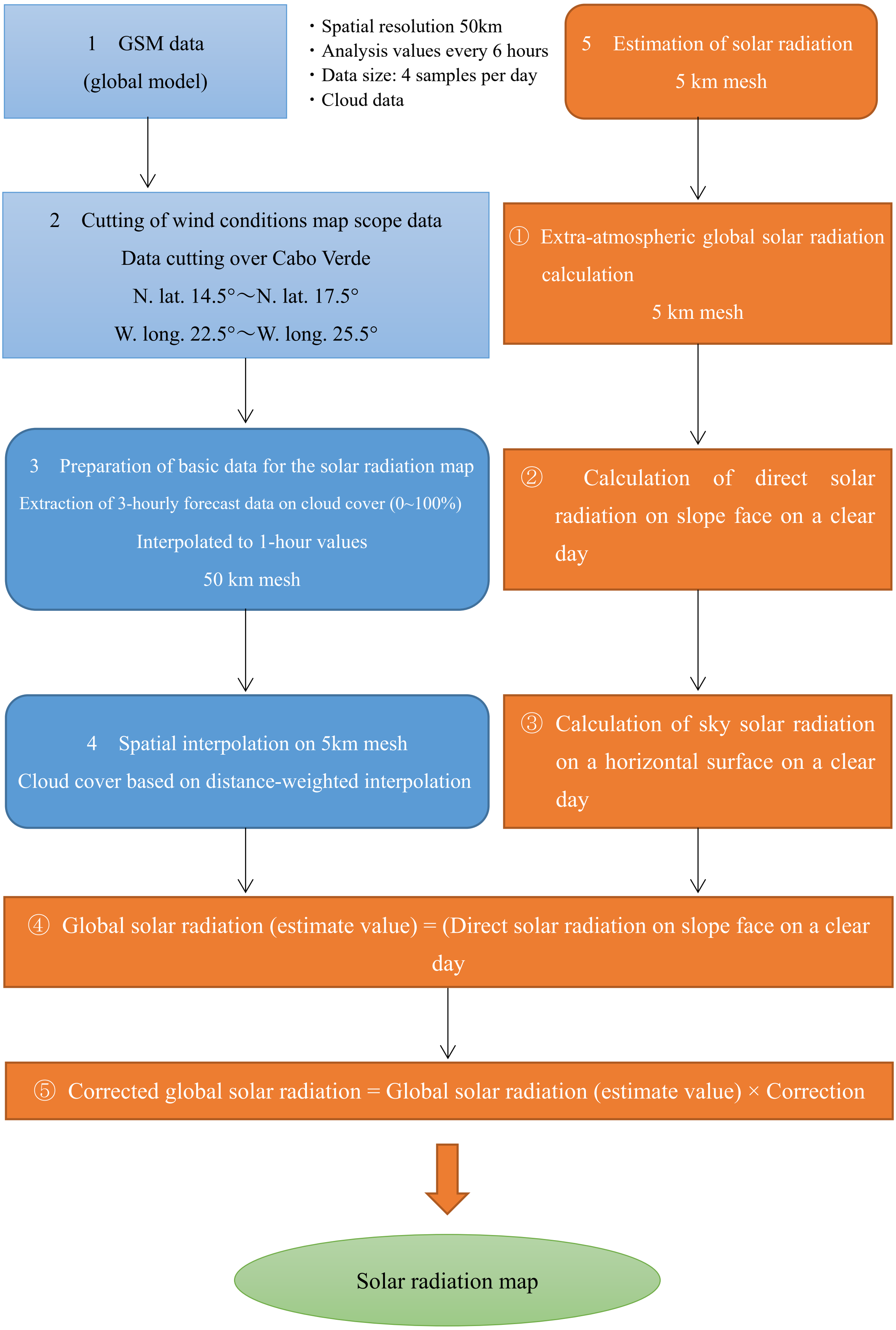


Source: I SÉRIE - NO 7 «B. O.» DA REPÚBLICA DE CABO VERDE - 3 DE FEVEREIRO DE 2012

Figure 8.3-1 Map of Global Solar Radiation in Cabo Verde

According to the official gazette, solar radiation of 1,800～2,000 kWh/m^2 per year can be anticipated in almost all parts of Cabo Verde.

Here, we have independently created a mean solar radiation map through conducting simulation in a manner similar to the wind conditions map by using GSM data from 2015. Figure 8.3-2 shows the flow of solar radiation map creation. Here, since “1 GSM data,” “2 Cutting of wind conditions map scope data” and “4 Spatial insertions to 5 km mesh” are the same as in wind conditions map creation, the following paragraphs describe only the parts that are different from wind conditions map creation, i.e. “3 Preparation of basic data for the solar radiation map” and “5 Estimation of solar radiation.”



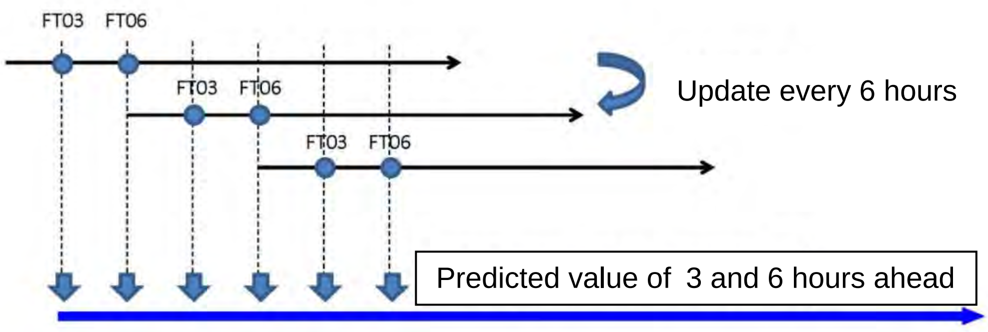
Source: JICA Study Team

Figure 8.3-2 Solar Radiation Map Flow

(1) Preparation of basic data for the solar radiation map

GPV data comprise four pieces of data taken every six hours at spatial resolution of 50 km, and linear interpolation was conducted as follows using analysis values (cloud cover) 3 hours ahead at each time (every 6 hours).

Figure 8.3-3 shows a schematic image of time interpolation of analysis values.



Source: JICA Study Team

Figure 8.3-3 Image of Time Interpolation of Analysis Values

(2) Estimation of solar radiation

① Calculation of extra-atmospheric global solar radiation

Extra-atmospheric global solar radiation (Q) is sought by the following formula from the solar azimuth ψ and elevation λ at an optional time at a location of optional latitude φ and longitude λ.

$$Q(w/m^2) = 1367(r^*/r)^2 \sin(\alpha)$$

Q : Extra - atmospheric global solar radiation

r^*/r : Geocentric distance of the Sun

α : Altitude of the Sun at an optional location

② Direct solar radiation on slope face on a clear day

Direct solar radiation on slope face is calculated by the following Bouguer formula:

$$J_n = J_{n0} \times P^m$$

J_n : Direct solar radiation on slope face (MJ/m^{2}h)

J_{n0} : Extra - atmospheric global solar radiation (MJ/m^{2}h)

P : Atmospheric transmissivity

m : Atmospheric mass

$$m = \eta \times mo$$

$$\eta = \left(1 - z/44308\right)^{5.527}$$

z : Altitude (m)

$$mo = \left\{\sin(h) + 0.15(h + 3.885)^{-1.253}\right\}^{-1}$$

③ Sky solar radiation on a horizontal surface on a clear day

Sky solar radiation on a horizontal surface is calculated by the following Nagata formula:

$$I_{sh} = J_{n0} \times \sin(h)(1 - P^{\mathrm{cosec}(h)}) \times K_{SD}$$

I_{sh} : Sky solar radiation on a horizontal surface (MJ/m^{2}h)

J_{n0} : Extra-atmospheric global solar radiation (MJ/m^{2}h)

P : Atmospheric transmissivity

h : Altitude of the Sun

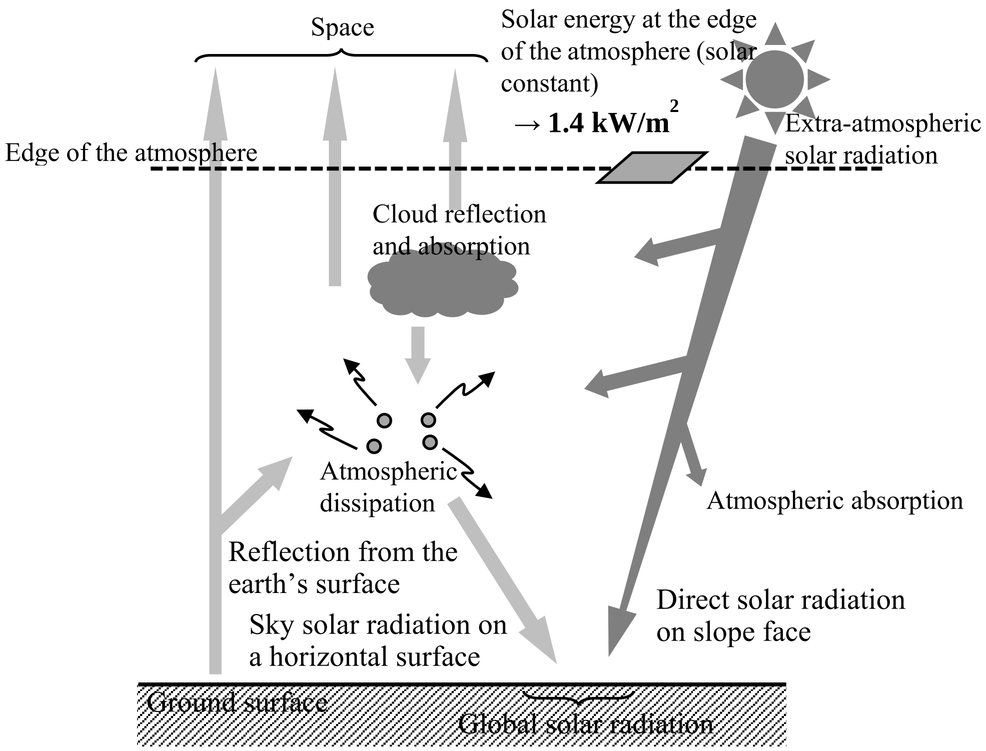
K_{SD} : $(0.66 - 0.32\sin(h) \times \{0.5 + (0.4 - 0.3p)\sin(h)\}$

(Note) Shionomisaki data is used for the atmospheric transmissivity

④ Global solar radiation (estimate value)

The global solar radiation is obtained through multiplying the direct solar radiation on slope face on a clear day and sky solar radiation on a horizontal surface on a clear day by the cloud cover (0~100%) (see Figure 8.3-4).

Global solar radiation = (direct solar radiation on slope face on a clear day
+ sky solar radiation on a horizontal surface on a clear day)
× cloud cover (0～100%)



Source: Solar Construction Design Guide, New Energy and Industrial Technology Development Organization (NEDO), Japan

Figure 8.3-4 Outline of Global Solar Radiation

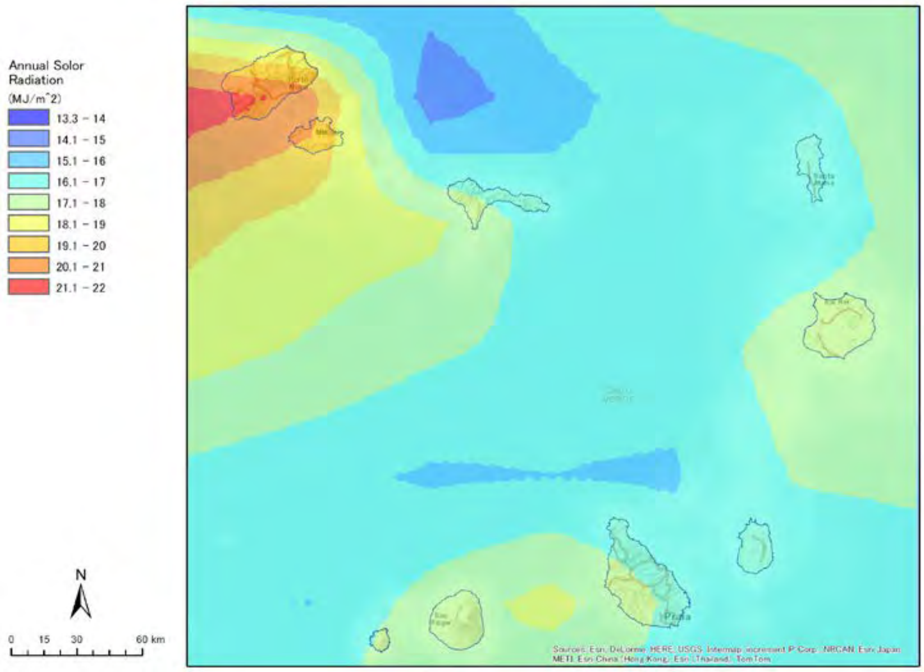
⑤ Global solar radiation

In estimating global solar radiation, since the local atmospheric transmissivity cannot be acquired, data from Shionomisaki in Japan was used. As a result, disparities arose with local measured values, so the local global solar radiation was adopted upon conducting the following correction.

Global solar radiation = global solar radiation (estimate value)
× correction coefficient

(Note) Correction coefficient = 1.2

Figure 8.3-5 shows the solar radiation map that was created by the above method.



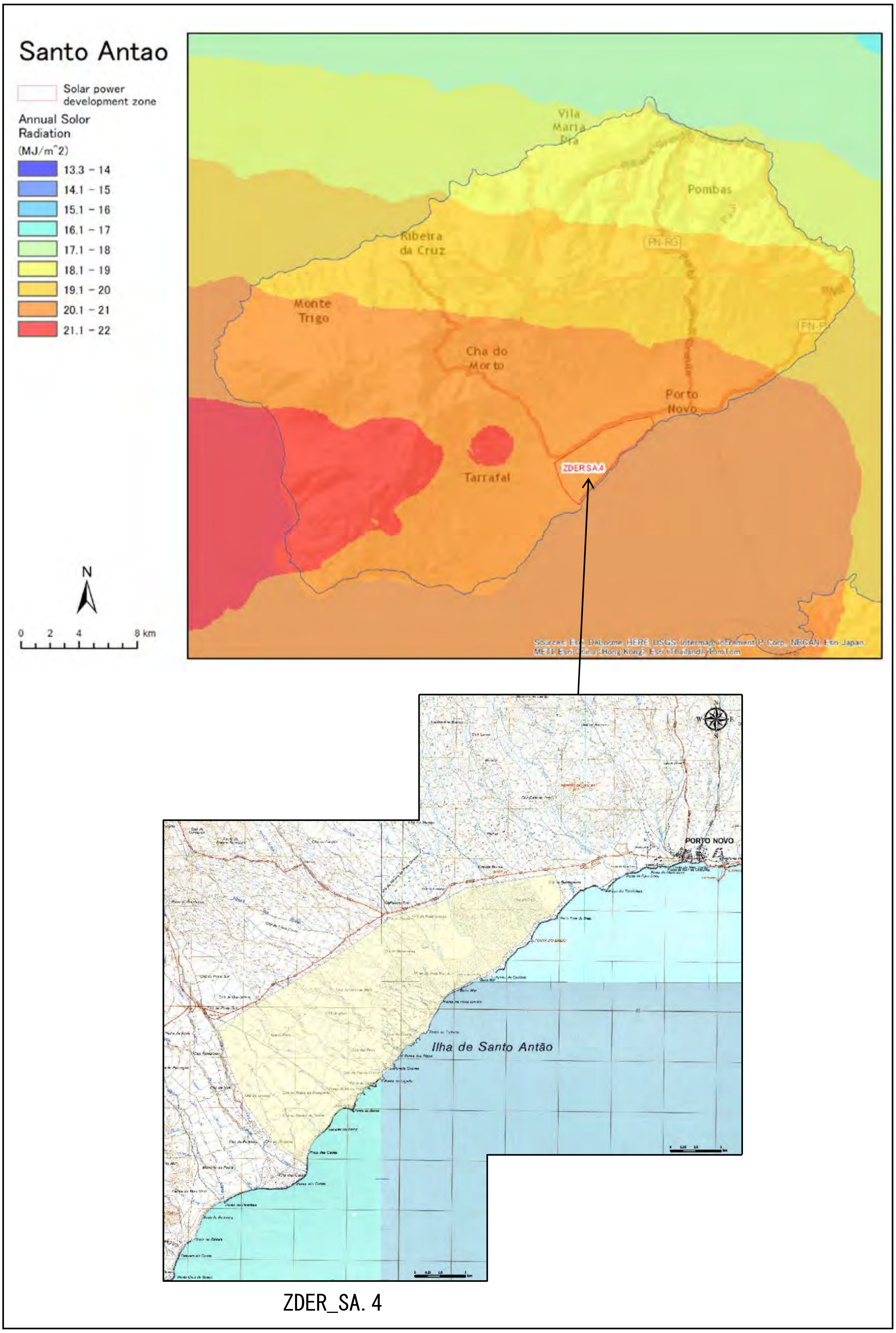
Source: JICA Study Team

Figure 8.3-5 Mean Solar Radiation Map for Cabo Verde based on GPV Data Simulation

In the government gazette's official solar radiation map, almost the entire region has roughly the same solar radiation except for the north side of Santo Antão Island, however, in the solar radiation map created in the simulation here, the solar radiation differs according to each island and shows disparity with the official version ranging from 16 MJ/m^2/day (annual 1,622 kWh/m^2) to 22 MJ/m^2/day (annual 2,230 kWh/m^2). Moreover, depending on the island, although values are low, roughly the same solar radiation can be anticipated, so the solar radiation map in the official gazette is generally deemed to be appropriate.

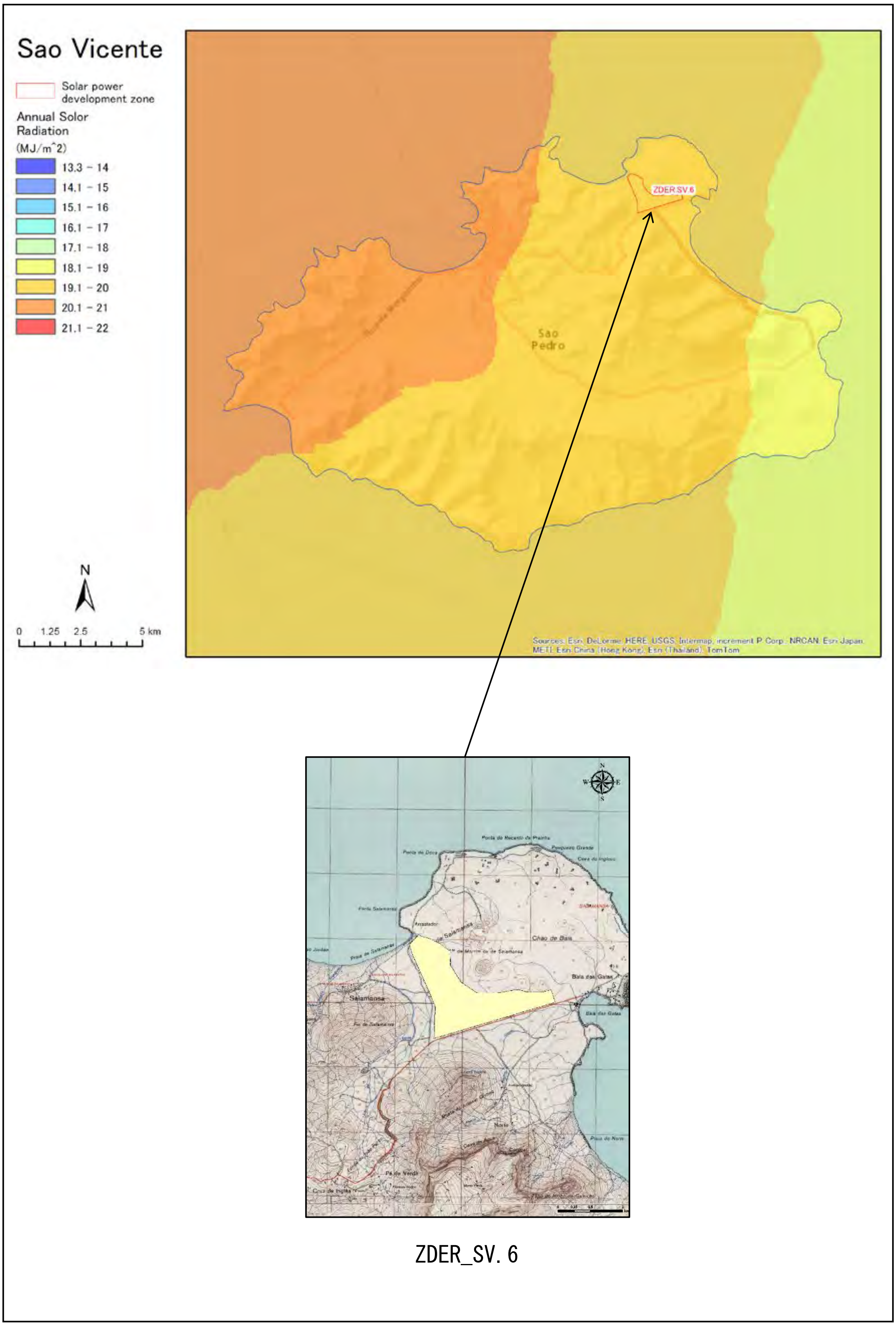
Thus, favorable solar radiation can be obtained over all of Cabo Verde, however, in consideration of the effects of cloud cover, elaboration is sought through eliminating areas that have high probability of cloud formation when selecting the ZDER. Generally, in precipitous islands, lots of clouds tend to occur on the upwind side, whereas it is difficult for clouds to form on flat islands. This trend is well expressed on the cloud area map stated in the official gazette, with a lot of cloud forming over Santo Antão and Fogo Islands and not so much over Sal Island. The ZDERs have been selected upon taking such information into account in addition to environmental factors, terrain, access to the power network and so on.

Figure 8.3-6 to Figure 8.3-14 show the solar power generation ZDER with the map, which was superimposed on the solar radiation map of Figure 8.3-5 on each island.



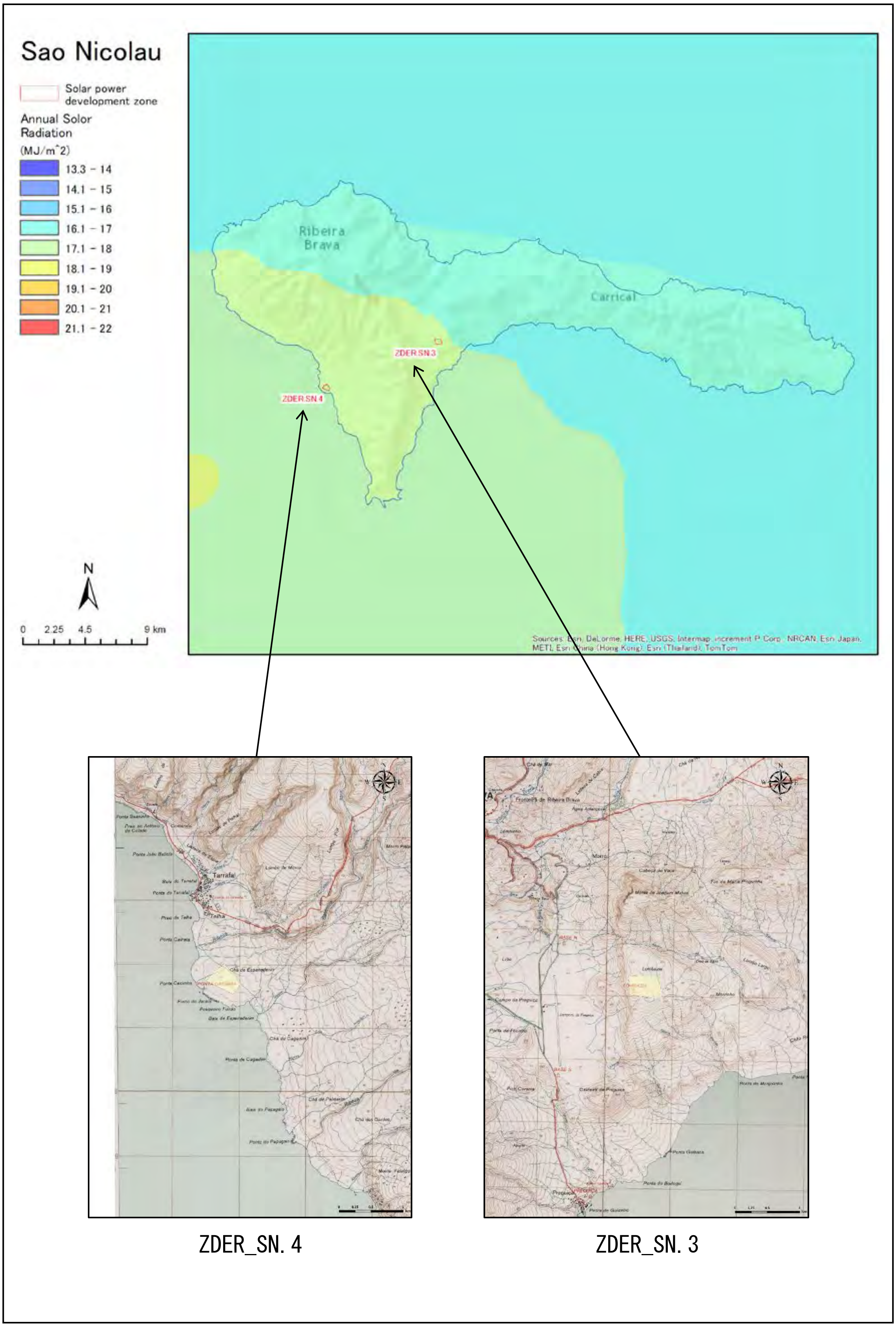
Source: JICA Study Team based on Information from DGE and original data

Figure 8.3-6 Solar power generation ZDER on Santo Antão



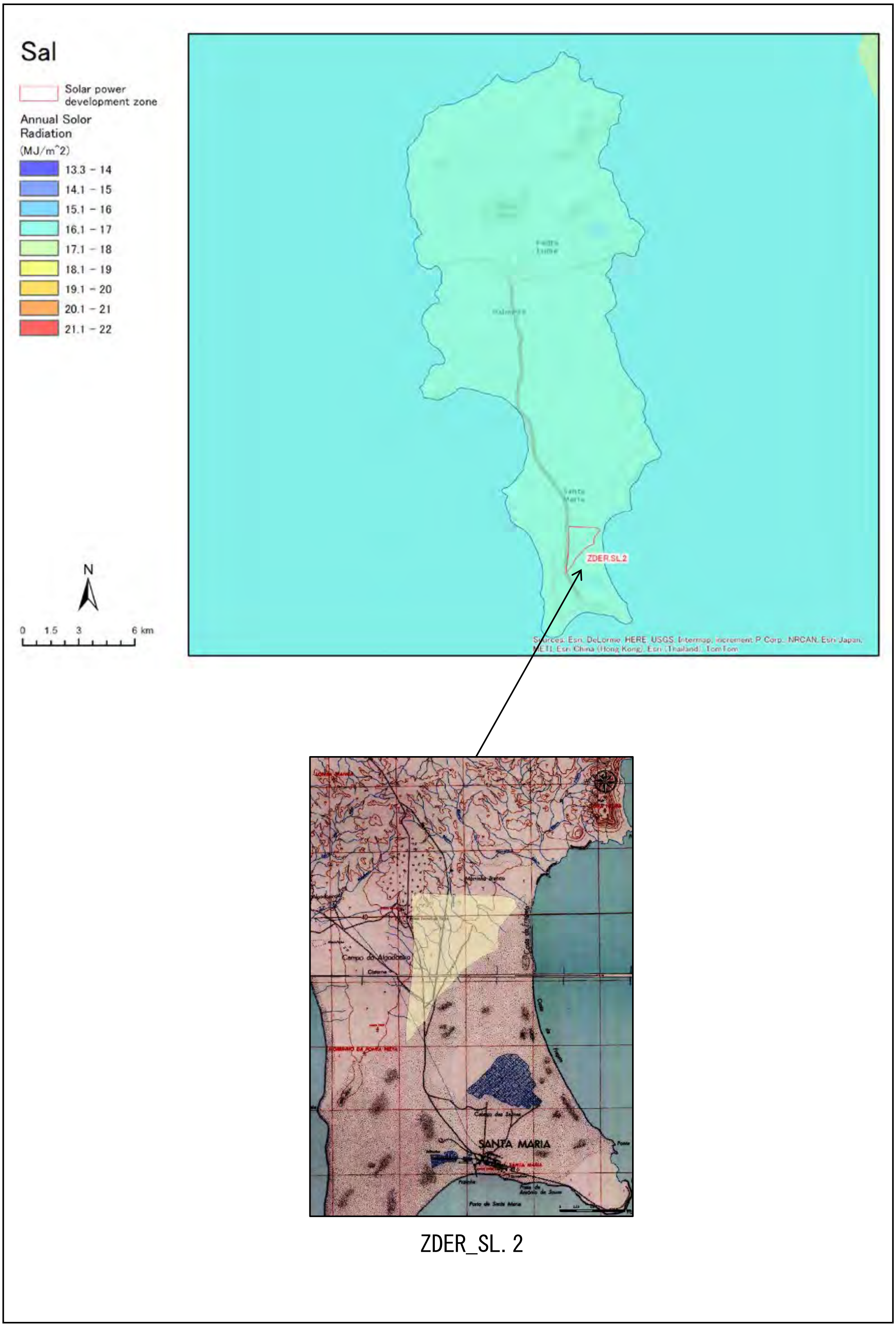
Source: JICA Study Team based on Information from DGE and original data

Figure 8.3-7 Solar power generation ZDER on São Vicente



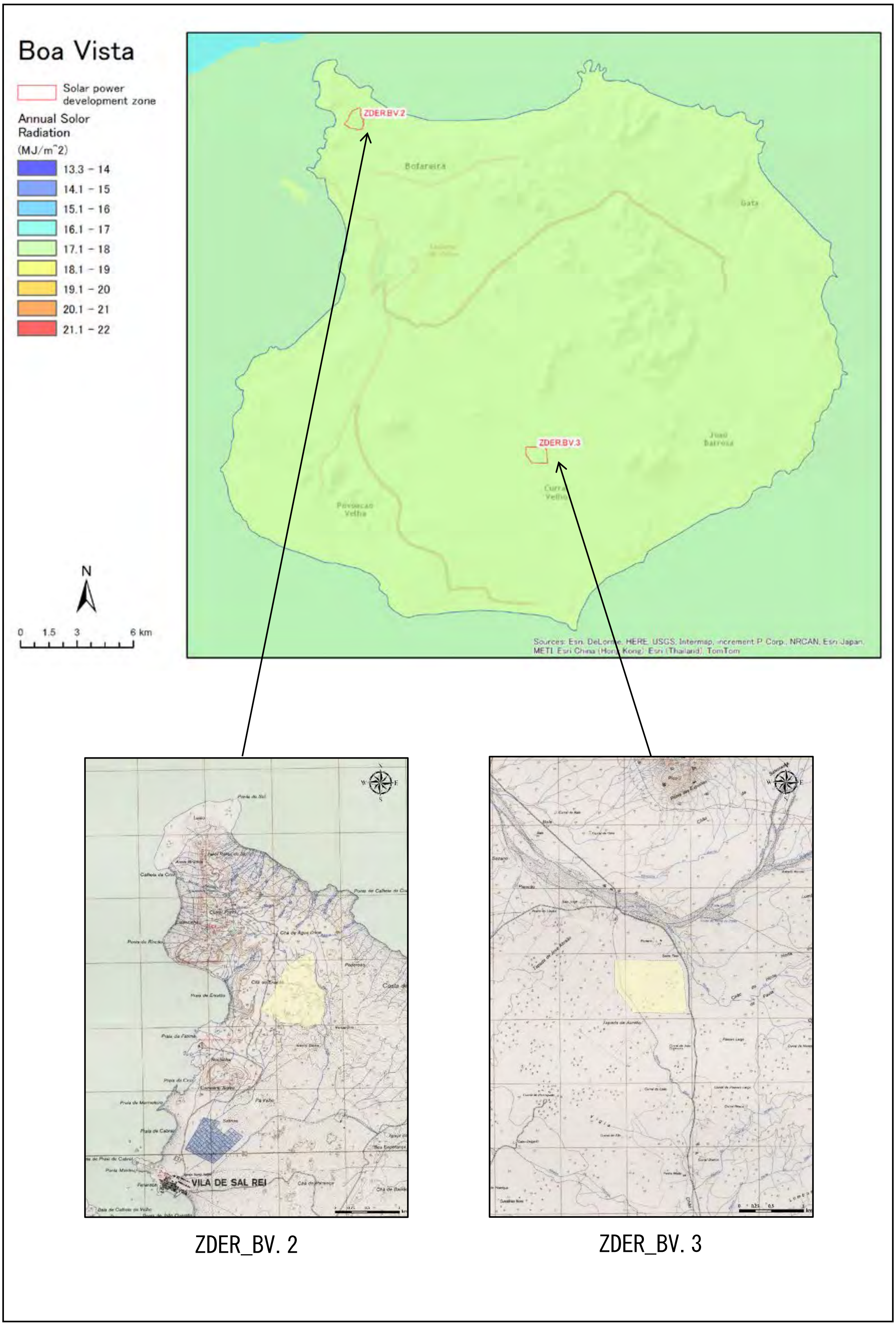
Source: JICA Study Team based on Information from DGE and original data

Figure 8.3-8 Solar power generation ZDER on São Nicolau



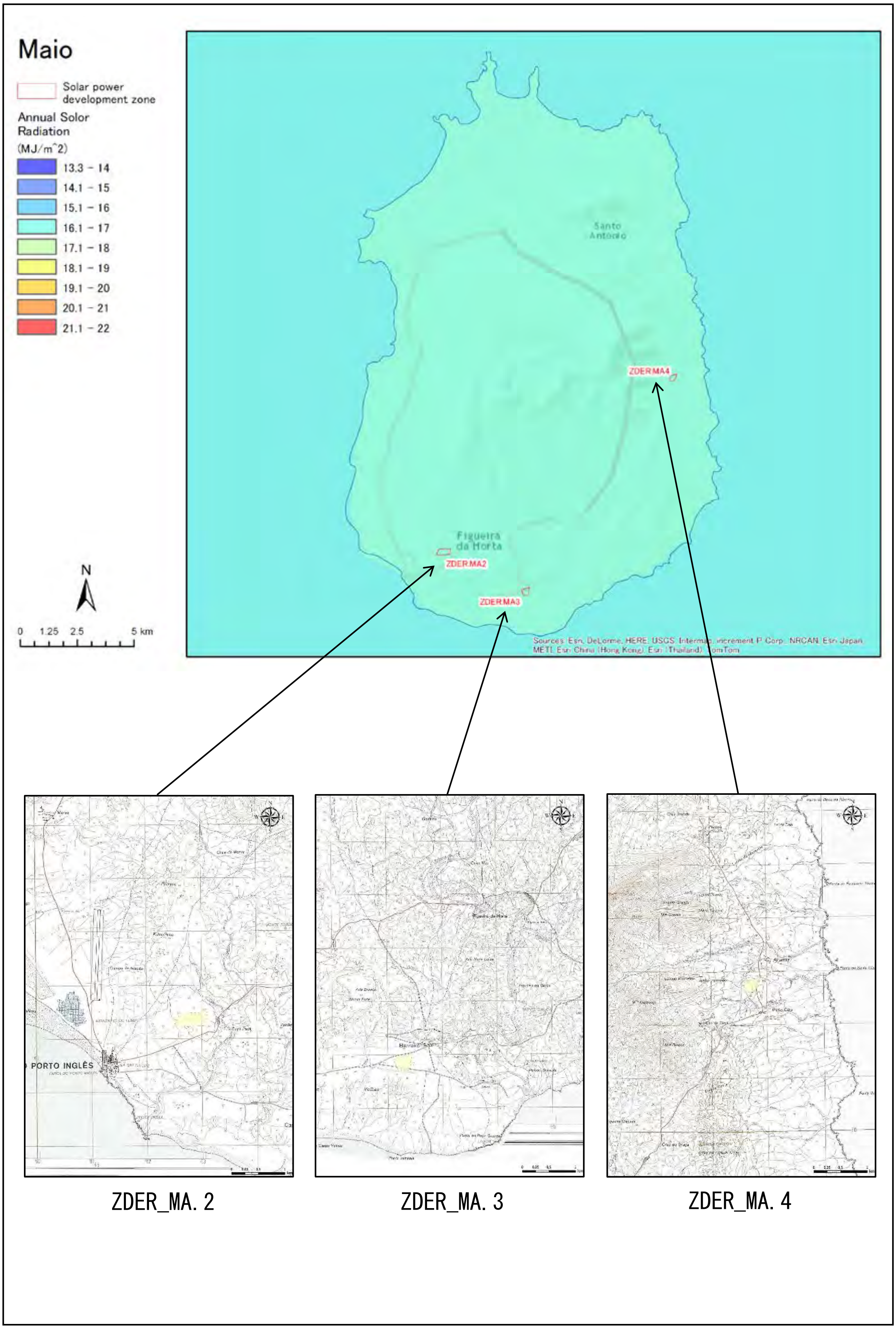
Source: JICA Study Team based on Information from DGE and original data

Figure 8.3-9 Solar power generation ZDER on Sal



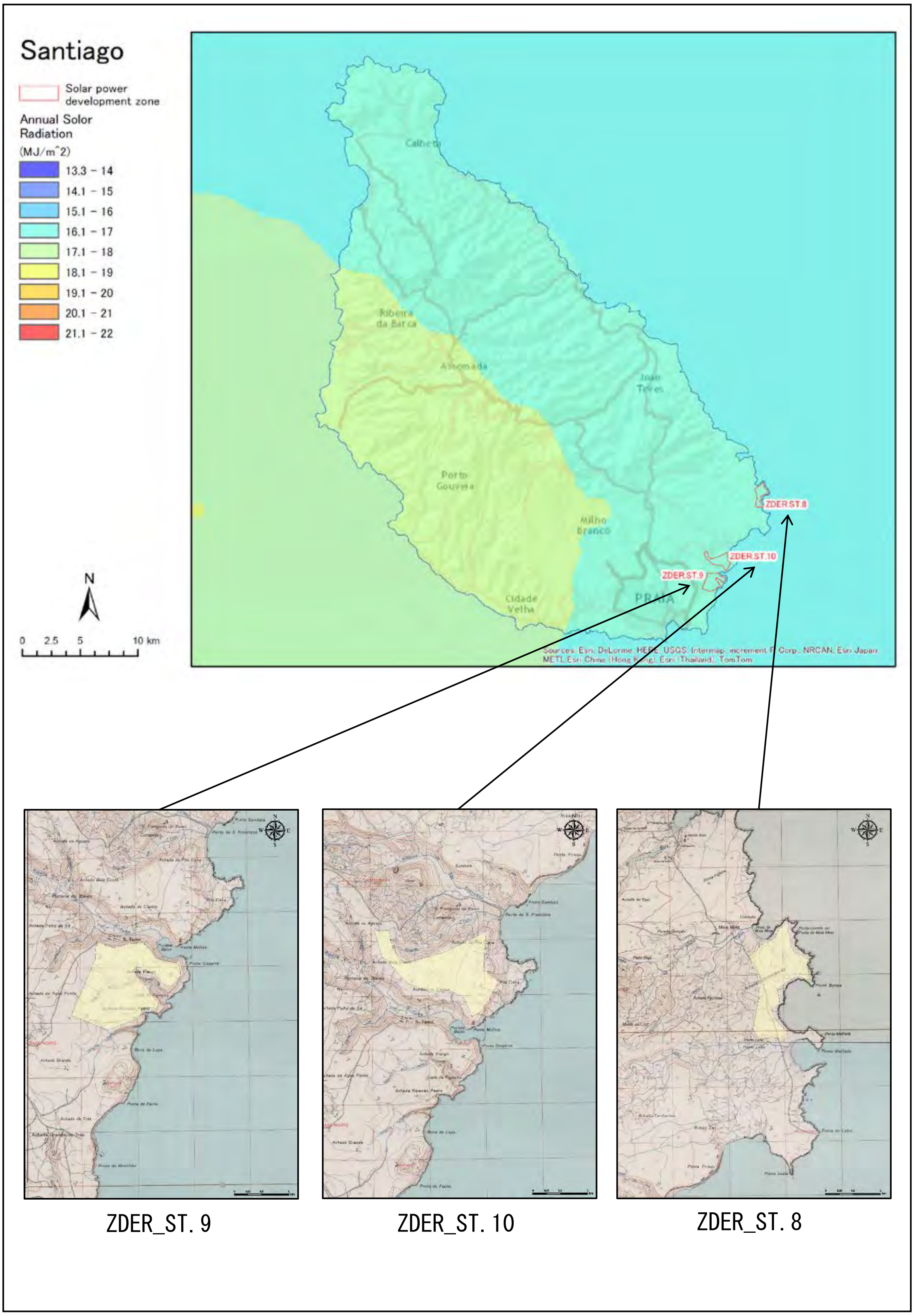
Source: JICA Study Team based on Information from DGE and original data

Figure 8.3-10 Solar power generation ZDER on Boa Vista



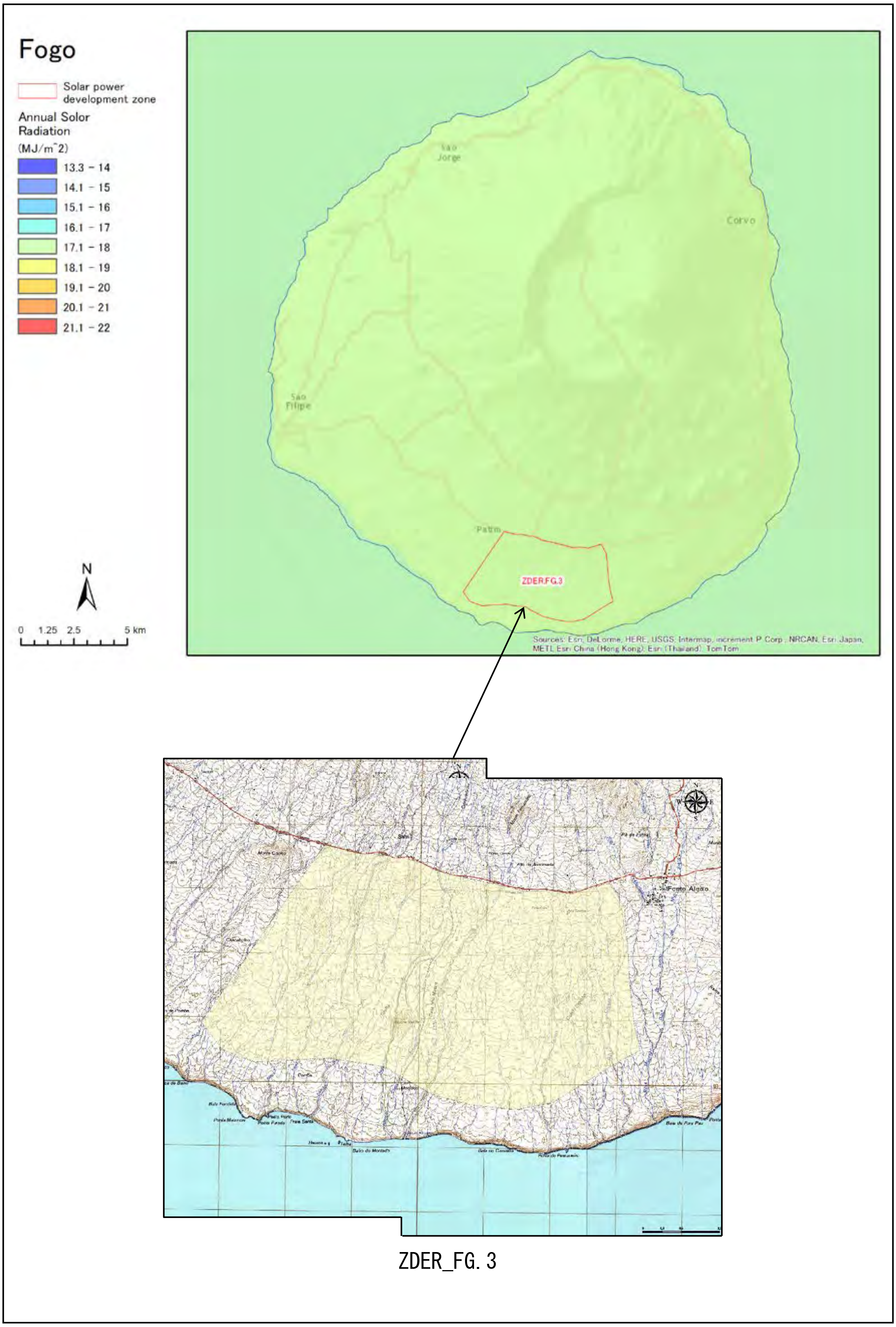
Source: JICA Study Team based on Information from DGE and original data

Figure 8.3-11 Solar power generation ZDER on Maio



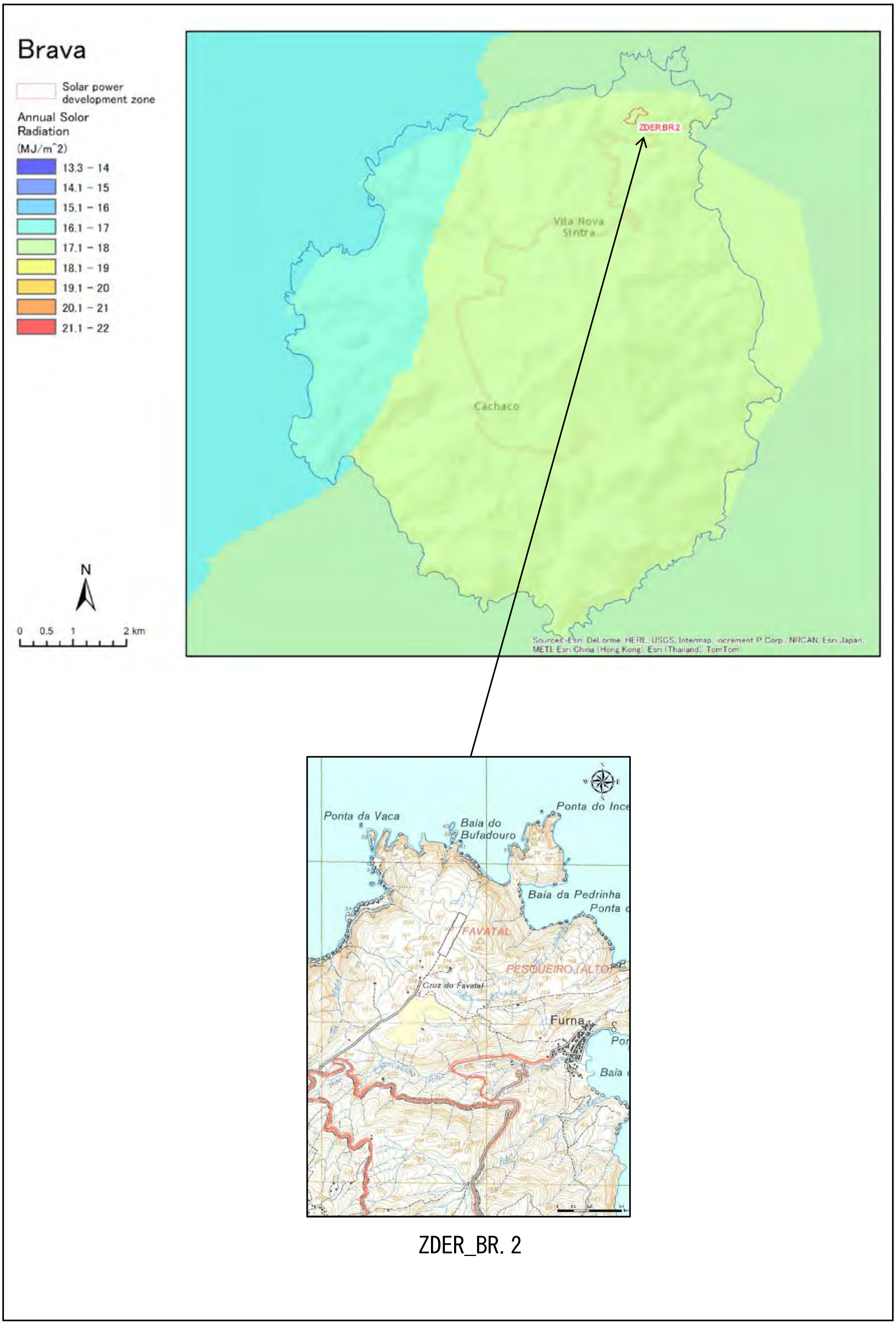
Source: JICA Study Team based on Information from DGE and original data

Figure 8.3-12 Solar power generation ZDER on Santiago



Source: JICA Study Team based on Information from DGE and original data

Figure 8.3-13 Solar power generation ZDER on Fogo



Source: JICA Study Team based on Information from DGE and original data

Figure 8.3-14 Solar power generation ZDER on Brava

Table 8.3-1 shows the solar power generation potential at each ZDER. Over Cabo Verde overall, there is potential for the installation of approximately 1,500 MW of solar power generation equipment.

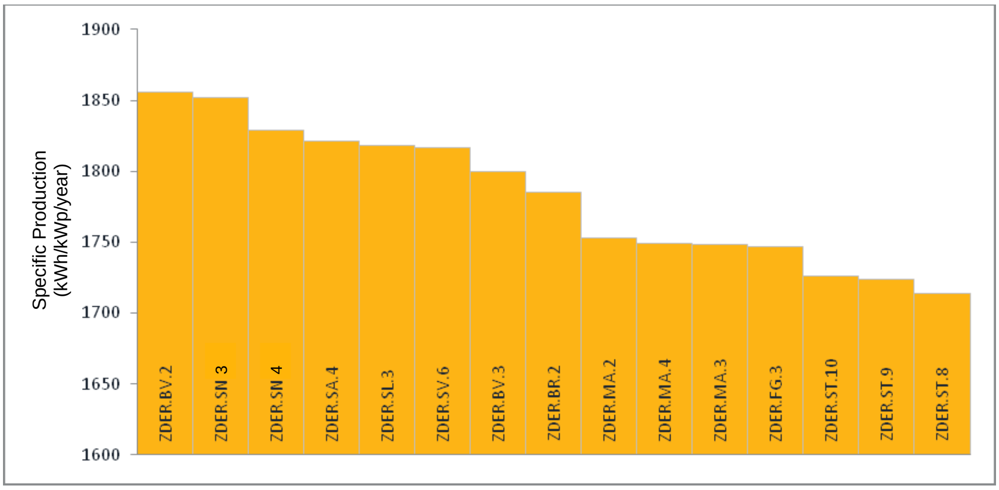
Table 8.3-1 Renewable Energy Development Zones (solar power generation)

Island	ZDER	Potential a (MW)	Area b (km^2)	b/a (m^2/kW)
Santo Antao	SA.4	176.5	3.54	20.1
Sao Vicente	SV.6	62	1.24	20.0
Sao Nicolau	SN.3	5	0.15	30.0
	SN.4	5	0.13	26.0
Sal	SL.2	98.5	1.92	19.5
Boa Vista	BV.2	30	0.69	23.0
	BV.3	30	0.79	26.3
Maio	MA.2	6	0.13	21.7
	MA.3	3	0.07	23.3
	MA.4	3	0.06	20.0
Santiago	ST.8	53	1.08	20.4
	ST.9	89	1.78	20.0
	ST.10	73	1.46	20.0
Fogo	FG.3	928.5	18.62	20.1
Brava	BR.2	3	0.06	20.0
Total	−	1,565.5	31.72	−

Source: I SÉRIE — NO 7 «B. O.» DA REPÚBLICA DE CABO VERDE — 3 DE FEVEREIRO DE 2012

Table 8.3-1 also shows the area per unit of solar power generation output. In Japan, the necessary area for installation of mega solar equipment is said to be 10~15 m^2 per kW. Since this takes the effects of shadows from adjacent solar panels into account, in Cabo Verde, which has a lower latitude than Japan, the optimum angle of solar panels is smaller than in Japan, which means that less area is needed for installation. Even taking into account space for construction of roads and installation of control instruments inside the ZDER, it is judged that the given areas can be comfortably secured.

In each ZDER, the amount of energy generated by a standard 1 MW mega solar plant is calculated using commercially available software (PVSyst) assuming the layout of solar panels that ensures optimum solar radiation, temperature and quantity of solar power generation. The results are shown in Figure 8.3-15. Moreover, based on the values read from this graph, assuming installation of solar power generation over each entire ZDER, the results of calculating the potential generated energy are shown on the left side in Table 8.3-2 (since these figures are read from the graph, there may be some error). As a result, it is estimated that Cabo Verde overall has annual solar power generating capacity of 2,700 GWh per year and this figure is also introduced in the government gazette.



