STUDY ON SMALL POWER GRID MODEL WITH AN EMS THAT CONTROLS DIESEL GENERATORS, PV AND STORAGE BATTERIES

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ABSTRACT

Global installed capacity for solar-powered electricity has seen an exponential growth as costs for solar power are falling rapidly. A photovoltaic system (PV) can contribute to reduce greenhouse gas emission and generation cost. Therefore, many countries, especially island countries such as the Pacific Island have been installing PV enthusiastically with using fund from public aid organizations such as development banks. However, PV which is intermittent power source can cause the degradation of power quality or blackout at worst. Particularly a grid in a small island tends to be affected badly by fluctuation of PV output.
In this paper, we will study the impact by a large capacity of PV on a small grid in Tarawa, Kiribati. Furthermore, we will also implement a feasibility study with installing an Energy Management System (EMS), more PV and storage batteries as a solution. This study was funded by Japanese Ministry of Economy, Trade and Industry (METI).

INTRODUCTION

Electricity supply on remote islands is costly in general due to high price of fossil fuel including transportation fee. In addition, fossil fuel emits a large amount of carbon dioxide (CO2). Based on these facts, the Pacific Island countries, where consist of small islands and are sensitive to sea level rise due to global warming, have been changing their power source from fossil fuel to renewable energy. Several public aid organizations has been supporting them to install renewable energy source as well.
IRENA (International Renewable Energy Agency) suggested RRA (Renewable Readiness Assessment) that shows introduction of renewable energy and saving energy in 2025 to Kiribati, one of Pacific island countries. The suggestion sets the goal that cost reduction of consumption of fossil fuel 45% compared to the current result of Tarawa