Source: I SÉRIE —NO 7 «B. O.» DA REPÚBLICA DE CABO VERDE —3 DE FEVEREIRO DE 2012

Figure 8.3-15 Results of Simulation of Annual Power Generation in Standard Equipment at Each ZDER

Table 8.3-2 Solar Power Generation Potential on Each Island

Island	ZDER		Yearly Production			Yearly Production (Original radiation data)		
		Specific production (kWh/kWp/year)	Potential of ZDER (MWh)	Potential of Island (MWh)	Specific production (kWh/kWp/year)	Potential of ZDER (MWh)	Potential of Island (MWh)	2015 (MWh)
Santo Antao	SA.4	1,821	321,407	321,407	1,943	343,022	343,022	13,399
Sao Vicente	SV.6	1,817	112,654	112,654	1,842	114,219	114,219	71,122
Sao Nicolau	SN.3	1,852	9,259		1,680	8,399		
	SN.4	1,829	9,147	18,406	1,660	8,298	16,697	5,964
Sal	SL.2	1,817	178,975	178,975	1,551	152,809	152,809	67,764
Boa Vista	BV.2	1,856	55,676		1,684	50,508		
	BV.3	1,801	54,030	109,706	1,634	49,014	99,522	30,982
Maio	MA.2	1,752	10,514		1,496	8,977		
	MA.3	1,749	5,248		1,494	4,481		
	MA.4	1,750	5,250	21,012	1,494	4,482	17,940	2,687
Santiago	ST.8	1,714	90,842		1,463	77,561		
	ST.9	1,724	153,436		1,472	131,004		
	ST.10	1,726	125,998	370,276	1,474	107,577	316,142	212,281
Fogo	FG.3	1,747	1,622,090	1,622,090	1,585	1,471,501	1,471,501	12,218
Brava	BR.2	1,786	5,358	5,358	1,620	4,860	4,860	2,575
Total	–	–	2,759,883	2,759,883	–	2,536,711	2,536,711	418,992

Source: JICA Study Team based on I SÉRIE—NO 7 «B. O.» DA REPÚBLICA DE CABO VERDE—3 DE FEVEREIRO DE 2012

Since these results are based on the global solar radiation shown in Figure 8.3-1, correction was implemented using the global solar radiation data from simulation based on GSM data. Here, detailed data on global solar radiation at each ZDER corresponding to Figure 8.3-1 cannot be obtained, however, since solar radiation of 1,800~2,000 kWh/m^2 is acquired over almost the entire region, the intermediate value of 1900 kWh/m^2 was simply assumed for conducting correction through comparison with the global solar radiation based on simulation as shown on the right side of Table 8.3-2. On comparing these results with total demand in 2015, there is deemed to be enough generation capacity to satisfy demand on the islands through developing and introducing solar power generation in the ZDERs.

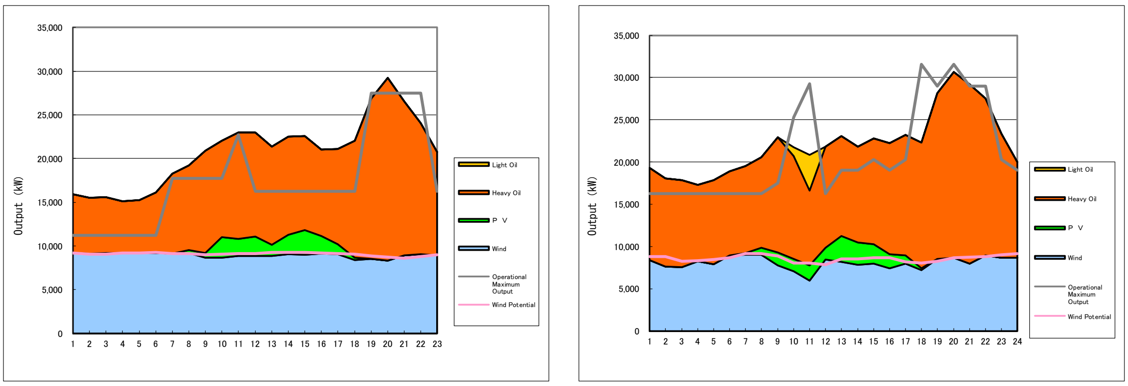
8.4 Harmonization of Diesel Power Generation and Solar Power Generation

If renewable energy output is unstable, this will impact operation of diesel power generation. Solar power generation is subject to large fluctuations in output when sunlight is obstructed by clouds. When such fluctuations become large and rapid, diesel power generation is unable to keep pace, leading to frequency fluctuations and situations where diesel power generation cannot start fast enough. This problem becomes especially marked when demand is small and the power supply ratio from renewable energy is high.

(1) Santiago Island

On Santiago Island, the equipment rated capacity of renewable energy comprises 9.35 MW of wind power and 4.28 MW of solar power, meaning that solar power accounts for 31% of all renewable energy capacity. In addition, as was stated in section 8.1.2, solar power generation can only provide a maximum output corresponding to around 80% of rated output. When this is taken into account, the impact of solar power generation output fluctuation with respect to all renewable energy output is smaller than that of wind power generation.

Here, confirmation is conducted using actual supply and demand. As conditions for the days when solar power generation output fluctuations are large, a day when the daily power generation is roughly 70% of the annual peak power generation upon referring to the actual output from solar power generation on Sal Island has been extracted (a day with the kind of output pattern indicated in Figure 8.1-17 (b)). Moreover, the conditions of days when the impacts of renewable energy output fluctuations are large, demand is small and the amount of power generated from renewable energy (wind power) is large are added to give the daily supply and demand example shown in Figure 8.4-1.



(a) 2015.2.21 (b) 2015.4.25

Source: JICA Study Team based on Information from Electra

Figure 8.4-1 Impact of Renewable Energy Output Fluctuations (Santiago)

In Figure (a), even around 13:00 when the solar power generation output is considered to be fluctuating, wind power generation is fairly stable, and diesel power generation is also operating stably (grey curve in the graph). Moreover, at the 15:00 cross section when solar power generation output is large, solar power generation is 2.8 MW and wind power generation is 9.0 MW with respect to demand of 22.6 MW.

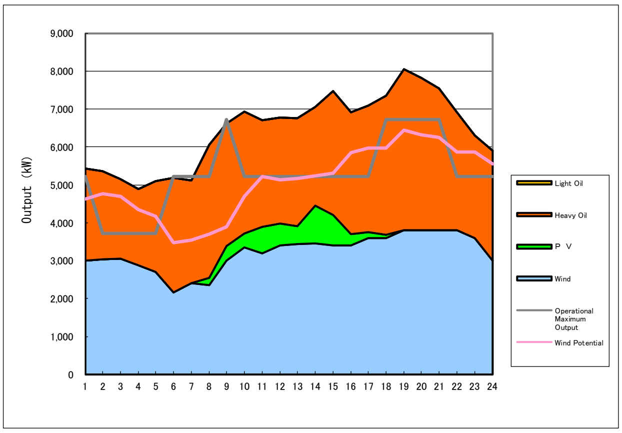
Meanwhile, in Figure (b), because output from wind power is not stable, internal combustion generation is started and stopped frequently. In the current energy mix, more than fluctuations in solar power generation, output fluctuations in wind power generation have a greater impact on the operation of internal combustion generation. (In Figure (b), at the 13:00 cross section, solar power generation is 3.0 MW and wind power generation is 8.2 MW with respect to demand of 23.1 MW).

Incidentally, because solar power generation output is given as 1-hour values, it was not possible to ascertain the impact of fluctuations on frequency.

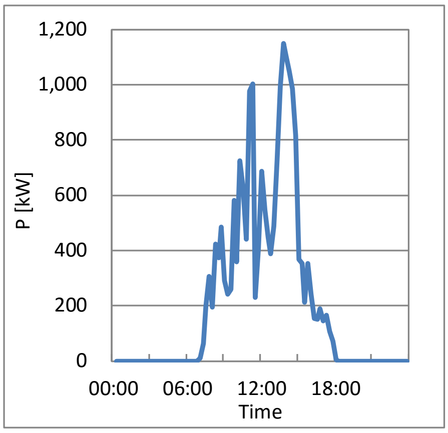
(2) Sal Island

On Sal Island, the equipment rated capacity of renewable energy comprises 7.65 MW of wind power and 2.14 MW of solar power, meaning that solar power accounts for 22% of all renewable energy capacity. In addition, since solar power generation on Sal Island can only provide output corresponding to under 60% of rated output, compared to Santiago Island, the impact of solar power generation output fluctuation is smaller than that of wind power generation.

As is also the case on Santiago Island, a day when the impacts of renewable energy output fluctuations are large has been extracted to provide the supply and demand example shown in Figure 8.4-2.



(a) Supply and demand situation (Electra supply only)



(b) Solar power generation output

Source: JICA Study Team based on Information from Electra

Figure 8.4-2 Impact of Renewable Energy Output Fluctuations (Sal, 2015.10.27)

From the figure, it can be seen that there are fluctuations in solar power generation output but that they do not have an impact on the starting and stopping of internal combustion generation. A factor behind this was that because wind conditions on this day were favorable and limitations were placed on wind power output, the wind power generation was stably operated. Moreover, at the 14:00 cross section, solar power generation is 1.0 MW and wind power generation is 2.6 MW with respect to demand of 7.0 MW). As was also the case in Santiago, it was not possible to ascertain the impact of fluctuations on frequency.

9. Transmission and Distribution Facilities

As for transmission & distribution system in Cabo Verde, 20kV is a standard voltage and 60kV is used only at Santiago Island, the capital of the country with the largest demand. 6kV or 10kV voltage distribution is still used in some region and it brings its operators difficulties with system operation and material and/or equipment procurement. From the point of operators' efficiency, 6/10kV voltage is desired to be replaced by 20kV.

Constant strong wind and little rain in Cabo Verde has made overhead distribution faults' risk higher caused by flying objects or salt. However, by recent project, those distribution lines have been replaced by underground cables and their fault risk has decreased dramatically.

(1) Transmission/distribution enhancement projects

Transmission/Distribution facilities in Cabo Verde have been upgraded by "Santiago Generation & Transmission Enhancement Program (P1)", "Electricity Transmission and Distribution Network Development Project (Target: 6 islands) (P2)", and "Reinforcement of Electrical Power Production and Distribution System for the islands of Santo Antão, Fogo, São Nicolau and Boa vista (ORET)".

- ✓ Raise distribution voltage from 10kV to 20kV
- ✓ Build new transmission network to decrease radial network
- ✓ Replace existing overhead lines to underground cables to improve security
- ✓ Enlarge distribution capacity by resizing conductors
- ✓ Apply optical fiber to distribution system for telecommunication

Currently, transmission/distribution construction has almost completed and its reliability has improved steadily. On the other hand, at Boa Vista Island, where electricity is supplied by AEB instead of Electra, distribution facilities haven't been upgraded and outage risk has gone up because of those facilities' aging. Some enhance measures to distribution facility like other islands are desirable.

(2) SCADA（Supervisory Control And Data Acquisition）

In the P2 Project, SCADA systems are planned to be introduced to Santiago, São Vicente and Sal islands. Currently SCADA can control switchgears of the transmission/distribution system and can collect data of demand only. In the future, however, SCADA planned to collect DG and renewable energy generation data and have function of EMS (Energy Management System) and DMS (Demand Management System). According to the consultant, because DG generation system in Cabo Verde is unique different from the global standard, there looks to be much technical difficulty to implement the future plan. Manufacturer of SCADA system is ALSTOM. Currently ALSTOM is customizing other country's system but its specification is not yet fixed. Electra has a plan to make SCADA collect the metrological data like solar radiation and wind speed, forecast the future demand, and select suitable DG unit to start up automatically. It takes long time to implement the plan to get renewable energy companies' agreement.

(3) Transmission/distribution network

In Cabo Verde, utility company is planning to concentrate one power plant in each island and close other old plants. In order to achieve the plan, transmission/distribution grid system should be aimed loop rather than radial.

At Maio and Fogo, because the transmission/distribution network has formed loop, electricity supply would be possible using alternative route wherever fault occurs in the loop and the reliability increased dramatically. Other island, however, weak radial transmission/distribution system is left.

At Santiago, even though 60kV transmission system has been introduced, the risk that the system cannot be used still remains because it uses overhead double circuit towers which may be damaged by a flying object. Alternative 20kV system would be necessary in case 60kV system is not available.

(4) Requirement of the locations for energy storage system

Fundamentally, if an energy storage system locates near the existing DG power plant or large scale renewable power plant, reinforcement of the existing transmission/distribution for load supply is unnecessary and it becomes economical. Contrarily, if storage locates far from those power plants or high demand area because the location cost is cheaper, in addition to access transmission line construction, reinforcement of existing grid due to lack of transmission capacity and replacement of protection equipment due to direction of power flow changes may necessary and it may be costlier in the end. Very large space is necessary for location of an energy storage system (for example, 50MW NAS battery needs two football grounds area) but it needs to consider not only cost (land price, access facility construction cost, existing facility reinforcement cost, etc.) but also maintenance and environmental aspects totally.

If joint location with a newly constructed renewable power plants is possible, it is desirable both in economy and operation aspects because low cost coordination may be organized between renewable power plants and energy storage system.

At Santiago, considering 60kV voltage system has sufficient capacity in thermal and system stability rather than 20kV, new renewable energy should be accessed to 60kV transmission lines or the secondary bus of 60kV substations for its future expansibility.

In this chapter, describes "Current status of transmission/distribution facility" in 9.1, "Current system operation" in 9.2, "Grid code now at draft stage" in 9.3, and "Current problems concerning current transmission/distribution system and countermeasures to them" in 9.4.

9.1 Outline of transmission and distribution facilities

Cabo Verde's power generation, transmission and distribution facilities have been developed through support projects by the World Bank, African Development Bank and other nations including the Netherlands and Japan. Even at present, efforts are made for the development of transmission and distribution systems through the Netherland's OERT Project and PTDSD Project (Power Transmission and Distribution System Development Project) (planned construction period: March 2012 – 2017).
The PTDSD Project covers six islands of Santo Antão, São Vicente, Sal, Maio, Santiago and Fogo and three islands (São Vicente, Sal and Santo Antão) will receive the Supervisory Control and Data Acquisition (SCADA) system.
In Cabo Verde, underground transmission and distribution lines are used in many instances and overhead lines are seen mainly in the mountains or in rural regions. The transmission and distribution line size and transformer capacity are selected based on the load served. Generally, large-sized cables are used in trunk lines and smaller-sized ones for branch lines. Pole-mounted transformers (PMT) are seen in some regions' electrified areas, but ground-mounted transformers (GMT) are utilized in most cases.
The medium voltage line adopts a three-phase three-line system, and the neutral is grounded through the grounding transformer at the power station. The Medium Voltage lines are buried in densely-populated areas but are an overhead type in sparsely-populated areas. Most utility poles for overhead lines are made of wood; however, some concrete or steel poles have been used to mount transformers and long-span cables. The glass insulators for transmission and distribution lines are being replaced with silicone ones. The insulators used at substations are the ceramic type. In the case of underground power lines, the standard cables are laid in PVC conduit. Transmission and distribution facilities are shown in Figure 9.1-3 from Figure 9.1-1 as an example.
The transmission and distribution systems of the islands are described from 9.1.1 to 9.1.9 below.


Figure 9.1-1 Overhead High Voltage and Medium Voltage lines and conductors


Figure 9.1-2 Pole-mounted and ground-mounted transformers


Figure 9.1-3 Switchgears (left: made in out modeled Portugal, right: made in new-style Spain)

9.1.1 Santo Antão

On Santo Antão, New Port Nova PS was constructed and connected to Riberia Grande PS via 20kV transmission lines thanks to the projects below, allowing New Porto Novo PS to supply full power and ensuring reliable connection of the Porto Novo system and Riberia Grande system. The work for the Porto Novo system included the expansion, extension and addition of Medium Voltage and Low Voltage lines, and installation of protection relay and other systems.

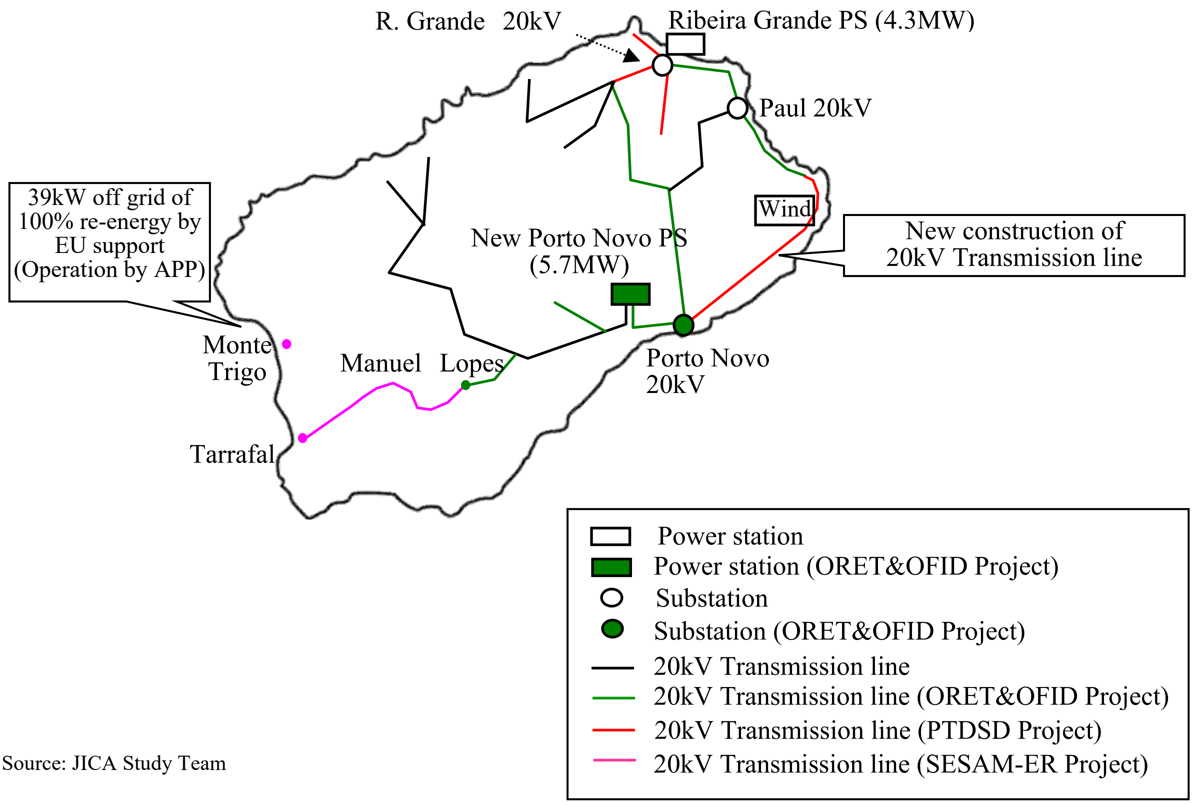
These projects are summarized below and the configuration of Santo Antão's main systems is shown in Figure. 9.1-4.

(1) ORET Project

- Construction of New Port Novo PS (the existing Port Nova PS is scrapped)
- Connection of New Port Novo PS and Riberia Grande PS via 20kV transmission lines
- Connection of areas that received power from small-scale PSs to the grid

(2) PTDSD Project

- Looping of Medium Voltage - transmission lines (transmission line constructed between Port Nova and Riberia Grande)
- Measures for the housing development in Porto Novo, Paul and Ponta do Sol
- Voltage increase for the 10kV- transmission lines of the Riberia Grande/Ponta do Sol systems (10kV→20kV)



Source: JICA Study Team

Figure 9.1-4 Configuration of Santo Antão's main systems

9.1.2 São Vicente

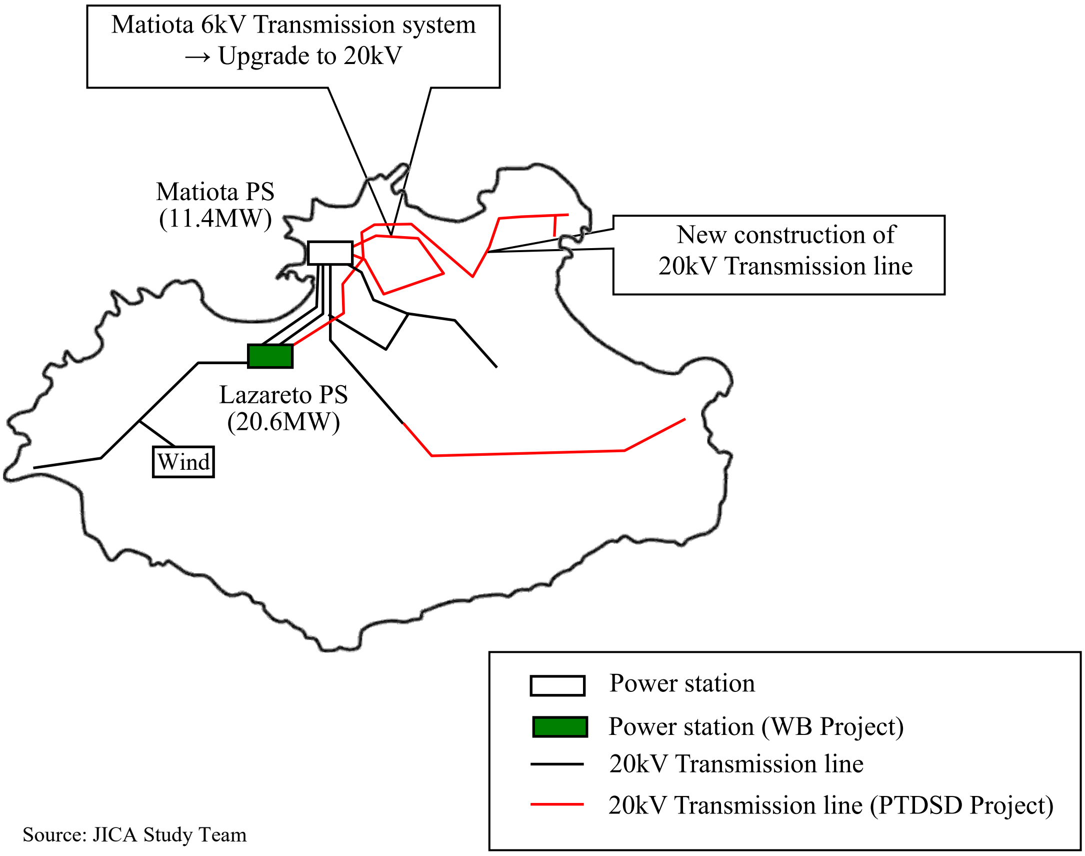
São Vicente used to have many outdated transmission and distribution facilities. Thanks to the following projects, the island's systems have gone through reinforcement and renewal work that included the review of the Medium Voltage and Low Voltage transmission/distribution networks and facilities. These projects are summarized below and the configuration of São Vicente's main systems is shown in Figure. 9.1-5.

(1) Projects by the World Bank and African Development Bank (AfDB)

- Addition to Lazareto PS by the World Bank (5.52MW×2)
- New construction of wind PS by AfDB (5.95MW)

(2) PTDSD Project

- Voltage increase for the 6kV transmission lines of Matiota system (6kV→20kV)
- Measures for the urban development in Mindelo and resort development in the Salamansa area (new substation and distribution line construction)
- Residential zone expansion (new distribution line construction), Low Voltage distribution line reinforcement and renewal of degraded lines (power line replacement)



Source: JICA Study Team

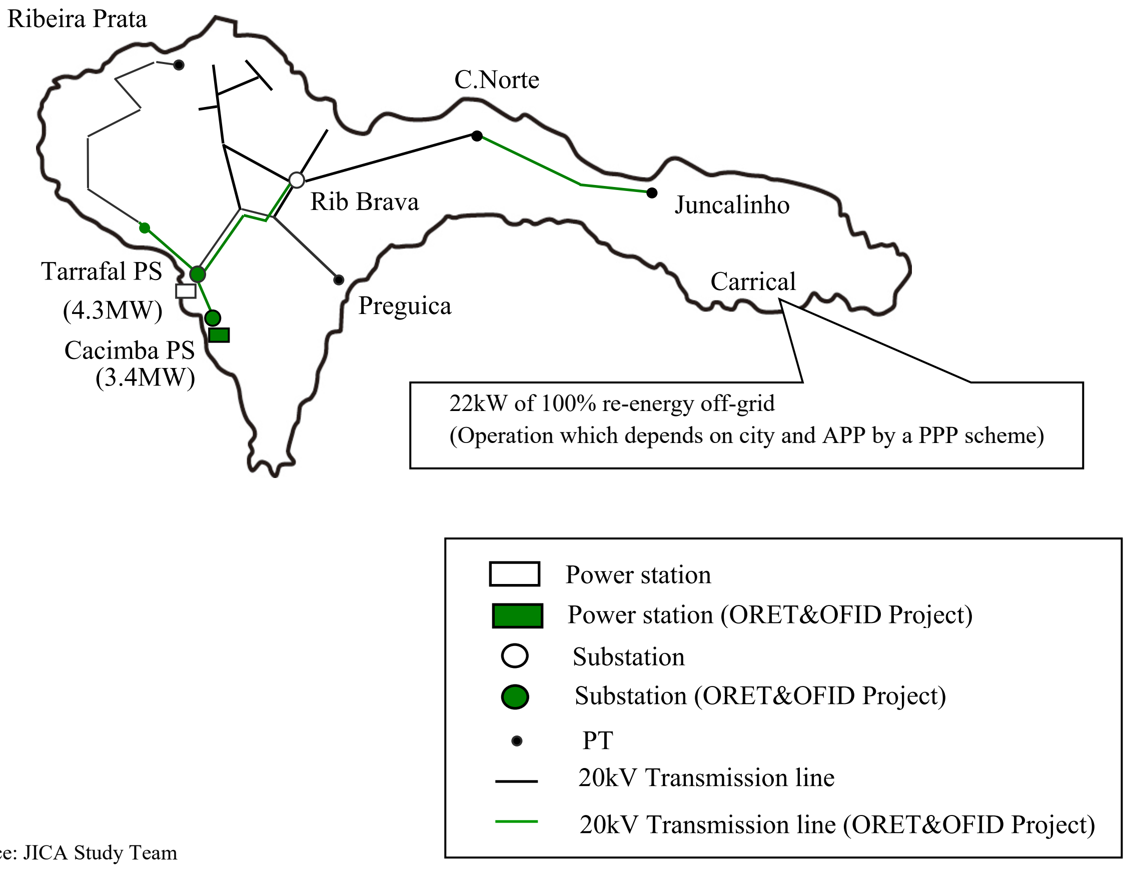
Figure 9.1-5 Configuration of São Vicente's main systems

9.1.3 São Nicolau

São Nicolau's systems have been improved with the new construction, reinforcement and renewal work of the power stations and transmission/distribution facilities, thanks to the ORET Project by the Netherland. (Refer Figure 9.1-7 and Figure 9.1-8)
The project is summarized below and the configuration of São Nicolau's main systems is shown in Figure. 9.1-6.

(1) ORET Project

- New construction of Cacimba PS (renewal of Tarrafal PS) and reinforcement of Tarrafal distribution substation
- 20kV transmission line reinforcement (between Cha de Norte and Juncalinho, and from Tarrafal to Ribeira Prata and to Ribeira Brava)



Source: JICA Study Team

Figure 9.1-6 Configuration of São Nicolau's main systems

Figure 9.1-7 20kV Transmission facilities (between R.Brava and Cacimba PS)

Figure 9.1-8 20kV underground cable leading-in steel tower
(between C.Norte and Juncalinho)

9.1.4 Sal

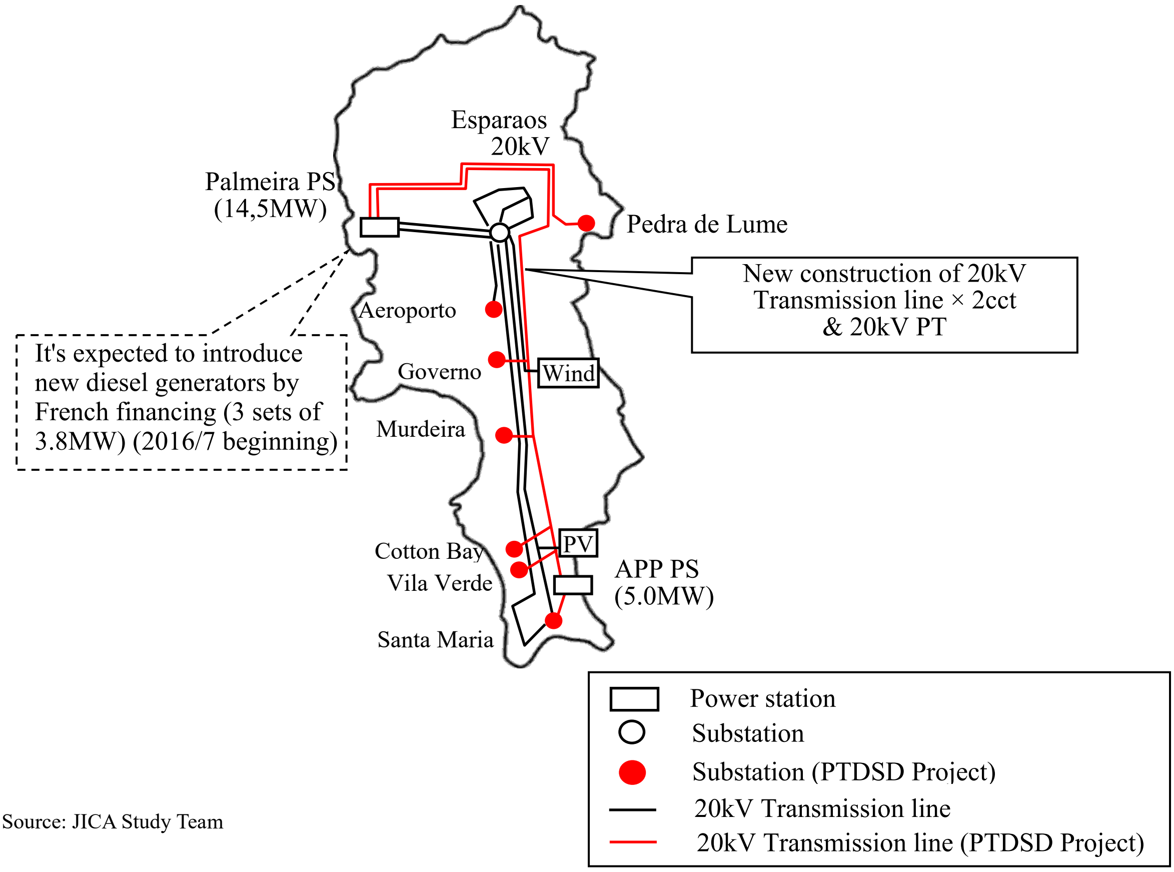
Emphasis has been placed on securing power supply capability that satisfied the demand in Sal, where resort development has been actively promoted. The 20kV Medium Voltage underground transmission line connecting Palmeria PS and Santa Maria, a resort area in the southern region, had two 240mm^2 cables (of which one has suffered aged deterioration), and could not transmit enough power to meet the demand whenever one of the cables failed. To address the situation, another cable was added to the transmission line, resulting in enhanced supply reliability. These projects are summarized below and the configuration of Sal's main systems is shown in Figure. 9.1-9.

(1) Projects by Agence Francaise de Development and African Development Bank (AfDB)

- Addition at Palmeria PS by Agence Francaise de Development
- New wind PS construction by AfDB (7.65MW)

(2) PTDSD Project

- Power line reinforcement from Palmeria to Santa Maria and to Pedra de Lume
- New construction of Murudeira SS and transmission lines from Palmeria PS
- 20kV transmission line reinforcement (between Espargos and Palmeira) and renewal of degraded Low Voltage distribution lines



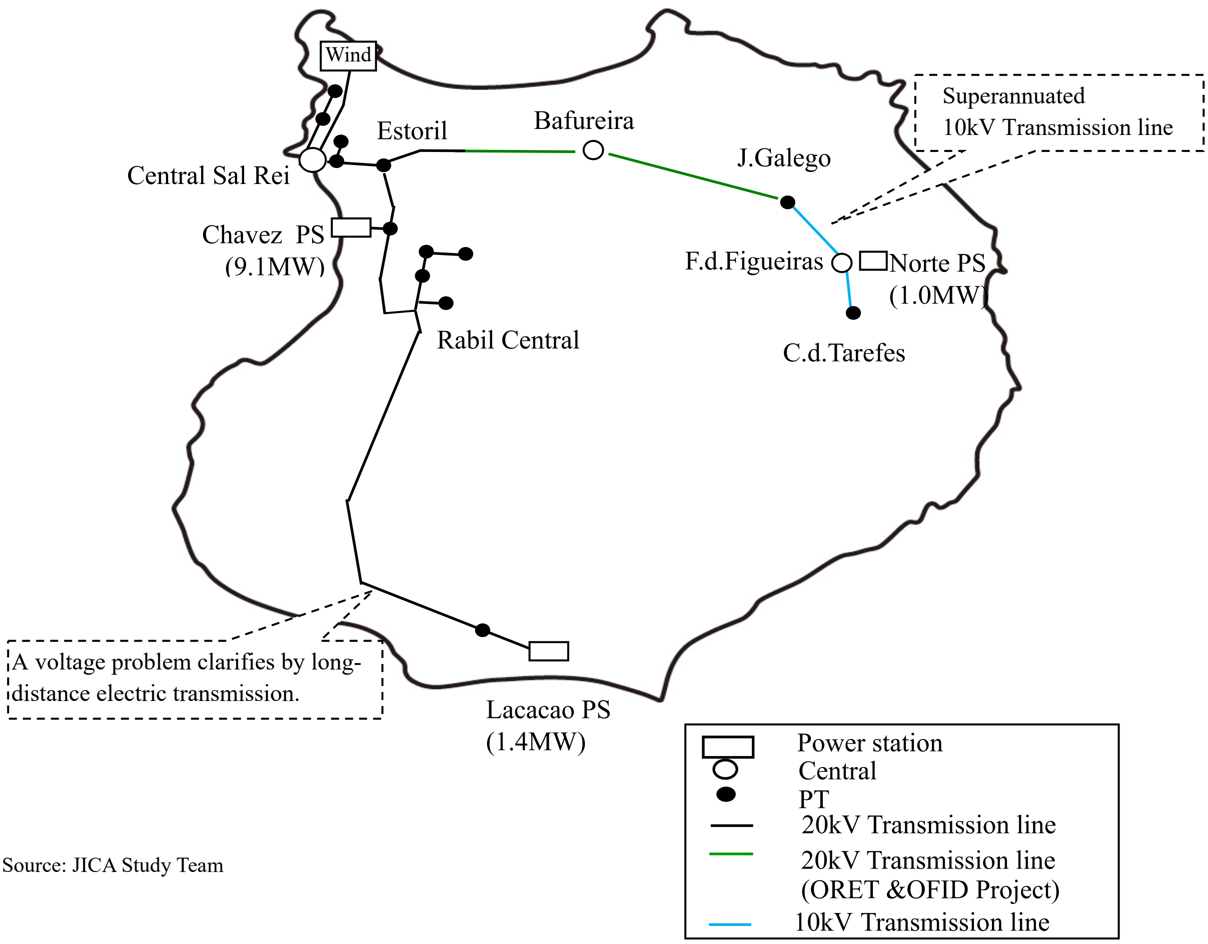
Source: JICA Study Team

Figure 9.1-9 Sal Configuration of Sal's main systems

9.1.5 Boa Vista

Power supply facilities concentrate in the northern region of Boa Vista, and demand from hotels, etc. is mainly in the central and southern regions. The northern region was electrified by a small independent grid system, and now has been connected to the trunk system under the ORET Project. The 20kV distribution line from Chavez PS to Sal REI desalination plant is a weak section of the system, as it is an overhead line and has had power failures resulting from aged deterioration. The power failures were not caused by Cabeolica's wind farm which is further down the route.

At the south, due to the distance of 25km that underground cables (400mm^2 aluminum) run between Chavez PS and Central Lacação PS, issues are emerging, which include voltage drop during the hours of light load due to lower demand from the hotels. Currently, AEB hopes for the installation of voltage stabilization systems. For a plan of the large-scale demand which will be hotels later to be expected from now on, power supply addition by a diesel generator is being also considered. The project is summarized below and the configuration of Boa Vista's main systems is shown in Figure. 9.1-10. (Refer from Figure 9.1-11 to Figure 9.1-16)



Source: JICA Study Team

Figure 9.1-10 Configuration of Boa Vista's main systems

-

Figure 9.1-11 Transmission line connection point at Bafureira

(photo on the left is of the steel tower for transmission to the J.Galego side, that on the right is a housing for the unit for receiving power from Chavez PS)

* the existing PS owned by the city will be scrapped in FY2016 after the electrification

Figure 9.1-12 Transmission line connection point at J.Galego

Figure 9.1-13 10kV line leading-in pole at F.d.figueiras

Close-up of the cable box
(severe corrosion due to rust)

Figure 9.1-14 Connection point at C.d.Tarefes
(stationary 25kVA transformer is housed in the container)

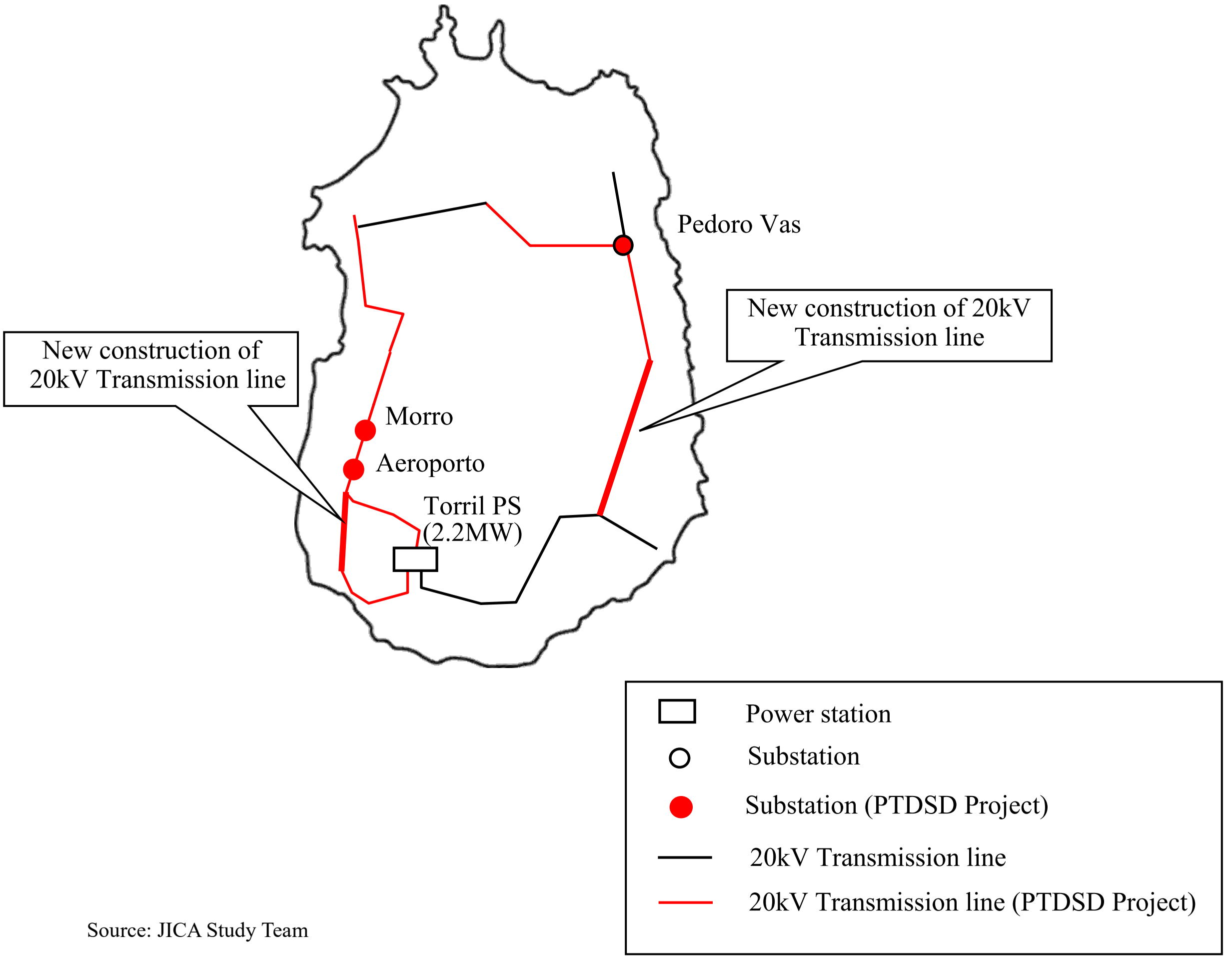
Figure 9.1-15 20kV overhead transmission line in the north-western region

Figure 9.1-16 Resort hotel under construction in the southern region

9.1.6 Maio

The system was provided Maio island with by the looping of Medium Voltage distribution lines (new construction between Figueria Seca and Alcatraz) and renewal of degraded Medium Voltage and Low Voltage distribution lines (power line replacement) by a PTDSD project.

The configuration of Maio's main systems is shown in Figure. 9.1-17.



Source: JICA Study Team

Figure 9.1-17 Configuration of Maio's main systems

9.1.7 Santiago

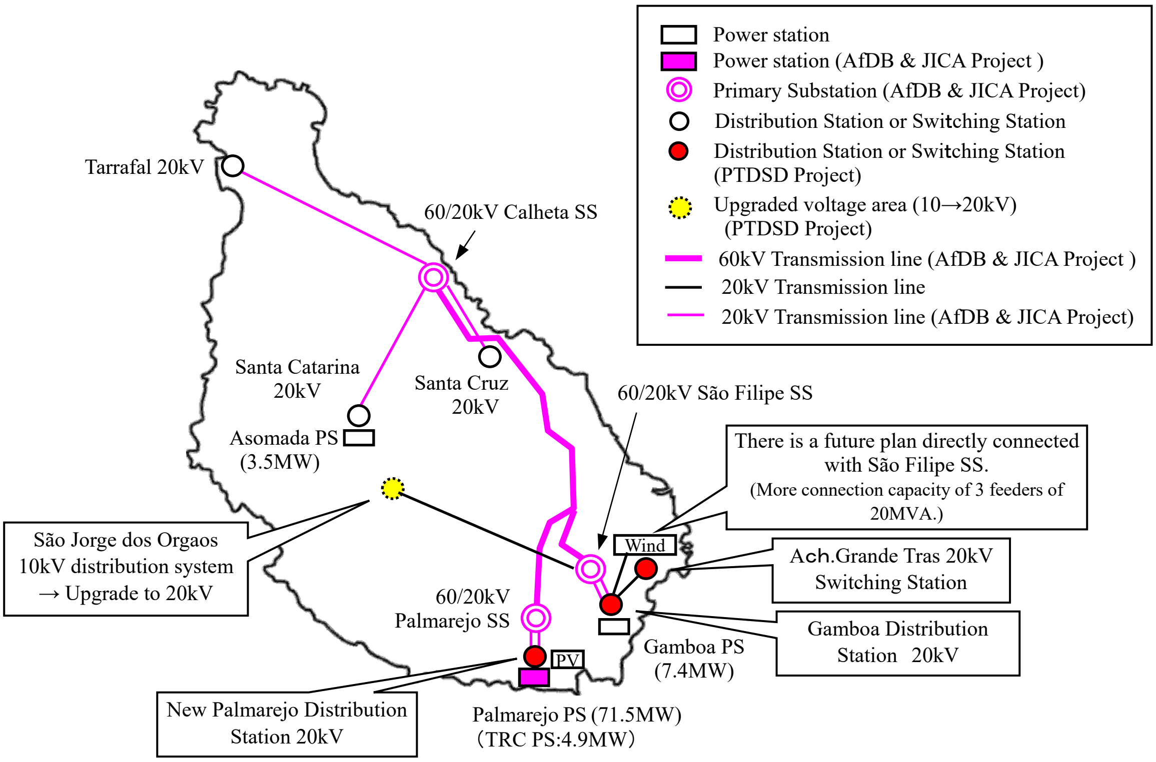
The projects below brought changes to Santiago's transmission/distribution systems, and as a result the island's major areas have been connected via 60kV High Voltage and 20kV Medium Voltage transmission lines, and electricity produced at Palmarejo PS can now be distributed to meet all the power demand of Santiago. There has been some expansion and addition of Medium Voltage and Low Voltage lines. Protection relay and other systems have been installed on Santiago in response to total power failures that occurred in the Praia system due to the activation of the protection relay, etc. (detection of failures in the direction of Porto Mosquito) at Palmarejo PS. There is a plan to concentrate the monitoring functions on Santiago and create a load dispatching center covering three islands including São Vicente and Sal. The past projects are summarized below and the configuration of Santiago's main systems is shown in Figure. 9.1-18. (Refer from Figure 9.1-19 to Figure 9.1-21)

(1) Projects by African Development Bank (AfDB) and JICA

- Palmarejo PS, added with new diesel generators (2×11.38MW), was connected to Calheta PS via a 60kV transmission line, and Santa Cruz PS, Santa Catalina PS and Tarrafal PS are connected via 20kV transmission lines and then scrapped. There is a plan for AfDB to add a wind PS.

(2) PTDSD Projects

- Voltage increase for the São Jorge dos Orgaos 10kV transmission line (10kV→20kV)
- Expansion of Achada Grande Tras industrial zone (distribution line reinforcement, SS building installation, etc.)
- Work for residential zone expansion, Low Voltage distribution line reinforcement and renewal of degraded lines (power line replacement)



Source: JICA Study Team

Figure 9.1-18 Configuration of Santiago's main systems

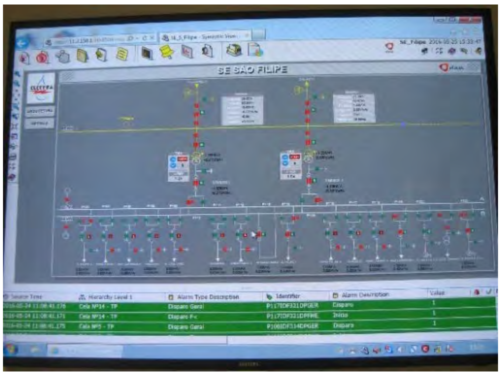
Figure 9.1-19 Palmarejo SS

SS premises (space for 2 extra banks)

Transformer nameplate (made in Portugal)

20kV Switchgear

Space for extra 20kV switchgears



Monitoring and control screen

SCADA

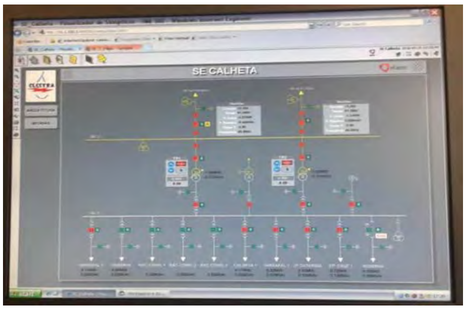
Figure 9.1-20 São Filipe

SS premises

Transformer nameplate (made in Italy)

20kV Switchgear

Space for extra 20kV switchgears



Monitoring and control screen

SCADA

Figure 9-1.21 Calheta SS

9.1.8 Fogo

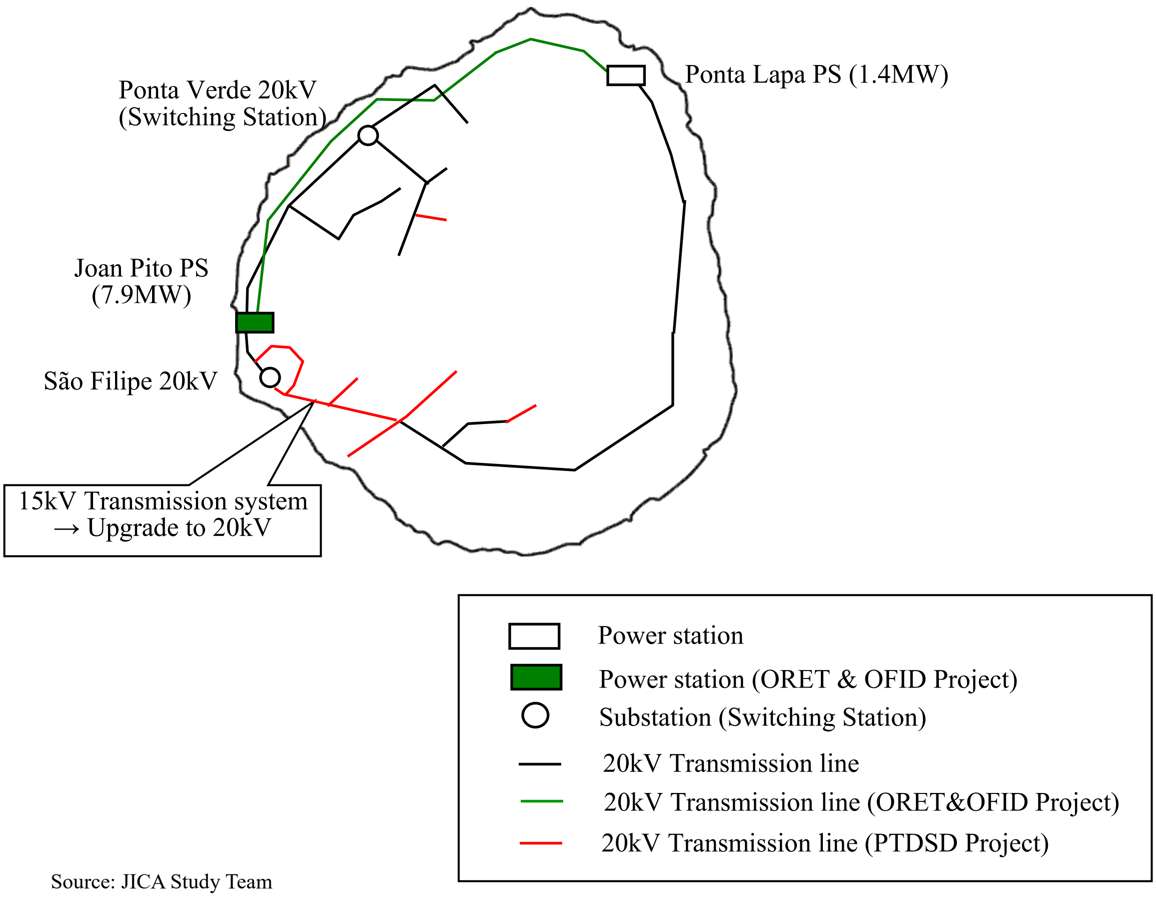
In Fogo island Medium Voltage lines different up to now, and transmission/distribution facilities were superannuated. However, after the projects below, the Medium Voltage lines were unified to 20kV and the transmission and distribution networks were developed to form a loop around the island, etc. enhancing the system reliability. These projects are summarized below and the configuration of Fogo's main systems is shown in Figure. 9.1-22.

(1) ORET Project

・Joan Pito PS was newly constructed and connected to Ponta Lapa PS via a 20kV transmission line (the existing São Filipe PS and Ponta Verde PS were scrapped)

(2) PTDSD Project

・Voltage increase for the São Filipe system's 15kV transmission lines (15kV→20kV)
・Residential zone expansion in São Filipe (new transformer and distribution line construction)
・Renewal of degraded Low Voltage distribution lines (power line replacement) and electrification (new transformer installation)



Source: JICA Study Team

Figure 9.1-22 Configuration of Fogo's main systems

Figure 9.1-23 Steel tower with a transformer

Figure 9.1-24 Low Voltage distribution lines

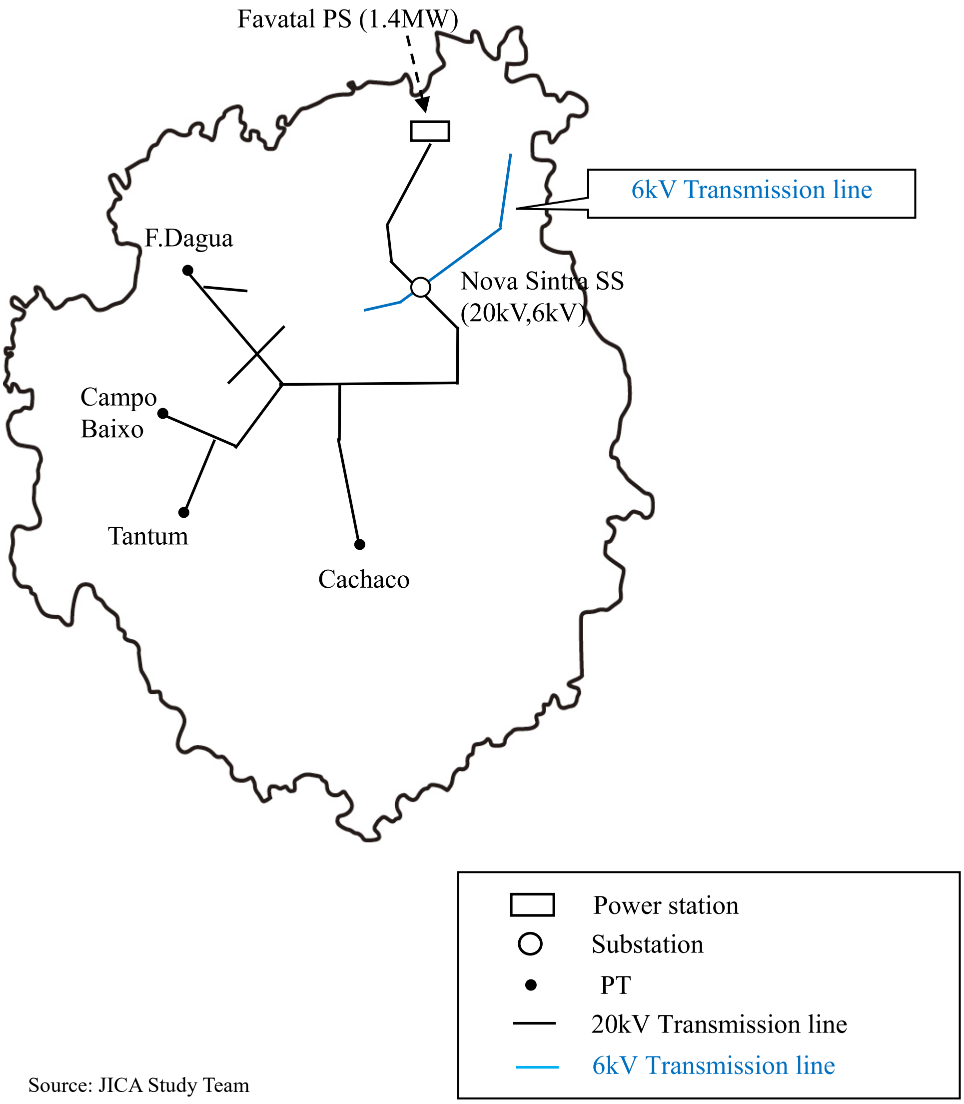
Figure 9.1-25 Residential electric power meter

9.1.9 Brava

Generators were added and transmission/distribution systems were improved in Brava in 2008. However, since then, the island has not seen projects similar to those that took place in other islands involving new construction, reinforcement or renewal of facilities. There, the facilities have been allowed to age and now suffer deterioration, and 6kV Medium Voltage transmission lines are still in existence. (Refer Figure 9.1-27)

A 150kW wind turbine was once connected to the grid; however, it has ceased operation due to aged deterioration. The wind turbine was used for dump-load operation (to consume energy with the use of dummy load (resistance) when there was excess energy). (Refer Figure 9.1-28)

The configuration of Brava's main systems is shown in Figure. 9.1-26.



Source: JICA Study Team

Figure 9.1-26 Configuration of Brava's main systems

20kV switchgear (left: by EFACEC, center: by ALSTOM) and transformer (back right)

6kV switchgear (by ALSTOM)
(two feeders)

House transformer: 250kVA (by GONELLA)
(20kV/400V)

Figure 9.1-27 Nova Sintra SS

Figure 9.1-28 Decommissioned wind turbine facility

9.2 System Operational Status

The voltage classes of Cabo Verde are shown in Table 9.2-1. Currently, high-voltage operation is used only at Santiago. The unification to 20kV is promoted for better efficiency in operation and material procurement. But remaining areas about Brava and Boa Vista are using by 10/6kV voltage.

Table 9.2-1 Definition of voltage classes

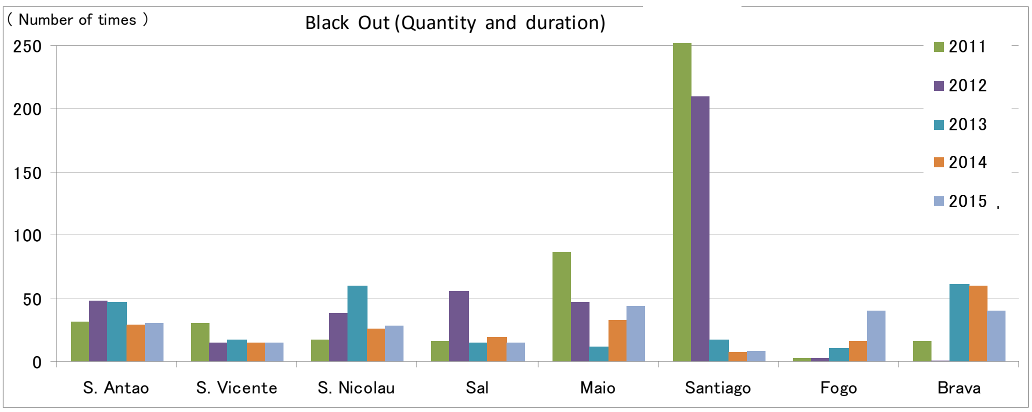
Voltage class	Voltage	Target voltage
High Voltage (HV)	60 kV or higher	60kV (transmission line, transformer, etc.)
Medium Voltage (MV)	1kV or higher but less than 60kV	20kV, 15kV, 10kV and 6kV (transmission and distribution line, transformer, etc.)
Low Voltage (LV)	Less than 1kV	400 V (LV distribution line, etc.)

Source: JICA Study Team

Cabo Verde States of the distribution and transmission systems are maintained by projects such as international donor-assisted power generation, transmission/distribution business and system reliability has been enhanced steadily. The blackout number of times which occurred from 2011 to 2015 is indicated on figure 9.2-1 at 8 island (except for Boa Vista island). Next the outage time which occurred from 2011 to 2015 is indicated on figure 9.2-2 in 4 island north. After 2013, the blackout number of times and outage time tend to decrease overall together from a chart. But, it increases in the blackout number of times about Maio and Fogo. Details of the reason for this is unclear, but is thought to cause effects of natural disasters caused by cyclone in 2015.

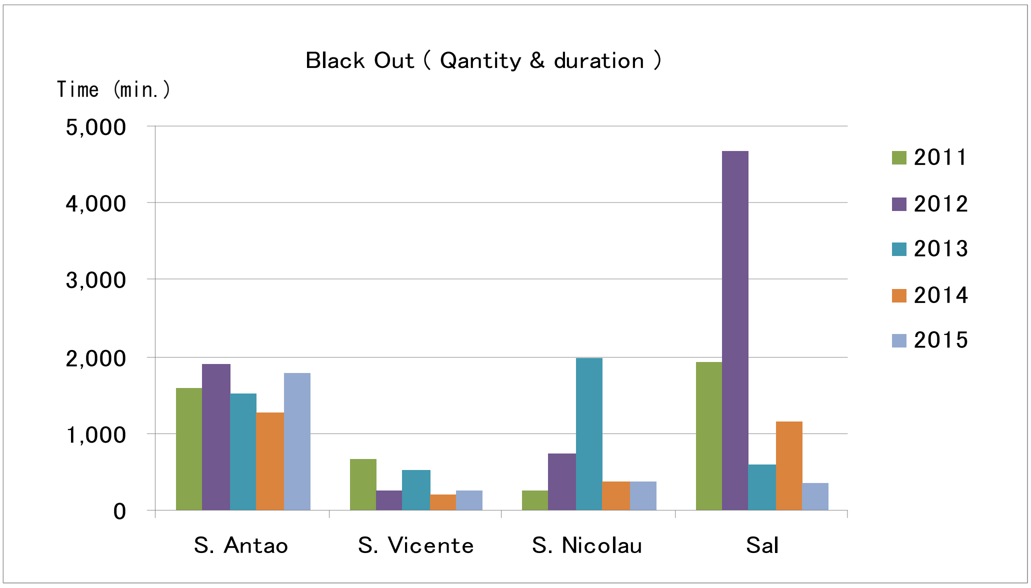
The blackout number of times until April, 2016 and outage time are indicated on figure 9.2-3 from 2014 which occurred at Boa Vista. Time decreases more than 2014 years by the blackout number of times and a blackout in 2015, but it's the pace in which last year is exceeded because the blackout number of times as of April is last year's about half in 2016. Trouble about a diesel generator in the power plant seems to occupy most for the main cause of the blackout occurrence at Boa Vista.

For facilities countermeasures of utility grid to seem necessary about Boa Vista and Brava, the problems and future's countermeasures, etc. are described in 9.4.



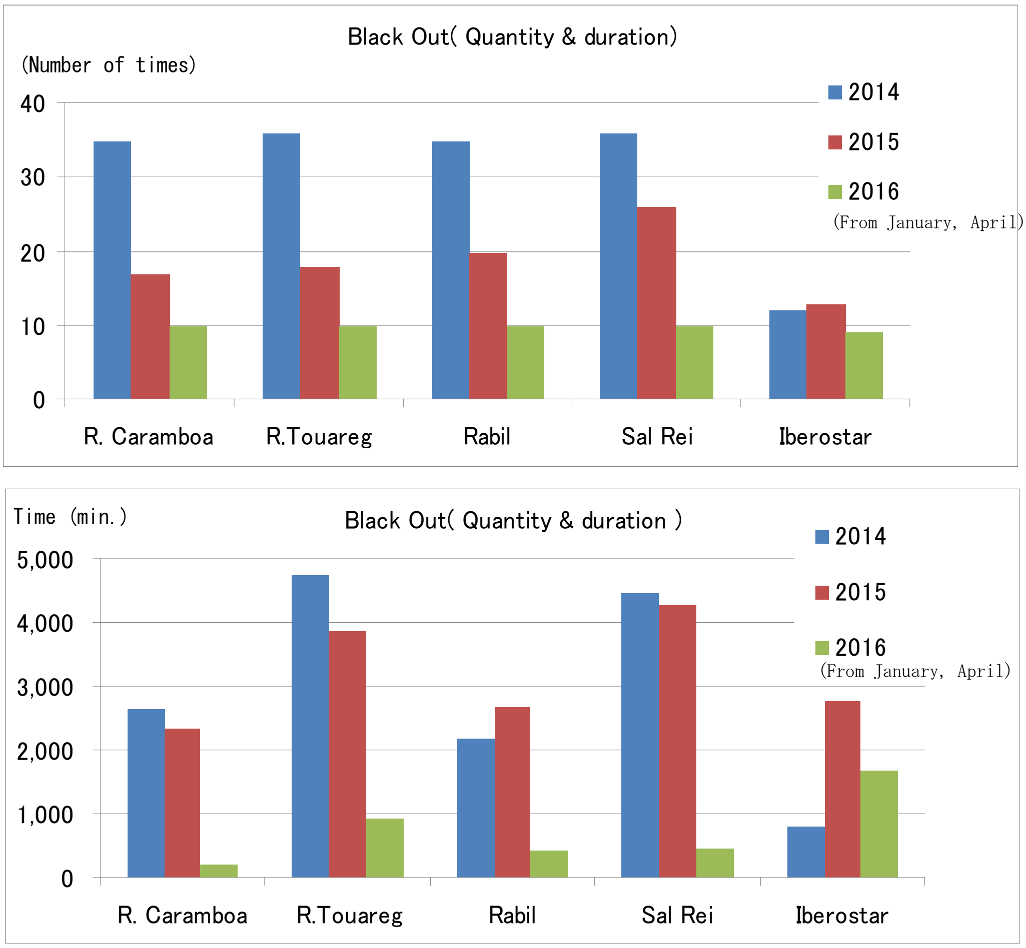
Source: JICA Study Team based on Information from Electra

Figure 9.2-1 blackout generation status (8 island except for Boa Vista island)



Source: JICA Study Team based on Information from Electra

Figure 9.2-2 Situation of blackout occurrence time (4 island north)



Source: JICA Study Team based on Information from AEB

(the top: blackout number of times, lower : outage time)

Figure 9.2-3 Blackout generation status in Boa Vista island

9.3 Grid Code

In Cabo Verde, there are no particular standards related to electric power, although power facilities were installed according to Portuguese standards when EDP of Portugal previously invested in ELECTRA. However, now that Cabo Verde has established an energy road map in which it plans to expand renewable energy sources with a view to reducing dependence on fossil fuels, work is being advanced on formulation of grid interconnection requirements, i.e. a Grid Code, to ensure that power network stability and quality are secured with respect to the future expansion of renewable energy sources. Under support from GIZ (Gesellschaft für Internationale Zusammenarbeit) of Germany, the German company DIG SILENT plans to formulate the Grid Code by February 2016 while referring to the European Network of Transmission System Operators (ENTSO-E) and codes in various other countries. The Grid Code is scheduled to go into effect after it has acquired government approval.

(1) Target power sources

Except for micro grids in off-grid areas, all grid-connected power source equipment such as diesel power generation and renewable energy sources and storage battery systems are targeted.

(2) Voltage classes

Table 9.3-1 Voltage Classes

Voltage class	Voltage	Target voltage
High voltage (HV)	60 kV or more	60 k V
Medium voltage (MV)	1 kV or more but less than 60 kV	6 kV, 10 kV, 15 kV, 20 kV
Low voltage (LV)	Less than 1 kV	400 V

Source: JICA Study Team

(3) Power source categories

Power source categories are grouped according to grid connection requirements stipulated in the European ENTSO-E standard. Categories are grouped according to voltage (low voltage and high voltage) and equipment capacity. Moreover, the requirements for sustaining the class-separate system stability are stipulated in the Grid Code.

Table 9.3-2 Power Source Categories

Category	Voltage	Equipment capacity
Class A	Less than 1 kV	0.8 kW or more but less than island Pmax* divided by 20 But it must be no greater than 100 kW
Class B	Less than 1 kV	Island Pmax* divided by 20 or more But it must be no greater than 100 kW
Class C	1 kV or more	less than Island Pmax* divided by 20
Class D	1 kV or more	Island Pmax* divided 20 or more but less than Pmax* divided by 10
Class E	1 kV or more	Island Pmax* / divided by 10 or more

* Pmax: Peak demand power

Source: JICA Study Team

(4) Grid interconnection requirements

Table 9.3-3 shows the grid interconnection requirements in the draft Grid Code.

Table 9.3-3 Grid Interconnection Requirements

Requirement	Class A	Class B	Class C	Class D	Class E
Voltage operation / reactive power operation	✓*	✓*	✓	✓	✓
Frequency operation	✓	✓	✓	✓	✓
Simulated inertia					✓**
Soft shutdown function		✓***		✓***	✓***
Remote control function	✓	✓	✓****	✓****	✓****
Automatic oscilloscope, monitoring and recording system				✓	✓

* Concerning low voltage, there is no need for a voltage adjustment function. See (a) Voltage operation/ reactive power operation for details.

** Function for simulating the same inertia as in diesel power generation in non-diesel power sources

*** Function for reducing power generation output to the lower limit and disconnecting with a change factor of 2% of rated output. In particular, this aims to suppress deterioration of network stabilization due to sudden power drops when wind power generation is cut out.

**** This shall be interconnected with the network operator’s SCADA system.

Source: JICA Study Team

(a) Voltage operation / reactive power operation

In Cabo Verde, since cables are adopted for medium voltage systems, which means that systems become capacitive at times of low load, it is necessary to take care regarding advance reactive power.

Table 9.3-4 Reactive Power Requirements

Voltage	Requirement
Low voltage	Power factor 0.98 or more
High voltage	Reactive power is supplied in the range of 0.95 (delayed) to 0.90 (lead). The power generating operator must submit the generation potential output curve (P-Q characteristics) to the network operator. Also, it is required for changes to power factor and reactive power settings to be made within 10 seconds.

Source: JICA Study Team

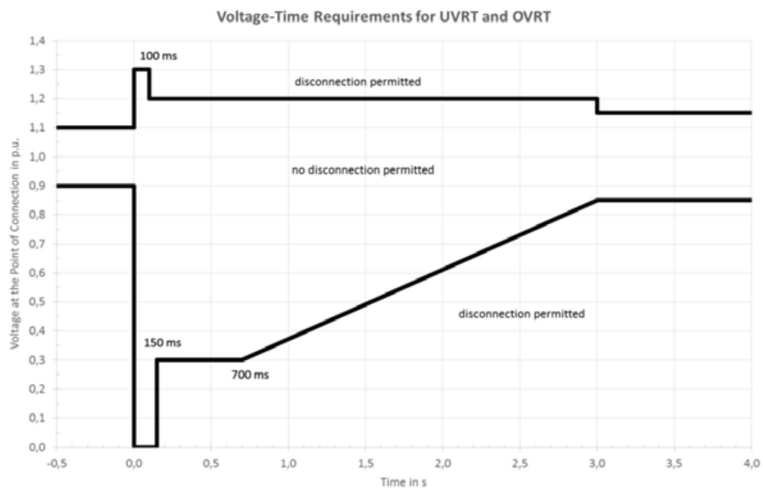
Except in cases of accidents in the interconnected grid, it is necessary to maintain power sources in parallel without conducting any unnecessary disconnections while the system voltage is in the range of ±10% the rated voltage.

In the event where rated voltage ±10% is exceeded, even when the system voltage is in the range of ±15% of the rated voltage, it is required for disconnection not to be conducted and voltage stability to be maintained for 1 minute upon satisfying the requirements shown in Table 4.1-5 and the scope of power generation continuation at times of instantaneous voltage drop.

Table 9.3-5 Requirements when Rated Voltage ±10% is Exceeded

Voltage	Requirement
Low voltage	－10 % or less : Diesel power generation is in parallel. Other power sources are at zero or minimum output. ＋10 % or more : No disconnection
High voltage	More than ±10 % : Voltage is maintained, i.e. reactive current is supplied, over the scope of the generation potential output curve (P-Q characteristics).

Source: JICA Study Team



Source: Advisory Services for the Development of a Grid Code for the Power Sector of Cabo Verde Grid Code Rev. 1.0

Figure 9.3-1 Operation Continuation (FRT) Function during Voltage Fluctuation

(b) Frequency operation

Stipulated frequency in Cabo Verde is 50Hz±2Hz, and it is required for power sources not to be disconnected due to frequency fluctuations that arise on the system side. Moreover, in cases where the range of 50 Hz±1 Hz is exceeded, it is necessary to manage power sources at the power factor specified for each power source category so that frequency is restored to the scope of 50 Hz±1 Hz.

Table 9.3-6 Power Source Management based on Frequency

Frequency	Power source / Power storage equipment (discharge)	Power storage equipment (charging)
47.0 Hz – 47.5 Hz	Cutoff when continued for 20 sec or more	Immediate cutoff or zero output
47.5 Hz – 48.0 Hz	Cutoff when continued for 90 sec or more	Immediate cutoff or zero output
48.0 Hz – 49.0 Hz	--	Suppress charging according to the change factor stipulated for the power source category.
49.0 Hz – 51.0 Hz	--	--
51.0 Hz – 52.0 Hz	Suppress output according to the change factor stipulated for the power source category.	--
52.0 Hz – 53.0 Hz	Cutoff when continued for 2 sec or more	Cutoff when continued for 2 sec or more

Source: JICA Study Team

(C) Remote control function

The network operator is able to issue a command to suppress output or disconnect power sources during emergencies in order to secure network stability. Power sources must be equipped with a remote control system to ensure that these operations are implemented within 10 seconds following issue of the command by the network operator.

For Class C, interconnection with the network operator's SCADA system is recommended, while for Class D and Class E it is required that the network operator's SCADA system be interconnected. The network operator's SCADA is required to have not only power source output suppression and disconnection functions but also information and setting functions necessary for controlling voltage and reactive power and stabilizing the network.

9.4 Problems of Transmission and Transformation Facilities.

9.4.1 Boa Vista

(1) System of the north and the northeast

The small-scale independent system of the north in Boa Vista island is being connected to the trunk system through the ORET project, but the 10kV system stays in the part of the northeast. Change to 20kV is wished for stabilization of the system and standard unification, but demand is small and a cost burden is a problem.

According to a hearing to AEB, the damage of rust of a steel tower by utility pole collapse and damage from salt water also generates the 10kV system by the cyclone which was the situation that degradation of facilities is terrible and occurred in September, 2015 by aging. Non-technical loss accounts for about 50 % in the 10kV supplying district area, and there is also non-payment of the electricity charges. A guardian tries to watch frauds such an electricity stolen and/or fraudulent metering, however, the effective resolve has not been accomplished. A measure, they'll strengthen it, the cost-effectiveness is in the situation that it isn't obtained because the demand scale is small. Further, it was said that the percentage in the case judged by the total of the whole island including the hotel demand was little.

Therefore, electric power meter exchange of ordinary homes as well as maintenance consideration of system facilities for the voltage upgrade to 20kV seem to need renewal maintenance of a low-tension distribution network from 10kV.

(2) System of the northwest

According to the interview with AEB, occurrence of a blackout has been decreased by the underground cables (400 mm^2 aluminum cable) which was installed by the ORET project. Switchgear facilities with a protection instrument is that it was changed in ORMAZABAL (made in Spain) from superannuated EFACEC (made in Portugal) and damage from salt water is canceled.

A weak point on the system is a route of superannuated overhead transmission line from Chavez power plant to Sal Rei, and the route undergo the influence by which it's for damage from salt water. Therefore, a renewal of overhead transmission line and undergrounding the transmission cables are necessary.

These countermeasures show a necessary part in a single line electrical schematic on figure 9.4-1. The specification of the transmission line such as the length and the type of the conductor of the transmission line which can be put each area is indicated in table 9.4-1.

JICA Study Team think the blue space of this list is suspended transmission line, and the maintenance by which the electric wire sizes are change and undergrounding the transmission cables are necessary.

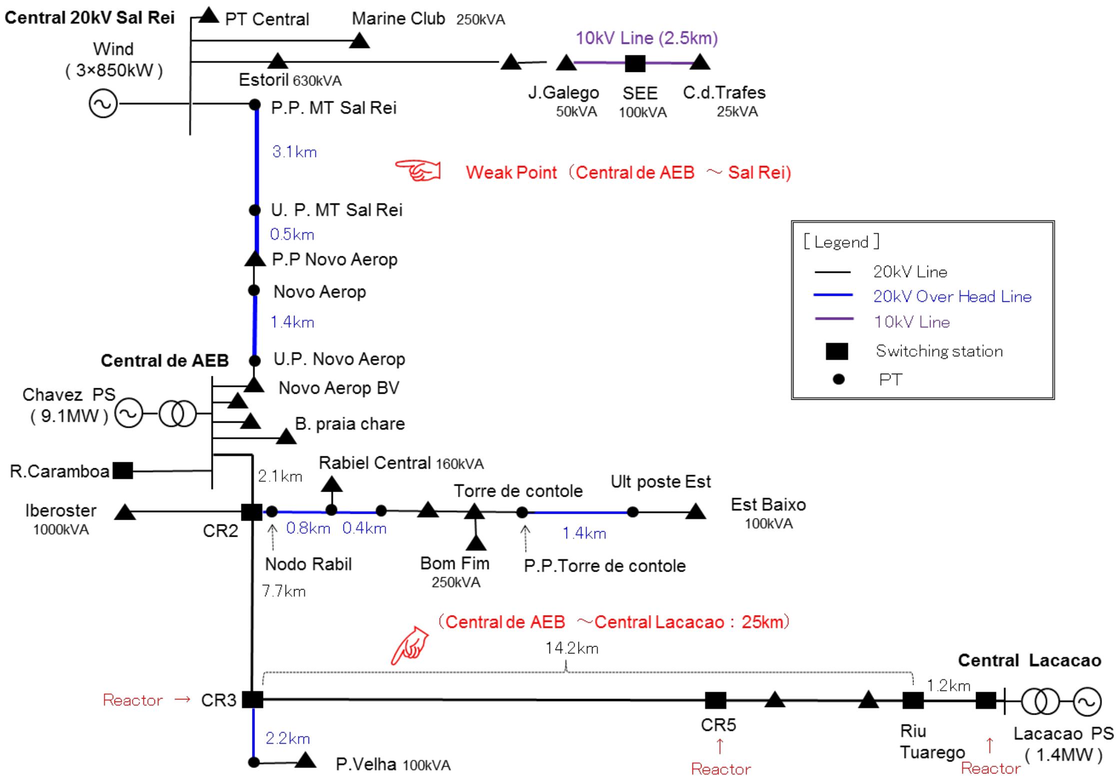
(3) System of the south

Northern Chavez power plant and southern Lacacao power plant is tied with the cable in the long-distance ground (about 25 km), but when there is little demand by which it's for hotels, system voltage rises, and the phenomenon by which the voltage becomes unstable occurs.

According to the interview with AEB, it was said that they had restrictions in driving number of diesel generator in voltage practical use in power plant by voltage rise of the system.

Therefore, the establishment which is the part way reactive coil as the adjustment of voltage facilities which absorbs reactive energy is considered. It's necessary to install in the most effective place about an installation site. For example, a tip of power line or a halfway point as shown in a single line electrical schematic on figure 9.4-1 does candidacy, and is considered. It's necessary to do research and examination in detail and select the most suitable spot separately about the installation part in detail. According to a hearing to AEB, the hotels where AEB is supplying the electric power and water are Marine Club (0.3MW), Iberoster (0.8MW), Riu Caramboa (1.7MW) and Riu Tuarego (1.7MW). AEB is ambitious in selling contract with Decamelon Hotel with seawater desalination plant and 4 sets of generator (550kVA x 4). Substantial demand increase is expected by the large-scale development by which demand in future's Boa Vista island is hotels. Therefore, AEB company is considering power supply addition of a diesel generator for new power supply securement. It'll plan to concentrate on 1 point in the future about seawater desalination plant in 3 points.

It's important to be advancing consideration overall including a stabilization countermeasure of the system as there is no hand return such as development of a power supply and system composition (loop-ization) newly at the top based on the realities of the current state, themes and future plans, etc. about future's system maintenance in Boa Vista island from such situation.



Source：JICA Study Team based on Information from AEB

Figure 9.4-1 Single line electrical schematic in Boa Vista island

Table 9.4-1 Specification of the power line (ground and overhead transmission line)

Starting node	～	Last stop node	length (m)	Type of conductor	Transmission capacity (A)
Central de AEB	～	CR2	2,100	Al 400	445
CR2	～	Central Lacacão	22,985	Al 400	445
CR2	～	Iberostar	2,404	Al 400	445
CR2	～	Primero Poste Rabil	80	As 50	175
Primero Poste Rabil	～	Nodo Rabil	800	As 50	180
Nodo Rabil	～	Ultimo Poste Rabil	400	As 50	180
Nodo Rabil	～	Rabil Central	30	Al 50	205
Ultimo Poste Rabil	～	P.P.Torre de controle	530	Al 50	205
P.P.Torre de controle	～	Ult poste Est	1,370	As 54.6	180
Torre de control	～	Bom Fim	600	Al 50	205
Ultimo Poste Est Baixo	～	Est Baixo	65	Al 50	205
Central de AEB	～	Riu Caramboa	1,420	Al 400	445
Central de AEB	～	Novo Aerop BV	550	Al 400	445
Central AEB	～	Bobagem praia chave	1,200	Al 240	455
Parque eolico	～	PT Central	4,970	Cu 50	180
Central Electra	～	Praia de Cruz	1,905	Al 50	205
Praia de Cruz	～	Marine Club	288	Al 50	205
Cabopadana	～	Imotur	710	Al 120	232
Central Electra	～	B. Sossego	1,599	Cu 50	180
Estoril	～	Emicela	1,610	Al 120	232
Central Electra	～	P. Poste Sal Rei	1,700	Al 50	205
P. P. MT Sal Rei	～	Poste Mazurca	2,131	As 50	175
Poste Mazurca	～	U. P. MT Sal Rei	980	As 50	175
U. P. Sal Rei	～	P. P. Novo Aerop	715	Al 120	232
P. P. Novo Aerop	～	U. P. Novo Aerop	1,365	As 50	175
U. P. Novo Aerop	～	Novo Aerop BV	100	Al 50	205
Poste Mazurca	～	Mazurca	30	Al 50	205
Parque eolico	～	Central Electra	4,960	Al 500	444
João Galego(10kV)	～	Cabeça dos tarafes(10kV)	2,500	Al 25	120

(note) blue space is transmission line and others are underground transmission line

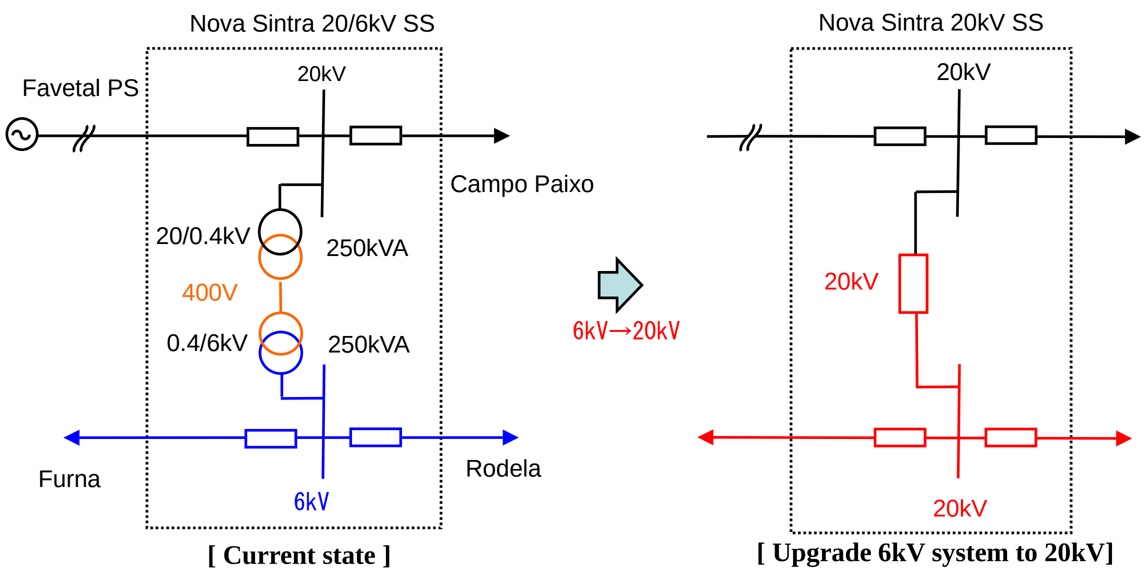
Source: JICA Study Team based on Information from AEB

9.4.2 Brava

Nova Sintra SS in Brava island is an office combined with a business office of Electra at present. The 6kV system is functioning as a power plant until 2000, and after the generator was abolished, comes at present in the state which is still left. According to a hearing to Electra, blackout occurs about 4 times from 3 a month. The cause is superannuated breaking of overhead line and earth fault accident by damage from salt water. It's restored by insulator cleaning at the time of a blackout by damage from salt water. Releasing time of a blackout needs about 5 minutes by the city and needs about 40 minutes from 20 minutes by a suburb. Further the present maintenance personnel are 7.

Protection relay in substation moves at the time of an accident by distribution lines, and there are cases by which a normal circuit does a trip occurs. Therefore, establishment of protection relay and a switch it's possible to remove an accident from which is needed immediately near the accident part. Appropriate decision of protection relay setting and protection cooperation seem necessary.

The growth rate of the sudden demand can't expect the demand scale of Brava from now on small relatively, but maintenance of the system will be needed in the future. After 2008, the power transmission and distribution isn't renewed. Therefore, 6kV transmission facilities and overall renewal in substation seem necessary because decrepitude of facilities are remarkable and 6kV lines are also left. So an example of substation overall renewal construction is indicated on figure 9.4-2. The plan which upgrade to 20kV system and installs 20kV switchgear during bus bars can consider in Nova Sintra substation. Therefore, existing 20/0.4kV and 0.4/6kV transformer become unnecessary and the efficiency by which facilities is reliability improvement and maintenance, etc. also becomes possible.



Source：JICA Study Team based on Information from Electra

Figure 9.4-2 Single line electrical schematic in Brava island
(left: current state, right: after countermeasure)

9.4.3 Santiago

Power generations and transmission/transformation facilities in Santiago island were maintained by donor support of each country. By these maintenances and improve, the blackout frequency of occurrence in Santiago decrease remarkably and improve the reliability of the system. About half of the insulator for power lines is that it was changed to a silicon insulator from an existing glass insulator according to a hearing to Electra, and cleaning work of the insulator which was being performed by handwork up to now is cut, and efficiency of service operation is also planned for. There seems to have been damage of a glass insulator by a resident before a measure.

SCADA system was introduced in São Filipe and Calheta Substation, by that, monitoring and control about system information became possible from a distant place. Therefore, these substations unattended it became. Monitoring and control is performed at central room of Palmarejo. The efficiency which are practical use of system facilities and maintenance, etc. by this SCADA introduction of the system is planned for.

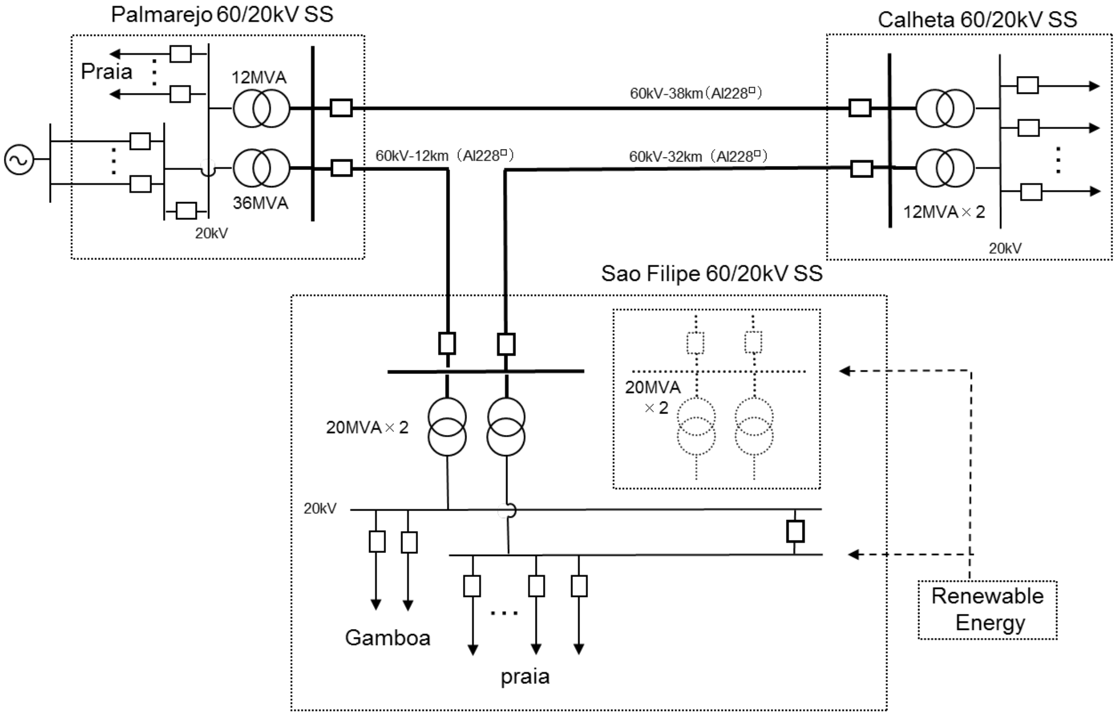
Optimum system operation of a diesel generator and the wind turbine is tried with the power transmission and distribution network supervision who made 3 island in Santiago, São Vicente and Sal the subject based on a general-purpose SCADA system. But there is also information for which the direct control from SCADA is difficult technically because the world standard is a different original system for national diesel generating system in Cabo Verde. The agreement of a renewable energy compnies is being also needed these realizations.

In São Filipe SS, transformer made in Portugal (20MVA x 2) is introduced by JICA support into a substation, but more expansion space of 2 transformers has been also reserved. The power incoming unit which assumed more connections of 3 wind farms is also prepared. Further only Cebeolica is connected to a Gamboa substation by 20kV transmission line (1 circuit) at present, but it'll be expected for the connection to be changed to São Filipe substation from now on.

We can think it's possible to connect 60kV as shown in figure 9.4-3 or 20kV to a substation bus bar as the renewable energy connection point by which future will be the wind firms which assumed renewable energy introduction.

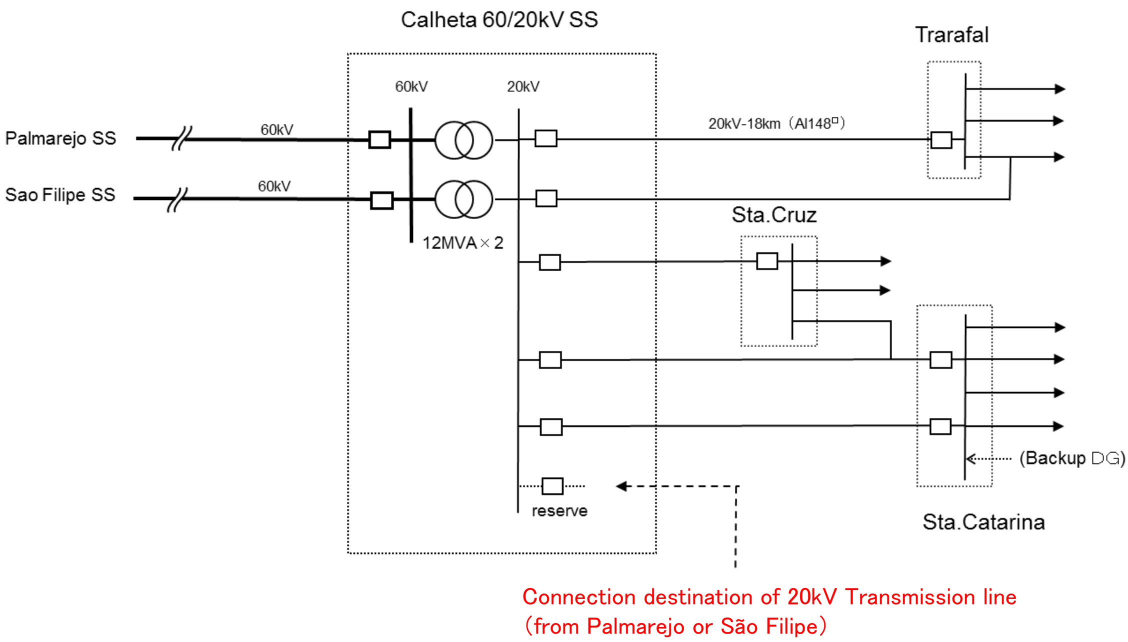
Expansion maintenance of the 20kV system will be considered as the plan the future for utility grid reinforcement in Santiago island. A diesel generator of Sta.Catarina (made of 2009 years) is the policy left as a power supply for backups for the time being at present, but it's necessary to consider the occasion it became impossible to use for a breakdown and the measure when abolishing. For example, the proposed measure which ties Calheta 60/20kV SS with 20kV transmission cable from Palmarejo 60/20kV SS or São Filipe 60/20kV SS as a substitution electric transmission route at the time of a route accident of 60kV transmission line is also considered.

Spare circuits of 20kV bus bar of Calheta SS can be proposed as a candidate as a connection destination. The single line electrical schematic is indicated on figure 9.4-4.



Source：JICA Study Team based on Information from Electra

Figure 9.4-3 Santiago single line electrical schematic (60kV system)



Source：JICA Study Team based on Information from Electra

Figure 9.4-4 Santiago single line electrical schematic (20kV system)

10. Approach to Expanding Introduction of Renewable Energy

10.1 Examination for Expanding Introduction of Renewable Energy

In examining the expansion of renewable energy introduction, in order to avoid excessive advance investment, it is important to examine ways to effectively utilize existing equipment, in particular make use of the suppressed output of existing wind power through expanding the operating scope (reducing minimum operation) of diesel power generators upon first considering the demand and supply conditions (Chapter 4) and conditions of electric power equipment (Chapter 5 to Chapter 9).

Moreover, concerning the economic effects, it is necessary to consider the effect of expanding the introduction of renewable energy in terms of reducing fuel costs for diesel power generation. Here, before going into the examination on expanding introduction of renewable energy, the following paragraphs sum up the situation regarding electric power equipment, in particular wind power generation equipment, which is important in expanding the potential of renewable energy.

(1) Construction of transmission and distribution equipment

- Integration of transmission and distribution networks that have differing supply areas on islands
- Resolution of non-electrified areas (raising of the electrification rate)
- Unification of voltage classes (20 kV and 60 kV)
- Promotion of underground cables (if overhead lines are adopted, then adoption of insulators with strong resistance to salt damage) and looping of transmission networks in built-up areas
- Installation of SCADA systems and other systems for monitoring and information collection

(2) Construction of power station

- Parallel with the construction of transmission and distribution equipment, establish a power supply setup of one power station per island.
  However, the JICA Study Team believes that, in advancing the expansion of renewable energy, the unit capacity of diesel power generation equipment is too large with respect to the scale of demand.

- Improvement of system stability and efficiency and expansion of operating scope based on the latest-model diesel power generators
- Many of the diesel power generators installed on the islands are relatively new models introduced from 2010 onwards.

(3) Power supply by wind power IPPs

- Cabeolica sells electricity generated from wind power on the islands of Santiago, São Vicente, Sal and Boa Vista.
- For the purpose of securing system stability, Electra and AEB suppress wind power output according to necessity.
- Electra suppresses generated energy that exceeds the PPA purchase quota (Take or Pay).

In light of the above preconditions, the "Contents of Examination for Expanding Introduction of Renewable Energy" shown in Table 10.1-1 will be advanced in a staged approach.

Table 10.1-1 Contents of Examination for Expanding Introduction of Renewable Energy

1 Calculation of sustainable theoretical wind power generation capacity (10.2)

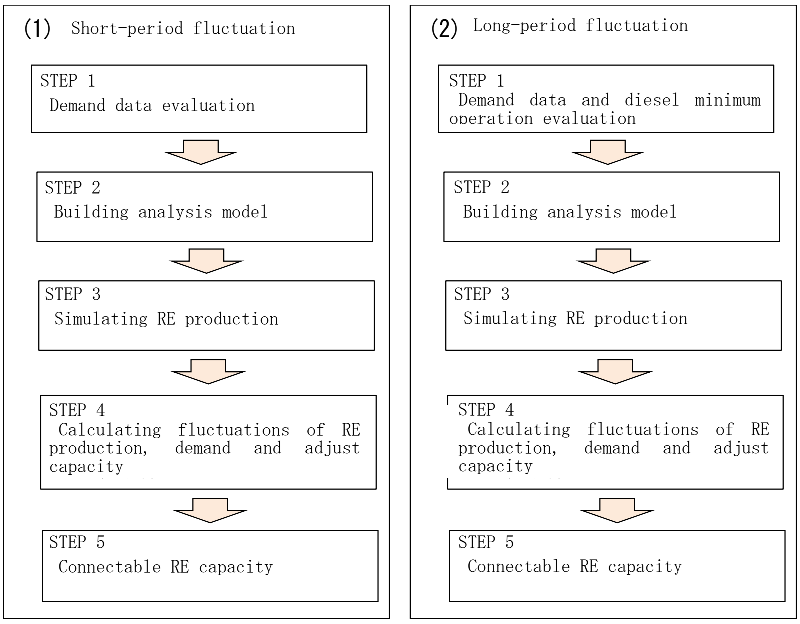
2 On islands that conduct wind power output suppression, effective utilization of output suppressed power through expansion in operating scope of diesel power generators (expansion of the share of renewable

3 Calculation of cost effectiveness through expansion of the share of renewable energy, introduction of wind power generation equipment and introduction of storage battery equipment (10.4)

Source: JICA Study Team

10.2 Thinking on Connectable Capacity for Renewable Energy without Output Suppression

In examining the potential for renewable energy equipment introduction without output suppression, the calculation method adopted for studying the grid interconnection potential of renewable energy based on system stability on remote islands in Japan will be used. KEPCO conducts calculations of output fluctuations over certain periods, specifically short-period fluctuations (20 minutes or less) and long-period fluctuations (more than 20 minutes), utilizing the results that have a smaller value. Figure 10.2-1 shows the process for examining the Connectable Capacity for Renewable Energy.



Source: JICA Study Team

Figure 10.2-1 Process for Examining Connectable Capacity for Renewable Energy without Output Suppression

The “Short-period fluctuations” and “Long-period fluctuations” in the examination of Connectable Capacity for Renewable Energy signify fluctuations in output from renewable energy equipment in the medium-period domain and long-period domain. In terms of the impact on power systems, the former is related to frequency fluctuations, and the latter to demand and supply operation (generation of excess power). Moreover, since the demand data from generators in Cabo Verde does not comprise hourly records, the examination here was implemented using hourly data from the information collection and confirmation survey implemented by the JICA Study Team.

Table 10.2-1 Generator Adjustment Methods according to Each Fluctuation Period

	Short-period domain	Medium- period domain	Long- period domain
Target period	A few minutes	A few minutes~20 minutes	More than 20 minutes
Control method	Governor-free (automatic control of governor)	LFC (load frequency control)	EDC (economic distribution control)
Definition when examining renewable energy connection	—	Short-period fluctuations	Long-period fluctuations

Source: JICA Study Team

(1) Calculation from the short-period fluctuation viewpoint

The following paragraphs describe the process for calculating the potential for renewable energy introduction without output suppression while taking short-period fluctuations into account.

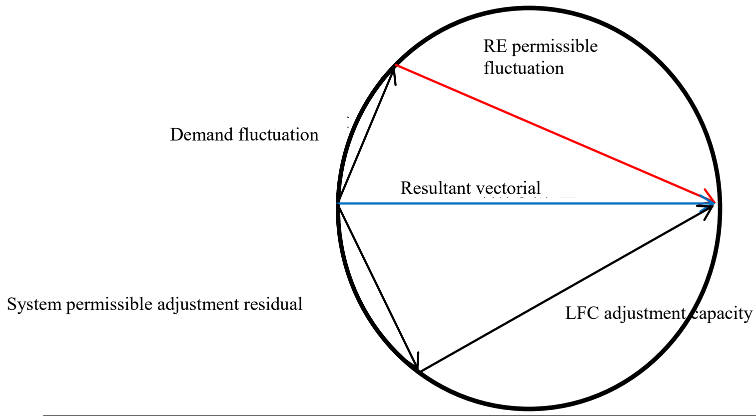
1) Step 1: Estimation of demand cross section

The hardest conditions when connecting renewable energy to the grid occur during minimum demand when the diesel power generation adjustment capacity decreases. Moreover, in cases of examining the introduction of solar power, it is necessary to examine the daytime minimum demand, while in cases of examining the introduction of wind power, it is necessary to examine the minimum demand. In Cabo Verde, wind power IPPs have already installed facilities and cooperative operation is conducted between wind power and diesel power generation; moreover, because there is extremely high potential for wind power generation, which is more cost advantageous than solar power generation equipment, the daily minimum demand will be used in the examination here.

2) Step 2: Selection of the actual system analysis model

Concerning calculation of the Connectable Capacity for Renewable Energy, the analysis model shown in Figure 10.2-2 will be used. Known as the algebraic method, this concept entails balancing the renewable energy permissible fluctuation and demand and supply through adjusting LFC (load frequency control of diesel power generation in Cabo Verde) and the system permissible adjustment residual.

Based on the particulars that were obtained in the survey, the same figure as the connection potential obtained from the system constants was obtained. Table 10.2-2 shows the particulars that were used in the study.



$$\sqrt{(\text{LFC adjustment capacity})^2 + (\text{system permissible adjustment residual})^2} \geqq \sqrt{(\text{Demand fluctuation})^2 + (\text{renewable energy permissible fluctuation})^2}$$

(Source) Institute of Electrical Engineers of Japan Technical Report No. 869 "Load Frequency Control at Normal Times and Emergency Times in Electric Power Systems", Figure 5.13

Figure 10.2-2 Analysis Model

Table 10.2-2 Particulars of the Analysis Model

Item	Explanation
Demand cross section	Use the time of minimum demand when the diesel power generation adjustment capacity declines. However, this does not include power interruptions.
Demand fluctuation	KEPCO uses demand fluctuations over 10 minutes or less. In Cabo Verde, since there are hardly any demand fluctuations in the vicinity of minimum demand, this is calculated as zero.
LFC adjustment capacity	In Japan, around 1~2% is aimed for on Electric Power System Council of Japan, ESCJ, rule. In Cabo Verde, since demand fluctuation is assumed to be zero, the harsh zero is assumed in calculations too.
Frequency characteristics of power generation equipment	Quoting the Cabo Verde grid code (draft), the recommended setting of 5% is adopted.
Frequency characteristics on the demand side	In this study, since this couldn't be confirmed, it is calculated as a harsh zero.
Permissible frequency	Quoting the Cabo Verde grid code (draft), 50Hz±2Hz is assumed. KEPCO applies 60Hz±0.3Hz in operations on remote islands.

Source: JICA Study Team

3) Step 3: Estimation of renewable energy output fluctuations

Generally speaking, in cases where wind power and solar power generation facilities have already been installed and data is already available for use in calculations, the output fluctuation rate is the value obtained by dividing the maximum output fluctuation range shown in Figure 10.2-3 by the rated total output of renewable energy equipment, however, in Cabo Verde, since wind conditions are stable and wind power output can be forecast with high accuracy, 50% of the forecast wind power generation output is assumed to be stable power supply in operation. Accordingly, the renewable energy output fluctuation in this calculation is also assumed to be 50%.

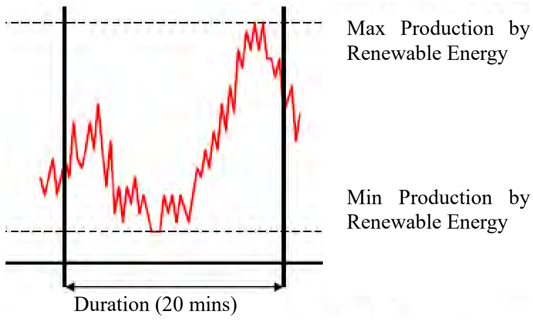


Figure 10.2-3 Renewable Energy Output Fluctuation Range

4) Step 4: Combination of renewable energy output fluctuation, demand, and adjustment capacity

The renewable energy output fluctuation constituting 50% of the forecast wind power generation output, demand constituting the minimum demand of the target area, and the LFC adjustment capacity are combined.

5) Step 5: Calculation of the Connectable Capacity for Renewable Energy without output suppression

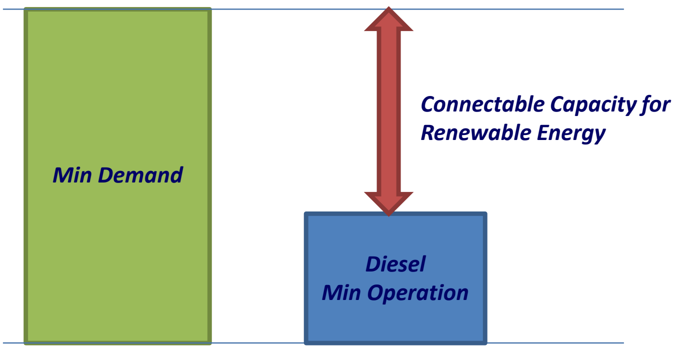
Based on Step 4, the Connectable Capacity for Renewable Energy without output suppression is calculated. The calculation results are shown in Table 10.2-4 at (3) Examination results

(2) Calculation from the long-period fluctuation viewpoint

In order to secure system stability, the operating range of diesel power generators is determined. The output lower limit value at which diesel power generators can operate is defined as the minimum operation. As renewable energy power sources increase, the share of renewable energy is raised through suppressing the output of diesel power generators, however, when the output of diesel power generators reaches the minimum operation, no more suppression can be conducted, so it becomes necessary to suppress the renewable energy power sources. Accordingly, the Connectable Capacity for Renewable Energy will be calculated upon taking the constraints of the minimum operation of diesel power generators into account. Figure 10.2-4 shows the schematic image for calculating the Connectable Capacity for Renewable Energy without output suppression.

Incidentally, Table 10.2-3 shows the particulars assumed in conducting calculation. Since the Connectable Capacity for Renewable Energy is increased through lowering the minimum operation, calculation is conducted on both the currently applied minimum operation (50% of nominal capacity) and nominal capacity of 30%, which is the operable range.

The fact that the main diesel equipment on the main islands of Cabo Verde can operate at nominal capacity of 30% was described in section 6.2.1 “Points and Issues in Expansion of Renewable Energy Introduction”.



Connectable Capacity for Renewable Energy ＝ Island minimum demand － Diesel Minimum Operation

Source: JICA Study Team

Figure 10.2-4 Image of Connectable Capacity for Renewable Energy from the Long-period Fluctuation Viewpoint

Table 10.2-3 Particulars in Calculation of Connectable Capacity for Renewable Energy

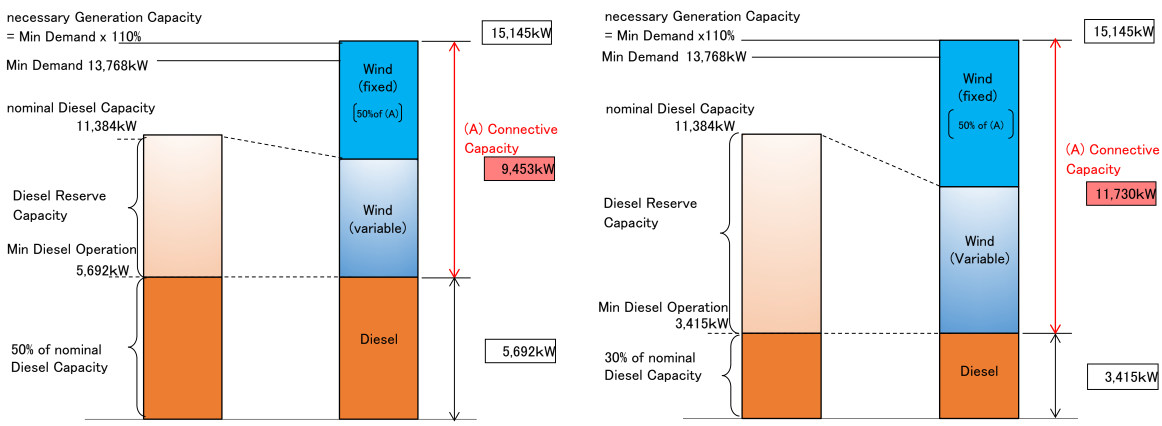
Item	Explanation
Demand cross section	・Use the minimum demand time, which is when the diesel power generation adjustment capacity declines. However, this does not include power interruptions.
Standby supply capacity	・Secure 10% standby capacity in consideration of demand fluctuations.
Diesel power generation minimum operation	Case 1: The same 50% as in current operation Case 2: Reduction to 30% in consideration of the operating range in the manufacturer's data, etc.
Wind power generation fluctuation	・In Cabo Verde, since wind conditions are stable and wind power output can be forecast with high accuracy, 50% of the forecast wind power generation output is assumed to be stable power supply in operation. Therefore, 50% is counted as the base output.
Other conditions	・The combined total of diesel power generation nominal capacity and the wind power generation base output indicated below will satisfy the standby supply capacity or higher. ・The diesel power generation reserve will cover the amount of wind power generation fluctuation.

Source: JICA Study Team

1) Santiago

Minimum demand: 13,768 kW [February 11, 2015]

Diesel power generation: 11,384 kW [maker: Wartsila (2015), power station: Palmarejo]



(i) Case of 50% minimum operation (ii) Case of 30% minimum operation

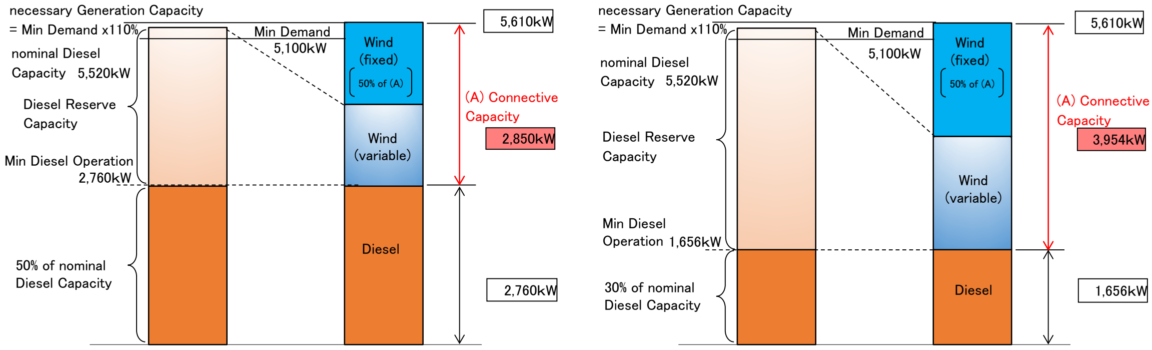
Source: JICA Study Team

Figure 10.2-5 Santiago Calculation Example

2) São Vicente

Minimum demand: 5,100 kW [March 1, 2015]

Diesel power generation: 5,520 kW [maker: Wartsila (2015), power station: Palmarejo]



(i) Case of 50% minimum operation (ii) Case of 30% minimum operation

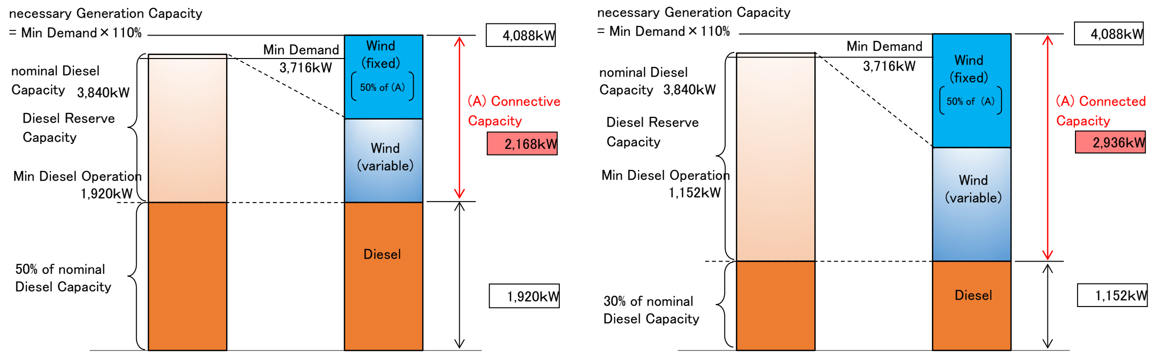
Source: JICA Study Team

Figure 10.2-6 São Vicente Calculation Example

3) Sal

Minimum demand: 3,716 kW [February 11, 2015]

Diesel power generation: 3,840 kW [maker: Caterpillar (2002), power station: Palmeira]



(i) Case of 50% minimum operation (ii) Case of 30% minimum operation

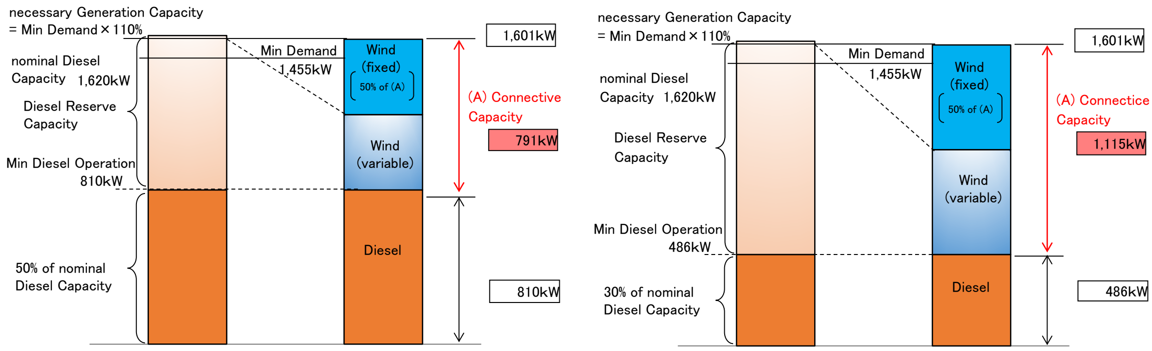
Source: JICA Study Team

Figure 10.2-7 Sal Calculation Example

4) Boa Vista

Minimum demand: 1,455 kW [May 26, 2015]

Diesel power generation: 1,620 kW [maker: Caterpillar (2015), power station: Chavez]



(i) Case of 50% minimum operation (ii) Case of 30% minimum operation

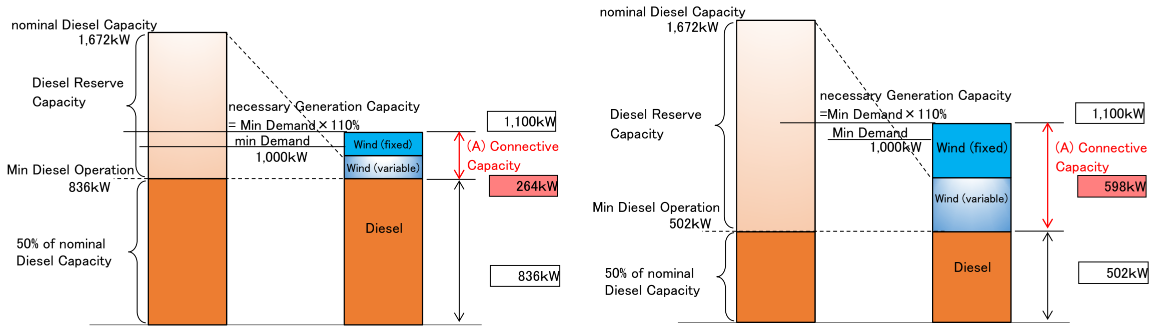
Source: JICA Study Team

Figure 10.2-8 Boa Vista Calculation Example

5) Fogo

Minimum demand: 1,000 kW [February 22, 2015]

Diesel power generation: 1,672 kW [maker: MAN (2015), power station: Joan Pinto]



(i) Case of 50% minimum operation (ii) Case of 30% minimum operation

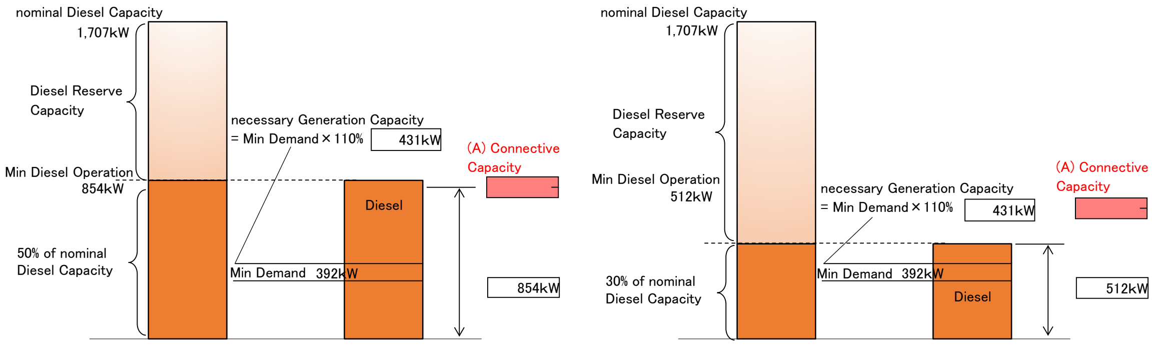
Source: JICA Study Team

Figure 10.2-9 Fogo Calculation Example

6) São Nicolau

Minimum demand: 392 kW [May 1, 2015]

Diesel power generation: 1,707 kW [maker: Perkins (2015), power station: Cacimba]



(i) Case of 50% minimum operation (ii) Case of 30% minimum operation

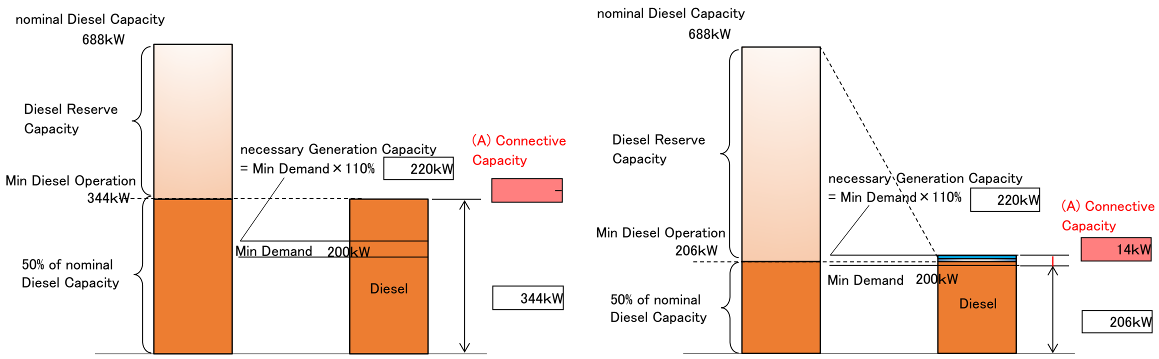
Source: JICA Study Team

Figure 10.2-10 São Nicolau Calculation Example

7) Maio

Minimum demand: 200 kW [March 19, 2015]

Diesel power generation: 688 kW [maker: Cummins (2008), power station: Tomil]



(i) Case of 50% minimum operation (ii) Case of 30% minimum operation

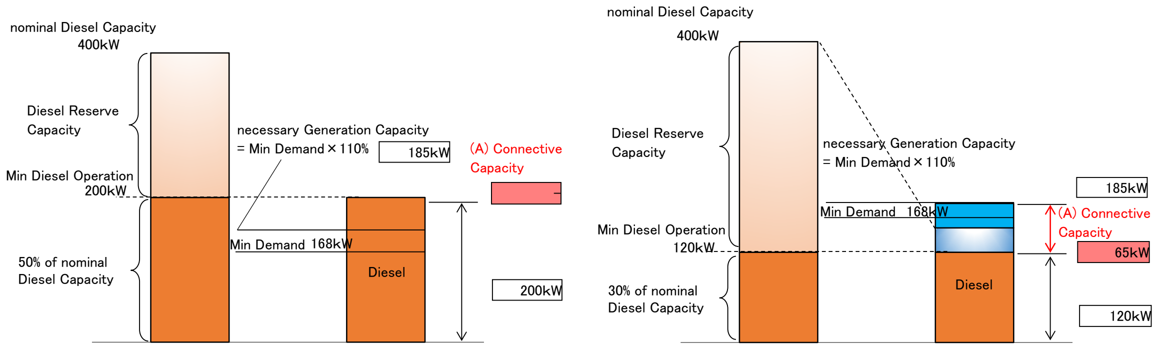
Source: JICA Study Team

Figure 10.2-11 Maio Calculation Example

8) Brava

Minimum demand: 168 kW [February 15, 2015]

Diesel power generation: 400 kW [maker: Perkins (2006), power station: Tomil]



(i) Case of 50% minimum operation (ii) Case of 30% minimum operation

Source: JICA Study Team

Figure 10.2-12 Brava Calculation Example

(3) Examination results

Table 10.2-4 shows the results of calculating Connectable Capacity for Renewable Energy without output suppression in terms of short-period fluctuations and long-period fluctuations. In Cabo Verde, the value calculated from the viewpoint of long-period fluctuations was the constraint on Connectable Capacity for Renewable Energy without output suppression. On São Vicente, Boa Vista and Sal, the introduction potential is already exceeded and suppression of wind power generation output is already being implemented.

Concerning Santiago too, the amount of wind power generation is roughly the same as the introduction potential. When solar power generation is taken into account, the Connectable Capacity for Renewable Energy is exceeded, however, wind power generation output rarely exceeds 50% and output suppression is not implemented.

Ordinarily, examination of the Connectable Capacity for Renewable Energy is conducted upon considering the impact on frequency in short-period fluctuations, however, in Cabo Verde, the Connectable Capacity for Renewable Energy is subject to constraints imposed by long-period fluctuations. Since there is high tolerance in the operating frequency of 50±2 Hz, rather than the impact of short-period fluctuations, the need to address long-period fluctuations is more of a constraint in the operation of diesel power generators.

However, when it comes to actually introducing equipment, care will be needed because it may become necessary to take short-period countermeasures depending on the results of detailed survey of system constants and confirmation of the permissible frequency on the demand side.

For reference purposes, an example of countermeasures in Japan is described in Section 10.2.2.

Table 10.2-4 Connectable Capacity for Renewable Energy without Output Suppression

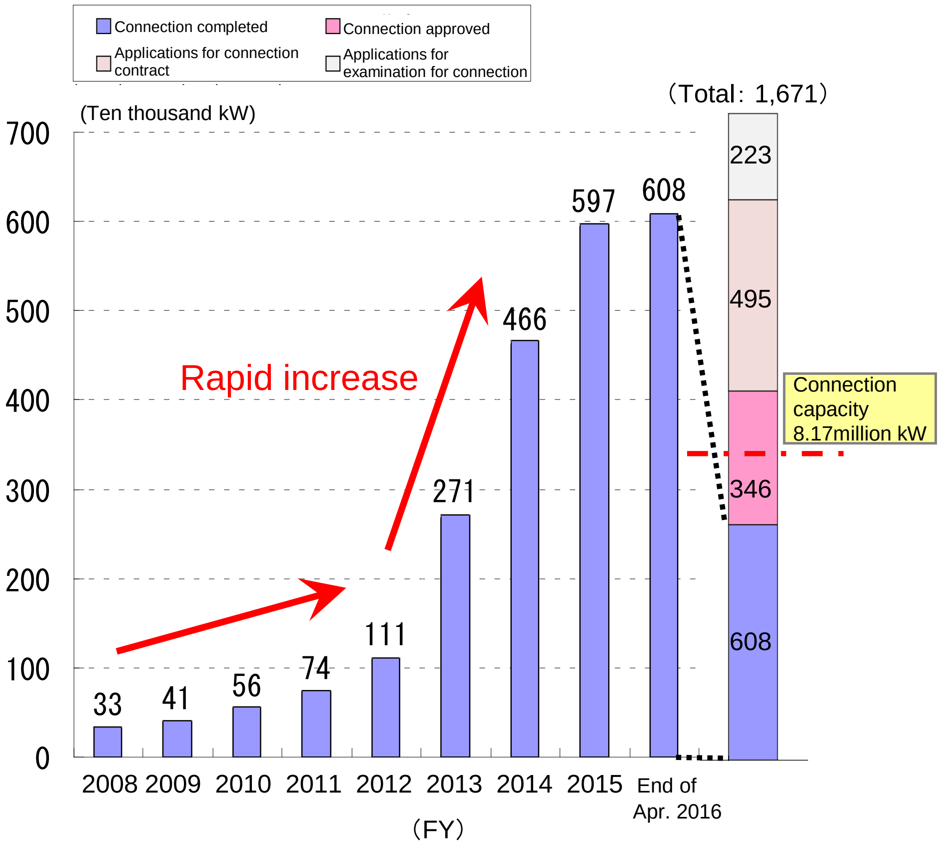
Island	Minimum demand	Connectable Capacity for Renewable Energy		
		Short-period fluctuations	Long-period fluctuations	
Santiago DG : 87,335 kW Wind : 9,350 kW PV : 4,280 kW	13,768 kW	22,029 kW	DG: 50%	9,453 kW
			DG: 30%	11,730 kW
São Vicente DG : 37,995 kW Wind : 5,950 kW	5,100 kW	8,160 kW	DG: 50%	2,850 kW
			DG: 30%	3,950 kW
Sal DG : 14,545 kW Wind : 7,650 kW PV : 2,140 kW	3,716 kW	5,946 kW	DG: 50%	2,170 kW
			DG: 30%	2,940 kW
Boa Vista DG : 14,114 kW Wind : 2,550 kW	1,455 kW	2,328 kW	DG: 50%	790 kW
			DG: 30%	1,120 kW
Fogo DG : 9,304 kW	1,000 kW	1,600 kW	DG: 50%	260 kW
			DG: 30%	600 kW
São Nicolau DG : 7,672 kW	392 kW	627 kW	DG: 50%	-
			DG: 30%	-
Maio DG : 2,176 kW	220 kW	352 kW	DG: 50%	-
			DG: 30%	14 kW
Brava DG : 1,416 kW	168 kW	269 kW	DG: 50%	-
			DG: 30%	65 kW

Source: JICA Study Team

10.2.1 Thinking and Operation of Connection Potential on Remote Islands of Japan (Case Study 1)

(1) Situation regarding introduction of renewable energy in Kyushu

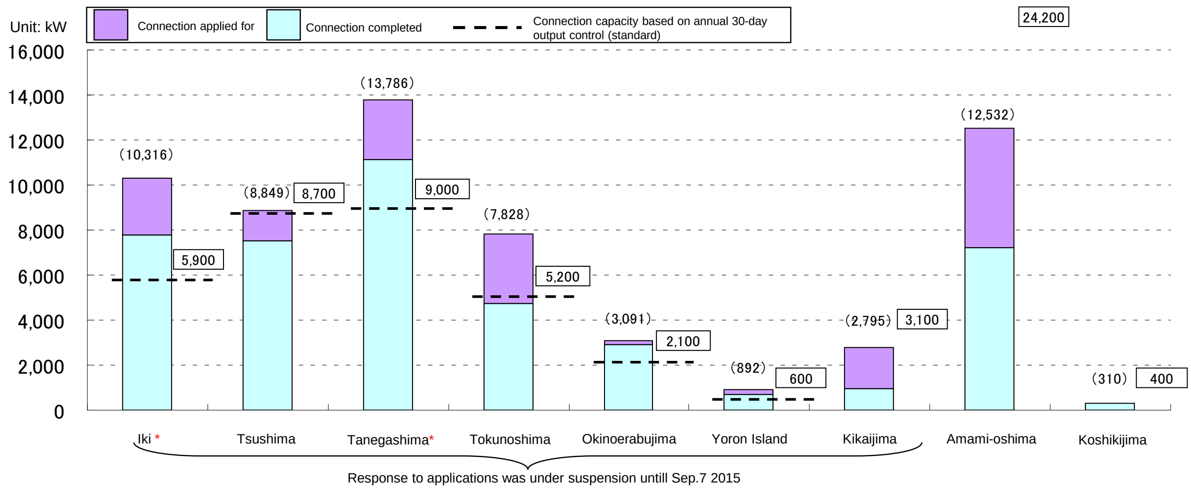
In the Kyushu region in southern Japan, following the start of the electric power feed-in tariff system (FIT) in July 2012, against a background of high purchase prices and easy development, the connected amount of solar power increased rapidly and had reached 6,080,000 kW by the end of April 2016, with more connections planned from now on too. When the approved and pending connection applications are also taken into account, the combined connected amount will increase to 16,710,000 kW, which is far in excess of the connection potential (8,170,000 kW) (Figure 10.2-13). Incidentally, concerning wind power generation, compared to the connection potential of 1,800,000 kW, current connections amount to 470,000 kW.



Source: KEPCO , Japan

Figure 10.2-13 Movements in the Introduced Amount of Solar Power Generation (KEPCO)

The above paragraph describes the conditions for the main island of Kyushu, however, introduction of renewable energy mainly comprising solar power has expanded rapidly on remote islands too, following the start of the FIT (see Figure 10.2-14). Currently, since it is likely that renewable energy output will exceed demand even allowing for output suppression, responses are being deferred with respect to new grid connection applications except for household small-scale solar power generation. On remote islands, since the solar power and wind power output characteristics and demand fluctuation characteristics differ between each island, it is necessary to calculate the connection potential for each case. Meanwhile, in order to limit the current burden placed on citizens in FIT and promote the balanced introduction of renewable energy, the Government of Japan enforced a revised Law Decree to review operation of FIT in January 2015. According to the revised Law Decree, renewable energy operators are also requested to cooperate for system stability and it is possible for system operators to conduct output suppression of renewable energy. Based on these results, the deferring of responses to applications for renewable energy has been suspended from January 2015 onwards and examination has been resumed into new connections.



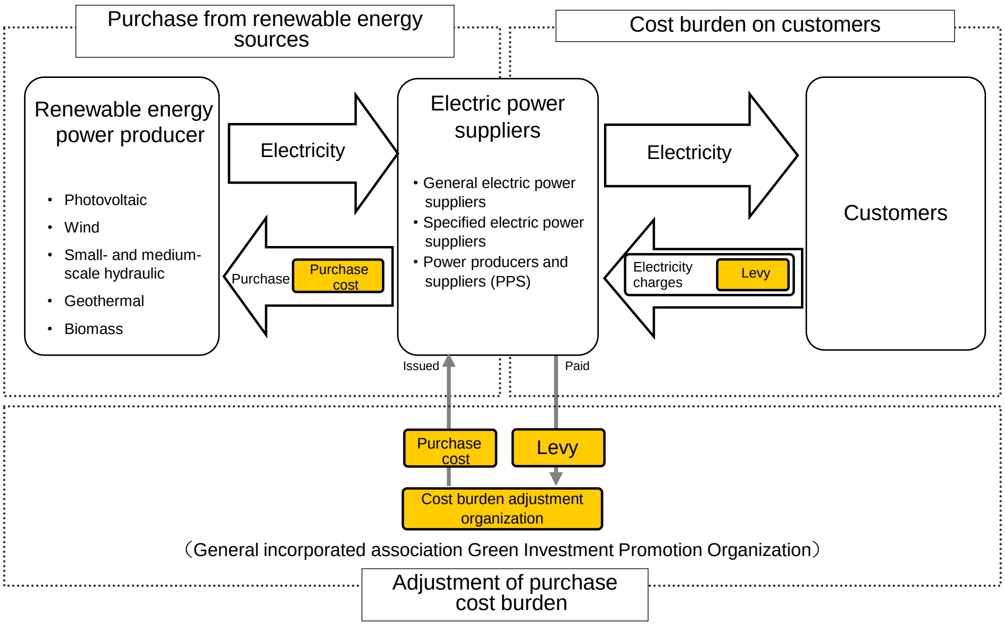
* Reference: Renewable energy output control has carried out a total of 6 times in Iki and 12 times in Tanegashima since 2015.
Source: KEPCO

Figure 10.2-14 Renewable Energy Connections on Remote Islands (April 2016)

Table 10.2-5 Law Decree concerning Renewable Energy Output Suppression (Japan)

	Operators approved after January 2015	Operators approved prior to January 2015
Target scope	All solar power generation equipment	Solar power generation equipment entailing contract output of 500 kW or more
Applicable scope	Output suppression without compensation up to 360 hours per year	Output suppression without compensation up to 30 days a year
Connection conditions	Equipment installation, cost bearing and other measures required for output control	—
Request method	Commands from system operators via IT networks	As a rule, commands by the previous day

[Reference: mechanism of Japan's feed-in tariff system (FIT)]



*In Japan's FIT system, consumers are expected to bear the purchase cost of renewable energy.

Source: JICA Study Team

(2) Thinking on renewable energy connection potential on remote islands of Japan

Thinking with respect to renewable energy connection potential is as was described previously in Section 10.2 (Connectable Capacity for Renewable Energy without output suppression), however, this is based on reference to the case of Japan, where the introduction of renewable energy increased rapidly against a background of a high-level FIT. Moreover, in the case of Japan, it should be noted that wind conditions are not as favorable as in Cabo Verde, maybe contributing to the rapid introduction of solar power.

Moreover, from January 2015 onwards, since system operators started implementing output suppression on solar power generation operators, the renewable energy connection potential has been increasing on condition that these conditions are accepted. The following paragraphs introduce the case of the output control approach that has been introduced on Kikaijima Island, one of the remote islands of Kyushu.

[Case of Kikaijima Island]

In Japan, following revision of the FIT in January 2015, it has become possible to seek cooperation from renewable energy operators, and for system operators to implement renewable energy output suppression. This means that, in cases where excess power occurs that exceeds the procurement capacity limit (reduction) of diesel power generators for system stability, the approach described in the contents of output suppression based on the revised Law Decree in Table 10.2-5 will be adopted.

In the case of Kikaijima Island, in order to be counted as an "operator approved prior to January 2015," low demand on the 30th day is used as the minimum demand used as the base for calculating the renewable energy connection potential. Judging from the demand performance on Kikaijima Island in fiscal 2014, the minimum daytime demand on the 30th day was 3,445 kW.

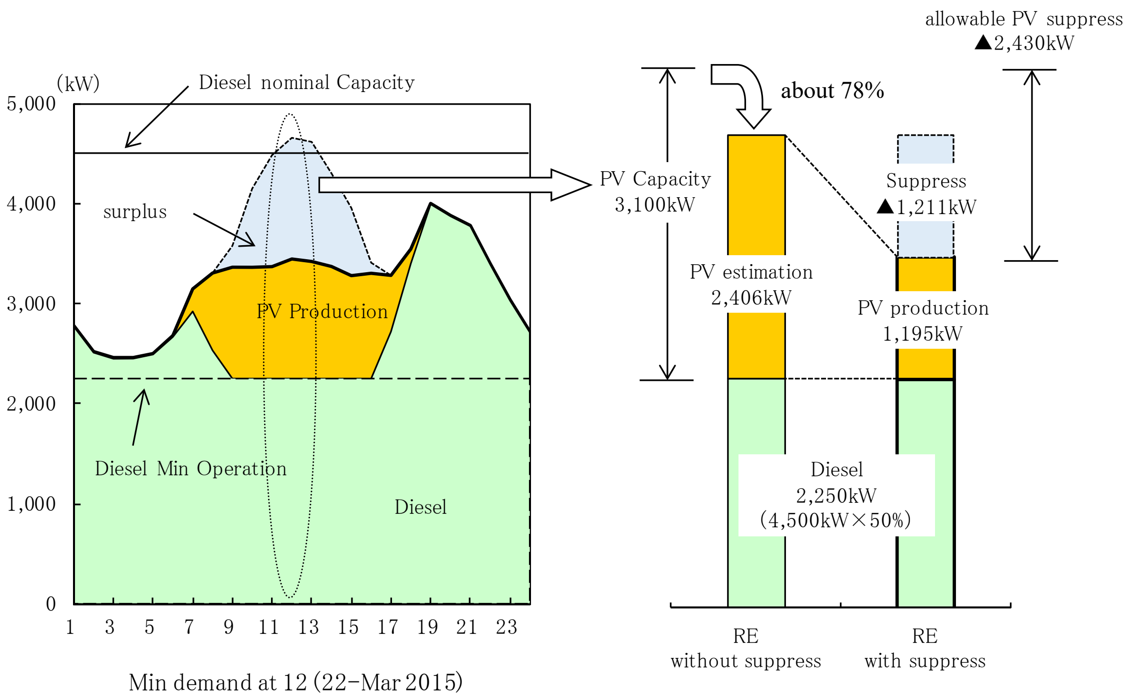
The minimum operation of diesel power generators is assumed to be 50%. Moreover, old diesel power generators that are expected to suffer from long-term stoppages (long lead times for procurement of parts no longer in production and so on) and be decommissioned in future due to troubles caused by aged deterioration have been excluded from the calculation.

Based on the above conditions, the renewable energy connection potential is calculated assuming the annual demand and supply balance (8,760 hours). The calculation conditions are as shown in Table 10.2-6, while the demand and supply image is shown in Figure 10.2-15.

Table 10.2-6 Conditions for Calculation of Renewable Energy Connectable Capacity (Kikaijima Island)

Demand	—	Minimum daytime demand: 3,445 kW (12:00, March 22, 2015)
Diesel power	Units	2,500 kW x 2 units, 4,500 kW x 1 unit
	Operation	The number of units that secures spare capacity (10%) assuming the renewable energy base portion and diesel power generation
	Minimum operation	50% of nominal capacity
Renewable energy	Stable output	10% of forecast output for solar power
	Actual output	Approximately 78% of forecast output of solar power

Source: JICA Study Team



Source: JICA Study Team

Figure 10.2-15 Image of Demand and Supply on Kikaijima Island

10.2.2 System Stabilization Measure Using Batteries in Japan (Case Introduction 2)

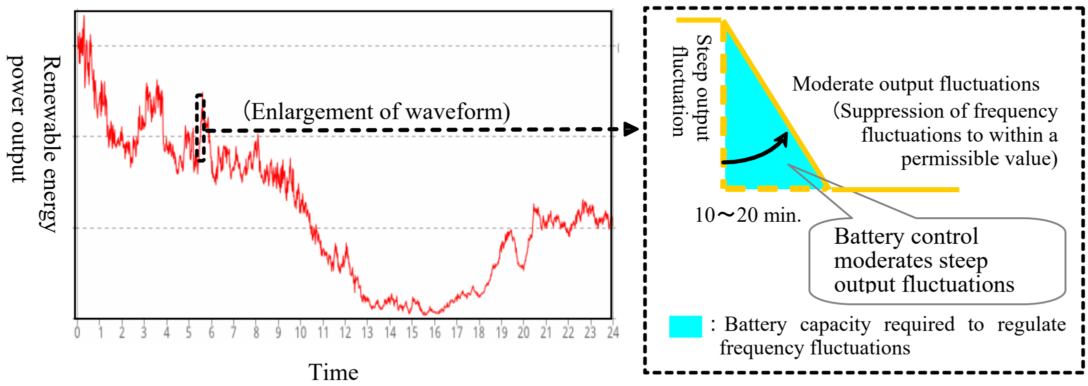
With a rise in the introduction rate of renewable energy in Cabo Verde to exceed 70% in the future, in the case that supplementation of and alternative provision of power by diesel generator as regulation capacity for short-cycle fluctuations is possible, a battery countermeasure will also be necessary. In this connection demonstration testing in Japan using batteries to counter short-cycle fluctuations is introduced below as a reference case.

(1) Approach to system stabilization on remote islands

When renewable energy is introduced into remote islands in large quantities, imbalance between supply capacity and demand occurs due to short-cycle fluctuations in renewable power output. As a countermeasure, the introduction of batteries to the system can provide control to moderate steep fluctuations. An image of mitigation of short-cycle fluctuations using batteries is shown in Figure 10.2-16.

In the Kyushu region, the target frequency control values are ±0.2Hz for the Kyushu mainland, and ±0.3Hz for remote islands, which is a very fine level of regulation compared to ±2Hz for Cabo Verde. The frequency distribution for 1 month on a remote island in Kyushu (1 second sampling actual values) is indicated in Figure 10.2-17 as an example. In particular, on remote islands in Kyushu, because system scale is small compared to the Kyushu mainland, when renewable energy with its large output fluctuations is interconnected with the system, there is a big effect on power quality including system frequency.

Concerning the installation of batteries, they can either be installed together with each renewable energy generation facility (distributed installation), or installed collectively for the whole power system (centralized installation). However, because the latter method can be expected to require a smaller quantity of batteries it is both more efficient and more economical.



Source: JICA Study Team

Figure 10.2-16 Image of battery output fluctuation regulation

Summary of month	
Number of data	2,592,000
Max	60.29 Hz
Min	58.91 Hz
Average	60.00 Hz
±0.3Hz%	100.000
±0.2Hz%	99.999
±0.1Hz%	99.903
Deviation number	5
Number of analysis	2,591,995

Source: JICA Study Team

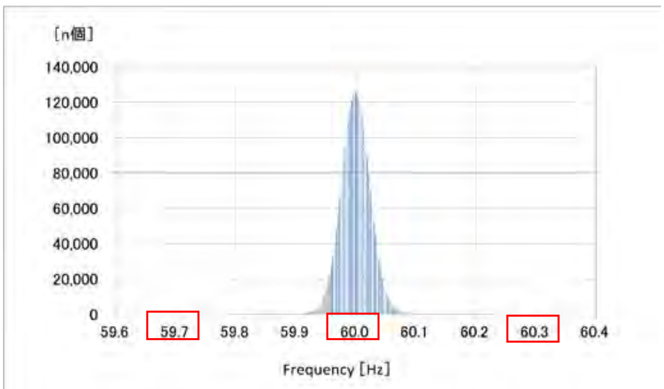
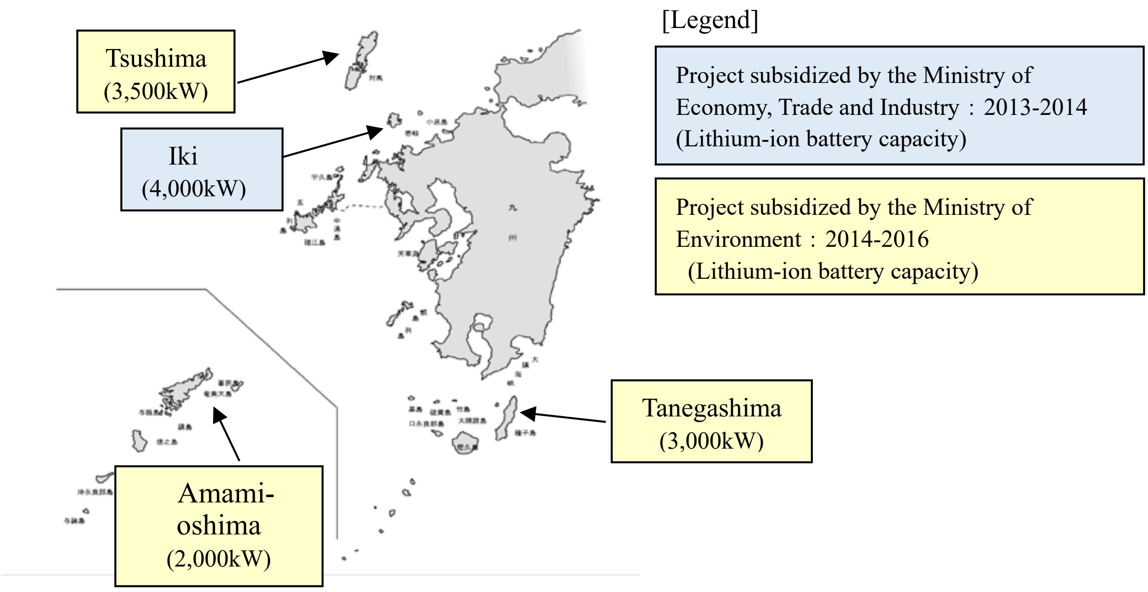


Figure 10.2-17 Frequency distribution on remote island (1 month)

(2) Demonstration testing on 4 remote islands in Kyushu

Demonstration testing on 4 remote islands in Kyushu (Iki, Tsushima, Tanegashima and Amami-oshima) is being carried out with a subsidy from the Japanese Government (Ministry of Economy, Trade and Industry, and Ministry of the Environment). To increase the possible amount of renewable energy that can be introduced, in this demonstration testing, batteries that can absorb output fluctuations of renewable energy have been installed, and verification being carried out includes verification of optimal operation method of diesel power generation within the system, mitigation of output fluctuations due to renewable energy, and the effect of battery control. In this demonstration testing, batteries are subject to repeated instantaneous charging and discharging, and for this reason lithium-ion batteries which have a small charge and discharge loss have been adopted. In addition, lithium-ion battery installation is compact and they are very portable.

The specifications of the remote island demonstration testing are shown in Figure 10.2-18 and details of demonstration sites are given in Figure 10.2-19 and Figure 10.2-20. Further, the results of demonstration testing on Iki are given as an example below in "(3) Demonstation testing on Iki."

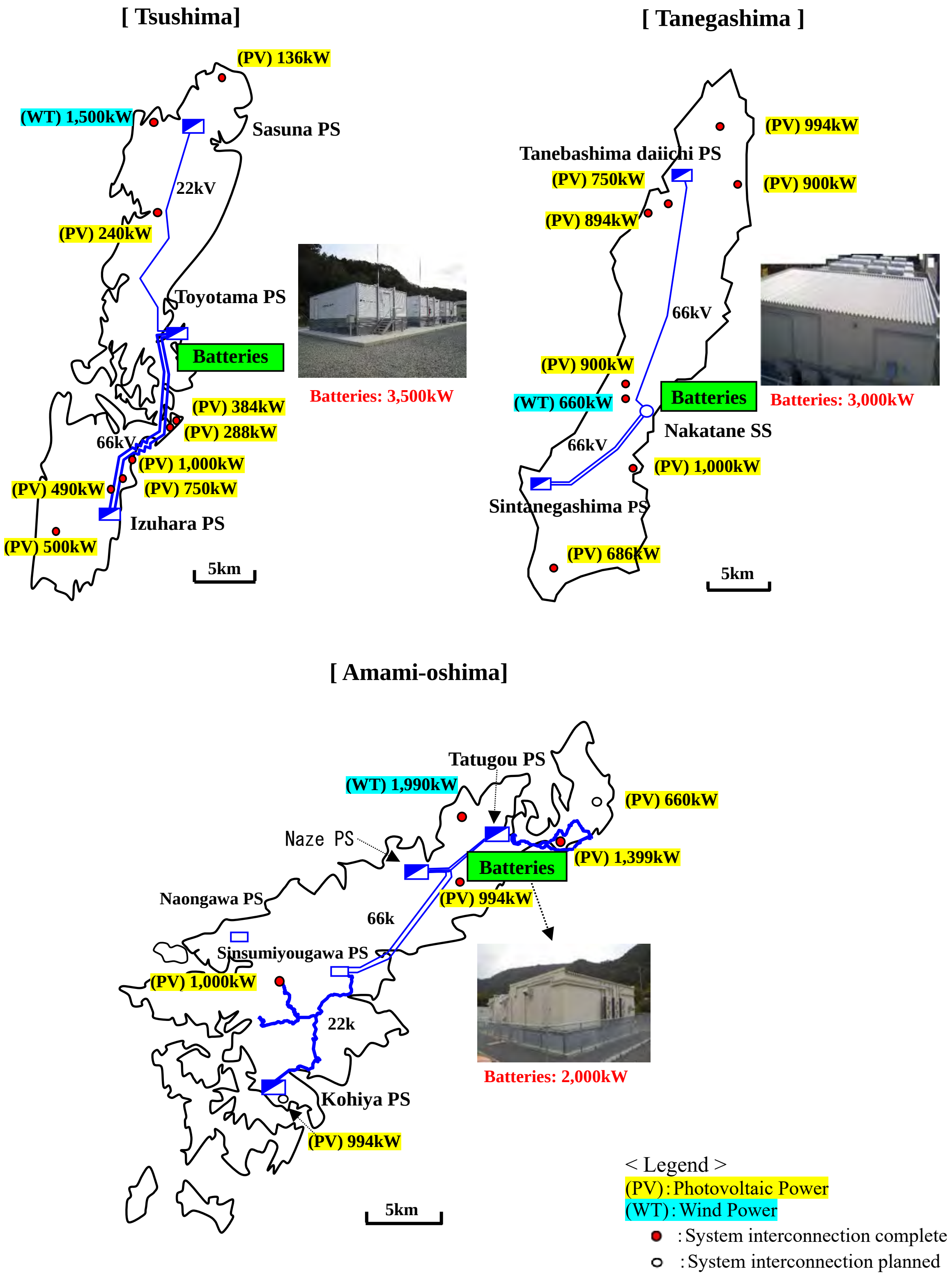


Testing Island	Iki	Tsushima	Tanegashima	Amami-oshima
System scale maximum power daytime minimum power	28,500 kW 9,000 kW	36,000 kW 14,000 kW	28,000 kW 11,000 kW	62,000 kW 19,000 kW
Renew. energy introduced Number of sites Capacity (>50kW/unit)	5 4,700 kW	9 5,288 kW	8 6,784 kW	4 5,377 kW
Photovoltaic power Wind power	3,700 kW 1,500 kW	3,788 kW 1,500 kW	6,124 kW 660 kW	3,393 kW 1,990 kW
Batteries (lithium-ion) rated output rated capacity	4,000 kW 1,616 kWh	3,500 kW 1,430 kWh	3,000 kW 1,161 kWh	2,000 kW 774 kWh
Battery manufacturer	GS Yuasa Corporation	Mitsubishi Electric	Toshiba	Toshiba
Total operating expenses	About EURO 4,557,000	About EURO 15,190,000		

(Note) Exchange rate of EUR/JPY on end of FY2015:131.66

Source: JICA Study Team

Figure 10.2-18 Overview of demonstration testing on four remote Islands (KEPCO)



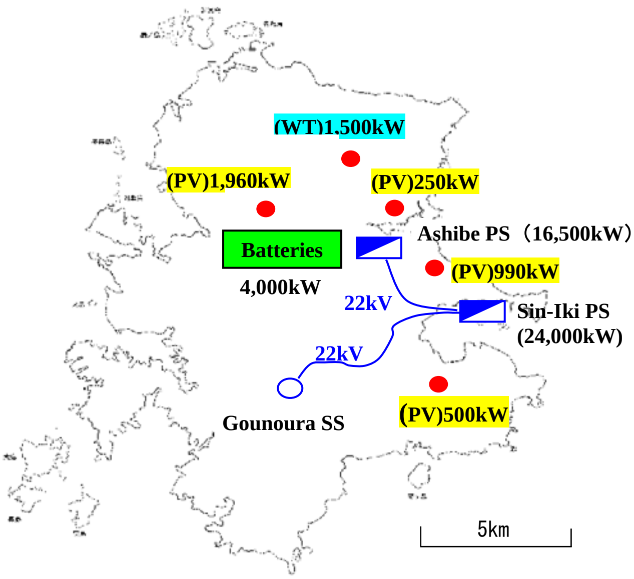
Source: JICA Study Team

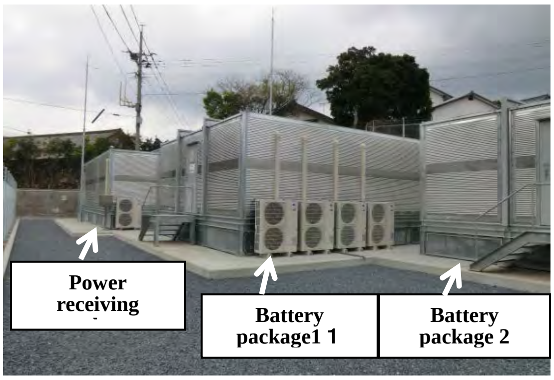
Figure 10.2-19 Demonstration testing sites (Tsushima, Tanegashima and Amami-oshima)

(3) Demonstration testing on Iki

(Iki's utility grid and battery system)

Electric power on Iki generated by Shin-Iki power station and Ashibe power station is supplied via distribution lines connecting the two power stations and Gonoura substation. The island's renewable energy comes from a wind power station (1.5MW) which is interconnected with Ashibe power station by a 6kV distribution line. Due to this wind power station, output frequency fluctuation reaches the permissible upper limit, therefore batteries are installed in a single location within the system. The battery system consists of a power-receiving facility and 2 battery packages, output (4MVA) being divided into 8 units (500kW x 8) with 4 units built into each package. This arrangement provides flexibility for equipment maintenance and experimental testing that requires use of batteries. (Refer Figure 10.2-20)





Overall configuration of batteries

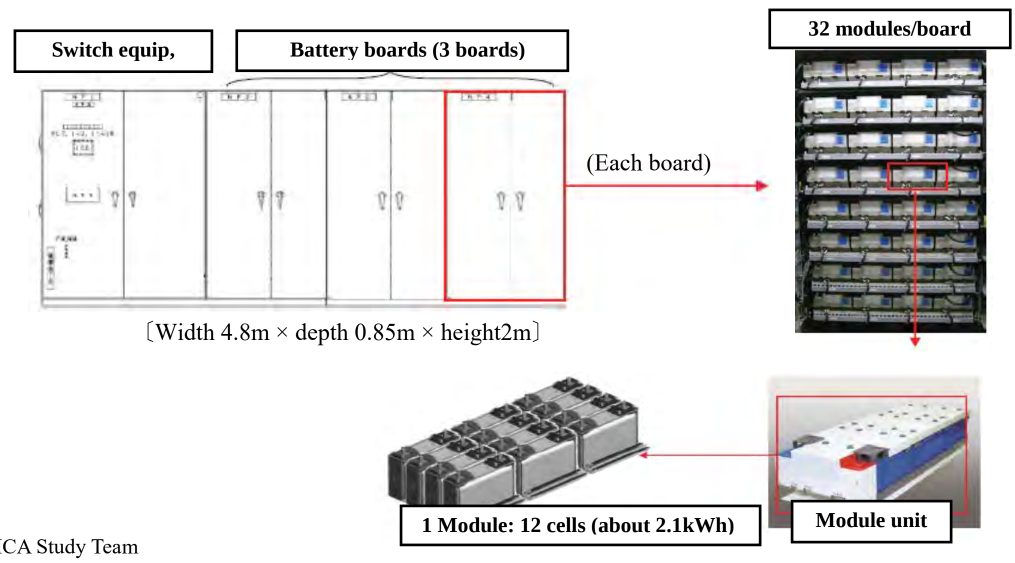
・Number of units：8 units

Battery unit

・Number of modules：96 modules/unit

(32 modules×3 boards)

・Unit capacity：202kWh/unit



Source: JICA Study Team

Figure 10.2-20 Demonstration testing site and battery system (Iki)

Table 10.2-7 Specifications of battery system (Iki)

【Lithium-ion batteries】

Item	Detail
Type	LIM50E
Cell number	1,152 (12×96 modules)
Rated capacity	285Ah(202kWh)
No, of units	8
Manufacturer	GS Yuasa

【AC/DC converter】

Item	Detail
Type	LIBS-F0500IRMB
Rated power	500kW
No. of units	8
Manufacturer	TMEIC

【Transformer for batteries 】

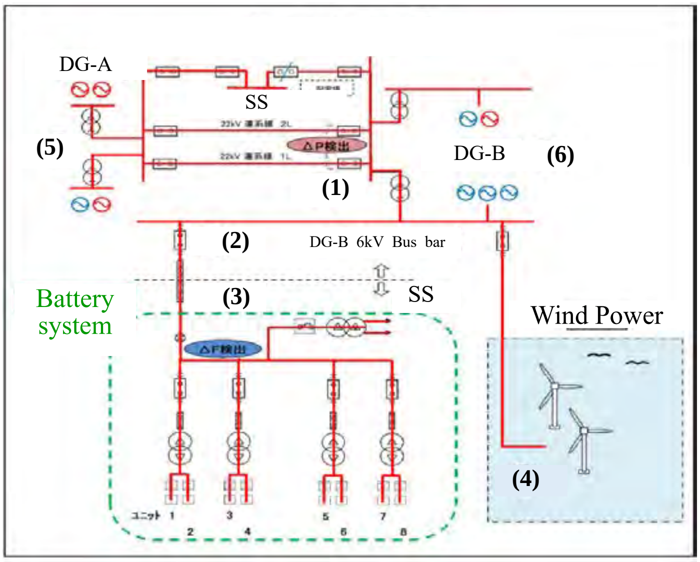
Item	Detail
Type	CV-FN
Rated capacity	1,000kVA
Rated primary voltage	6,600V
Rated secondary voltage	300V
No. of units	4
Manufacturer	Mitsubishi Electric

Source: JICA Study Team

(Stabilization control testing of wind power generation output fluctuation)

The schematic and measurement elements used for stabilization control testing of wind power generated output ((1) - (6)) are shown in Figure 10.2-21. In demonstration testing, when system disturbance occurred with fluctuation of wind generated output, stabilization control using batteries (control of frequency ΔF and interconnection line flow ΔP) was implemented. Measured values of waveforms for measurement elements (1) - (6) at such a time are shown in Figure 10.2-22. Through this stabilization control testing, it has been possible to confirm the fluctuation-mitigating effect of batteries against wind power output fluctuation. The main results of testing are noted below

- Using batteries, it is possible to suppress frequency fluctuation in a bus line interconnected with wind-generated power, even with changes in wind-generated output (approx. 600kW), to within approximately diesel generator dead band (±0.05Hz). (Waveform (2))
- Using batteries, short-cycle components of fluctuations in wind-generated output are countered. (Waveforms (3) and (4))
- Even for diesel generator A using frequency control (AFC), with the use of batteries, output fluctuations due to short-cycle fluctuation portions were reduced. (Waveform (5))



[Measurement elements]

(1) 22kV interconnection line flows [kW]

(2) Diesel generation B 6kV bus frequency [kW]

(3) Battery output [kW]

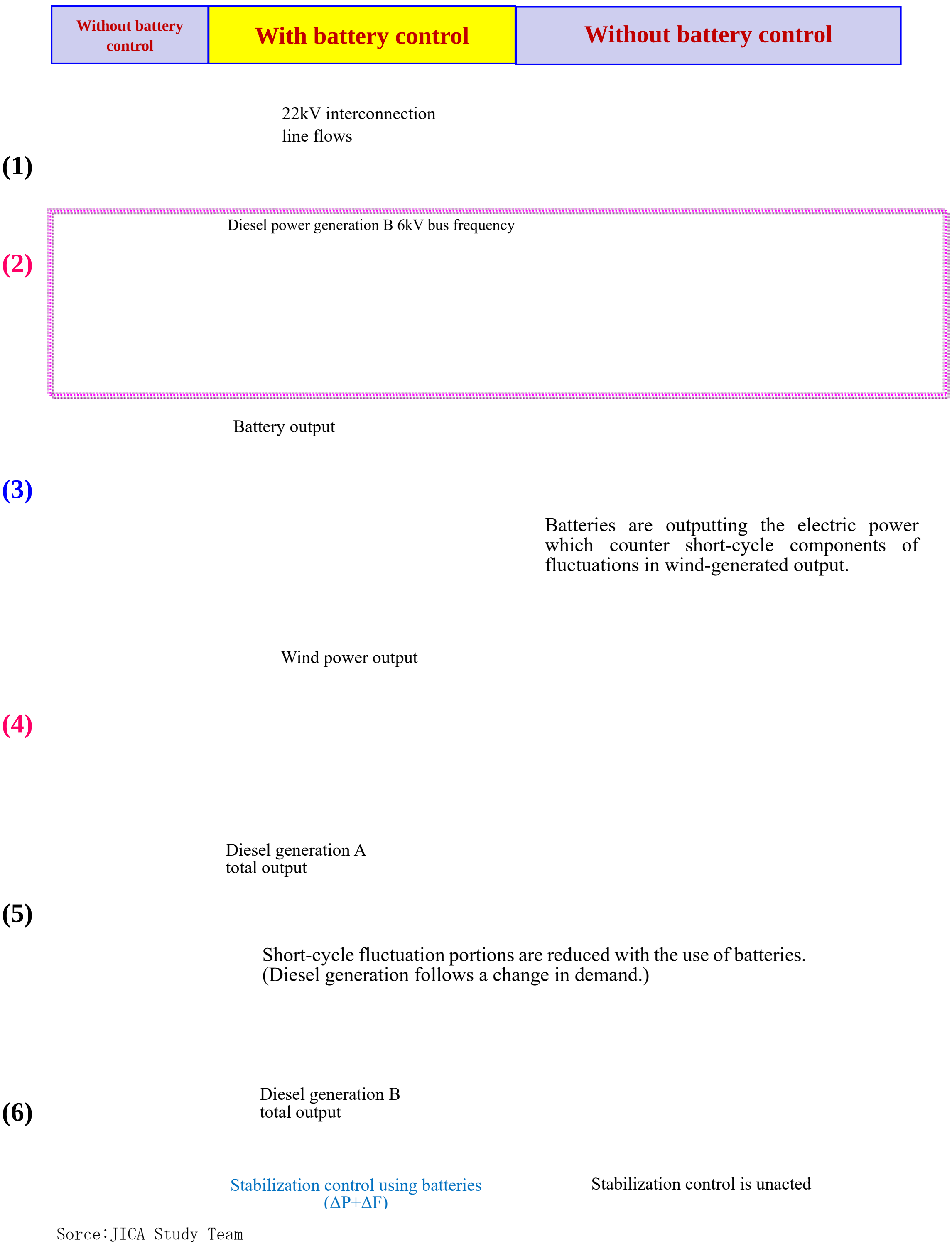
(4) Wind power output [kW]

(5) Diesel generation A total output [kW]

(6) Diesel generation B total output [kW]

Source: JICA Study Team

Figure 10.2-21 Iki demonstration testing distribution diagram (measurement points)

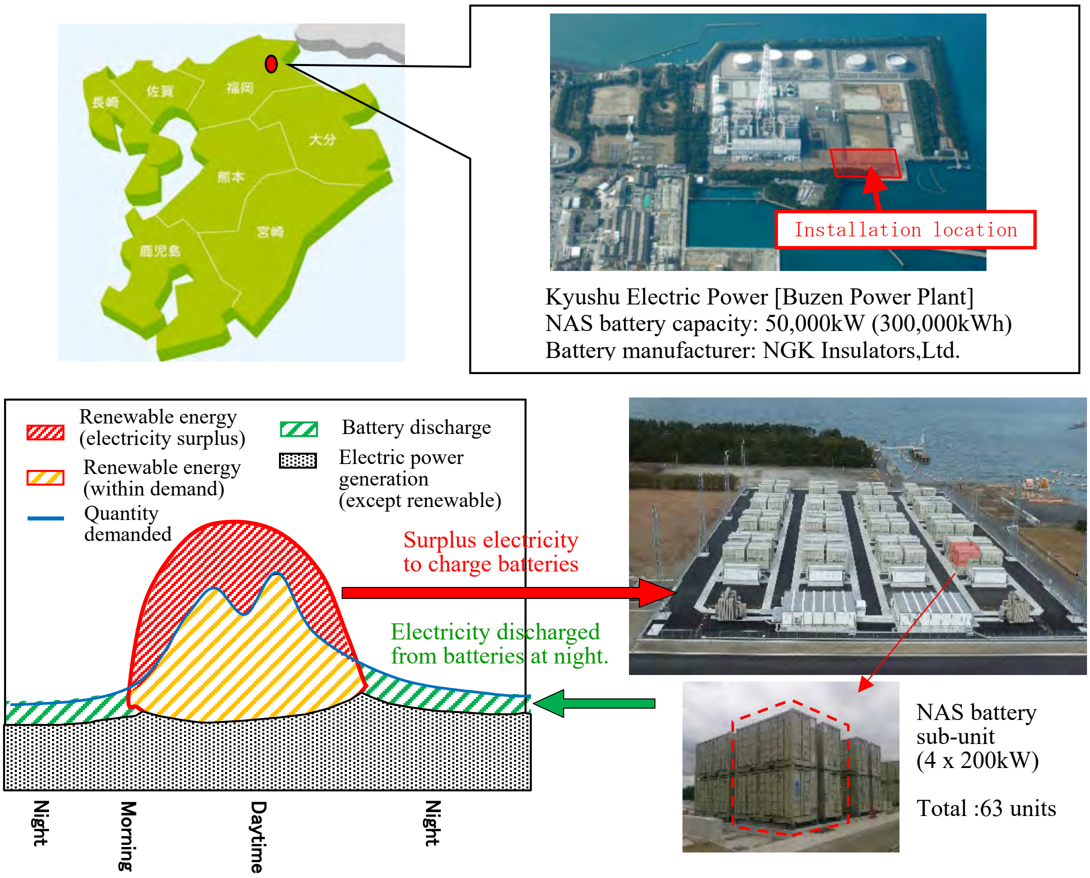


Source: JICA Study Team

Figure 10.2-22 Results of wind power output fluctuation stabilization control test

(4) Demonstration testing on Kyushu mainland (long-cycle fluctuation countermeasure)

In this demonstration testing, a large-capacity battery system (NAS batteries) is connected to an existing KEPCO transmission-transformation facility, which is being used to carry out verification of (1) improved demand-supply balance utilizing a power storage function equivalent to pumped storage, and (2) the effectiveness of applying system voltage control. (Period: 2015 - 2016)



Source: JICA Study Team

Figure 10.2-23 Image of demonstration testing and overview of test equipment.

(Demonstration testing – results and plans)

① In demand supply balance improvement testing, the operational cycle of batteries charging during the daytime when sunlight output becomes large, and discharging during the lighting time period when demand becomes large, was verified.

② In system voltage control testing, voltage control of a 66kV bus line was confirmed. Verification of the applicability of substituting equipment such as power condensers, and shunt reactors will now be carried out.

③ Verification of operational methods to minimize power storage system energy loss (system efficiency approx. 70% or higher) will be carried out.

④ A comprehensive evaluation will be carried out, which will include a comparison of the cost-effectiveness of power storage system with that of pumped-storage.

10.3 Effective Utilization of Existing Electricity from Wind Power with Output Suppression

As was indicated earlier in Table 10.2-4 (Connectable Capacity for Renewable Energy without output suppression), wind power generation on Sal, São Vicente and Boa Vista already exceeds the Connectable Capacity for Renewable Energy without output suppression, and wind power generation output suppression is being implemented. The estimated amount of electricity generated from wind power with output suppression in 2015 was estimated to be 12.2 GWh on Sal,10.7 GWh on São Vicente, and 2.2 GWh on Boa Vista.

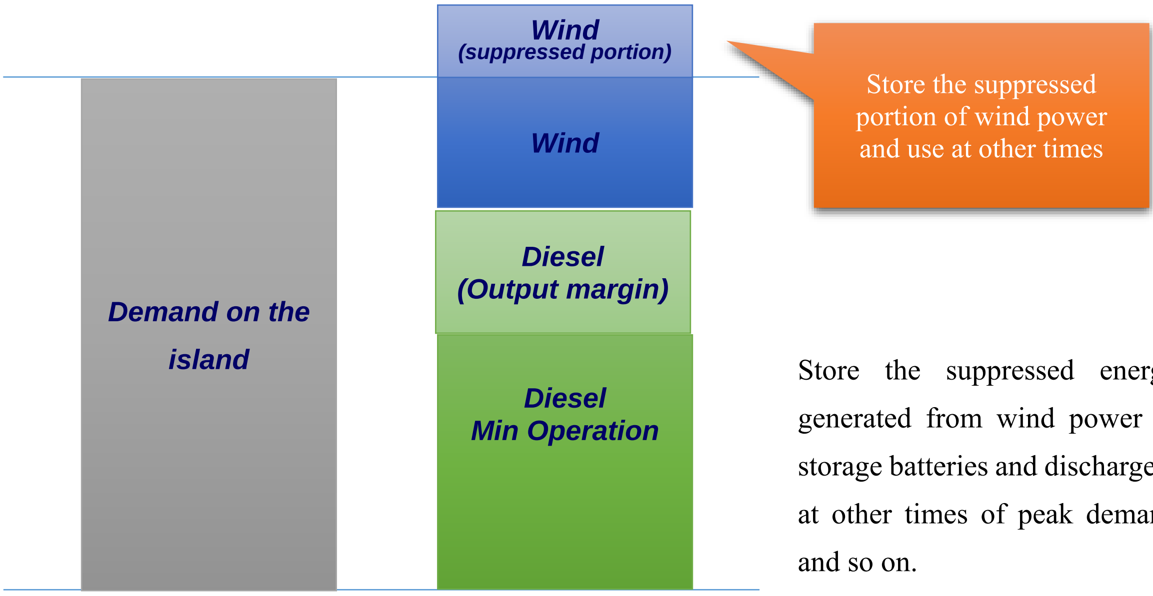
In this section, upon inventorying as far as possible the operating conditions of each generator unit on the three islands of Sal, São Vicente and Boa Vista, simulation is conducted into the effect of expanding introduction of renewable energy based on expanding the reduction in diesel power generators (minimum operation: 70→50%→30%). Also, the effect of expanding the ratio of renewable energy based on introduction of storage batteries is explained.

After that, simulation of the phased introduction of renewable energy based on amount of energy (kWh) is described in light of the strengthening of wind power generation, sensitivity analysis of storage battery capacity, and economic merits and demerits, (see 10.4).

Table 10.3-1 Outline of Simulation of Expansion of the Renewable Energy Ratio

1: Store the suppressed energy generated from wind power in storage batteries and discharge at times of peak demand. (The diesel power generation minimum operation remains as it is at present)
2: Lower the minimum operation of diesel power generators (without storage batteries)
3: Introduction of 1 and 2 (Lower the diesel power generators minimum operation and introduce storage batteries)

1 Case study of storing the suppressed energy generated from wind power in storage batteries and discharging at times of peak demand (Sal case)



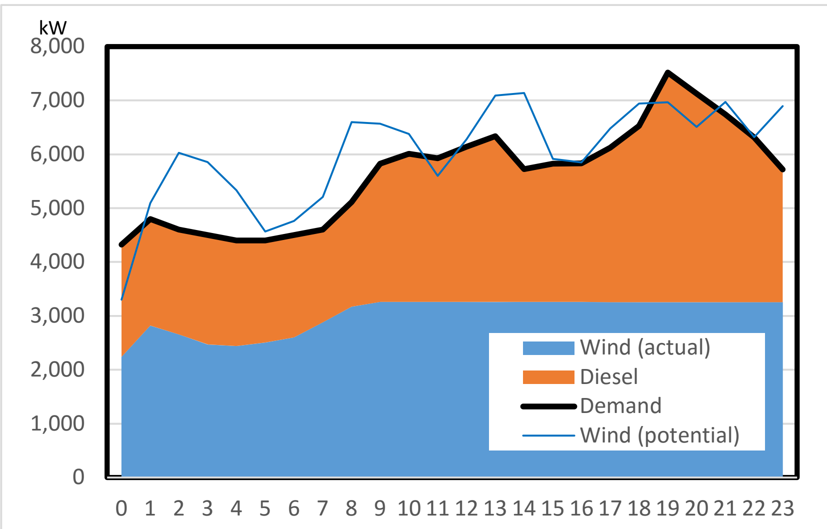
Store the suppressed energy generated from wind power in storage batteries and discharge it at other times of peak demand and so on.

Source: JICA Study Team

Figure 10.3-1 Image of Utilization of Suppressed Wind Power Energy based on Storage Battery Charging and Discharging

① Current conditions

- Sal has wind power generation potential that exceeds demand at times when wind conditions are favorable.
- The operating range of diesel power generators is minimum operation 50%.
- The share of energy from wind power generation in 2015 was 35%.



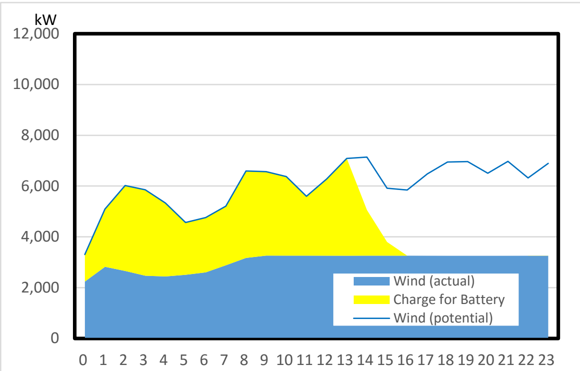
Source: JICA Study Team

Figure 10.3-2 Daily Load Curve when Wind Conditions are Favorable (January 6, 2015)

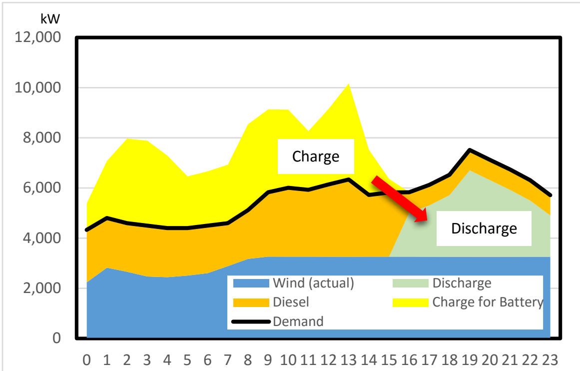
Charge in storage batteries and discharge at times of peak demand.
Assume the minimum operation from diesel power generation to be 50% of the current operation.

② Storage batteries

- The operating range of diesel power generators is assumed to be 50% of the current operation.
- Storage battery capacity is 4,800 kW x 6h, charging and discharging efficiency is 70% (assuming NAS compatible with large capacity), and the figure shows charging at 0:00-16:00 and discharging at 16:00-24:00.
- The share of energy from wind power generation in 2015 was 44%.



[Wind power energy breakdown]

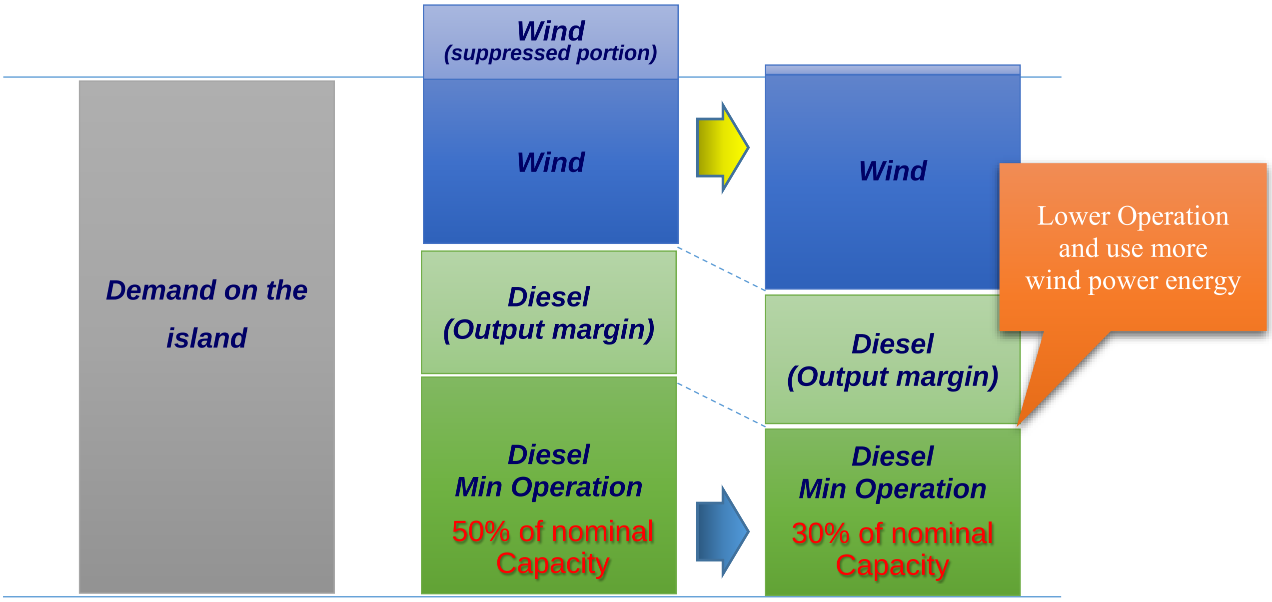


[Battery charging and discharging image]

Source: JICA Study Team

Figure 10.3-3 Daily Load Curve when Wind Conditions Are Favorable (January 6, 2015)

2 Case study of suppressing the minimum operation of diesel power generators (Sal case)



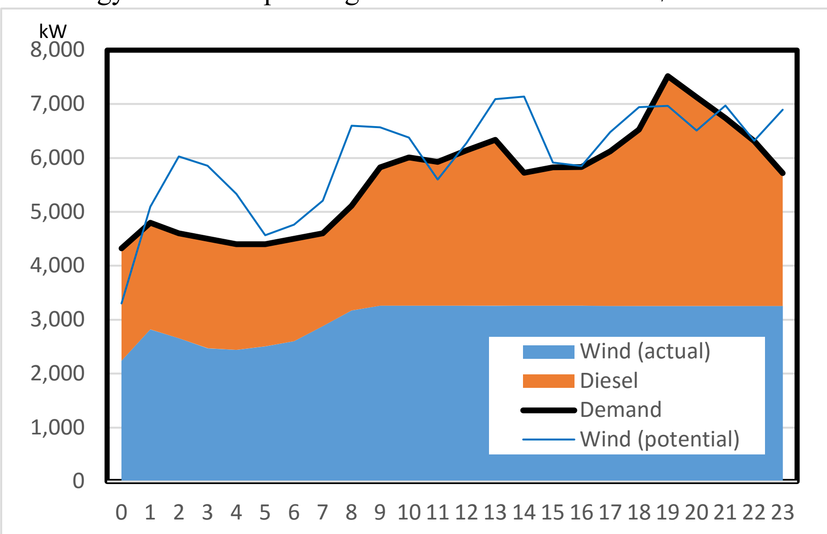
Source: JICA Study Team

Figure 10.3-4 Image of Expansion of the Renewable Energy Rate based on Lowering the Minimum operation of Diesel Power Generators

Lower the minimum operation of diesel power generators from the current 50% to 30%, and thereby effectively utilize the suppressed energy generated from wind power.

① Current conditions

- Sal has wind power generation potential that exceeds demand at times when wind conditions are favorable.
- The operating range of diesel power generators is minimum operation 50%.
- The share of energy from wind power generation in 2015 was 35%.



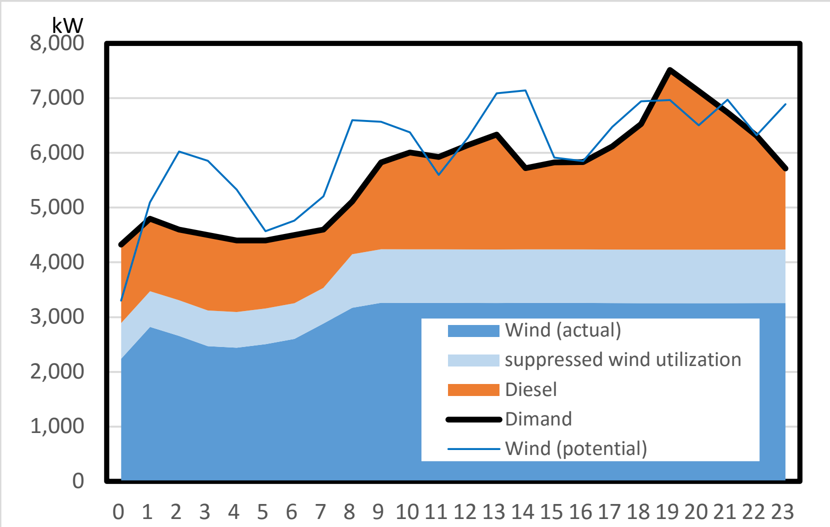
Source: JICA Study Team

Figure 10.3-5 Daily Load Curve when Wind Conditions Are Favorable (January 6, 2015)

Lower the minimum operation of diesel power generators to 30%

② Current operation ＋Diesel Minimum Operation of 30%

- Expand wind power generation based on current operation combined with lowering the minimum operation from diesel power generators to 30%.
- The ratio of wind power generated energy is expanded from the current 35%to 47%.



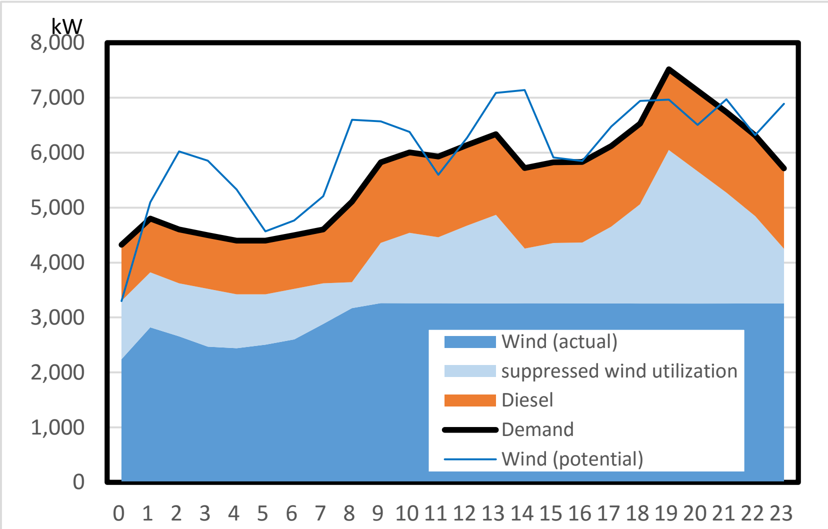
Source: JICA Study Team

Figure 10.3-6 Daily Load Curve at Current Operation ＋ Diesel Power Generators Minimum operation of 30% (January 6, 2015)

Theoretical value in case where diesel power is always operated at minimum operation of 30%.

③ Diesel minimum operation 30%

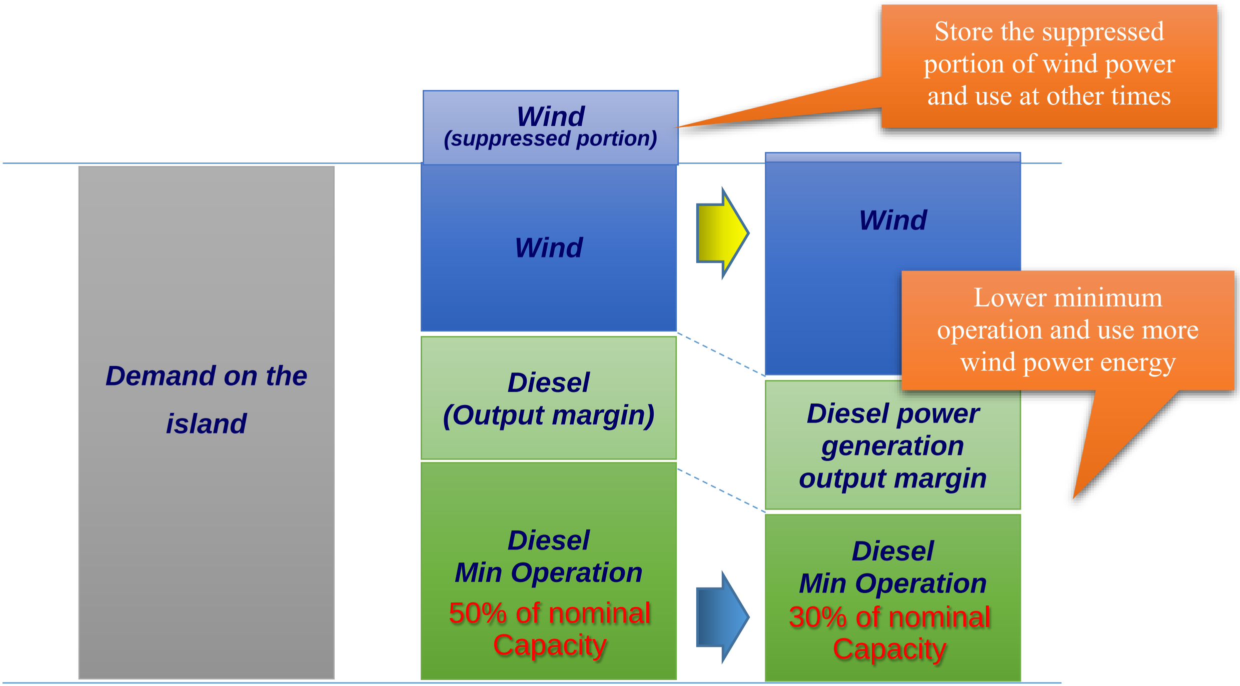
- Diesel power generators are always operated around the minimum operation of 30%, and wind power generation is expanded.
- The ratio of wind power wind power generated energy is expanded from the current 35%to 54%.
- It is recommended that measures be started from the above ② and that ③ be aimed for while confirming the stability of diesel power generators and system step-by-step.



Source: JICA Study Team

Figure 10.3-7 Daily Load Curve at Current Operation ＋ Diesel Power Generators Minimum operation of 30% (January 6, 2015)

3 Case study of implementing the measures in Case 1 and Case 2 (Sal case)



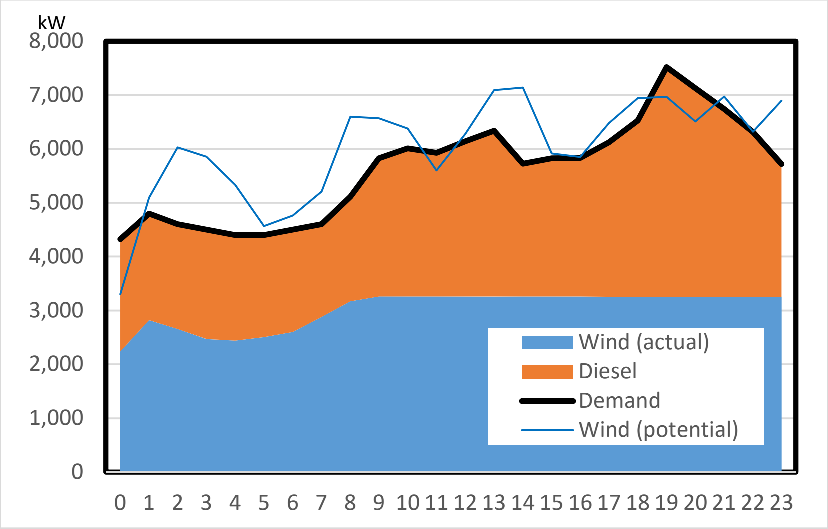
Source: JICA Study Team

Figure 10.3-8 Image of Expansion of the Renewable Energy Rate based on Lowering the Minimum operation of Diesel Power Generators

Lower the minimum operation of diesel power generators from the current 50% to 30%, and thereby expand the amount of energy generated from wind power: furthermore, if the energy generated from wind power is suppressed, use storage batteries in order to effectively utilize it.

① Current conditions

- Sal has wind power generation potential that exceeds demand at times when wind conditions are favorable.
- The operating range of diesel power generators is minimum operation 50%.
- The share of energy from wind power generation in 2015 was 35%.



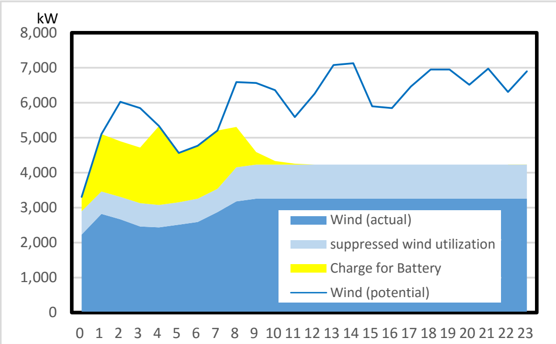
Source: JICA Study Team

Figure 10.3-9 Daily Load Curve when Wind Conditions Are Favorable (January 6, 2015)

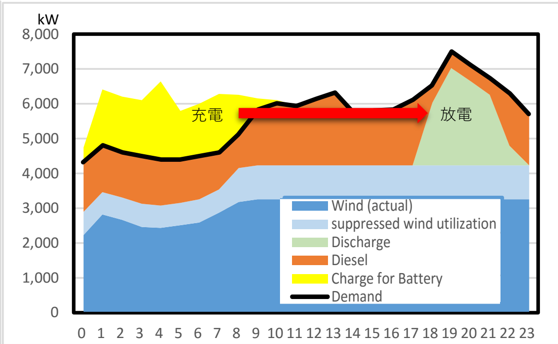
Lower the minimum operation of diesel power generators to 30%; charge energy in storage batteries and discharge at times of peak demand.

② Current operation ＋Diesel Minimum Operation of 30% ＋storage batteries

- Current operation combined with expansion of wind power generation by an amount equivalent to reduction of minimum operation from diesel power generators to 30%
- Storage battery capacity is 1,600 kW x 6h, charging and discharging efficiency is 70% (assuming NAS compatible with large capacity), and the figure shows charging at 0:00-18:00 and discharging at 18:00-24:00.
- The share of energy from wind power generation is expanded from the current 35%to 50%. However, the ratio when lowering the minimum operation from diesel power generators to 30% is 47%, so the effect in terms of expanding the renewable energy ratio is large.



[Wind power energy breakdown]



[Storage battery charging and discharging image]

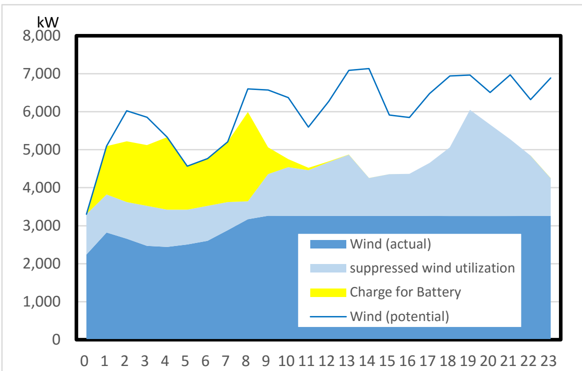
Source: JICA Study Team

Figure 10.3-10 Daily Load Curve in case of Current Operation ＋DG Operation at Minimum operation 30% + Storage Batteries (January 6, 2015)

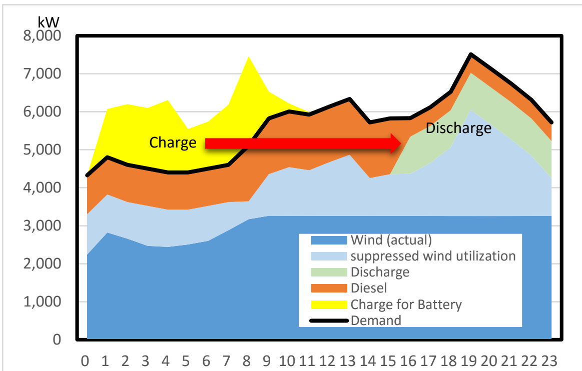
Theoretical value in case where diesel power is always operated at minimum operation of 30%.

③ Diesel generator operation at minimum operation 30% ＋ storage batteries

- Diesel power generators are always operated around the minimum operation of 30%, and wind power generation is expanded.
- Storage battery capacity is 1,600 kW x 6h, charging and discharging efficiency is 70% (assuming NAS compatible with large capacity), and the figure shows charging at 0:00-18:00 and discharging at 18:00-24:00.
- The share of energy from wind power generation is expanded from the current 35%to 57%. However, the ratio when lowering the minimum operation from diesel power generators to 30% is 54%, so the effect in terms of expanding the renewable energy ratio is large.
- It is recommended that measures be started from the above ② and that ③ be aimed for while confirming the stability of diesel power generators and system step-by-step.



[Wind power energy breakdown]



[Battery charging and discharging image]

Source: JICA Study Team

Figure 10.3-11 Daily Load Curve in case of DG Operation at Minimum operation 30% + Storage Batteries (January 6, 2015)

Table 10.3-1 lists the results of the simulations implemented so far. It has been confirmed that the ratio of renewable energy can be expanded by lowering the minimum operation of diesel power generators and introducing storage batteries. In particular, the effect of lowering the minimum operation of diesel power generators is large. Furthermore, simulation of maximizing the introduction of renewable energy in stages based on the amount of energy (kWh) is described later in light of the strengthening of wind power generation, sensitivity analysis of storage battery capacity, and economic merits and demerits (see 10.4).

Table 10.3-2 Effect of Expanding the Renewable Energy Ratio in Reference Cases

Island	Current conditions Diesel: Min 50 % OP Batteries: without	Case 1 Diesel: Min 50 % OP Batteries: with	Case 2 Diesel: Min 30 % OP Batteries: without	Case 3 Diesel: Min 30 % OP Batteries: with
Sal	RE rate: 35 %	RE rate: 44 % (Battery Capacity: 4,800 kW × 6h Battery utilization rate: 20.5 %)	RE rate: 54 %	RE rate: 57 % (Battery Capacity: 1,600 kW × 6h Battery utilization rate: 8.5 %)
São Vicente	RE rate: 30 %	RE rate: 35 % (Battery Capacity: 4,800 kW × 6h Battery utilization rate: 15.8 %)	RE rate: 47 %	RE rate: 48 % (Battery Capacity: 1,600 kW × 6h Battery utilization rate: 3.5 %)
Boa Vista	RE rate: 25 %	RE rate: 30 % (Battery Capacity: 1,600 kW × 6h Battery utilization rate: 10.0 %)	RE rate: 35 %	RE rate: 35 % (Battery Capacity: 1,600 kW × 6h Battery utilization rate: 0.7 %)

Note: RE means Renewable Energy
Source: JICA Study Team

10.4 Simulation for Renewable Energy Expansion

Even though Cabo Verde has abundant wind resources, wind power generation is currently suppressed from the demand & supply balance and economic reasons. Usually, when wind generation is likely to excess 50% of the demand of the island, Electra and AEB which operate load dispatching using wind power from Cabeolica will suppress the wind power by setting “set point” of the farm.

Moreover, in order to keep the DG’s generation output to 70 – 85% of the unit’s capacity aiming high combustion efficiency and from the reason relative high purchase price of the wind which is difficult to offset fuel cost of the DG described in 7.4, wind power is suppressed even if it’s below 50% of the demand.

Therefore, if surplus energy that has been suppressed is stored in battery system and discharged at the peak demand to compensate the DG output as constant energy source, it may contribute to cost reduction of the DG fuel.

In this section, we did simulation to know how much wind power can be obtained from the existing wind farm if the optimal battery capacity is using actual data and wind potential (theoretical output calculated from the meteorological data). In addition, we implemented the quantitative analysis when wind facility is newly introduced.
Currently, wind output is suppressed in São Vicente, Sal and Boa Vista. As for Santiago, even though wind is not suppressed, it has the largest demand in Cabo Verde. Therefore, four islands including Santiago where renewable energy development potential is high are selected as the targets for the simulation. Here is the objective and outline of the simulation.

(1) Objective of the simulation

We will study effect to DG fuel cost reduction, annual renewable energy rate (energy basis), and economic performance (period of return of investment) by using the measures below.

- Increasing renewable energy's maximum balance of the total demand (share target of energy basis at dispatching) from 50% to 70%
- Reinforcement of wind farm capacity
- Introduction of battery system

(2) Used data

One-hour data of demand, output of wind farm, theoretical output calculated from the meteorological data of each island. (24h x 365days)

(3) Target island

4 island (São Vicente, Sal, Boa Vista and Santiago)

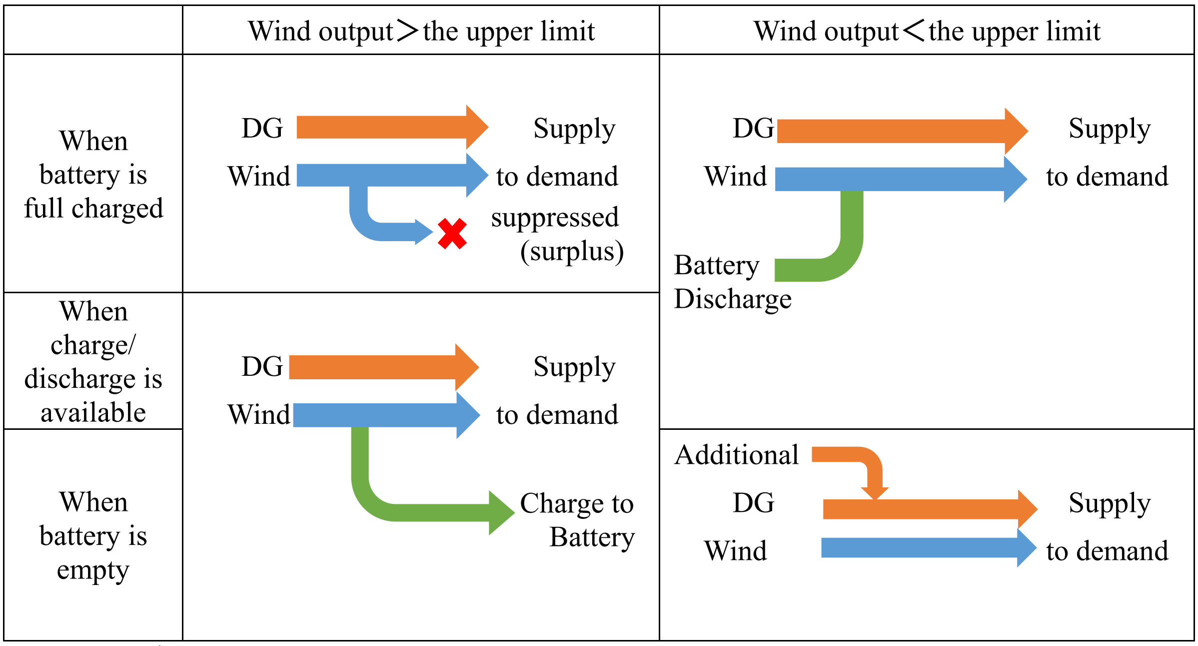
(4) Timing of charge/discharge of the battery and conditions

When wind output excess the upper limit (50-70% of the demand of the island)

→ Wind surplus output will be charged in battery but it is suppressed if the battery is full charged.

When wind output is within the upper limit

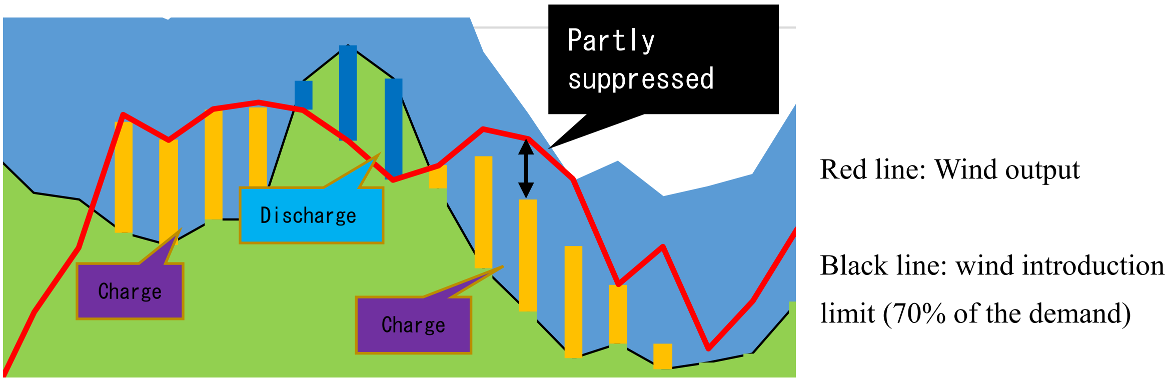
→ Battery will discharge energy to supply the demand but DG will increase output if the battery is empty.



Source: JICA Study Team

Figure 10.4-1 Image of using battery

Because battery has rated input/output (kW) and capacity (kWh), it cannot charge/discharge energy over the specifications. In case charge excess rated input, surplus energy is suppressed and in case discharge excess rated output, additional power is generated by DG.



Source: JICA Study Team

Figure 10.4-2 Image of charge/discharge

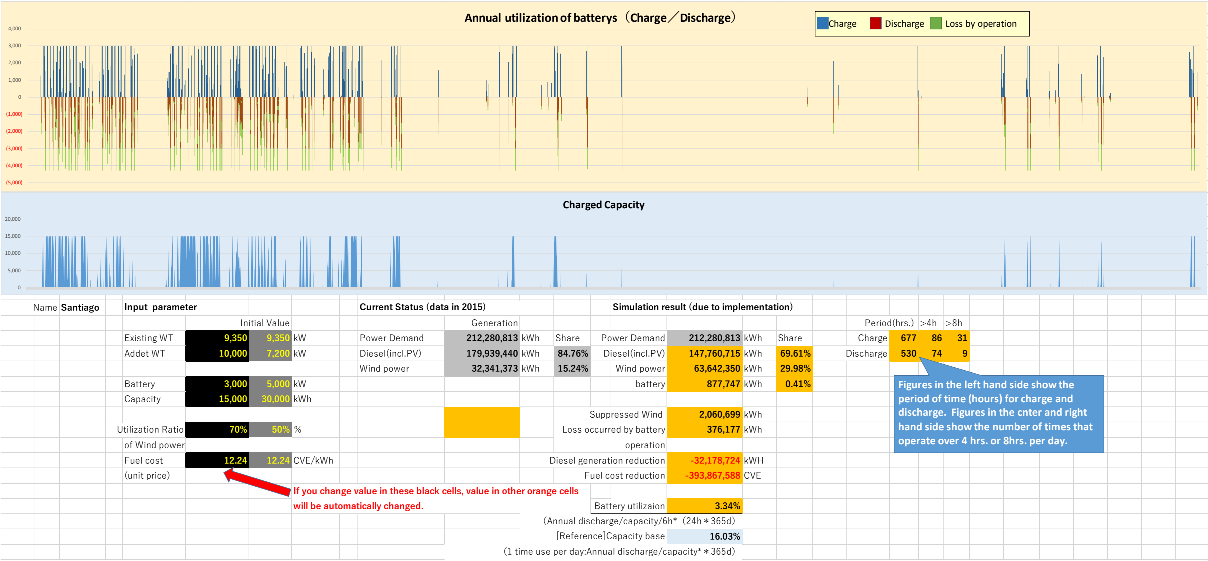
(5) Electric loss

When energy is charged/discharged, we assume that electric loss is generated due to AC/DC conversion and heater. Only 70% of charged energy is supplied and 30% is consumed in the battery.

(6) Parameters

In simulation, we studied the optimal system using those parameters below.

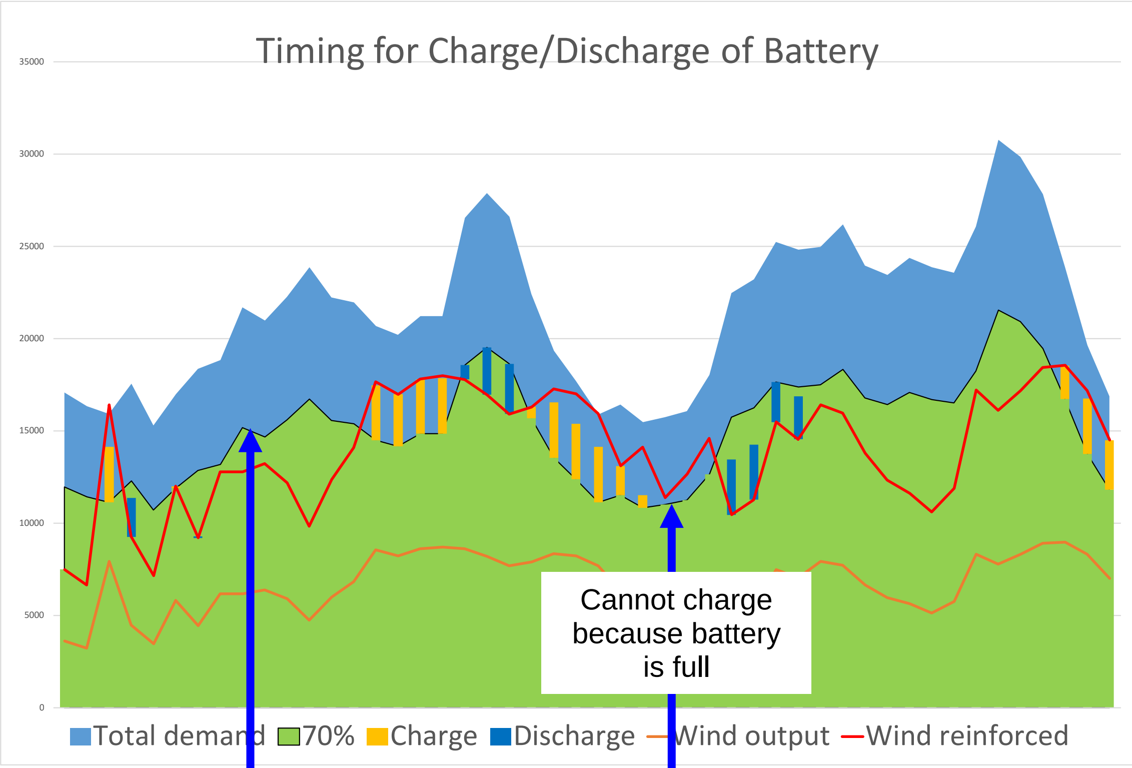
- The upper limit of renewable energy ratio (%)
- Reinforcement of wind farm capacity (kW)
- Rated input/output of battery (kW)
- Capacity of battery (kWh)



Source: JICA Study Team

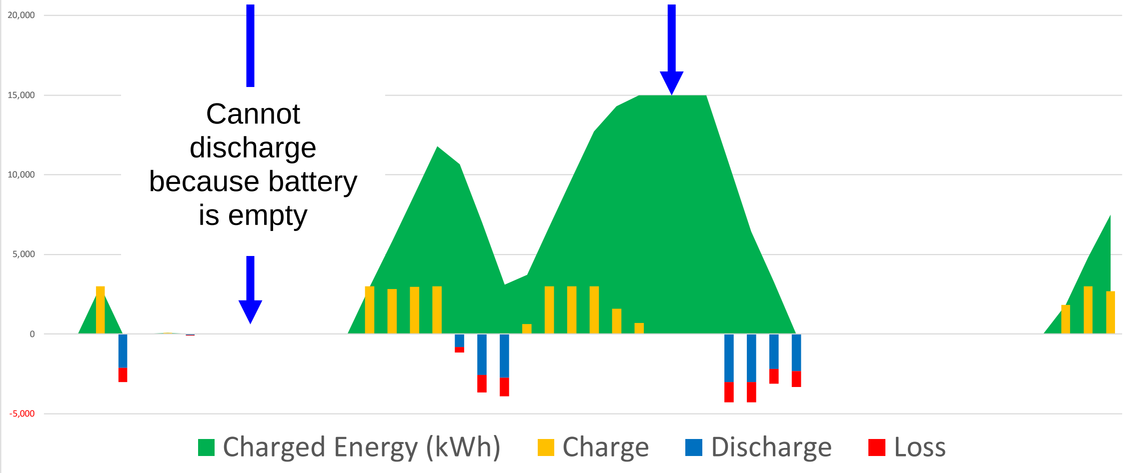
Figure 10.4-3 Screen of the simulation program

Though we used 24hx365d data in the simulation, we used January data, when the demand is not the highest but wind condition is the best, as the image example.



Source: JICA Study Team

Figure 10.4-4 Timing of charge/discharge of battery



Source: JICA Study Team

Figure 10.4-5 Charged energy curve due to charge/discharge of battery

10.4.1 Simulation of renewable energy expansion at São Vicente

(1) Current status

Peak demand in the island is approximately 12,100kW but existing wind farm capacity is 5,950kW, accounting for almost 50% of the peak demand. At São Vicente, even though strong and constant wind blows, operating upper limit of wind is targeted about 50% of the demand. Calculated annual wind potential based meteorological data is 29.8GWh but actual generation of the wind farm is only 19.5GWh. This means 1/3 of the wind potential is suppressed in vain.

(2) Options to expand renewable energy

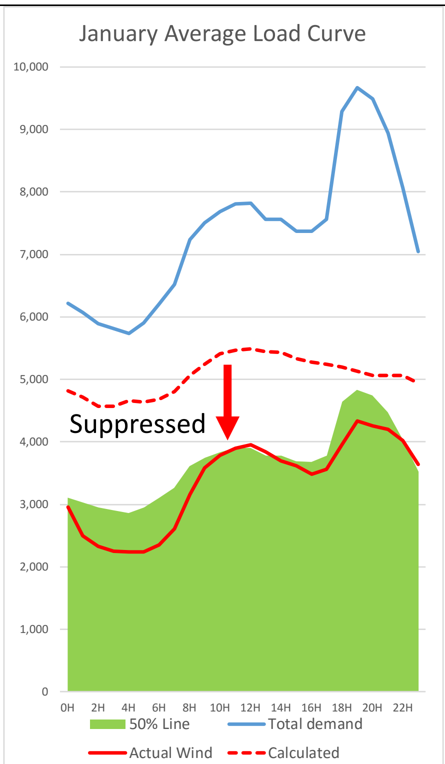
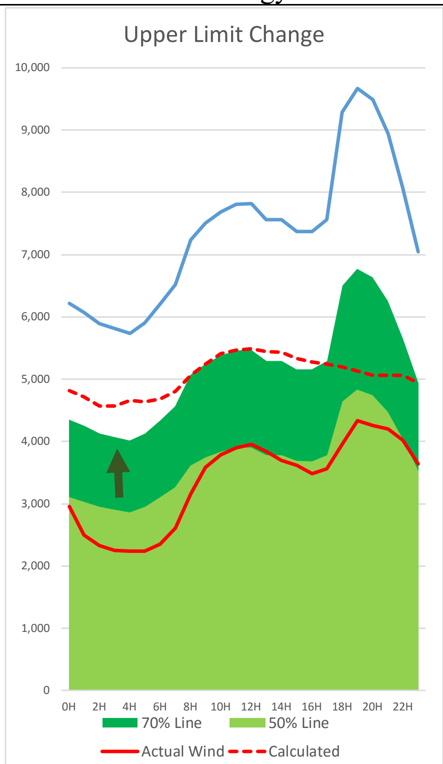
To increase the renewable energy rate, those countermeasures are applicable.

① Increase the operating ratio (upper limit) of renewable energy (→ effective utilization of the surplus energy)

② Introduce energy storage facility (→ effective utilization of the surplus energy)

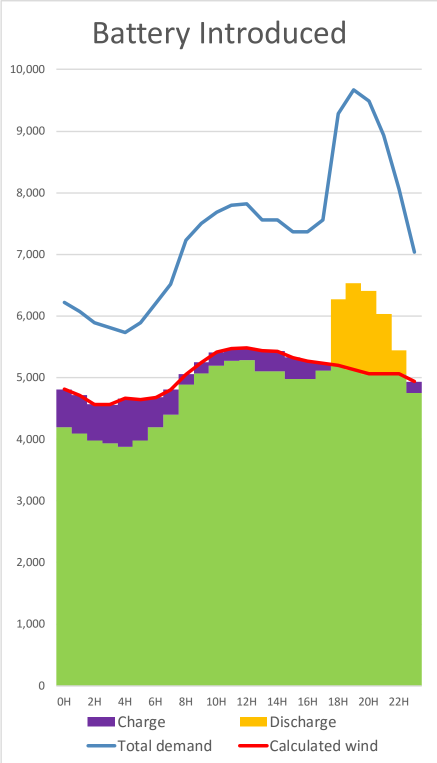
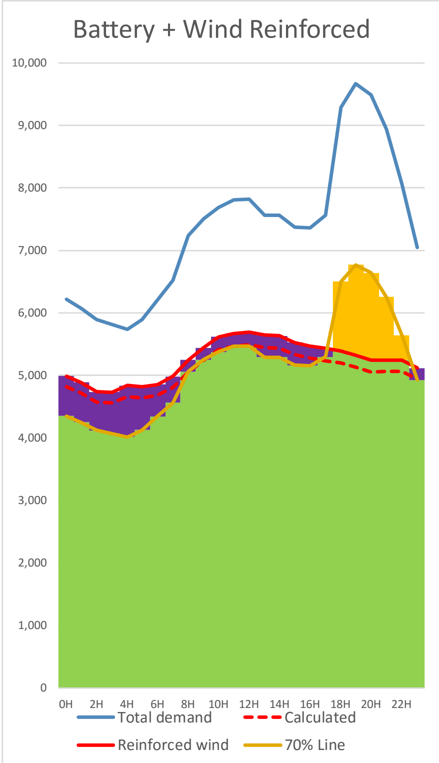
③ Reinforce wind farm capacity (→ expansion of wind generation)

Table 10.4-1 Option to expand renewable energy -1 (São Vicente)

Options	Present (Average of 2015 January)	① Increase the operating ratio of renewable energy
Images		
Description	Even if wind output is less than 50% of the demand, wind may be suppressed because of system stability and economy sometimes.	By increasing operating ratio from 50% to 70%, wind suppress cannot be eliminated but can be reduced drastically.

Source: JICA Study Team

Table 10.4-2 Option to expand renewable energy -2 (São Vicente)

Options	‘② Introduce energy storage facility	‘③ Reinforce wind farm capacity
Images		
Description	By introducing battery with enough capacity, theoretical generation potential can be utilized without suppress.	Because theoretical generation potential is close to 70% of the demand, further reinforcement of wind seems difficult. If the demand is likely to grow more, further wind can be introduced in the future. It is necessary to take care having too much wind capacity because surplus energy grows too.

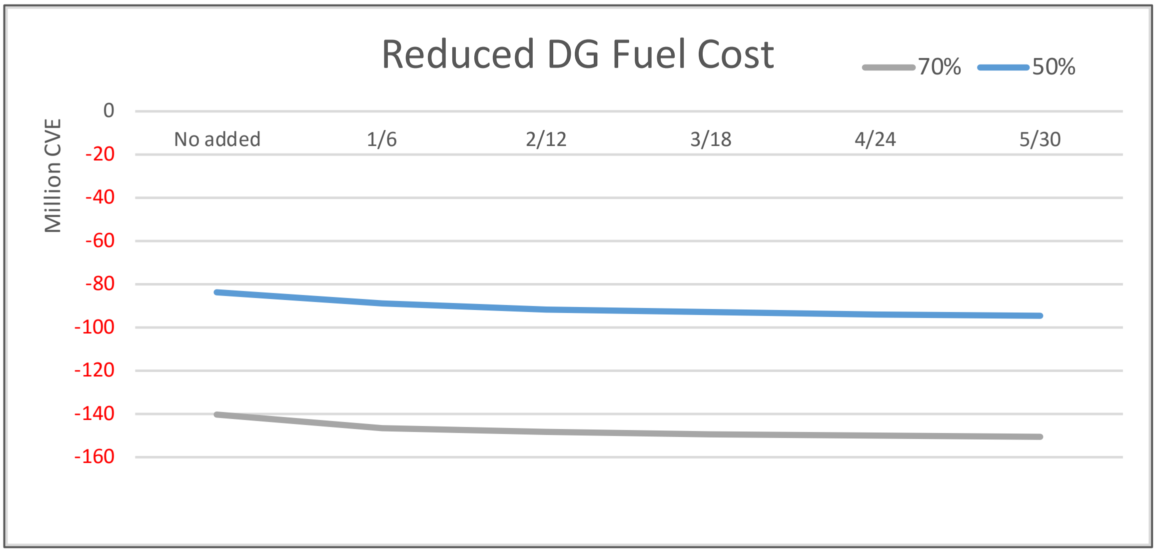
Source: JICA Study Team

(3) Evaluation of the options

In São Vicente, as about 1/3 of the theoretical wind potential has been suppressed, drastic effect will be expected only if ① increasing the operating ratio of renewable energy in Table 10.4-1. Analysis result of 3 cases listed in Table 10.4-2 and Table 10.3-2 will be described below.

1) Case 1 ①increase the operating ratio of renewable energy + ②introduce energy storage system

When adding NAS battery unit (rated output: 2MW, capacity: 12MWh) incrementally, we confirmed impact to the DG fuel cost reduction in both 50% RE rate and 70% RE rate conditions.



Source: JICA Study Team

Figure 10.4-6 DG fuel cost reduction when introducing battery

Table 10.4-3 Cost performance of investment when introducing battery

	NAS (MW/MWh)	No Added	1/6	2/12	3/18	4/24	5/30
	Introduction cost (EUR 1,000)	0	3,038	6,076	9,114	12,153	15,191
RE ratio 50%	Fuel cost reduction (CVE)	-84,172,496	-89,275,356	-91,630,315	-92,986,701	-94,016,959	-94,933,401
	Incremental merit (CVE)	-	-5,102,861	-2,354,959	-1,356,386	-1,030,258	-916,443
	DG share	62.29%	61.68%	61.39%	61.23%	61.10%	60.99%
	Invest return (Yrs)	-	66	142	247	325	366
RE ratio 70%	Fuel cost reduction (CVE)	-140,690,882	-146,785,842	-148,631,829	-149,515,542	-150,262,352	-150,858,980
	Incremental merit (CVE)	-	-6,094,960	-1,845,987	-883,713	-746,809	-596,629
	DG share	55.46%	54.72%	54.50%	54.39%	54.30%	54.23%
	Invest return (Yrs)	-	55	181	379	449	561

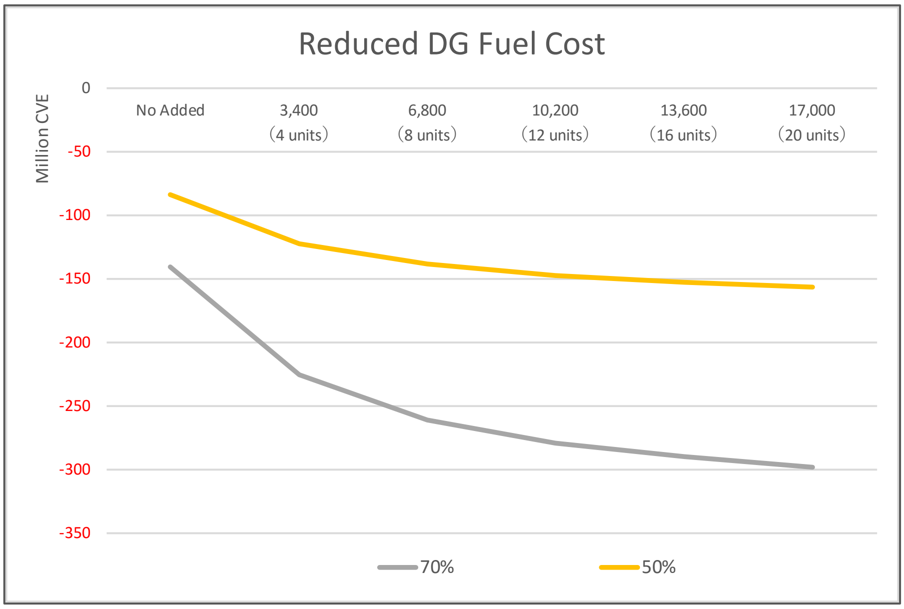
Source: JICA Study Team

As shown in Table 10.4-3, if battery is introduced, DG fuel cost can be reduced but even in the most optimal case (RE ratio: 70% NAS introduction: 1MW/6MWh), it takes 55 years to return investment and cost performance cannot be expected only for the demand shift of the surplus power. However, besides the long period storage, if it has several other functions like emergency substitute of DG plats or transmission system stabilizer, its value is expected to be added

The reason why NAS battery is chosen for the simulation is described in chapter 10.4.5.

2) Case 2 ①increase the operating ratio of renewable energy + ③reinforce wind capacity

When adding wind turbine (rated output: 850kW x 4 units) incrementally instead of introducing battery, we confirmed impact to the DG fuel cost reduction in both 50% RE rate and 70% RE rate conditions.



Source: JICA Study Team

Figure 10.4-7 DG fuel cost reduction when reinforcing wind capacity

Table 10.4-4 Cost performance of investment when reinforcing wind capacity

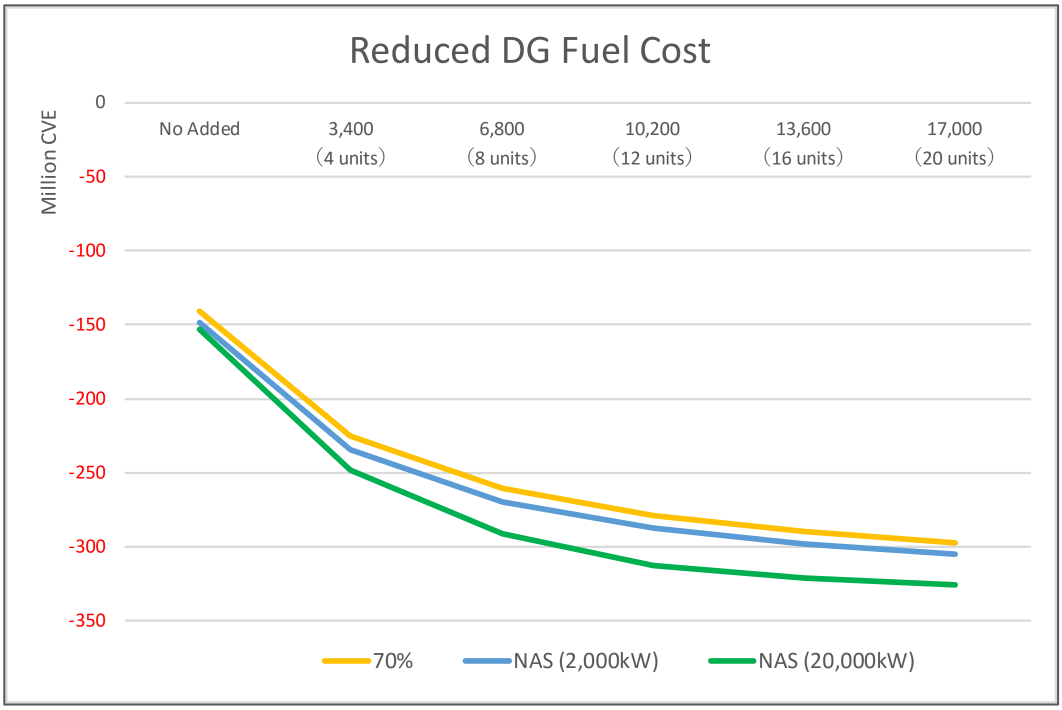
	Wind reinforced (kW)	No Added	3,400 (4 units)	6,800 (8 units)	10,200 (12 units)	13,600 (16 units)	17,000 (20 units)
	Introduction cost (EUR 1,000)	0	7,747	15,494	23,242	30,989	38,736
RE ratio 50%	Fuel cost reduction (CVE)	-84,172,496	-122,786,848	-138,564,875	-147,146,919	-152,565,850	-156,225,016
	Incremental merit (CVE)	-	-38,614,352	-15,778,028	-8,582,044	-5,418,931	-3,659,166
	DG share	62.29%	57.62%	55.72%	54.68%	54.02%	53.58%
	Invest return (Yrs)	-	22	54	100	158	233
RE ratio 70%	Fuel cost reduction (CVE)	-140,690,882	-225,607,181	-260,606,126	-278,828,066	-290,073,648	-297,721,280
	Incremental merit (CVE)	-	-84,916,299	-34,998,945	-18,221,939	-11,245,582	-7,647,632
	DG share	55.46%	45.19%	40.96%	38.75%	37.39%	36.47%
	Invest return (Yrs)	-	10	24	47	76	112

Source: JICA Study Team

As shown in Table 10.4-4, the more wind capacity increase, the more RE ratio grows. At the most optimal case (RE ratio: 70%, wind reinforce: 3,400kW), it takes 10 years to return the investment and the reinforcement seems worth considering if the life of facility is assumed 20 years.

3) Case 3 ①increase the operating ratio of renewable energy + ②introduce energy storage system + ③reinforce wind capacity

Setting RE ratio 70%, we examined the impact when NAS battery and additional wind is introduced. In the simulation, we studied both 2MW/12MWh and 20MW/120MWh NAS battery to confirm the impact of the battery capacity.



Source: JICA Study Team

Figure 10.4-8 DG fuel cost reduction when reinforcing wind and introducing battery

Table 10.4-5 Cost performance of investment when reinforcing wind and introducing battery

	Wind reinforced (kW)	No Added	3,400 (4 units)	6,800 (8 units)	10,200 (12 units)	13,600 (16 units)	17,000 (20 units)
RE ratio 70%	Fuel cost reduction (CVE)	-140,690,882	-225,607,181	-260,606,126	-278,828,066	-290,073,648	-297,721,280
	Incremental merit (CVE)	-	-84,916,299	-34,998,945	-18,221,939	-11,245,582	-7,647,632
	DG share	55.46%	45.19%	40.96%	38.75%	37.39%	36.47%
	Introduction cost (EUR 1,000)	0	7,747	15,494	23,242	30,989	38,736
	Invest return (Yrs)	-	10	24	47	76	112
RE ratio 70%+ NAS 2,000kW/ 12,000kWh	Fuel cost reduction (CVE)	-148,631,829	-234,619,278	-270,044,128	-287,277,679	-297,910,927	-305,293,432
	Incremental merit (CVE)	-	-85,987,449	-35,424,850	-17,233,551	-10,633,248	-7,382,505
	DG share	54.50%	44.10%	39.82%	37.73%	36.45%	35.55%
	Introduction cost (EUR 1,000)	6,076	13,823	21,571	29,318	37,065	44,812
	Invest return (Yrs)	-	18	43	88	143	206
RE ratio 70%+ NAS 20,000kW/ 120,000kWh	Fuel cost reduction (CVE)	-153,257,808	-248,496,008	-291,344,374	-312,740,229	-321,191,324	-325,520,349
	Incremental merit (CVE)	-	-95,238,200	-42,848,366	-21,395,855	-8,451,094	-4,329,026
	DG share	53.94%	42.42%	37.24%	34.65%	33.63%	33.11%
	Introduction cost (EUR 1,000)	60,763	68,510	76,257	84,004	91,751	99,499
	Invest return (Yrs)	-	79	176	353	894	1,745

Source: JICA Study Team

Even though the most effective combination is NAS battery: 2MW/12MWh and wind reinforcement: 3,400kV, it takes 21 years to collect the investment, which is 8-year longer than only adding wind farm.

(4) Conclusion

At São Vicente, where currently about 1/3 of the theoretical potential of the existing wind farm is suppressed, the most effective option is to increase RE operating ratio from 50% to 70%. Introducing battery is also effective but its impact is very limited.

10.4.2 Simulation of renewable energy expansion at Sal

(1) Current status

Peak demand in the island is approximately 10,700kW but existing wind farm capacity is 7,650kW, accounting for almost 70% of the peak demand. At Sal, even though strong and constant wind blows, operating upper limit of wind is targeted about 50% of the demand. Calculated annual wind potential based meteorological data is 31.0GWh but actual generation of the wind farm is only 19.2GWh. This means 40 % of the wind potential is suppressed in vain.

(2) Options to expand renewable energy

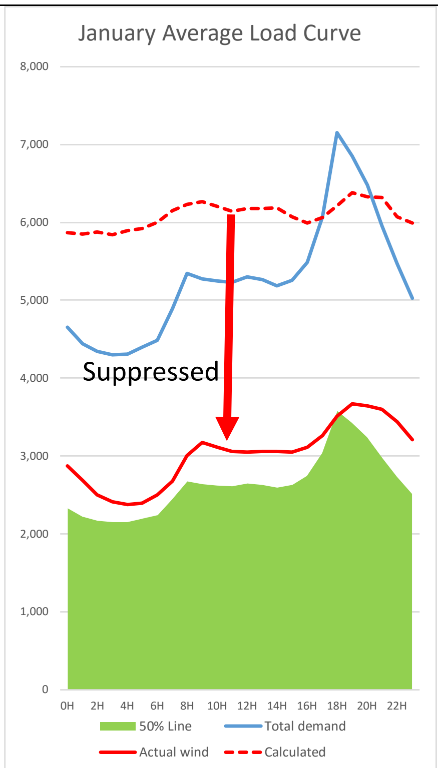
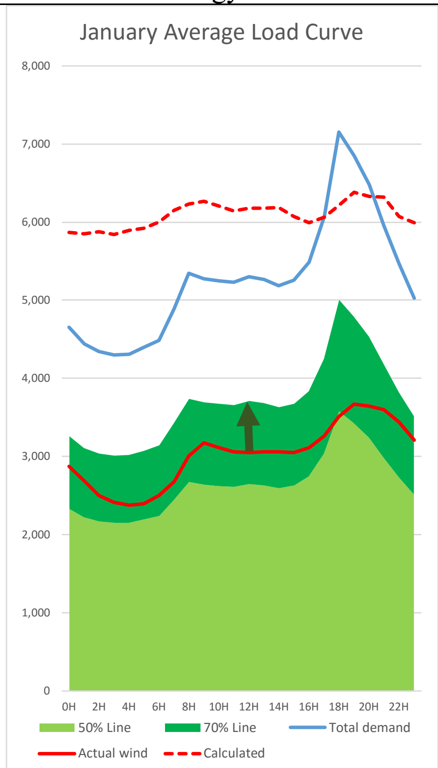
To increase the renewable energy rate, those countermeasures are applicable.

① Increase the operating ratio (upper limit) of renewable energy (→ effective utilization of the surplus energy)

② Introduce energy storage facility (→ effective utilization of the surplus energy)

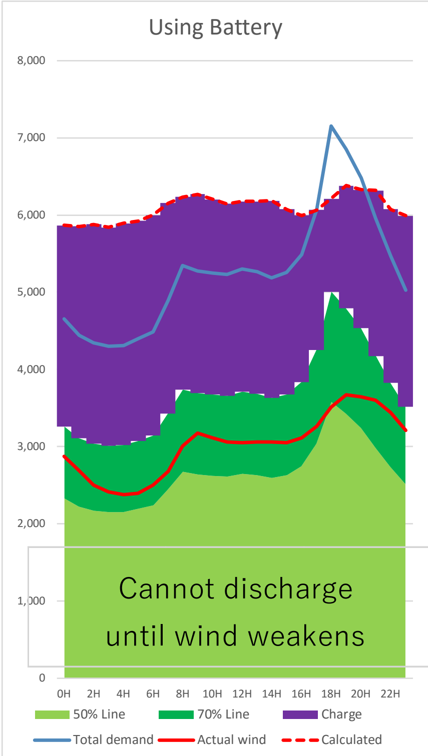
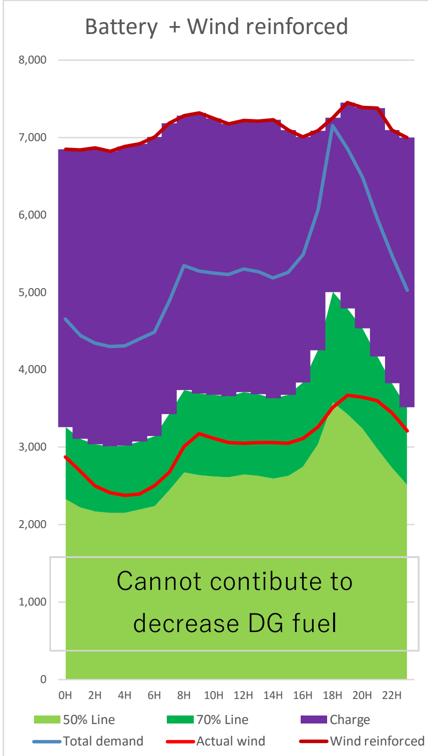
③ Reinforce wind farm capacity (→ expansion of wind generation)

Table 10.4-6 Option to expand renewable energy -1 (Sal)

Options	Present (Average of 2015 January)	① Increase the operating ratio of renewable energy
Images		
Description	Theoretical wind potential excess the demand except peak time in the evening. Surplus wind is suppressed but wind output accounts over 50% of the demand all day long.	By increasing operating ratio from 50% to 70%, wind suppress can be reduced but the amount is very limited.

Source: JICA Study Team

Table 10.4-7 Option to expand renewable energy -2 (Sal)

<table>
<tr><td>Options</td><td>‘② Introduce energy storage facility</td><td>‘③ Reinforce wind farm capacity</td></tr>
<tr><td>Images</td><td>
</td><td>
</td></tr>
<tr><td>Description</td><td>Because theoretical wind potential excess the demand except peak time in the evening, battery only can contribute to frequency adjustment but cannot contribute to DG fuel cost reduction.</td><td>Reinforcement of wind cannot contribute to DG fuel reduction because battery has no opportunity to discharge the stored energy.</td></tr>
</table>

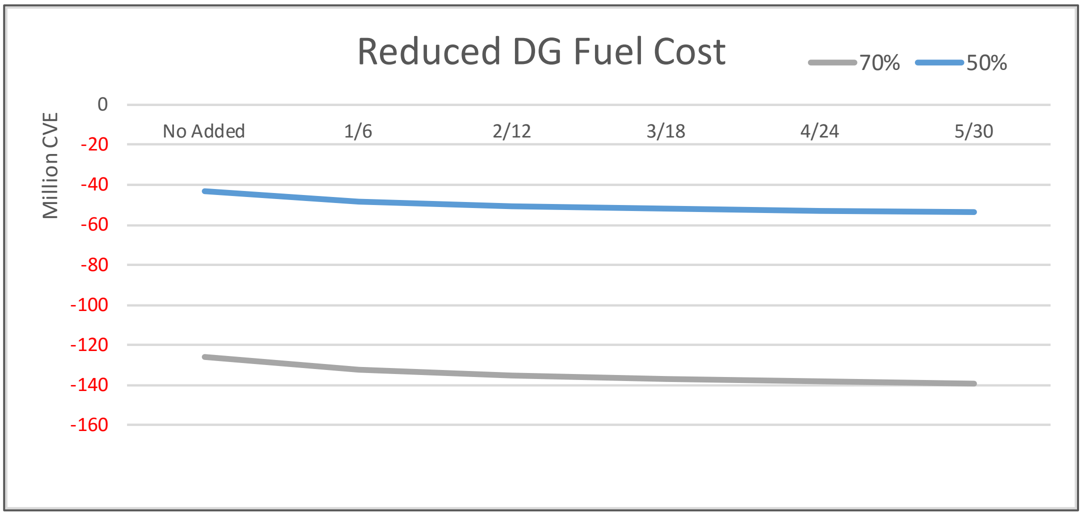
Source: JICA Study Team

(3) Evaluation of the options

In Sal, as about 40% of the theoretical wind potential has been suppressed, drastic effect will be expected only if ① increasing the operating ratio of renewable energy in Table 10.4-6. Analysis result of 3 cases listed in Table 10.4-6 and Table 10.4-7 will be described below.

1) Case 1 ①increase the operating ratio of renewable energy + ②introduce energy storage system

When adding NAS battery unit (rated output: 1MW, capacity: 6MWh) incrementally, we confirmed impact to the DG fuel cost reduction in both 50% RE rate and 70% RE rate conditions.



Source: JICA Study Team

Figure 10.4-9 DG fuel cost reduction when introducing battery

Table 10.4-8 Cost performance of investment when introducing battery

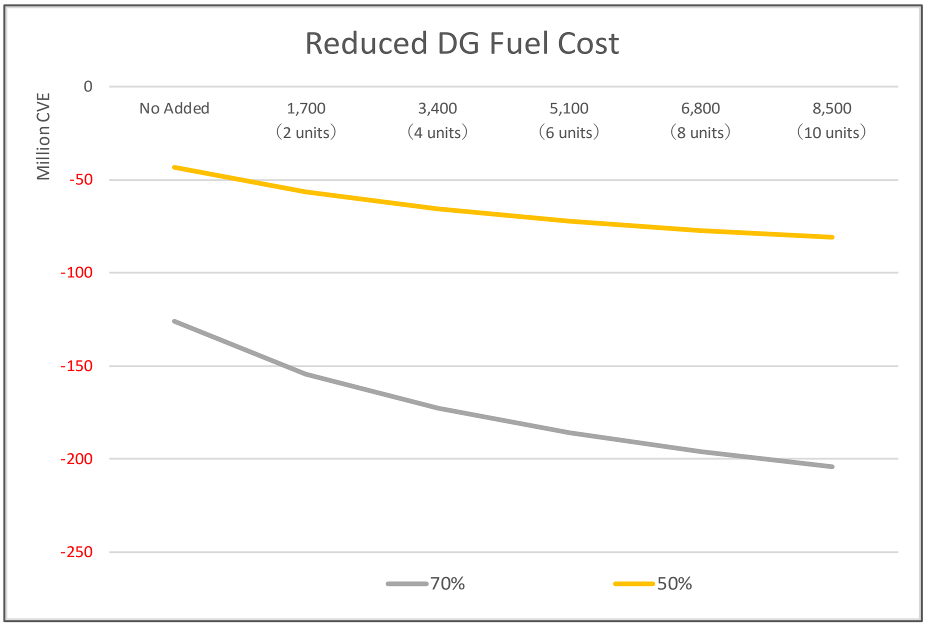
	NAS (MW/MWh)	No Added	1/6	2/12	3/18	4/24	5/30
	Introduction cost (EUR 1,000)	0	3,038	6,076	9,114	12,153	15,191
RE ratio 50%	Fuel cost reduction (CVE)	-43,389,377	-48,312,110	-50,678,239	-52,014,454	-52,942,076	-53,777,036
	Incremental merit (CVE)	-	-4,922,733	-2,366,129	-1,336,215	-927,622	-834,960
	DG share	59.38%	58.75%	58.45%	58.27%	58.15%	58.05%
	Invest return (Yrs)	-	68	142	251	361	401
RE ratio 70%	Fuel cost reduction (CVE)	-125,792,621	-132,334,919	-135,121,121	-136,868,534	-138,210,638	-139,410,264
	Incremental merit (CVE)	-	-6,542,298	-2,786,202	-1,747,413	-1,342,104	-1,199,626
	DG share	48.78%	47.94%	47.58%	47.35%	47.18%	47.03%
	Invest return (Yrs)	-	51	120	192	250	279

Source: JICA Study Team

As shown in Table 10.4-8, if battery is introduced, DG fuel cost can be reduced but even in the most optimal case (RE ratio: 70% NAS introduction: 2MW/12MWh), it takes 51 years to return investment and cost performance cannot be expected.

2) Case 2 ①increase the operating ratio of renewable energy + ③reinforce wind capacity

Instead of introducing battery, we confirmed impact to the DG fuel cost reduction if adding wind turbine (rated output: 850kW x 2 units) incrementally in both 50% RE rate and 70% RE rate conditions.



Source: JICA Study Team

Figure 10.4-10 DG fuel cost reduction when reinforcing wind capacity

Table 10.4-9 Cost performance of investment when reinforcing wind capacity

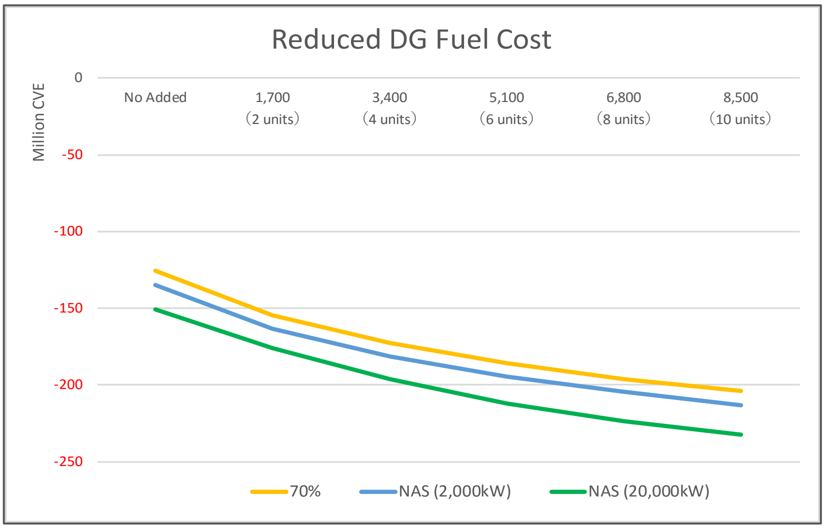
	Wind reinforced (kW)	No Added	1,700 (2 units)	3,400 (4 units)	5,100 (6 units)	6,800 (8 units)	8,500 (10 units)
	Introduction cost (EUR 1,000)	0	3,874	7,747	11,621	15,494	19,368
RE ratio 50%	Fuel cost reduction (CVE)	-43,389,377	-56,686,464	-65,767,597	-72,281,793	-77,176,089	-80,775,913
	Incremental merit (CVE)	-	-13,297,087	-9,081,133	-6,514,196	-4,894,296	-3,599,824
	DG share	59.38%	57.67%	56.50%	55.67%	55.04%	54.57%
	Invest return (Yrs)	-	32	47	66	87	119
RE ratio 70%	Fuel cost reduction (CVE)	-125,792,621	-154,562,423	-172,775,078	-186,016,984	-196,090,292	-203,874,309
	Incremental merit (CVE)	-	-28,769,802	-18,212,655	-13,241,905	-10,073,309	-7,784,017
	DG share	48.78%	45.08%	42.73%	41.03%	39.73%	38.73%
	Invest return (Yrs)	-	15	23	32	42	55

Source: JICA Study Team

As shown in Table 10.4-9, the more wind capacity increase, the more RE ratio grows. At the most optimal case (RE ratio: 70%, wind reinforce: 3,400kW), it takes 15 years to return the investment and the reinforcement seems worth considering if the life of facility is assumed 20 years.

3) Case 3 ①increase the operating ratio of renewable energy + ②introduce energy storage system + ③reinforce wind capacity

Setting RE ratio 70%, we examined the impact when NAS battery and additional wind is introduced. In the simulation, we studied both 2MW/12MWh and 20MW/120MWh NAS battery to confirm the impact of the battery capacity.



Source: JICA Study Team

Figure 10.4-11 DG fuel cost reduction when reinforcing wind and introducing battery

Table 10.4-10 Cost performance of invest when reinforcing wind and introducing battery

	Wind reinforced (kW)	No Added	1,700 (2 units)	3,400 (4 units)	5,100 (6 units)	6,800 (8 units)	8,500 (10 units)
RE ratio 70%	Fuel cost reduction (CVE)	-125,792,621	-154,562,423	-172,775,078	-186,016,984	-196,090,292	-203,874,309
	Incremental merit (CVE)	-	-28,769,802	-18,212,655	-13,241,905	-10,073,309	-7,784,017
	DG share	48.78%	45.08%	42.73%	41.03%	39.73%	38.73%
	Introduction cost (EUR 1,000)	0	3,874	7,747	11,621	15,494	19,368
	Invest return (Yrs)	-	15	23	32	42	55
RE ratio 70%+ NAS 2,000kW/ 12,000kWh	Fuel cost reduction (CVE)	-135,121,121	-163,366,641	-181,296,429	-194,349,674	-204,483,749	-213,127,437
	Incremental merit (CVE)	-	-28,245,520	-17,929,788	-13,053,245	-10,134,075	-8,643,688
	DG share	47.58%	43.94%	41.64%	39.96%	38.65%	37.54%
	Introduction cost (EUR 1,000)	6,076	9,950	13,823	17,697	21,571	25,444
	Invest return (Yrs)	-	39	61	84	108	127
RE ratio 70%+ NAS 20,000kW/ 120,000kWh	Fuel cost reduction (CVE)	-150,770,796	-176,130,878	-196,342,196	-212,237,457	-223,526,227	-232,259,825
	Incremental merit (CVE)	-	-25,360,082	-20,211,317	-15,895,261	-11,288,771	-8,733,598
	DG share	45.57%	42.30%	39.70%	37.66%	36.20%	35.08%
	Introduction cost (EUR 1,000)	60,763	64,636	68,510	72,383	76,257	80,131
	Invest return (Yrs)	-	281	353	448	631	816

Source: JICA Study Team

Even though the most effective combination is NAS battery: 20MW/120MWh and wind reinforcement: 3,400kV, it takes 25 years to collect the investment, which is 7-year longer than only adding wind farm.

(4) Conclusion

At Sal, where currently about 40% of the theoretical potential of the existing wind farm is suppressed, the most effective option is to increase RE operating ratio from 50% to 70%. Introducing battery is also effective but its impact is very limited.

10.4.3 Simulation of renewable energy expansion at Boa Vista

(1) Current status

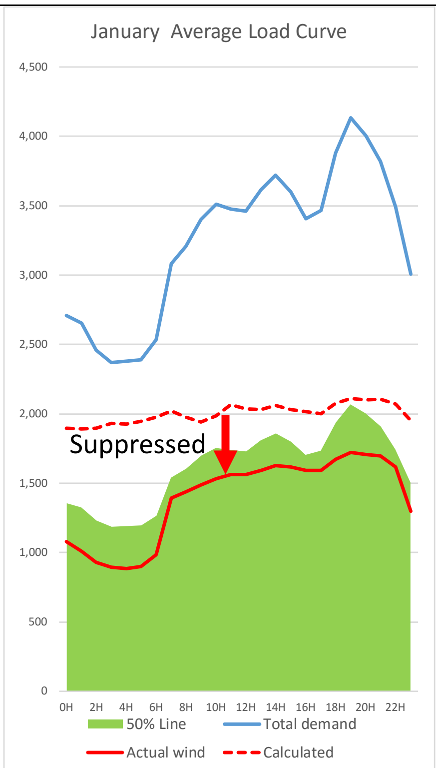
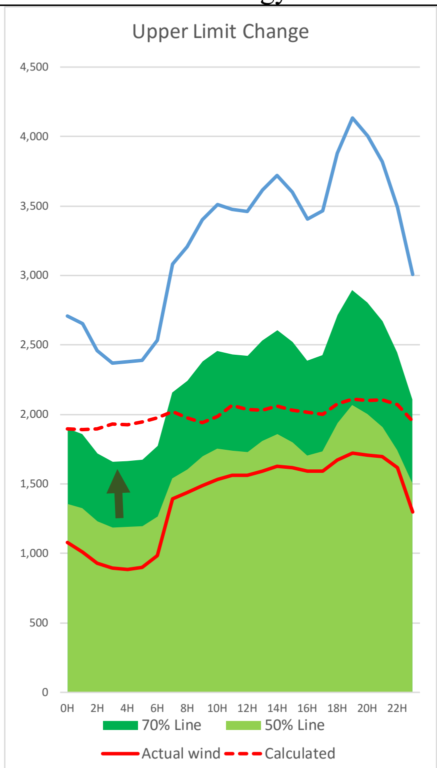
Peak demand in the island is approximately 6,100kW but existing wind farm capacity is 2,550kW, accounting for almost 40% of the peak demand. At Boa Vista, even though strong and constant wind blows, operating upper limit of wind is targeted about 50% of the demand. Calculated annual wind potential based meteorological data is 9.8GWh but actual generation of the wind farm is 7.8GWh. This means 20 % of the wind potential is suppressed in vain.

(2) Options to expand renewable energy

To increase the renewable energy rate, those countermeasures are applicable.

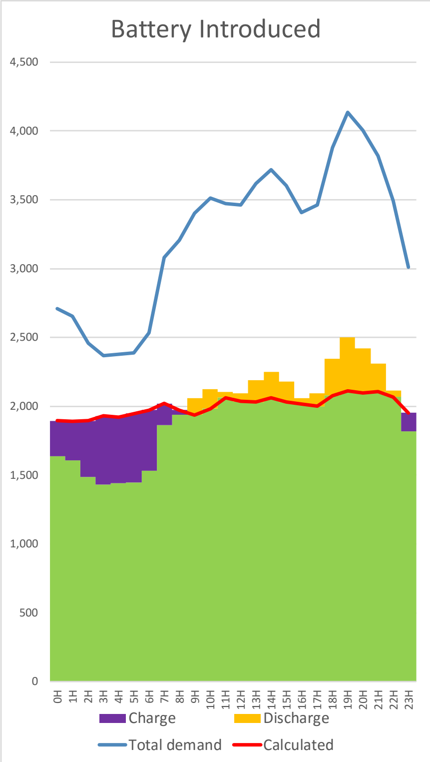
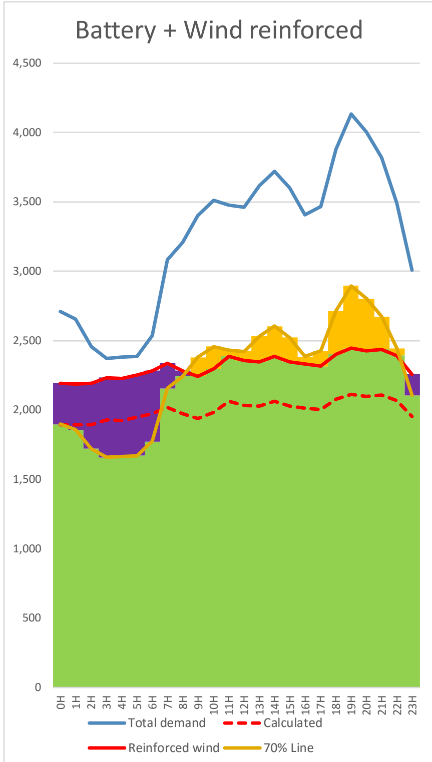
① Increase the operating ratio (upper limit) of renewable energy (→ effective utilization of the surplus energy)
② Introduce energy storage facility (→ effective utilization of the surplus energy)
③ Reinforce wind farm capacity (→ expansion of wind generation)

Table 10.4-11 Option to expand renewable energy -1 (Boa Vista)

Options	Present (Average of 2015 January)	① Increase the operating ratio of renewable energy
Images		
Description	To keep the system stability, even when the theoretical wind potential is under 50% of the demand, wind farm is sometimes suppressed.	By increasing operating ratio from 50% to 70%, wind suppress cannot be eliminated but can be reduced drastically.

Source: JICA Study Team

Table 10.4-12 Option to expand renewable energy -2 (Boa Vista)

Options	‘② Introduce energy storage facility	‘③ Reinforce wind farm capacity
Images		
Description	By introducing battery with appropriate battery, theoretical wind potential can be utilized without suppress.	Because theoretical generation potential is close to 70% of the demand, further reinforcement of wind seems difficult. If the demand is likely to grow more, further wind can be introduced in the future.

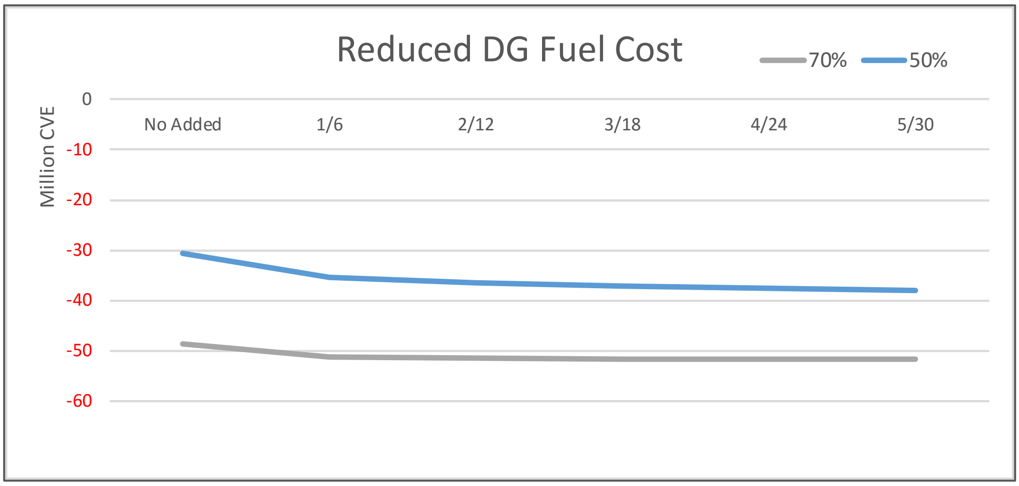
Source: JICA Study Team

(3) Evaluation of the options

In Boa Vista, as about 20% of the theoretical wind potential has been suppressed, drastic effect will be expected only if ① increasing the operating ratio of renewable energy in Table 10.4-1. Analysis result of 3 cases listed in Table 10.4-2 and Table 10.3-2 will be described below.

1) Case 1 ①increase the operating ratio of renewable energy + ②introduce energy storage system

When adding NAS battery unit (rated output: 1MW, capacity: 6MWh) incrementally, we confirmed impact to the DG fuel cost reduction in both 50% RE rate and 70% RE rate conditions.



Source: JICA Study Team

Figure 10.4-12 DG fuel cost reduction when introducing battery

Table 10.4-13 Cost performance of invest when introducing battery

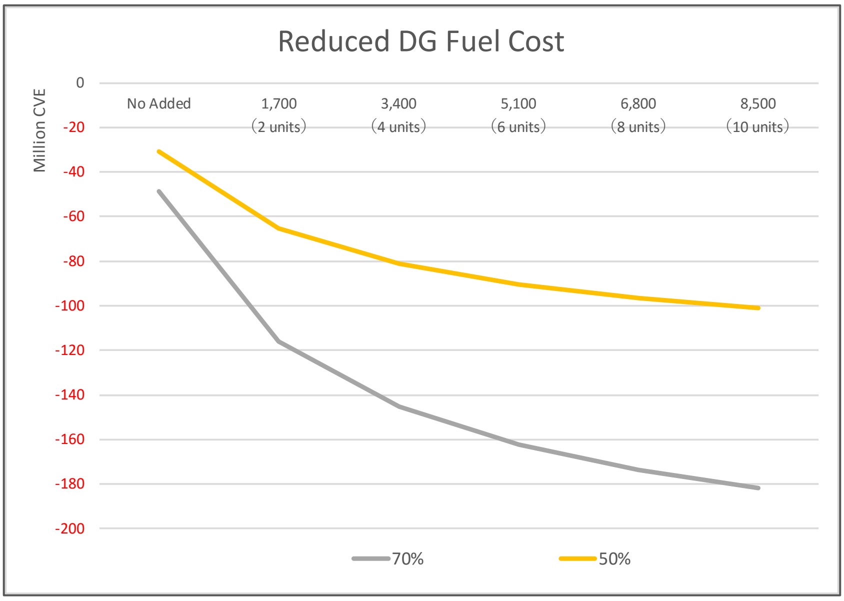
	NAS (MW/MWh)	No Added	1/6	2/12	3/18	4/24	5/30
	Introduction cost (EUR 1,000)	0	3,038	6,076	9,114	12,153	15,191
RE ratio 50%	Fuel cost reduction (CVE)	-30,699,633	-35,330,994	-36,509,495	-37,188,189	-37,666,799	-38,051,782
	Incremental merit (CVE)	-	-4,631,361	-1,178,501	-678,694	-478,610	-384,983
	DG share	69.02%	68.15%	67.93%	67.80%	67.71%	67.64%
	Invest return (Yrs)	-	72	284	494	700	870
RE ratio 70%	Fuel cost reduction (CVE)	-48,620,025	-51,307,586	-51,520,126	-51,618,619	-51,690,817	-51,716,685
	Incremental merit (CVE)	-	-2,687,562	-212,540	-98,493	-72,198	-25,868
	DG share	65.65%	65.15%	65.11%	65.09%	65.08%	65.07%
	Invest return (Yrs)	-	125	1,576	3,401	4,640	12,950

Source: JICA Study Team

As shown in Table 10.4-13, if battery is introduced, DG fuel cost can be reduced but even in the most optimal case (RE ratio: 70% NAS introduction: 2MW/12MWh), it takes 86 years to return investment and cost performance cannot be expected.

2) Case 2 ①increase the operating ratio of renewable energy + ③reinforce wind capacity

Instead of introducing battery, we confirmed impact to the DG fuel cost reduction if adding wind turbine (rated output: 850kW x 2 units) incrementally in both 50% RE rate and 70% RE rate conditions.



Source: JICA Study Team

Figure 10.4-13 DG fuel cost reduction when reinforcing wind capacity

Table 10.4-14 Cost performance of investment when reinforcing wind capacity

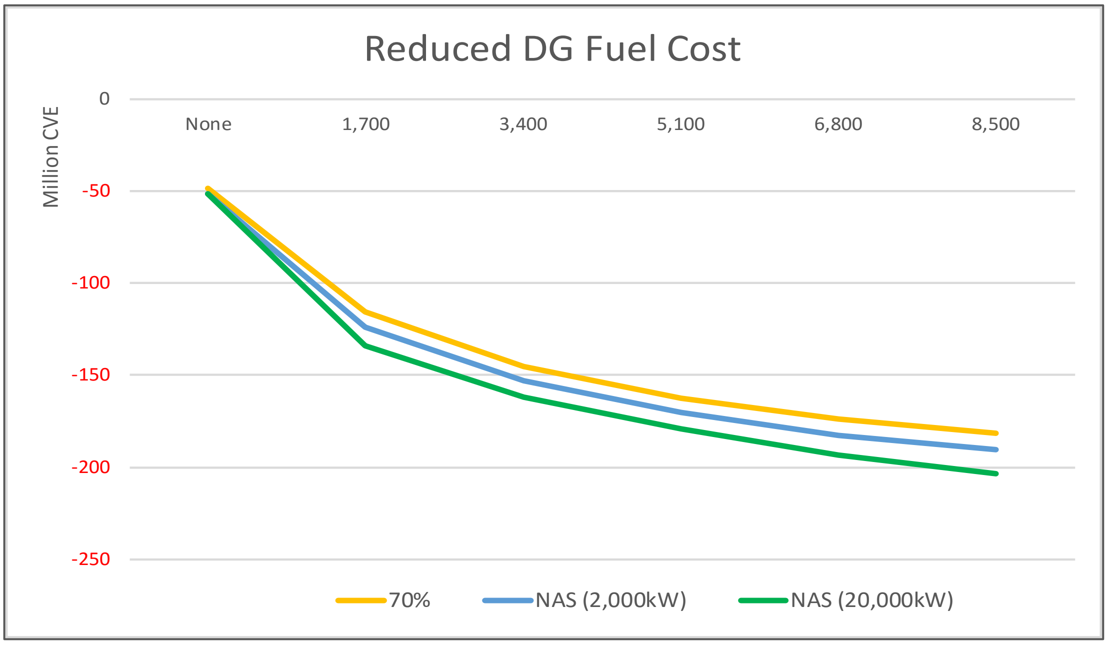
	Wind reinforced (kW)	No Added	1,700 (2 units)	3,400 (4 units)	5,100 (6 units)	6,800 (8 units)	8,500 (10 units)
	Introduction cost (EUR 1,000)	0	3,874	7,747	11,621	15,494	19,368
RE ratio 50%	Fuel cost reduction (CVE)	-30,699,633	-65,401,821	-81,095,374	-90,384,353	-96,572,061	-100,825,057
	Incremental merit (CVE)	-	-34,702,188	-15,693,553	-9,288,979	-6,187,708	-4,252,997
	DG share	69.02%	62.50%	59.56%	57.81%	56.65%	55.85%
	Invest return (Yrs)	-	12	27	46	69	100
RE ratio 70%	Fuel cost reduction (CVE)	-48,620,025	-115,850,481	-145,282,978	-162,279,522	-173,546,760	-181,722,750
	Incremental merit (CVE)	-	-67,230,457	-29,432,496	-16,996,544	-11,267,238	-8,175,990
	DG share	65.65%	53.03%	47.50%	44.31%	42.20%	40.66%
	Invest return (Yrs)	-	6	15	25	38	52

Source: JICA Study Team

As shown in Table 10.4-14, the more wind capacity increase, the more RE ratio grows. At the most optimal case (RE ratio: 70%, wind reinforce: 3,400kW), it takes 6 years to return the investment and the reinforcement seems worth considering if the life of facility is assumed 20 years.

3) Case 3 ①increase the operating ratio of renewable energy + ②introduce energy storage system + ③reinforce wind capacity

Setting RE ratio 70%, we examined the impact when NAS battery and additional wind is introduced. In the simulation, we studied both 2MW/12MWh and 20MW/120MWh NAS battery to confirm the impact of the battery capacity.



Source: JICA Study Team

Figure 10.4-14 DG fuel cost reduction when reinforcing wind and introducing battery

Table 10.4-15 Cost performance of investment when reinforcing wind and introducing battery

	Wind reinforced (kW)	No Added	1,700 (2 units)	3,400 (4 units)	5,100 (6 units)	6,800 (8 units)	8,500 (10 units)
RE ratio 70%	Fuel cost reduction (CVE)	-48,620,025	-115,850,481	-145,282,978	-162,279,522	-173,546,760	-181,722,750
	Incremental merit (CVE)	-	-67,230,457	-29,432,496	-16,996,544	-11,267,238	-8,175,990
	DG share	65.65%	53.03%	47.50%	44.31%	42.20%	40.66%
	Introduction cost (EUR 1,000)	0	3,874	7,747	11,621	15,494	19,368
	Invest return (Yrs)	-	6	15	25	38	52
RE ratio 70%+ NAS 2,000kW/ 12,000kWh	Fuel cost reduction (CVE)	-51,520,126	-123,902,816	-153,028,899	-170,411,077	-182,507,273	-190,460,907
	Incremental merit (CVE)	-	-72,382,690	-29,126,084	-17,382,177	-12,096,196	-7,953,634
	DG share	65.11%	51.52%	46.05%	42.79%	40.52%	39.02%
	Introduction cost (EUR 1,000)	6,076	9,950	13,823	17,697	21,571	25,444
	Invest return (Yrs)	-	15	38	63	91	138
RE ratio 70%+ NAS 20,000kW/ 120,000kWh	Fuel cost reduction (CVE)	-51,716,685	-134,301,873	-162,064,830	-179,365,758	-193,198,674	-203,227,844
	Incremental merit (CVE)	-	-82,585,188	-27,762,957	-17,300,928	-13,832,917	-10,029,169
	DG share	65.07%	49.57%	44.35%	41.11%	38.51%	36.62%
	Introduction cost (EUR 1,000)	60,763	64,636	68,510	72,383	76,257	80,131
	Invest return (Yrs)	-	86	257	412	515	711

Source: JICA Study Team

As shown in Table 10.4-15, If introducing 2MW/12MWh battery and reinforcing 1,700kW or 3,400kW wind, it takes 15 years to return the investment and the investment seems worth considering if the life of facility is assumed 20 years.

4) Conclusion

At Boa Vista, where currently about 20% of the theoretical potential of the existing wind farm is suppressed, the most effective option is to increase RE operating ratio from 50% to 70%. Introducing battery is also effective but its impact is very limited.

10.4.4 Simulation of renewable energy expansion at Santiago

(1) Current status

Peak demand in the island is approximately 35,300kW but existing wind farm capacity is 9,350kW, accounting for almost 25% of the peak demand. At Santiago, there are 162 hours, when wind output excess the 50% of the demand, in 8,760hours (24hour x 365days), accounting for 1.8% of the year. That means wind output has not been suppressed actually.

In other word, wind resource in Santiago is currently utilized even though there is no battery there.

(2) Options to expand renewable energy

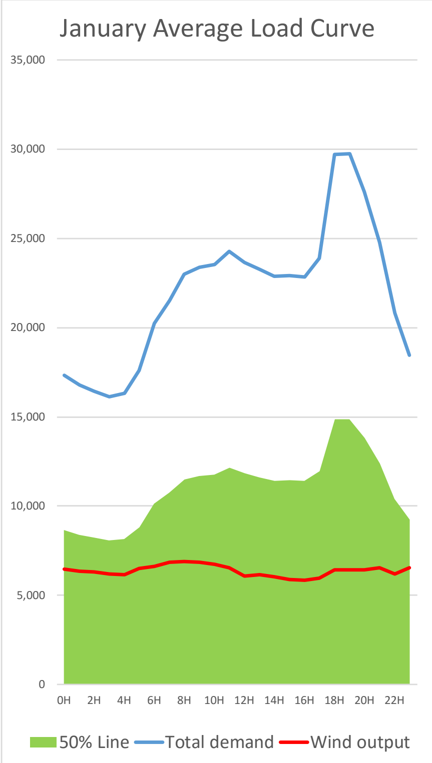
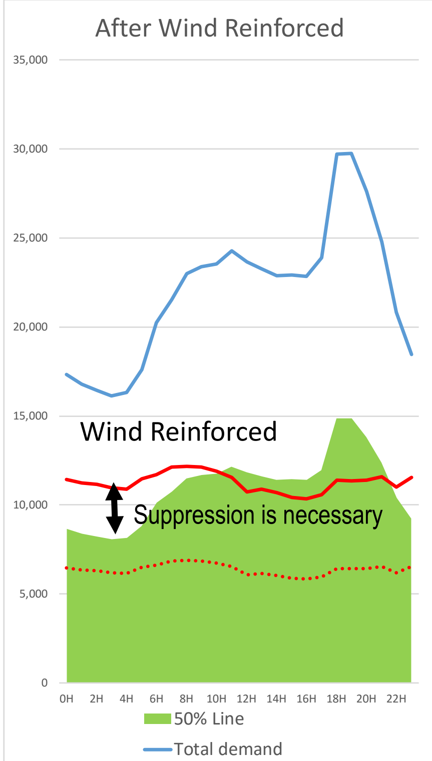
To increase the renewable energy rate, those countermeasures are applicable.

① Reinforce wind farm capacity (→ expansion of wind generation)

② Increase the operating ratio (upper limit) of renewable energy (→ effective utilization of the surplus energy)

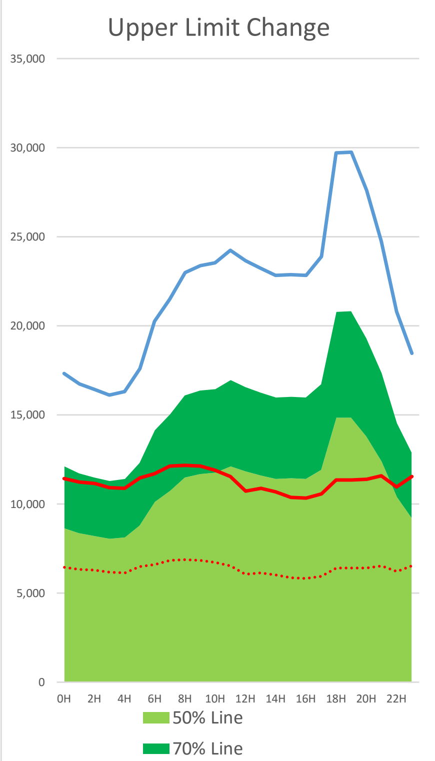
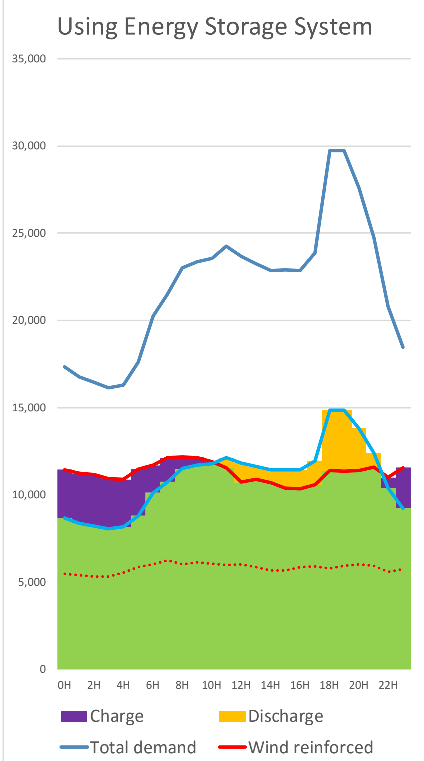
③ Introduce energy storage facility (→ effective utilization of the surplus energy)

Table 10.4-16 Option to expand renewable energy -1 (Santiago)

Options	Present (Average of 2015 January)	① Reinforce wind farm capacity
Images		
Description	Wind output is always less than 50% of the demand and wind resource is fully utilized.	By reinforcing wind farm, operating ratio grows and when the output excess the 50% of the demand, wind needs to be suppressed.

Source: JICA Study Team

Table 10.4-17 Option to expand renewable energy -2 (Santiago)

<table>
<tr><td>Options</td><td>② Increase the operating ratio of renewable energy</td><td>③ Introduce energy storage facility</td></tr>
<tr><td>Images</td><td>
</td><td>
</td></tr>
<tr><td>Description</td><td>By increasing operating ratio from 50% to 70%, wind suppress becomes unnecessary and resource will be fully utilized.</td><td>By introducing energy storage system like battery, surplus energy is charged and discharged when available.</td></tr>
</table>

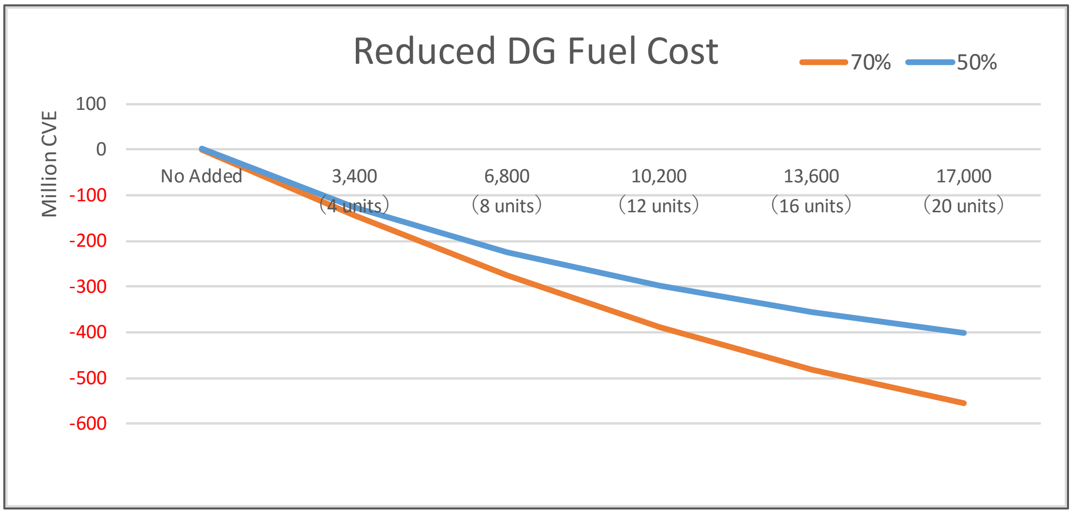
Source: JICA Study Team

(3) Evaluation of the options

In Santiago, different from other three main islands, existing wind farm has been fully utilized. Therefore, the first step is ①to reinforce the wind farm capacity. Analysis result of 3 cases listed in Table 10.4-16 and Table 10.4-17 will be described below.

1) Case 1 ①reinforce wind capacity + ②increase the operating ratio of renewable energy

When adding wind turbine (rated output: 850kW x 2 units) incrementally, we confirmed impact to the DG fuel cost reduction in both 50% RE rate and 70% RE rate conditions.



Source: JICA Study Team

Figure 10.4-15 DG fuel cost reduction when reinforcing wind capacity

Table 10.4-18 Cost performance of investment when reinforcing wind capacity

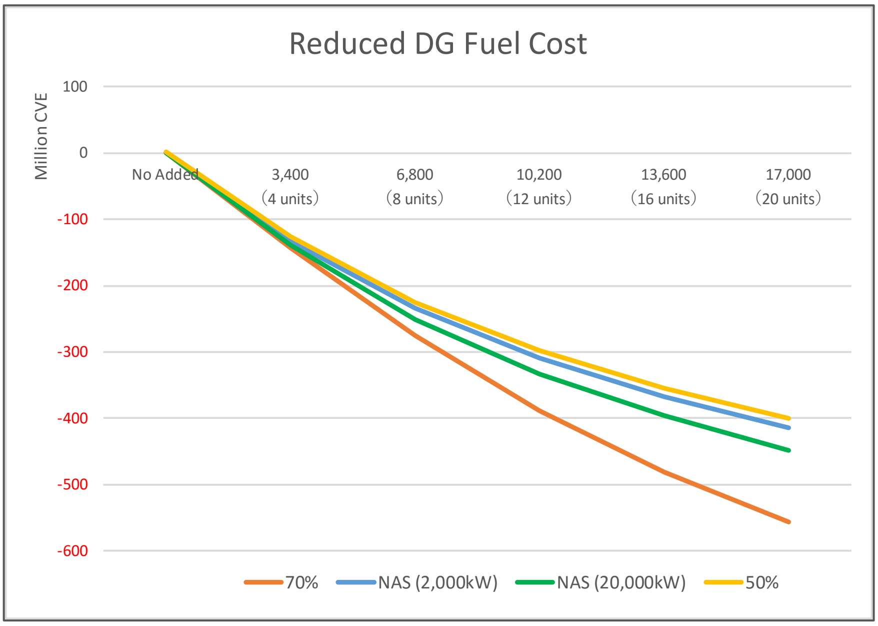
	Wind reinforced (kW)	No Added	3,400 (4 units)	6,800 (8 units)	10,200 (12 units)	13,600 (16 units)	17,000 (20 units)
	Introduction cost (EUR 1,000)	0	7,747	15,494	23,242	30,989	38,736
RE ratio 50%	Fuel cost reduction (CVE)	1,222,517	-126,371,445	-224,838,782	-298,130,308	-354,592,101	-400,159,634
	DG share	84.81%	79.90%	76.11%	73.29%	71.12%	69.36%
	Invest return (Yrs)	-	6.8	7.6	8.6	9.6	10.7
RE ratio 70%	Fuel cost reduction (CVE)	-19,085	-142,783,164	-275,552,554	-389,167,155	-481,472,495	-556,115,430
	DG share	84.76%	79.27%	74.16%	69.79%	66.23%	63.36%
	Invest return (Yrs)	-	6.0	6.2	6.6	7.1	7.7

Source: JICA Study Team

As shown in Table 10.4-18, the more wind capacity increase, the more RE ratio grows. At the most optimal case (RE ratio: 70%, wind reinforce: 3,400kW), it takes 6 years to return the investment and the reinforcement seems worth considering if the life of facility is assumed 20 years.

2) Case 2 ①reinforce wind capacity + ③introduce energy storage system

Instead of increasing operating ratio of wind, we confirmed impact to the DG fuel cost reduction if adding wind turbine (rated output: 850kW x 2 units) incrementally. In the simulation, we studied both 2MW/12MWh and 20MW/120MWh NAS battery to confirm the impact of the battery capacity.



Source: JICA Study Team

Figure 10.4-16 DG fuel cost reduction when reinforcing wind capacity and introducing battery

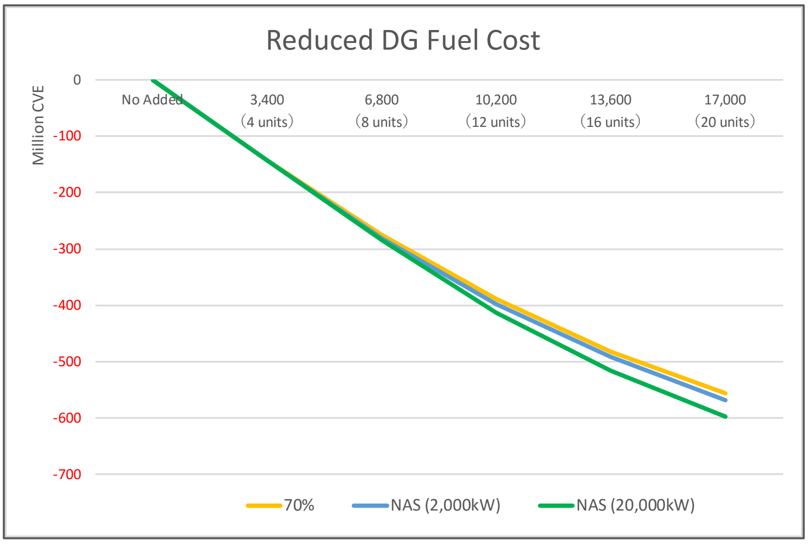
Table 10.4-19 Cost performance of investment when reinforcing wind capacity and introducing battery

Source: JICA Study Team

As shown in Figure 10.4-16, at the most optimal case (NAS battery: 2MW/12MWh, wind reinforce: 6,800kW, NE ratio 50%), the impact to the DG cost reduction is less than only changing NE operating ratio from 50% to 70%.

3) Case 3 ①reinforce wind capacity + ②increase the operating ratio of renewable energy + ③introduce energy storage system

Setting RE ratio 70%, we examined the impact when NAS battery and additional wind is introduced. In the simulation, we studied both 2MW/12MWh and 20MW/120MWh NAS battery to confirm the impact of the battery capacity.



Source: JICA Study Team

Figure 10.4-17 DG fuel cost reduction when reinforcing wind, introducing battery and increasing operating ratio of renewable energy

Table 10.4-20 Cost performance of investment when reinforcing wind, introducing battery and increasing operating ratio of renewable energy

	Wind reinforced (kW)	No Added	3,400 (4 units)	6,800 (8 units)	10,200 (12 units)	13,600 (16 units)	17,000 (20 units)
RE ratio 70%	Fuel cost reduction (CVE)	-19,085	-142,783,164	-275,552,554	-389,167,155	-481,472,495	-556,115,430
	DG share	84.76%	79.27%	74.16%	69.79%	66.23%	63.36%
	Introduction cost (EUR 1,000)	0	7,747	15,494	23,242	30,989	38,736
	Invest return (Yrs)	-	6.0	6.2	6.6	7.1	7.7
RE ratio 70%+ NAS 2,000kW/	Fuel cost reduction (CVE)	-64,509	-143,655,685	-280,586,733	-398,101,876	-492,187,741	-567,984,422
	DG share	84.76%	79.24%	73.97%	69.44%	65.82%	62.91%
	Introduction cost (EUR 1,000)	6,076	13,823	21,571	29,318	37,065	44,812
	Invest return (Yrs)	-	10.6	8.5	**8.1**	8.3	8.7
RE ratio 70%+ NAS 20,000kW/	Fuel cost reduction (CVE)	-112,940	-143,745,109	-284,378,872	-412,989,895	-515,748,543	-597,391,610
	DG share	84.76%	79.23%	73.82%	68.87%	64.92%	61.77%
	Introduction cost (EUR 1,000)	60,763	68,510	76,257	84,004	91,751	99,499
	Invest return (Yrs)	-	52.6	29.6	22.4	19.6	18.4

Source: JICA Study Team

As shown in Table 10.4-20, if large scale capacity battery is introduced, its impact is very limited. In the most optimal case (NAS introduction: 2MW/12MWh, wind reinforcement: 10,200kW, RE ratio: 70%,), difference of the impact to DG cost reduction between with battery and without battery is very little.

(4) Conclusion

At Santiago, where currently wind output is not suppressed, the most effective option is to increase RE operating ratio from 50% to 70%. Introducing battery is difficult because of its financial aspects.

10.4.5 Examination of power storage facilities

(1) Candidates for power storage

Since wind power facilities of Cabo Verde can produce a constant amount of energy throughout a day, the excess power can be stored during light-load hours at night and morning and discharged during peak hours after evening to supplement output from diesel and wind power generation.

On the other hand, output from wind power generation is generally stable regardless of the hour, and the difference in power demand is small between peak hours and non-peak hours in Cabo Verde. The aforementioned simulation for renewables expansion revealed that the peak-shift effect of the power storage facility might be limited. Thus, care must be taken to be cost effective when selecting output and capacity (time) of the power storage facility, so that they are not excessive.

The Lithium-ion battery is generally recommended for power storage, if a measure with a quick response is needed against short-cycle fluctuations, while the NAS battery is proposed as the long-cycle fluctuation measure based on cost and ease of installation. Pumped-storage hydropower could be one of the candidates for large-scale power storage since it has a good track record and knowledge accumulated over the years. However, the issue is the large-scale construction, coupled with long work period time and high cost.

This section describes the introduction of the NAS battery of 4.8MW (28.8MWh) and 1.6MW (9.6MWh), calculated as the optimal scale for Santiago and São Vicente based on the simulation result above, and the operation cost. It then compares it with 5MW (30MWh) pumped-storage hydropower as an alternative power storage system for Santiago.

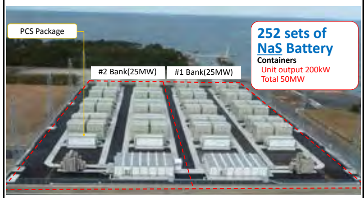
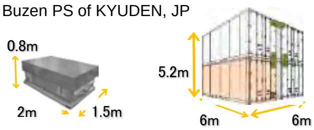
(2) Characteristics of battery and pumped-storage hydropower

[Battery]

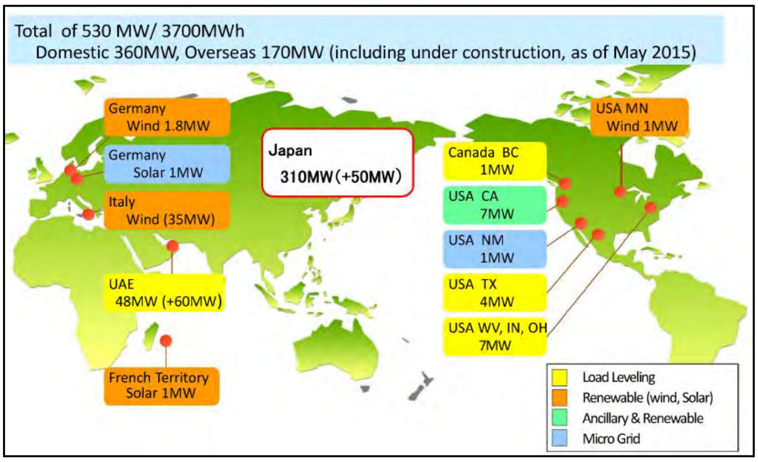
For the comparison with pumped-storage hydropower, the NAS battery was selected after comprehensive assessment, since it can have a large capacity to respond to long-cycle fluctuations for over 4 hours, and boasts long life, record of worldwide utilizations and reliability. The NAS battery is compact-sized and easy to transport and has the best price per capacity since containerized transportation is possible (see the table below for the comparison of battery characteristics).

Ever since the NAS battery became commercially available in 2002, those equivalent to 530MW (3700MWh) have been introduced all over the world (as of May 2015). The applications include frequency fluctuation control for renewables (ancillary service), output correction, load leveling, and micro-grid stabilization among others. With abundant resources available for NAS battery materials, cost reduction through mass production and market expansion are expected (see the following table for the cases of NAS battery introduction).

Table 10.4-21 Comparison of battery characteristics

Type	Lithium-ion battery	Redox flow battery	NAS battery
Example of use	 Minamisoma SS, Tohoku Electric, JP   Module: 40-45Ah (W187×D383×H127mm) Cell: 20-23Ah (W116×D22×H106mm) *size, etc. are examples, photo from Toshiba Website	 Yokohama Works, Sumitomo Electric, JP Redox flow battery (1MW, 5MWh) Battery panel 1× **electrolyte tanks** (cathode, anode) x 8 sets *size, etc. are examples. Photo from Sumitomo Elect website	 Buzen PS of KYUDEN, JP  1unit (1MW, 4.9MWh) module: cell×24 *size, etc. are examples. Photo from KYUDEN website
Characteristics	Charge/discharge with oxidation/ reduction of lithium. High output obtained with relatively small capacity due to high output density → optimal as a short-cycle fluctuation measure	Charge/discharge by changing the vanadium ions in the electrolyte. Easy to increase the system capacity (kWh) by addingt the electrolyte tank → optimal as a long-cycle fluctuation measure	Uses sodium for anode, sulfur for cathode, and β- alumina as electrolyte Low cost per capacity, capacity can be increased. Excellent responsiveness → optimal as a long- and short-cycle fluctuation measure
Scale (portability)	Medium	Large	Small
Life	Medium (10 years)	Long (10-20 years)	Long (15 years)
Cost	kW: Low kWh: High (US$2000/kWh) Capacity increase proportional to the cell base price	kW: Medium kWh: Medium (US$1200/kWh) Capacity increase proportional to electrolyte and tanks	kW: Medium kWh: Low (US$500/kWh) Capacity increase proportional to the no. of containers
Major maker	Toshiba, Hitachi, GS Yuasa, NEC, Samsung (KR), LG(KR)	Sumitomo Electric, Pacific Northwest NationalLaboratory (US)	NGK INSULATORS, LTD
Introduction	Tohoku Electric, JP (40MW/40MWh) KEPCO, JP (5MWh(4 remote islands))	Hokkaido Electric, JP (15MW/60MWh)	KEPCO, JP(50MW/300MWh) Chugoku Electric, JP (4.2MW/25.2MWh)

Source: JICA Study Team based on interviews and publications from manufactures



Source: provided by NGK INSULATORS, LTD

Figure 10.4-18 Cases of NAS battery introduction

[Pumped-storage hydropower]

The scale of pump-storage hydropower facilities is about 500MW on world average (the average capacity was obtained from about 350 PSs worldwide based on the data from DOE's Global Energy Storage Database). The pumped-storage hydropower development tends to have a larger scale and requires environmental monitoring and protection measures. Thus, this type of undertaking faces issues such as a long development lead time for survey and design, and high cost. For example, if a one million kW-class dam pumped-storage hydro PS is to be built, the development stage could last over 10 years and the construction could cost more than 2 billion US dollars. On the other hand, the price per kWh could be reduced since economies of scale could be expected.

Island areas, however, generally have smaller systems, which will require pumped-storage hydropower facilities of smaller scales. In such cases, the cost tends to be rather high since economies of scale do not apply. Seawater pumped-storage hydropower might sometimes be considered to secure necessary water. However, the use of seawater raises many issues different from those associated with general-use facilities intended for fresh water. With only one facility in the world (Okinawa Yanbaru Seawater Pumped-Storage Power Station in Japan) that was put to practical application, there are many factors that could raise cost, including the need to custom-order equipment and facilities. Given these facts, JICA Study Team finds it hard to suggest seawater pumped-storage hydropower as the first choice for power storage.

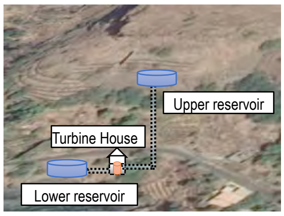
The Study Team thinks it reasonable to choose the storage method that uses freshwater reservoir tank rather than the dam even if the introduction of pumped-storage hydropower is to be considered.

For the economical operation of a pumped-storage hydro PS, enough excess power is needed for pumping, along with a load pattern that allows for efficient and frequent power generation (discharge).

It must be noted that the pumped-storage hydro PS cannot be operated efficiently if the gap between peak demand hours and non-peak hours is small and renewable output is even.

In the government's vision for renewables expansion "Cabo Verde 100% Renewable: A Roadmap to 2020" announced in 2013, an idea was listed to use renewable-based electricity that is stored in a large-scale power storage system during seasons of unfavorable wind condition. The specific measures included pumped-storage hydropower and methanation. However, the Study indicates that seasonal power interchange through power storage will incur enormous cost, which will be hard to recover due to excessive facility and low usage. JICA Study Team believes that the idea needs to be set aside as an issue for future consideration.

Table 10.4-22 Comparison of pumped-storage hydropower facilities

	Reference case		For Cabo Verde
Storage	① Dam (river)	② Dam (seawater)	Reservoir (desalinated water circulation)
Image	 Photo: KEPCO's Omarugawa PS（1,200MW）	 Photo: J-POWER Okinawa Yanbaru PS（30MW）	 Photo: Google, Facility image: JICA Study Team
Calculation scale	Output: over 1GW (5-8hrs.)	Output: over 30MW (6hrs.)	Output: 5MW (8hrs.)
Construction period	40-70 years	17 years	2-3 years
Construction cost	Total construction cost: Approx. 1,5 billion Euro or more (Approx. 200 Euro/kWh Approx.1,500 Euro /kW or more)	Total construction cost: Approx. 274 million Euro (Approx.1,500 Euro /kWh Approx. 9,100 Euro /kW)	Total construction cost: Approx. 55 million Euro (Approx.1,375 Euro /kWh Approx.11,000 Euro /kW)
Service life	40-70 years	Record: 18 years* *Okinawa Yanbu Seawater Pumped Storage PS, JP(started operation in 1999 and decommissioned in 2016)	30-50 years
Remark	Large-scale development requiring environmental monitoring and protection measures. Long construction period and high cost	Large-scale development requiring environmental monitoring and protection measures. Cost is rather high due to the need for consideration for marine life and salinity measures, including maintenance cost	Small-scale development with smaller environmental impact. No precedent in the world, and cost is relatively high due to smaller scale

(Note) exchange rate used: EUR/JPY：131.66 (as of the end of 2015)

Source: reference case ① and reservoir-type (freshwater circulation) prepared by the Study Team, reference case ②: data published in J-POWER website

(3) Comparison of battery and pumped-storage hydropower

The construction and operation cost was tentatively calculated based on the specs below, for the NAS battery with 4.8MW (28.8MWh) and 1.6MW (9.6MWh) which were determined to be optimal for Santiago and São Vicente, and the 5MW (30MWh) reservoir-type (freshwater circulation) pumped-storage hydropower plant as an alternative power storage facility for Santiago.

Table 10.4-23 Common specs for cost comparison of battery and pumped storage hydropower

Item	Value
Electricity tariff of Cabo Verde (recognize as revenue from facility installation. Final unit price of 2015)	0.23 Euro/kWh
Diesel fuel cost (unit price) (recognize reduction in fuel use as revenue, average of 2015 record)	0.11 Euro/kWh
Wind power purchase (unit price) (calculate based on Electra's actual purchase price of 2014)	0.13 Euro/kWh
Capacity factor (assume discharge of 6hr/day, 4 months off including summertime)	17%
Interest (i.e. lowest interest soft loan)	0.1%
Depreciation period	20 years

Source: JICA Study Team

The specs for calculation above are only for the purpose of comparing the economic performance between the battery and pumped storage hydropower, and capacity factor and interest assume the most favorable conditions. The wind is steady throughout a day in Cabo Verde. However, the changes in the demand curve do not always match the optimal charge/discharge pattern of the power storage facility, and the wind condition worsens in a few months over summer. Thus, it must be noted that capacity factor differs greatly from the specs used in the cost comparison. The result of the cost comparison based on the specs in Table 10.4-23 are shown in Table 10.4-24.

Table 10.4-24 Cost comparison of battery and pumped storage hydropower

Pumped-storage hydropower (5MW)	
Type	Variable-speed, with fresh water
Output	5 MW
Capacity	40 MWh
	8 h
Years of service (4 months off/yr.)	30 Year
Charge/discharge loss	70 %
Construction cost	
Facility cost	**5,624,000,000 JPY**
・Electrical facility, reservoir tank, etc. ・Excluding power receiving/transforming facility ・Excluding transportation cost and customs duty	
Construction cost (civil engineering, structure)	**1,489,000,000 JPY**
Total	**7,113,000,000 JPY**
131.7	**54,025,520 EUR**
(EX. rate on the end of 2015 : EURO/JPY)	
Electricity sales as revenue for operation	**0.23EUR/kWh**
Electricity supply cost (20-year average)	**0.42EUR/kWh**
Wind power purchase cost (of electricity supply)	**0.13EUR/kWh**

Battery① (4.8MW)	
Type	Na-S(Sodium-sulfur)
Output	4.8 MW
Capacity	28.8 MWh
	6 h
Years of service (4 months off/yr.)	20 Year
Charge/discharge loss (incl. auxiliary power)	70 %
Construction cost	
Facility cost	**2,341,071,083 JPY**
・NAS Battery : 50,000JPY／kWh ・Excluding power receiving/transforming facility ・Excluding transportation cost and customs duty	
Construction cost	**532,036,806 JPY**
・Incl. system coordination cost	
Total	**2,873,107,889 JPY**
131.7	**21,822,177 EUR**
(EX. rate on the end of 2015 : EURO/JPY)	
Electricity sales as revenue for operation	**0.23EUR/kWh**
Electricity supply cost (20-year average)	**0.28EUR/kWh**
Wind power purchase cost (of electricity supply)	**0.13EUR/kWh**

Battery② (1.6MW)	
Type	Na-S(Sodium-sulfur)
Output	1.6 MW
Capacity	9.6 MWh
	6 h
Years of service (4 months off/yr.)	20 Year
Charge/discharge loss (incl. auxiliary power)	70 %
Construction cost	
Facility cost	**1,049,790,377 JPY**
・NAS Battery : 50,000JPY／kWh ・Excluding power receiving/transforming facility ・Excluding transportation cost and customs duty	
Construction cost	**284,867,350 JPY**
・Incl. system coordination cost	
Total	**1,334,657,727 JPY**
131.7	**10,137,154 EUR**
(EX. rate on the end of 2015 : EURO/JPY)	
Electricity sales as revenue for operation	**0.23EUR/kWh**
Electricity supply cost (20-year average)	**0.37EUR/kWh**
Wind power purchase cost (of electricity supply)	**0.13EUR/kWh**

Source: JICA Study Team

The cost comparison of the 5MW-class pumped-storage hydropower (with reservoir and freshwater circulation) and battery (NAS battery) revealed that pumped-storage hydropower's cost for construction and power supply is almost twice as big as that of the battery. For freshwater circulation, the desalination cost for the freshwater stored in the reservoir must be considered. However, it was not included in the calculation and will further increase the operation cost of pumped-storage hydropower. Although JICA Study Team did not calculate cost for seawater pumped-storage hydropower, it has more disadvantages than that using freshwater in terms of construction period, environmental protection, salinity measures, etc.

Thus, for JICA Study Team, it is hard to choose pumped-storage hydropower as an option for renewables expansion considering Cabo Verde's demand scale. The battery (NAS battery) is more desirable.

The options for the battery include the lithium-ion battery, which has been used widely to address short-cycle fluctuations as explained earlier (Table 10.4-21 Comparison of battery characteristics). However, JICA Study Teams decided not to examine this battery in the Study since a separate calculation revealed that the construction cost for the lithium-ion battery with the same capacity (4.8MW/28.8MWh) is higher by more than 50%.

The 1.6MW-class NAS battery without advantages of scale have somewhat higher facility cost (unit price) than the 5MW-class battery, but not to the level of the 5MW pumped-storage hydropower.

(4) Sensitivity analysis for battery's economic performance

The calculation above (Table 10.4-24 Cost comparison of battery and pumped-storage hydropower) is based on the high capacity factor and current wind power purchase price, assuming that almost 100% of the facility's power storage capacity is charged/discharged (6-8 hrs.) once every day. The economic performance such as electricity supply unit price and capital cost recovery will change with the three parameters of ①capacity factor, ② wind power purchase price and ③ diesel fuel cost (unit price).

In this section, the sensitivity analysis was conducted for the battery's economic performance using the 4.8MW/28.8MWh-NAS battery and changing the three parameters. The specs other than the three parameters below were the same as those used earlier (Table 10.4-23 Common specs for cost comparison of battery and pumped-storage hydropower).

Table 10.4-25 Specs for sensitivity analysis for battery's economic performance

Item	Value	Description
① Capacity factor	17%	Discharge 6hrs/day, 4 months off including summer
	8%	Assume about half the capacity factor above
② Wind power purchase price	13 Euro Ct./ kWh	Calculated based on Electra's 2014 wind power purchase record
	3 Euro Ct./ kWh	If Electra can buy power from Cabeolica beyond Take-or-Pay amount at lower price
	7 Euro Ct./ kWh	Intermediate value of the two prices above
③ Diesel fuel cost (unit price)	11 Euro Ct./ kWh	Historically-low unit price in Santiago and São Vicente (2015 record)
	33 Euro Ct./ kWh	Assume price increase from future crude price rebound (level from 3-4 years ago)
	22 Euro Ct./ kWh	Intermediate value of the two prices above

Source: JICA Study Team

1) Scenario where the battery capacity factor is 17%

The economic performance was analyzed based on whether the electricity supply cost (average cost over the 20-year operation period (Euro Ct./kWh)) using the battery is less than Cabo Verde's electricity tariff (unit price) (23 Euro Ct./kWh). The result is compiled in Table 10.4-26 and Fig. 10.4-19 as "Result of sensitivity analysis for the battery's economic performance."

According to the analysis result, the cost will be below the electricity tariff (unit price) (23 Euro Ct./kWh) even with the current wind power purchase price (13Euro Ct./kWh), if the capacity factor is 17%, full-charge/6 hours of discharge is repeated almost every day, and the diesel fuel cost (unit price) doubles to 22 Euro Ct./kWh. It makes the scenario an economically one.

If the fuel cost (unit price) remains the current level of 11 Euro Ct./kWh, the scenario is not economically feasible even if less diesel fuel is burned, unless the wind power purchase cost is reduced, etc. In other words, even if the facility operates at full capacity with the capacity factor of

17%, the battery offers no economical advantage unless the crude oil price rises or wind power purchase (unit price) goes down.

2) Scenario where the battery capacity factor is 8%

If the battery's capacity factor remains 8%, the electricity supply cost will not be less than the electricity tariff (unit price), even if the wind power purchase (unit price) is down to 3 Euro Ct./kWh from the current 13 Euro Ct./kWh, unless the diesel fuel cost (unit price) triples to 33 Euro Ct./kWh level. Even with the diesel fuel cost (unit price) of 33 Euro Ct./kWh, the electricity supply unit price will not be below the electricity tariff (unit price), unless the wind power purchase (unit price) goes down to 0.7 or 0.3 Euro Ct./kWh.

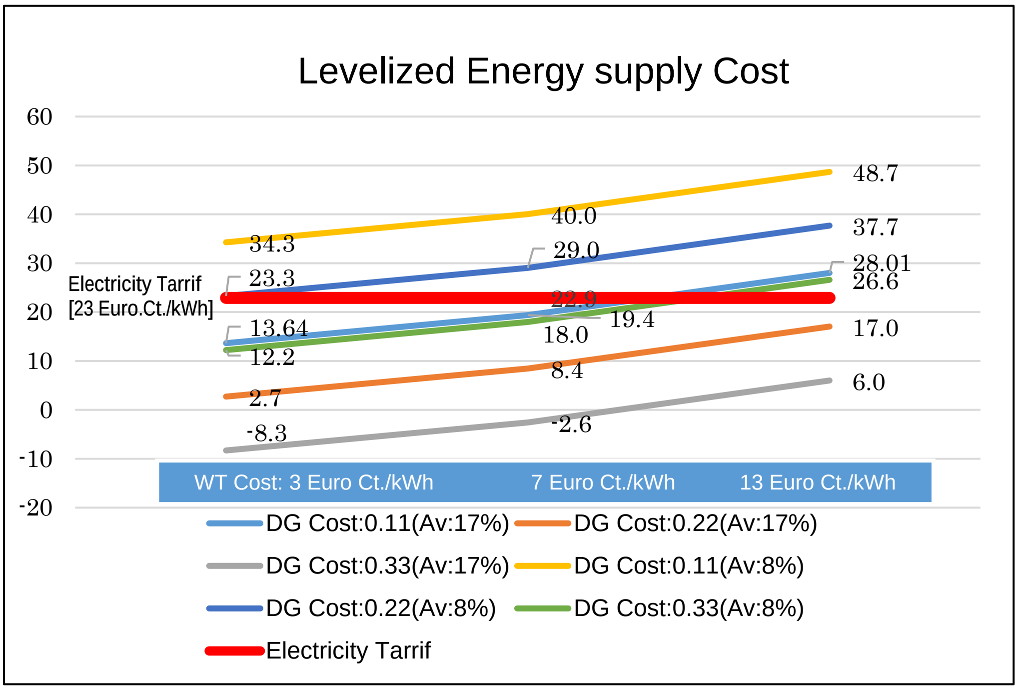
In sum, if the battery operates with capacity factor of 8% and at half-capacity (3-hour discharge at full output) on daily average or less, it will be very hard to achieve economic performance.

Table 10.4-26 Result of sensitivity analysis for battery's economic performance

Diesel fuel cost (Euro Ct./kWh)		**Wind power purchase** (Euro Ct./kWh): WT Cost:3	WT Cost:7	WT Cost:13
Capacity factor (17%)	DG Cost:11(Av:17%)	**13.64**	**19.4**	28.01
	DG Cost:22(Av:17%)	**2.7**	**8.4**	**17.0**
	DG Cost:33(Av:17%)	-8.3	-2.6	6.0
Capacity factor (8%)	DG Cost:11(Av:8%)	34.3	40.0	48.7
	DG Cost:22(Av:8%)	23.3	29.0	37.7
	DG Cost:33(Av:8%)	**12.2**	**18.0**	26.6
Tariff	**Electricity Tariff**	22.9	22.9	22.9

Note: figures in the table are electricity supply cost (Euro Ct./Kwh) using the battery under the respective conditions, and those circled by red are the combinations that offer the cost below the electricity tariff

Source: prepared by the Study Team



Source: JICA Study Team

Figure 10.4-19 Result of sensitivity analysis for battery's economic performance

10.4.6 Overall evaluation

JICA Study Team summarizes the findings from the simulation of renewables expansion, and proposes specific measures for renewables expansion most feasible for Cabo Verde, together with issues associated with their implementation.

JICA Study Team compiled the scenarios where wind power use is increased to 50% and 70% of demand in Tables 10.4-27 and 10.4-28 below. It was on the premises that the margin of reduction is increased for diesel power (6.2.1 Key points and challenges towards renewables expansion) and based on the wind power resources (Table 7.3-22) and the result of examining the optimal power storage facility (10.4.5) as confirmed in the Study.

As for photovoltaic power generation, the Study confirmed abundance of resources; however, photovoltaic power suffers technological and economical inferiority due to high facility cost (kWh) and power generation being restricted to daytime, whereas wind power boasts excellent wind condition and developmental potential. Thus, the Study conducted simulation focusing on wind power. The supplemental and situational introduction of photovoltaic power should be considered for the future from the viewpoint of ensuring energy security dispersing energy resource suppliers.

Table 10.4-27 Rate of renewables and evaluation with 50% wind power use

Santiago

	Rate of Renewable(kWh)		Capacity	Evaluation
RE expansion simulation **[50% wind power operation]**	Current status	15.2%	-	Room for wind power introduction without suppression is about 10MW, similar to the current capacity. Currently, most of wind power output is utilized; so the rate of renewables will not increase just by improving wind power operation. The rate will increase by 11% with the addition of 10MW wind power. The contribution by the battery for long-cycle fluctuation measures to the rate is limited at a few %. → additional wind power offers great benefit
	Increased wind power use	15.2%		
	Added wind power	26.6%	10MW	
	Battery introduction	27.3%	4.8MW/28.8MWh	

São Vicente

	Rate of Renewable(kWh)		Capacity	Evaluation
RE expansion simulation **[50% wind power operation]**	Current status	27.5%	-	Since wind power is controlled, the rate of renewables will increase by 10% with improved wind power operation. Adding wind power is difficult now due to siting problem. The contribution by the battery for long-cycle fluctuation measures to the rate is limited at a few %. → fundamental survey of the wind power development site is needed.
	Increased wind power use	37.7%	-	
	Added wind power	37.7%	0 [Issue of area selection]	
	Battery introduction	38.5%	1.6MW/9.6MWh	

Sal

	Rate of Renewable(kWh)		Capacity	Evaluation
RE expansion simulation **[50% wind power operation]**	Current status	35.0%	-	Since wind power is controlled, the rate of renewables will increase by 5% with improved wind power operation. It will further increase by 5% by adding more wind power. The contribution by the battery for long-cycle fluctuation measures to the rate is limited at a few %. → additional wind power offers benefit
	Increased wind power use	40.5%	-	
	Added wind power	45.0%	7MW	
	Battery introduction	46.5%	4.8MW/28.8MWh	

Boa Vista

	Rate of Renewable(kWh)		Capacity	Evaluation
RE expansion simulation **[50% wind power operation]**	Current status	25.2%	-	Since wind power is controlled, the rate of renewables will increase by 6% with improved wind power operation. It will further increase by 9% by adding more wind power. The contribution by the battery for long-cycle fluctuation measures to the rate is limited at a few %. → additional wind power offers benefit
	Increased wind power use	31.0%	-	
	Added wind power	39.9%	3MW	
	Battery introduction	40.9%	1.6MW/9.6MWh	

Source: JICA Study Team

Santiago has ample room for wind power introduction and can bring in additional 10MW or so without output control. The rate of renewables will increase by 11% with the addition of 10MW wind power, which is the capacity of the current facilities. However, without this addition, the rate of renewables will hardly increase even if the operation practice is changed. The contribution to the rate of renewables made by the battery that stabilizes long-cycle fluctuation using excess wind power output was limited with just a few percent. The level of contribution was also just a few percent even when three islands were included and when the wind power use was increased to 70% of demand.

São Vicente has many areas with an inclination over 10%, which creates problem in wind condition and facility construction. At this point, any addition of wind power seems difficult. On the other hand, the island practices output control and can switch to 50% wind power operation, which will increase the rate of renewables by 10% without incurring cost.

Sal and Boa Vista can expect the rate of renewables to go up by 10% or more by raising the wind power use to 50% and adding wind power of about 7MW and 5MW respectively. Next, the scenario with 70% wind power use is explained.

Table 10.4-28 Rates of renewables and evaluation with 70% wind power use

	Rate of Renewable(kWh)		Capacity	Eveluation
RE expansion simulation **[70% wind power operation]**	Current status	15.2%	-	Room for wind power introduction without suppression is about 10MW, similar to the current capacity. Currently, most of wind power output is utilized; so the rate of renewables will not increase just by improving wind power operation. The rate will increase by 15% with the addition of 10MW wind power. The contribution by the battery for long-cycle fluctuation measures to the rate is limited at a few %. → additional wind power offers great benefit
	Increased wind power use	15.2%	-	
	Added wind power	30.0%	10MW	
	Battery introduction	30.5%	4.8MW/28.8MWh	

São Vicente

	Rate of Renewable(kWh)		Capacity	Eveluation
RE expansion simulation **[70% wind power operation]**	Current status	27.5%	-	Since wind power is controlled, the rate of renewables will increase by 18% with improved wind power operation. Adding wind power is difficult now due to siting problem. The contribution by the battery for long-cycle fluctuation measures to the rate is limited at a few %. → fundamental survey of the wind power development site is needed
	Increased wind power use	44.5%	-	
	Added wind power	44.5%	0 [Issue of area selection]	
	Battery introduction	45.4%	1.6MW/9.6MWh	

Sal

	Rate of Renewable(kWh)		Capacity	Eveluation
RE expansion simulation **[70% wind power operation]**	Current status	35.0%	-	Since wind power is controlled, the rate of renewables will increase by 16% with improved wind power operation. It will further increase by 9% by adding more wind power. The contribution by the battery for long-cycle fluctuation measures to the rate is limited at a few %. → additional wind power offers benefit
	Increased wind power use	51.2%	-	
	Added wind power	60.4%	7MW	
	Battery introduction	62.0%	4.8MW/28.8MWh	

Boa Vista

	Rate of Renewable(kWh)		Capacity	Eveluation
RE expansion simulation **[70% wind power operation]**	Current status	25.2%	-	Since wind power is controlled, the rate of renewables will increase by 9% with improved wind power operation. It will further increase by 7% by adding more wind power. The contribution by the battery for long-cycle fluctuation measures to the rate is limited at a few %. → additional wind power offers benefit
	Increased wind power use	34.4%	-	
	Added wind power	51.5%	3MW	
	Battery introduction	52.7%	1.6MW/9.6MWh	

Source: JICA Study Team

If the wind power use is raised to 70% and the wind power facilities are added to the islands in the same scale as the 50% use scenario, the rate of renewables exceeds 50% for both Sal and Boa Vista. For Santiago, additional wind power of 10MW was assumed like the previous scenario; however, the rate of renewables only increased to about 30% from the current 15%.

The table below organizes the above simulation result based on the power generation (kWh) and rate of renewables (%). If the wind power use was 50%, the rate of renewables for the four islands is about 33.4% (weighted average based on the amount of energy for each island) even with additional wind power, falling short of 50%, which is the current goal of Cabo Verde.

Even if the rate of renewables for Sal and Boa Vista exceeds 50% after raising the wind power use to 70% as described earlier, the rate of renewables for Cabo Verde will be only 39.9%. Since Santiago accounts for 50% of the country's demand (based on power generation), the rate of renewables will not reach 50% even when the other three islands use up the diesel power operation margin (reduction margin), unless Santiago's rate of renewables drastically increases, in other words, unless a major addition in wind power is made.

Table 10.4-29 Rate of renewables/power generation with 50% wind power use

	Current status	Increased wind power use	Added wind power	Battery introduction
Santiago	15.2%	15.2%	26.6%	27.3%
S.Vicente	27.5%	37.7%	37.7%	38.5%
Sal	35.0%	40.5%	45.0%	46.5%
B.Vista	25.2%	31.0%	39.9%	40.9%
4 Islands Total	21.3%	24.6%	32.6%	33.4%

(unit: kWh)

	Current status	Increased wind power use	Added wind power	Battery introduction
Santiago	32,266,684	32,266,684	56,390,883	57,910,206
S.Vicente	19,456,427	26,646,259	26,646,259	27,141,017
Sal	19,171,693	22,163,527	24,642,559	25,436,068
B.Vista	7,812,744	9,604,543	12,362,382	12,674,899
4 Islands Total	78,707,548	90,681,012	120,042,083	123,162,189

Note: the top is the rate of renewables (%) in the total demand, the bottom power generation

Source: JICA Study Team

Table 10.4-30 Rate of renewables/power generation with 70% wind power use

	Current status	Increased wind power use	Added wind power	Battery introduction
Santiago	15.2%	15.2%	30.0%	30.5%
S.Vicente	27.5%	44.5%	44.5%	45.4%
Sal	35.0%	51.2%	60.4%	62.0%
B.Vista	25.2%	34.4%	51.5%	52.7%
4 Islands Total	**21.3%**	**27.8%**	**39.1%**	**39.9%**

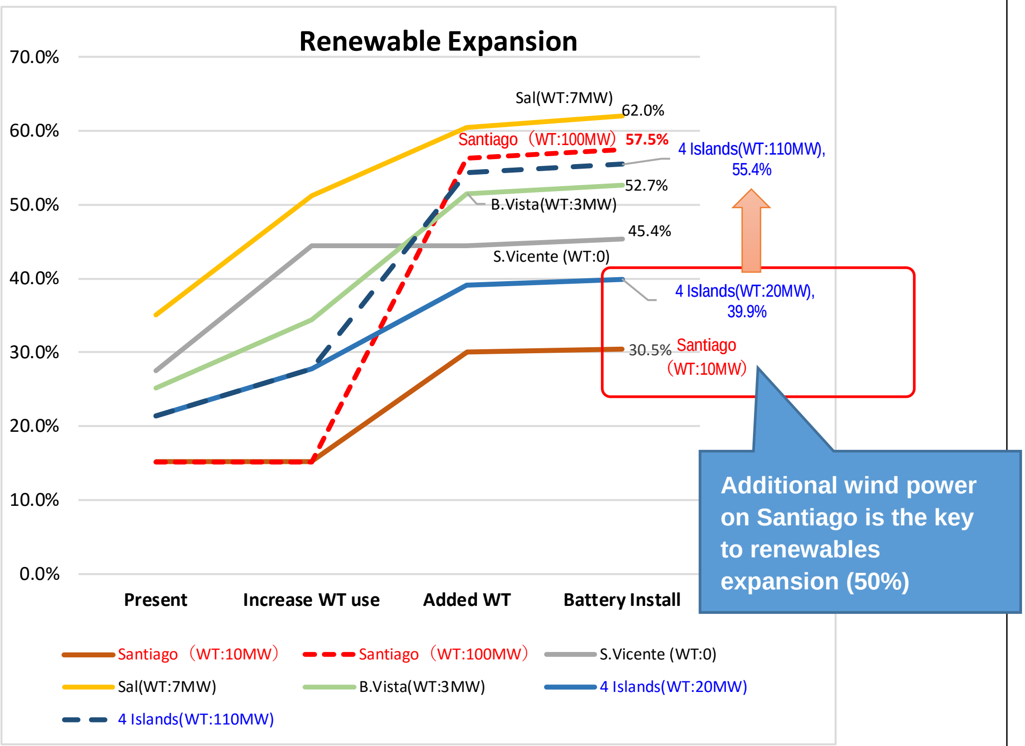
	Current status	Increased wind power use	Added wind power	Battery introduction
Santiago	32,266,684	32,342,932	63,684,244	64,745,648
S.Vicente	19,456,427	31,452,480	31,452,480	32,088,598
Sal	19,171,693	28,019,076	33,053,754	33,929,350
B.Vista	7,812,744	10,657,945	15,955,934	16,327,723
4 Islands Total	78,707,548	102,396,185	144,146,413	147,091,319

Note: the top is the rate of renewables (%) in the total demand, the bottom power generation

Source: JICA Study Team

For the sensitivity analysis toward the achievement of Cabo Verde's renewable goal of 50%, the Study Team proposes adding a 100MW wind farm (or facilities distributed over the island) on Santiago.

The Study Teams analyzes that Santiago has developable wind power resources of about 100MW, based on the official gazette, topography of the development zones, detailed weather data review, site survey and wind condition simulation. Fig. 10.4-20 below shows the contribution additional 100MW of wind power on Santiago will make to the rate of renewables. The four-island average will reach 55%.



	Present	Increased wind power use	Added wind power	Battery install
Santiago（WT:10MW）	15.2%	15.2%	30.0%	30.5%
S.Vicente (WT:0)	27.5%	44.5%	44.5%	45.4%
Sal(WT:7MW)	35.0%	51.2%	60.4%	62.0%
B.Vista(WT:3MW)	25.2%	34.4%	51.5%	52.7%
4 Islands (WT:20MW)	**21.3%**	**27.8%**	**39.1%**	**39.9%**
Santiago（WT:100MW）	**15.2%**	**27.5%**	**56.3%**	**57.5%**
4 Islands(WT:110MW)	**21.3%**	**27.8%**	**54.3%**	**55.4%**

Note: WT is added wind power capacity. For Santiago and four-island total, two cases are listed to analyze the contribution the additional 10MW and 100MW wind power make to the rate of renewables (sensitivity).

Source: JICA Study Team

Figure 10.4-20 Contribution of additional wind power on Santiago to the rate of renewables

As described above, JICA Study Team examined the renewables expansion for the main four islands that seem to offer room for the introduction of renewables in terms of operation and facility. The expansion of renewables is possible without imposing too much burden. To give full weight to economic performance, the full-fledged battery introduction must be considered while utilizing the wind condition and regulation capability of diesel power. The following angles must be included in the consideration: ① increasing wind power use from 50% to 70% in stages (examine potential issues, etc.), ② adding wind power, and ③ verifying system stability, maintenance of power quality and output correction by diesel power as the rate of renewables goes up.

Especially the cost and advantage of the battery must be examined from the medium- to long-term standpoint, by focusing on the fact that the battery for short-term stabilization is more common than that for long-term stabilization worldwide and produced more result when used in grid.

Also for pumped-storage hydropower, care must be taken not to confuse the introduction with the goal, since it involves issues such as high cost.

10.4.7 Obstacle to going 100% renewable

In Chapter 3 above, JICA Study Team reviewed the characteristics and issues of the Renewable Roadmap 2020 announced by Cabo Verde in 2013 for the Study.

This section presents the challenges for going 100% renewable using the current technology and cost as a reference, so that the measures for going 100% renewable will not be implemented in an ambiguous fashion without initiative or realistic verification.

The wind condition varies greatly by season in Cabo Verde. For example, the capacity factor of the wind power facilities on Santiago reached 68% in January 2015 when it was windiest, while it went down to 10% in July, about 1/7 of the January figure.

The additional wind power needed to meet the island's entire demand with wind power generation was calculated by simulation, assuming that the wind condition does not change by season. The calculation yielded 95,000kW (about 2.7 times the island's demand scale of 35,300kW). Then JICA Study Team calculated the battery capacity, which is charged using the excess power between November and April including that from the new additions, and is discharged in July – October when power is insufficient. The capacity obtained was 50GWh.

KEPCO's NAS battery (50MW/300MWh) is one of the world's largest batteries at present; however, the battery for Santiago obtained through the tentative calculation was 66MW/50GWh, with the power storage capacity 167 times that of KEPCO's battery. The simple comparison might not suffice, but it will require at least an area equivalent to 300 soccer fields and construction cost of several trillion yen when estimated based on KEPCO's NAS battery.

Table 10.4-31 Details of NAS battery installation

	KEPCO's NAS battery	Santiago's battery
Output	50MW	66MW (1.3 times greater)
Capacity	300MWh	50GWh (167 times greater)
Installation area	14,000km^2 (two soccer grounds)	23,000,000 km^{2*} (330 soccer grounds)
Construction cost	20 billion yen	3.3 trillion yen*

Note: "*" is tentatively calculated by comparing the capacity to that of KEPCO's NAS battery

Source: JICA Study Team

Source: KEPCO

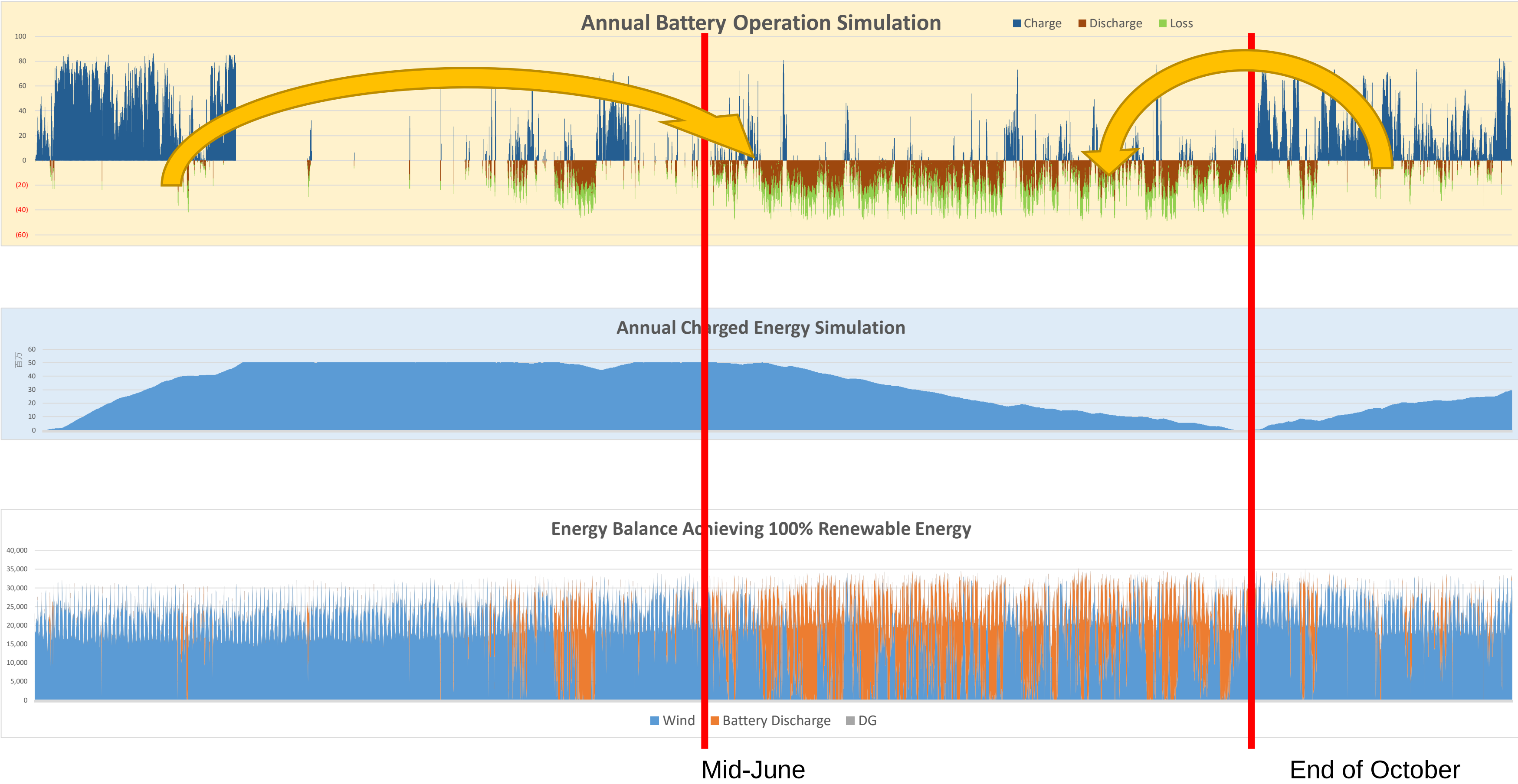
Figure 10.4-21 One of the world's largest NAS battery systems

Since the island welcomed two diesel generators in 2012 and again in 2015 with the support from the World Bank and other donors, the need to increase the rate of renewables seems small especially when considering the huge investment. The table below shows additional wind power and battery capacity needed to achieve 100% renewable on the main islands.

Table 10.4-32 Installed capacity and cost to achieve 100% renewables on the islands

Island name	Santiago	São Vicente	Sal	Boa Vista
Demand scale	35.3MW	12.1MW	10.7MW	6.1MW
Added wind power	95MW	23MW	40MW	45MW
Battery output	66MW	28MW	10MW	6.1MW
Battery capacity	50,000MWh	1,000MWh	760MWh	1,000MWh
Estimated construction cost (battery cost)	3.37 trillion yen (3.33 trillion yen)	75 billion yen (67 billion yen)	66 billion yen (51 billion yen)	84 billion yen (67 billion yen)

Source: JICA Study Team



Source: JICA Study Team

Figure 10.4-22 illustrated simulation result of going 100% renewable in Santiago

After examining items above, JICA Study Team believes that going 100% renewable (wind power) is technically achievable on islands of Santiago' scale even though it is not a realistic option when cost-effectiveness is taken into consideration.

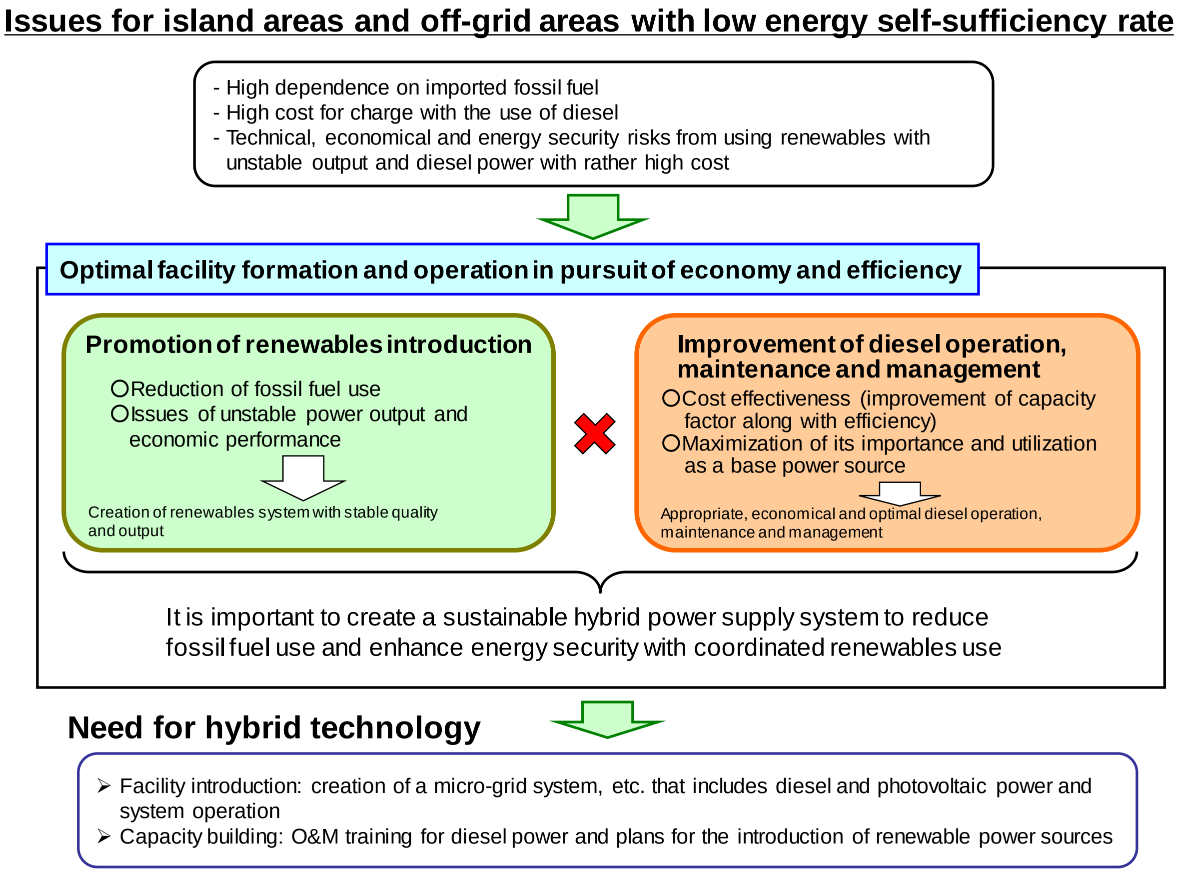
When discussing renewables expansion, too much emphasis on the goal tends to diminish the importance of level-headed examination of the options with thorough consideration of alternatives, maturity of technologies and economic performance.

In EU and developed countries, many cases have been reported, where political agenda led the introduction of FIT and subsidies for renewables promotion (taxes), etc. without due consideration. It often resulted in a sharp rise in the electricity tariff (impact from FIT-related levy, etc.) or the failure of the renewable scheme itself due to revenue shortfalls.

The Study Team has experience of receiving renewable power beyond what is perceived possible and conducting demonstrations on remote islands of Japan. For example, based on the experience, JICA Study Team cannot suggest pumped-storage hydropower as the first option for an island area, knowing its long development period, high cost and risk in ensuring sufficient use. Instead, batteries for long-cycle fluctuations are excellent in terms of cost and portability, and are becoming more suitable for general use in step with the market growth.

JICA Study Team recommends, instead of photovoltaics that will be relatively expensive, wind power as a renewable power source, since Cabo Verde has ample experience operating wind power, wind power offers both quality and quantity in conformity with the grid code, and output is relatively level and easy to utilize.

There are techniques that are not new and may even be considered old, such as output control capability of diesel power and wind power as a base power source. JICA Study Team believes that it will be important in the future to focus on the operational advantages of these techniques and take approaches that reduce cost through hybrid operation of renewables and diesel power in a way to utilize their strong points. The figure below illustrates the way to solve issues through hybrid operation.



Source: prepared by the Study Team

Figure 10.4-23 Solving issues through hybrid operation of diesel and renewables

10.5 Examination of Introducing Renewable Energy to Islands with Small Demand

On Maio and Brava, where demand is small, and Fogo and São Nicolau, where the capacity of new diesel power generation is large in relation to demand, as was explained in section 10.2, there is hardly any potential for expansion of renewable energy without renewable energy output suppression. Accordingly, in order to advance the expansion of renewable energy on these islands, it is necessary to conduct renewable energy output suppression and install power storage equipment.

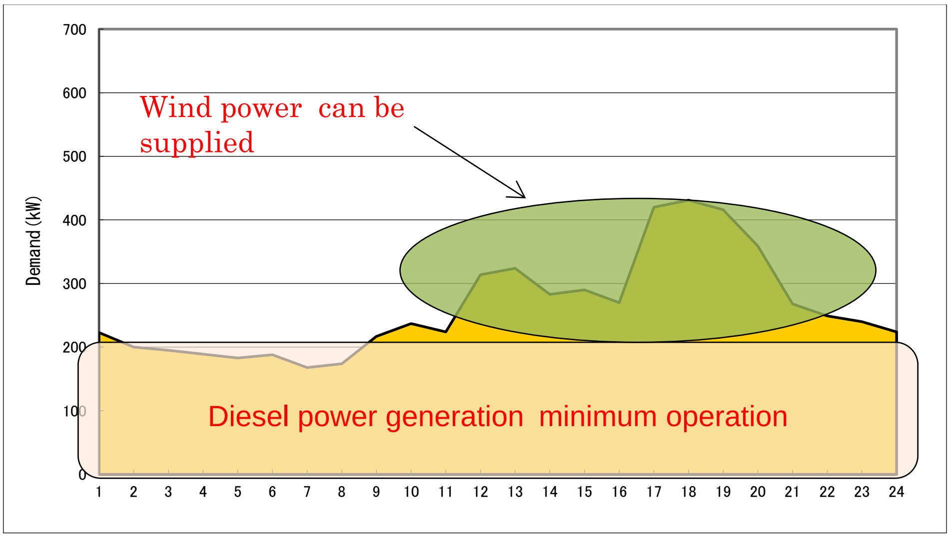
However, because introducing small-scale renewable energy equipment and power storage equipment is more expensive than diesel power generation, there is a possibility if implemented as a demonstration experiment on a model island selected for expanding the renewable energy rate as a policy, however, there is little incentive for introduction without such special measures.

Thus, under the current free competitive environment, it is difficult for renewable energy to be expanded, however, the important points to consider and an example in the case of expanding renewable energy on an island with small demand are introduced here. Brava is here examined as the model island with small demand. Previously a 150 MW windmill was introduced and operated on Brava, although it is now out of commission.

10.5.1 Expansion of Renewable Energy through Suppressing Renewable Energy Output

The demand for power on Brava is 170~600 kW and peak demand occurs between 18:00 and 22:00. There are four diesel power generators, and in the hypothetical case where a 400 kW Perkins generator is used, the minimum operation (assuming 50% of nominal capacity) would be 200 kW.

In this case, even if output suppression of wind power were implemented, the times in which power could be supplied from wind power generation would be limited (Figure 10.5-1). Accordingly, it will be necessary to consider the introduction of the storage batteries described later if it is intended to expand renewable energy.



Source: JICA Study Team

Figure 10.5-1 Load Map for Brava

10.5.2 Important Points to Consider when Expanding Renewable Energy through Introducing Storage Batteries

When introducing storage batteries and expanding renewable energy, it is recommended that the following points be considered and that careful examination be implemented in light of demonstration testing, etc.

(1) Responding to fault currents

In the case of using only synchronous generators (or predominantly using synchronous generators), since fault current is appropriately distributed according to the capacity of the synchronous generators, it is possible to continue operation provided that this is within the overcurrent resistant range of the generators. However, in the case of PCS, because the fault current concentrates on the PCS, there is an issue in that the overcurrent resistance of the semiconductor elements causes instantaneous stoppage, hence fault currents cannot be supplied.

Table 10.5-1 Countermeasures during Occurrence of Fault Currents

Item	Synchronous generator	PCS
Current supply	Supply via impedance corresponding to Xd'(20%~30% of own capacity)	Supply via impedance of connected transformer and filter (a few % of own capacity)
Overcurrent resistance	10 times or more if over a short period	The instantaneous overcurrent resistance of elements is the limit.
Voltage drop	The drop under the same current increases as the generator capacity decreases.	Steady voltage operation if in the operating range (around rated capacity ±10%), but stoppage when the operating range is deviated from.

Source: JICA Study Team

(2) Responding to frequency fluctuations (demand-supply imbalance)

In the case of using only synchronous generators (or predominantly using synchronous generators), demand-supply imbalance is expressed as frequency deviation, and output correction can be performed by means of governor-free function, etc. In the case where the PCS introduction amount is increased, from the viewpoint of securing governor-free capacity, it is necessary for the PCS to have similar control functions to those of synchronous generators.

Table 10.5-2 Characteristics during Frequency Fluctuation (Demand-Supply Imbalance)

Item	Synchronous generator	PCS
Operation during demand-supply imbalance	The demand-supply imbalance is expressed as frequency deviation.	Output is instantaneously adjusted for demand-supply balance. Accordingly, operation is stopped when the output scope is exceeded.
Frequency maintenance	The frequency fluctuation automatically triggers output correction via governor-free control, etc.	Generally, steady frequency operation is conducted. (Demerit: the entire demand-supply imbalance is incurred).

Source: JICA Study Team

(3) Responding to total stoppage of diesel power generation

If PCS has the same synchronous generator interconnection functions as diesel power generation, normal operation can be continued even if all diesel power generation is stopped. If the PCS has no overcurrent resistance, it is necessary to implement PCS overcurrent resistance measures in order to counter inrush components on the demand side and inrush in the distribution transformer, etc.

Table 10.5-3 Characteristics during Stoppage of Diesel Power Generation

	Synchronous generator	PCS
Operating constraints	If governor-free capacity can be secured within the generation output range, conditions are the same as in conventional generators.	Generally speaking, since operation is conducted at low frequency, control is possible if the demand-supply fluctuation is within the generation output range.
Overcurrent resistance	10 times or more of rated capacity if over a short period	Operation instantaneously stops if the overcurrent of elements is exceeded.

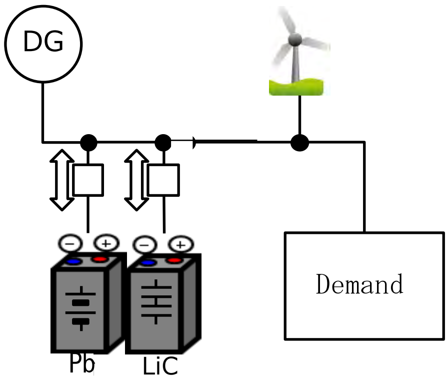
Source: JICA Study Team

10.5.3 Examples of Introducing Systems with Expanded Renewable Energy in Consideration of PCS Characteristics

According to the PCS features described above (10.5.2), there is a possibility that the PCS could stop operating and power interruptions could arise due to system faults or demand-supply fluctuations, etc. in the case where storage batteries and solar power generation, etc. are increased. To prevent such situations from occurring, system examples geared to expanding renewable energy while at the same time securing system stability are proposed below.

Case A Construction of a micro grid system

The instability caused when introducing renewable energy is resolved through implementing short-period and long-period fluctuation compensation by means of storage batteries, conducting voltage compensation by means of diesel generator reduction and increase control and reactive power control, and so on.



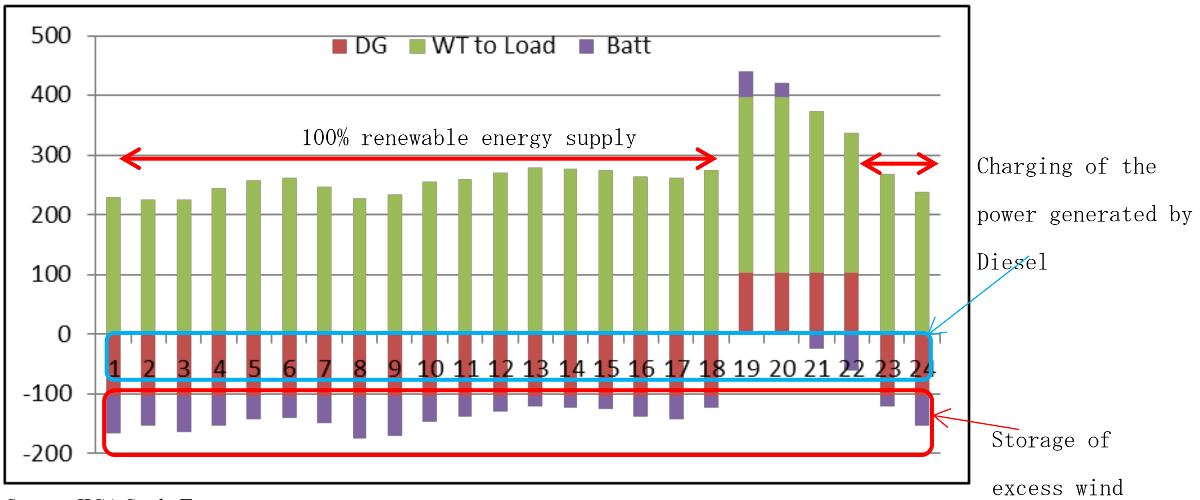
- Wind power 300 kW x 1 unit
- Connect storage batteries of approx. 1.8MWh (for long-period use) to the existing system, and operate diesel generators as voltage source.

Reference price
Windmill 300kW×1 unit: EURO 1.5 M
Storage battery: EURO 4.6 M
(Including PCS, power receiving equipment, control device and building)

Remarks: Because diesel generators are old in Brava, there is a possibility to install new ones and EMS system.

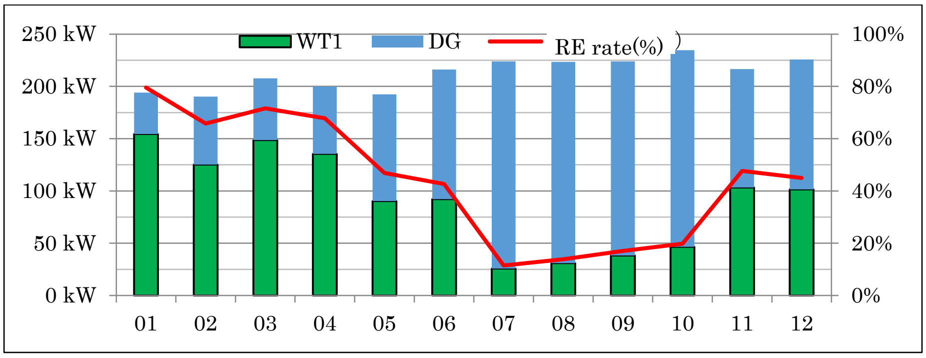
(Note) Exchange rate of EUR/JPY on End of FY2015:131.66
Source: JICA Study Team

In order to expand the renewable energy rate, conduct maximum power supply from wind power generation, while using diesel power for adjusting voltage and charging in storage batteries. At times when the wind power generation output declines or at peak demand, power will be supplied from the diesel power generation and storage batteries. Doing this will enable the renewable energy rate to be raised to 63% in January when wind conditions are good and 47.5% throughout the year.



Source: JICA Study Team

Figure 10.5-2 Average Load Curve in January



Source: JICA Study Team

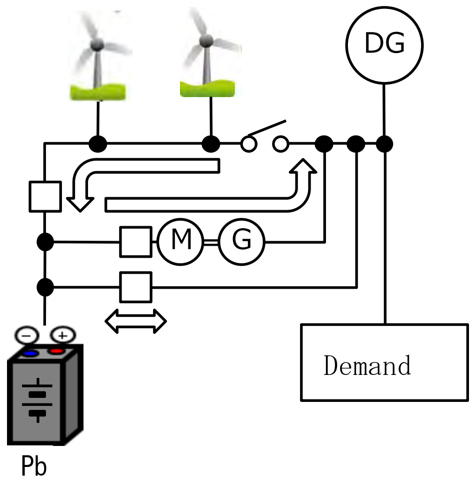
Figure 10.5-3 Monthly Generated Energy and Renewable Energy Rate

Case B Construction a new renewable energy system and aim for maximum introduction of renewable energy

The instability caused when introducing renewable energy is resolved through implementing short-period and long-period fluctuation compensation by means of a storage battery and motor generator (M-G) set, voltage compensation by means of reactive power control, and so on. Depending on the residual capacity of the storage battery, it is theoretically possible to achieve 100% renewable energy supply.

The feature of this system is that a storage battery-driven synchronous generator can be used instead of an existing internal combustion engine to supply power by means of control of the synchronous generator torque via an M-G set in which the drive-inverter is connected to a large-capacity storage battery. While adopting similar operation to conventional power supply based on one existing diesel power generator, it is theoretically possible to conduct system operation that uses no fuel at all (however, in summer, since no wind power generation output can be anticipated, diesel power generation is necessary).

However, since such a system has not so far been extensively proven, it is necessary to gradually increase the renewable energy rate while implementing demonstration testing in small-scale systems and so on.



(Note) Exchange rate of EUR/JPY on End of FY2015:131.66
Source: JICA Study Team

- ●Wind power 300kW x 2 unit
- ●New installation of renewable energy system
- ●Motor & generator set (M-G set) Approx. 500kW
- ●Introduce storage batteries of approx. 1.8 MWh, and connect to the existing system via motor generator and PCS.

Reference price
Windmill 300kW x 2: EURO 3.0 M
Storage battery: EURO 4.6 M
(Including PCS, power receiving equipment, control device and building)
MG: EURO 1.1 M
PCS and electric: EURO 0.4 M

Remarks: Because diesel generators are old in Brava, there is a possibility to install new ones and EMS system.

10.6 Proposal for Renewable Energy Expansion

10.6.1 Four Schemes based on the study

In this chapter, based on the study, four schemes to promote the expansion of renewable energy and grid stabilization in the Republic of Cabo Verde are given.

During the examination concerning expansion of renewable energy, it was confirmed that increasing use of wind power and installing more wind power facilities would be effective means of increasing the share of renewable energy (see chapter 10.4-6 “Overall evaluation”).

Since the Government of Cabo Verde raised its share of investment in the private power concern AEB on Boa Vista to more than 50% in May 2016, it is now able to examine the formation of a loan for Boa Vista via AEB in addition to Electra.

In the case of wind power, which can be expected to provide a certain degree of output under favorable wind conditions, the direct need for storage batteries to counter long-cycle fluctuations will not be so high in the immediate future, however, this may be proposed in the future as a means of addressing situations where the share of renewable energy becomes close to what the system can bear. On the other hand, regarding the necessity of introducing pump storage hydropower, in terms of utilization and economic efficiency, it is currently assumed to be unrealistic.

(1) Wind power generation development

[Targets] Santiago/Sal/Boa Vista

Cabo Verde has extremely high potential for wind power development. IPPs are assumed when considering wind power generation, however, if similar guarantees can be offered through a government-financed corporation (for example, Electra), it is possible to consider project formation in Cabo Verde based on a low-interest loan.

(2) Power transmission and distribution construction

[Targets] Santiago/Boa Vista/Brava

All 3 islands have issues, however, grid expansion and high needs need due to tourism development and expansion of renewable energy are forecast on for Boa Vista, where levels of deterioration and fragility are extreme. Utilization of short-period storage batteries can also be considered as a means of ensuring grid stabilization. As an emergency measure, a package may also be considered with long-period storage batteries (Ns-S). On Boa Vista, since the density of demand is high and hotel construction will increase from now on, there is also a need for quality.

(3) Technology cooperation in operation of diesel power generation

[Targets] Santiago/Boa Vista/Sal/São Vicente

In order to realize expansion of renewable energy, it is necessary to improve the capacity to reduce diesel output (adjustment capacity). In order to establish the optimum O&M including quality and produce efficiency, in terms of both base power sources and output coordination power sources, it is also necessary to enhance EDC operating technology. A package of dispatching experts to Cabo Verde and implementing technical training would be effective.

(4) Introduction of micro grids to remote islands

[Target] Maio/Fogo/Brava

Solar power has previously been introduced to non-electrified areas under EU assistance.

Small remote islands have little scope for connecting renewable energy to the grid, while the topography of Fogo and Brava make it difficult to develop wind power. Accordingly, the introduction of solar power could be considered (including the case of replacing diesel with storage batteries as a coordinating power source), even though it is relatively expensive. Since it is difficult to anticipate profits, it will be difficult to organize a loan.

Four schemes together with the background for each one are shown in following Table 10.6-1

Table 10.6-1 Expected scheme for Expansion of Renewable Energy and Grid Stabilization in Cabo Verde

I. Scheme

	Item	1. Wind power generation development	2. Power transmission and distribution construction	3. Cooperation in operation of diesel power generation	4. Introduction of micro grids to remote islands	Remarks
Expected scheme in light of the results of examining expansion of renewable energy	Scheme	**Loan**	**Loan**	**Technical cooperation**	**Grant**	In the examination concerning expansion of renewable energy, it was confirmed that increasing use of wind power and installing more wind power facilities are effective means of increasing the share of renewable energy. In the case of wind power, which can be expected to provide a certain degree of output under the favourable wind conditions, direct needs for storage batteries to counter long-period fluctuations will not be so high in the immediate future, however, this may be proposed in the future as a means of addressing situations where the share of renewable energy becomes tight. Since the Government of Cabo Verde raised its share of investment in the private power concern AEB on Boa Vista to more than 50% in March 2016, it has become able to examine the formation of a loan for Boa Vista via AEB in addition to Electra.
	Target area	3 main islands where wind power development is possible (Santiago/Sal/Boa Vista)	3 islands where issues were found in equipment (Santiago/Boa Vista/Brava)	4 main islands for increasing use of renewable energy (Santiago/Boa Vista/Sal/São Vicente)	3 islands with minor demand （Maio/Fogo/Brava）	
	Outline	Cabo Verde has extremely high potential for wind power development. IPPs are assumed when considering wind power generation, however, if similar guarantees can be offered through a government-financed corporation (for example, Electra), it is possible to consider project formation in Cabo Verde based on a low-interest loan.	All 3 islands have issues, however, grid expansion and high needs due to tourism development and expansion of renewable energy are forecast on Boa Vista, where levels of deterioration and fragility are extreme. Utilization of short-period storage batteries can also be considered as a means of ensuring grid stabilization. As an emergency measure, a package may also be considered with long-period storage batteries (NAS). On Boa Vista, since the density of demand is high and hotel construction will increase from now on, needs also exist regarding quality.	In order to realize expansion of renewable energy, it is necessary to expand the reduction in diesel (adjustment capacity). In order to establish the optimum O&M including quality and exhibit efficiency in terms of both base power sources and output coordination power sources, it is also necessary to enhance EDC operating technology. A package of dispatching local experts and implementing training in Cabo Verde would be effective.	Solar power has previously been introduced to non-electrified areas under EU assistance. Small remote islands have little scope for connecting renewable energy to the grid, while the topography of Fogo and Brava make it difficult to develop wind power. Accordingly, introduction of solar power is considered (including the case of replacing diesel with storage batteries as a coordinating power source), even though it is relatively expensive. Since it is difficult to anticipate profits, it will be difficult to organize a loan.	
	Period	Preparatory survey: 1 year / Construction: 3-5 years	Preparatory survey: 1 year / Construction: 2-3 years	Preparatory survey: 1 month: Implementation: 1 year	Preparatory survey: 1 year / Implementation: 1-2 years	
	Amount (rough)	60 million USD (20,000kW×3,000 USD) ※In case of 100MW: 300 million USD	10-30 million USD ※The needs and targets need to be narrowed down	1 million USD	10 million USD (a few million USD each)	

II. Background to examination

		Santiago	São Vicente	Sal	Boa Vista	Santo Antão	São Nicolau	Maio	Fogo	Brava
Current conditions	Population	294,100	81,000	33,700	14,500	40,500	12,400	7,000	35,800	5,700
	Area	991km²	227km²	216km²	620km²	779km²	343km²	269km²	476km²	64km²
	Diesel (MW)	**87.32 (87%)**	**38.00 (86%)**	**19.57 (67%)**	**14.11 (85%)**	**10.53 (95%)**	**7.67(100%)**	**2.18(100%)**	**9.3(100%)**	**1.42(100%)**
	Renewable energy total (MW)	**13.63 (13%)**	**5.95 (14%)**	**9.83 (33%)**	**2.55 (15%)**	**0.50 (5%)**	**-**	**-**	**-**	**-**
	Wind power (MW)	9.35	5.95	7.65	2.55	0.50				
	Solar (MW)	4.28		2.18						
	Peak power (MW)	35.3	12.1	10.7	6.1	3	1.2	0.5	2.4	0.6
	Minimum power (MW)	13.8	3.3	3.7	1.5	0.8	0.3	0.2	1	0.2
	Generated energy (GWh)	212.2	71.1	67.8	31	13.4	6	2.7	12.2	2.6
		(51%)	(17%)	(16%)	(7%)	(3%)	(1%)	(1%)	(3%)	(1%)
Renewable energy development potential	Assessment	・Cabo Verde overall has abundant wind power reserves, and there is future high potential for development of 102MW, 154.7MW and 45.1MW respectively on Santiago, Sal and Boa Vista, where the demand for power is expected to grow from now on. However, on São Vicente, Fogo and Brava, wind conditions are poor and construction of facilities is made difficult by existence of numerous areas with inclination of 10 degrees or more. Accordingly, development at the current time is difficult and there is need for environmental reassessment. ・There is enough solar power potential to exceed Cabo Verde's current total energy requirement, however, due to the high equipment costs (kWh) and fact that power can only be generated during daytime and so on, solar power is less advantageous than wind power or diesel power. There are numerous technical and economic issues. ※Assessments of wind power and solar power are conducted inside the development zones designated by the Government of Cabo Verde. Particularly concerning wind power, which has been poorly assessed in parts, it is necessary to consider drastic revision of development standards, etc. including review of the zones.								
	Wind power (MW)	**102**	**0.9**	**154.7**	**45.1**	**14.5**	**23**	**8.5**	**0**	**0.9**
	(Current conditions)	(9.35)	(5.95)	(7.65)	(2.55)	(0.50)				
	Solar (GWh)	**316.1**	**114.2**	**152.8**	**99.6**	**343**	**16.7**	**17.9**	**1471.5**	**4.9**
	(Current conditions)	(5.25)		(2.67)						
Condition of transmission and distribution network	Assessment	・The transmission and distribution network in Cabo Verde, Brava excluded has undergone sufficient expansion and modernization for the immediate future in the PTDSF ①② projects (JICA, AfDB, WB) and ORET project implemented in the past 10 years. Residual issues will be described below. ・Concerning Santiago, São Vicente and Sal, preparations are being made to introduce SCADA intensive monitoring to the central hub of Santiago under PTDSD ②, and introduction of EMS (Energy Management System) is also being considered for the future. (Action is pending because discussions need to be held regarding the integration of differing specifications and makers' diesel communication and control methods, and control items in wind power IPPs).								
	PTDSD①② targets	○	○	○		○		○	○	-
	ORET targets				○	○	○		○	-
	Immediate issues	Expansion of the 20kV system (securing alternative routes when failures arise in the 60kV route)			Renewal of the deteriorated northeast 10kV system (upgrading to 20kV) Renewal of the deteriorated northwest 20kV overhead transmission lines Measures to counter voltage instability in the southern long-distance underground lines					Renewal of the deteriorated 6kV system and substations (upgrading to 20kV)

Source：JICA Study Team

10.6.2 Study steps for wind power development

Regarding the study steps of wind power development, as the 1st candidate of proposed schemes described in Table 10.6-1 “Expected scheme for Expansion of Renewable Energy and Grid Stabilization in Cabo Verde” will be explaind.

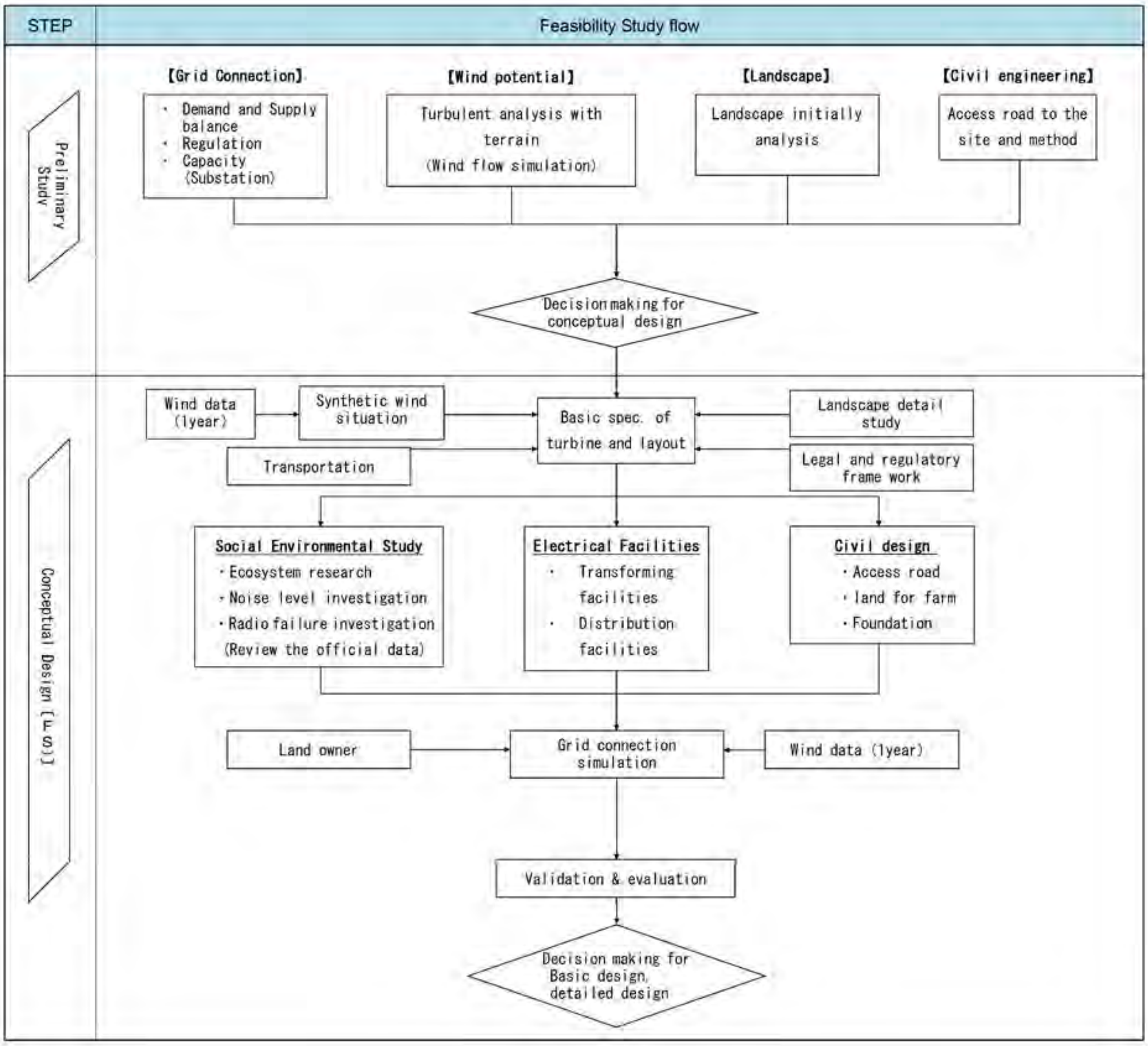
Cabo verde has sufficient potential to develop wind power generation. However, due to the following issues, in order to proceed a realistic study and development, deeply consideration of issues is important.

- Detailed survey of terrain and wind conditions should be conducted for the review of wind power development zone
- The grid code for renewable energies connection is still in the process of establishment
- Scientific demand forecast with the view point of economy has not been conducted
- In order to maintain the grid stability and enhance the energy efficiency, power flow analysis with the data of demand forecast is necessary

Based on the issues above mentioned, the flow of feasibility study is shown in the following figure 10.6-1. Study steps are divided in 2 sections as preliminary and conceptual design. To avoid reworks and cost increase, firstly, the study for finding out the initial issues should be conducted and as the second step, the conceptual design (FS) should be followed.

For the conceptual design, field test of the wind speed should be implemented at least 1 year, that why the period of the whole feasibility study including preliminary would be 1.5 to 2 years.

Though, Japan is an island country and face a lot of constrained conditions to develop wind power such as isolated location, mountains, typhoon and so on, due to a lot of experiences of development and operation of wind farms, can contribute to Cabo Verde’s wind power with its technic and engineering.



Source：JICA Study Team

Figure 10.6-1 Feasibility Study Flow

10.6.3 Proposal for efficient use of renewable energy and sustainable energy supply

(1) Government-led wind power introduction and operation

At this moment, a power purchase agreement (PPA) between Electra and Cebeolica would have no legal problems and speaking generally would not be a particularly unfair contract. However, comparing Electra's serious financial situation and Cabeolica's profitable situation, in considering the future direction of the wind power development, government-owned enterprises like Electra should develop projects as the owner of those projects using international soft loans with a government guarantee.

In the short term, for collecting development cash, when the Cabo Verde Government promotes a foreign IPP developer, if Electra's deficit continues and foreign currency earnings from wind power are out flowed to project owners, the negative effect on the national account will be significant.

Furthermore, currently, Electra and Cebeolica have a contract with a take-or-pay clause, and usually the obligatory purchase amount is achieved and the overflow amount is suppressed. In other words, there is a continuing situation of a huge dump. To improve the renewable energy utilization ratio, Electra should use this suppressed energy as much as possible, however, due to the current conditions of the tariff, increases of wind purchase have been stacked.

Therefore, both Electra and Cebeolica should make an effort to find a way to utilize more suppressed energy based on the discount tariff.

(2) Minimizing power loss and improving collection of uncollected tariffs on Santiago

As shown in the evaluations in the previous chapters 2.1.2 and 4.2.2, as a solution for Electra, which is facing a serious financial situation, minimizing energy supply loss and improving collection of uncollected electricity tariffs are urgent and important issues. Therefore, as the most effective action to be taken, necessary solutions for loss improvement and uncollected tariffs in Santiago should be considered and carried out promptly.

The Cabo Verde Government should recognize that securing the sound management of Electra is a major premise for stable energy supply and stabilization of the country's industrial base, and should support activities of Electra proactively.

(3) Purpose of power storage facilities and pursuit of economic efficiency

As the result of this study, it can be understood that since Cabo Verde is a small island nation with stable wind, it is not a situation in which a large scale pump storage hydro power and batteries would be practicable in terms of either technology or economy. Particularly, from the point of view of cost, power storage technology is still being developed, and as the 1st priority in creating a scheme, economic issues should be pursued, while recognizing that these technologies are being expected in the future. (However, in the near future, the need for the introduction of batteries as a countermeasure to short-cycle fluctuation is anticipated.)

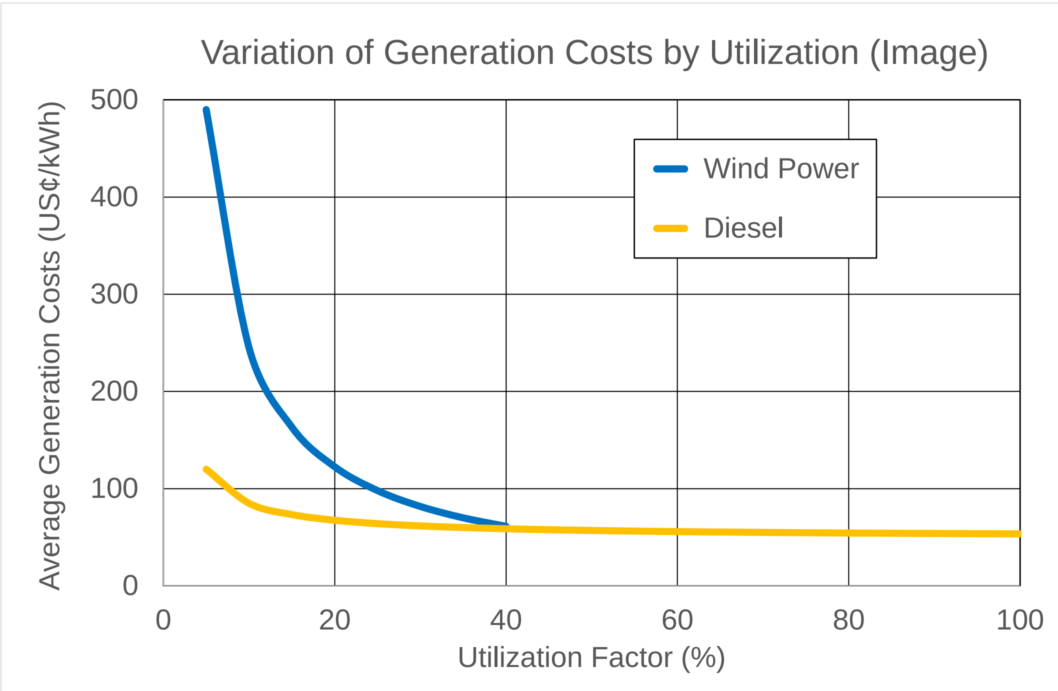
At this time, before choosing power storage facilities, by just improving the capacity to reduce diesel output (adjustment capacity) and installing wind power, renewable energy utilization would be increased significantly and basically it would be possible to recover the cost of this.

10.7 Prospective Measures for More Renewable Energies

This section shows the suggestions for the measures to utilize more renewable energies, especially variable renewable energies (VRE).

10.7.1 Issues to Be Concerned for the Introduction of VRE

VRE (e.g., wind power and solar) has higher ratio of fixed costs over variable costs compared with conventional energies such as diesel. Therefore, the average generation cost steeply increases with lower utilization factor.



Source：JICA Study Team

Figure 10.7-1 Image of the Variation of Generation Costs vs Utilization Factor

As the penetration of renewable energy becomes higher, the output of VRE might be capped due to the restriction of minimum output of existing power sources such as diesel and/or network instability. However, such execution of capping should be minimized. Otherwise, the total costs for electric power system will increase and it will place fixed and chronic burden on power sector and furthermore, it may interfere with economic development.

10.7.2 Suggested Measures for Further Renewable Energy Utilization (Technical)

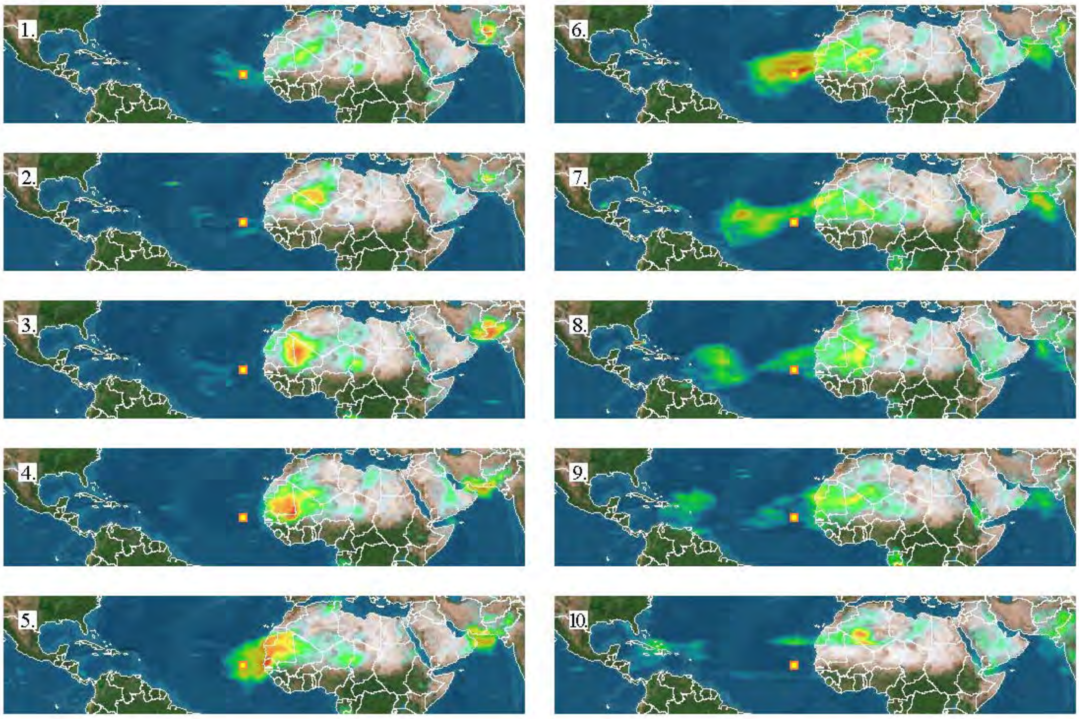
(1) Improving Accuracy of Demand Forecast

In order to improve the utilization of VRE that cannot follow fluctuating demand, it is necessary to predict the demand accurately from time to time. For the purpose, it is essential not only to collect demand data for several years but also to record instantaneous demand data to the feeder at lower level as practical. Smart meters are effective device for such purpose. The demand data of each customer from time to time, every few to dozens of minutes, collected via smart meter, can be utilized for the segmentation of customers, the estimation of characteristics of demand of each segment, real-time demand forecast, and/or reasonable tariff system.

(2) Improving Accuracy in Evaluating Supply Capacity of VRE

Even for VRE, it is possible and necessary to improve the accuracy of output forecast. The specific measures are, for example, accurized estimation for insolation and wind conditions, and meticulous management of the performances of facilities. An example of the former is collecting weather data outside generation site that related with the situation of the site for output forecast. An example of the latter is estimating the contamination and/or degradation of solar panels for generation with a clean and trouble-free solar panel for the reference of output and aging.

It is thought that sand dust, one of the major causes of the diminished output of solar power station, is from Sahara Desert and carried by Trade Wind. Thus, it may be effective to optimize the schedule to clean solar panels in consideration of global meteorological information.



Source: Image data of NASA arranged by JICA Study Team

Figure 10.7-2 Sand Blast Westering from Sahara Desert to Atlantic Sea

(3) Introduction of Demand Response

Even though the accuracy of the forecast of VRE output is improved, there is still uncertainty remained and the more VRE penetrates, the more difficult to balance only by supply-side of the grid. It is an idea to install batteries to absorb the fluctuation but it may be more advantageous to introduce demand response. A primitive example is the introduction of electric water heaters and thermal/cool storage with timing switch to turn during light-load hours (i.e., midnight and daytime). Another idea, for Cabo Verde that depends raw water on desalination, is the scheduled operation of water conversion plant. In addition, the introduction of smart meters as mentioned in (2) (a) to sophisticate the grid will realize more flexible demand response.

10.7.3 Suggested Measures for Further Renewable Energy Utilization (Institutional/Political)

(1) Extension of settlement period for wind power under take-or-Pay scheme

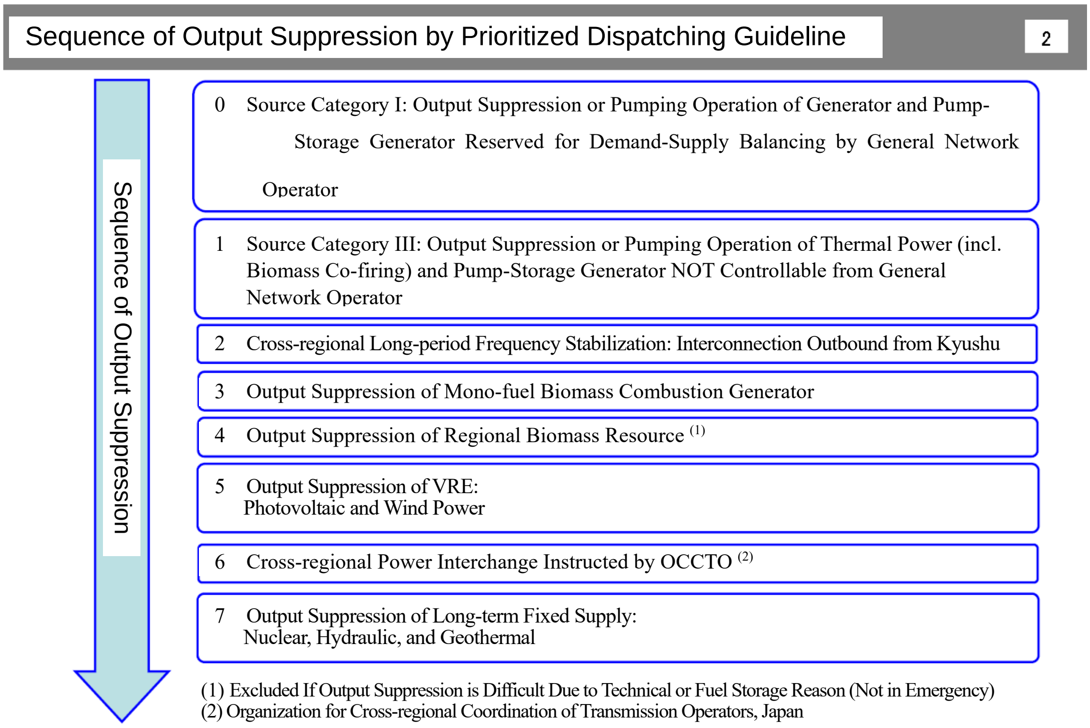
The amount of to be purchased is set for each month and the carry-over period is three months. However, JICA Study Team found that some part of the wind energy cannot be utilized sometimes since wind condition and electricity demand fluctuates out of expected seasonal cycle. Therefore, the impact of the uncertainty of seasonal cycle may be mitigated to extend the Take or Pay period over one month and to set carry-over period more than three months (e.g., half year to one year).

(2) Virtual Interconnection between Islands

Wide area interconnection is generally applied to mitigate the uncertainty caused by VRE but it is not applicable to Cabo Verde with small land different from continental countries. In addition, due to the topographic features, it is very difficult to interconnect islands. However, in Cabo Verde, "virtual" inter connection between islands is applicable without installing transmission lines. It means that, for example, when the predetermined amount wind power is not (or will not be) achieved in an island (e.g., Sal), the unreceived amount is transferred to another island with excessive capacity to swallow wind power (e.g., Santiago). If the incentive for the transfer is set appropriately, both parties, supplier and buyer, are happy and as the result, the potential of the renewable energy in the country is utilized more and the fossil fuel for power generation is consumed less. This scheme can be applied not only to adjust the short-term fluctuation (approx. within one year) but also to compensate the middle-term demand/supply imbalance, differences of penetration ratio in the course of VRE implementation among islands.

(3) Establishing Rules for Prioritized Dispatching

In Japan, electric power system management has become quite difficult due to recent rapid penetration of renewable energy. Especially during the hours with lower demand, the shortage of capability to absorb when too much supply flows into the grid is a critical issue. Recently, in consideration of the situation, the Organization for Cross-regional Coordination of Transmission Operators, Japan (OCCTO) set a guideline for grid operators to set the priority to de-synchronize generators when power supply, including VRE, exceeds demand.



Source: KEPCO, Japan (Trans. by JICA Study Team)

Figure 10.7-3 Sequence of Output Suppression by Prioritized Dispatching Guideline

In Cabo Verde, due to small power system and without mitigation of fluctuation via wide-area interconnection, the disturbance of power system by VRE is acute. Thus it is indispensable to implement such guideline as above, so that power system is operated stably and to assure the transparency and equity for stakeholders. In addition, demand response, if installed, can be incorporated in the dispatching guideline to mitigate the shortage of balancing capability in grid and as the result, the utilization of VRE will be improved.

(4) Introduction of Spot Market to utilize excess renewable power

Although the option contract for the wind power over "take or pay" quantity, such excessive energy is scarcely utilized. Establishing a short-time spot market may be helpful to utilize such unused energy.

10.7.4 Comprehensive and Long-term Measures

(1) Warm/Cold Thermal Storage

Resort business is a key industry in Cabo Verde and the energy demand for hot water and cryogenic energy is high for such facilities. Thus, in addition to batteries, heat or ice storage is prospective technology to store energies. Specifically, installing timed water heater for each room of apartment house to utilize off-peak electricity. Another example is industrial refrigerator with thermal storage for peak-cut to assure balancing capability in low-demand period as well as peak-shaving. However, please note that solar water heater may have an advantage over the combination of photovoltaic generation and electric boiler. The point is to choose the best option in consideration of overall energy supply chain without sticking to electricity.

(2) Electric Car/Bicycle and Ecotourism

Introduction of Electric Car and Bicycle (collectively EV) is easy for Cabo Verde because no transportation for long distance and wide area is necessary for island countries. For a suggestive example, rental electric scooters are provided for tourists in Teshima, Kagawa Prefecture in Seto Inland Sea in Japan. The vehicles are introduced since the sightseeing areas in the island are scattered in the island and the elevation of the points differ and on-foot trip is not adequate. Teshima, with the area of 14.4km^2 and the perimeter of 20km, is smaller than the islands of Cabo Verde. However, similar idea may be applied for Cabo Verde with a limited operation zone in an island. Otherwise, the effective range of electric scooters (approx. 30-50km) may be substantially extended with charging station or battery reload.

Another pertinent example is Zermatt, Switzerland. No internal combustion vehicle cannot operate in predesignated zero-emission zone in the town; only EV or horse cart are permitted for transportation in order to obey strict environmental conservation policy. Also in Cabo Verde, similar strategies may be introduced in cooperation with eco-tourism to add value to sightseeing resources. EV may be introduced as the buggies in beach or the shuttle buses between airport and resort area.

It is recommended to implement such programs as social experiments in special zones or model regions rather than widely and shallowly. Also, for funding, such scheme should be designed to attract private investment by the companies (e.g., tourism, EV, and affiliates) wishing to improve corporate image or to promote products so as to establish win-win public-private relationship.

(3) Hydrogen by RE and Applications

There have been a lot of studies to utilize electrolytic hydrogen by RE in several countries. Hydrogen itself is expected for multi-fuel combustion in diesel engines but storage and transportation is bottleneck. On the other hand, dimethyl ether (DME) and gas to liquid (GTL) synthesized from hydrogen can be handled just like conventional liquid fuels but such processes are still in research and development phase.

Thus, such technologies are not for practical use currently but there is potential for a breakthrough by an innovation to resolve a bottleneck. Therefore, the development of the pertinent technologies should be watched closely.

(4) Exploitation of Unutilized Coastal Energies

Cabo Verde, as a maritime country, is supposed to have abundant unutilized coastal energies in neighboring sea area as well as on land RE. There are the examples of technologies for utilization.

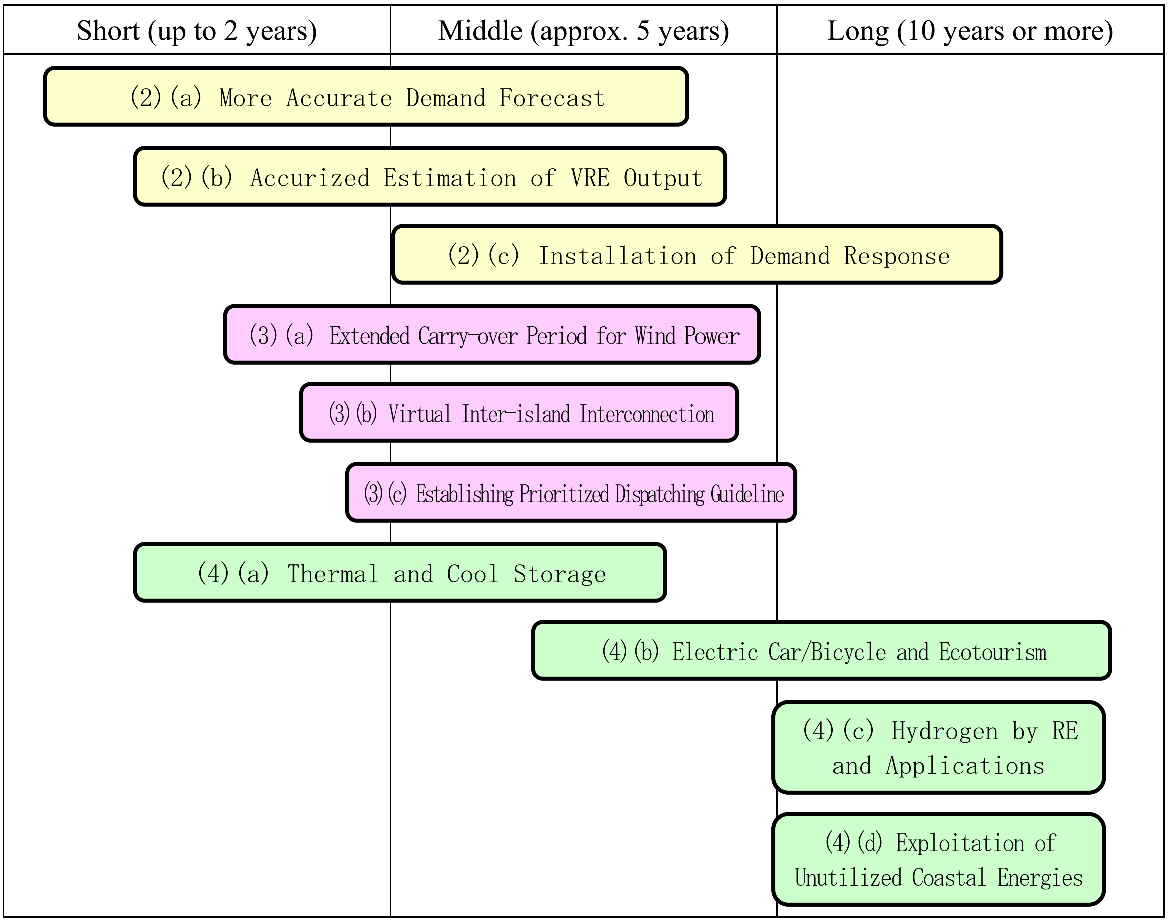
- Tidal Power Generation
- Offshore Wind Farm
- Ocean Thermal Energy Conversion (OTEC)
- Wave Power Generation

While the former two technologies are with fluctuating output as so-called VRE, the latter two will provide relatively constant output. Since these technologies are at the stage of research, development, or demonstration, the introduction should be well-considered, not hastily. However, it is necessary to watch future progress carefully to counterpoise against other options (e.g., cost reduction of batteries, breakthrough in hydrogen related technologies) and conventional technologies to plan a flexible strategy to be adjusted to the uncertainty of future scenario.

10.7.5 Summary

The measures described above are categorized into short term (present - ca 2 years), middle term (ca 5 years), and long term (10 years or more) as shown in Table 10.3-F01.

Table 10.7-1 Scenario of the Measures for RE Utilization in Future



Source: JICA Study Team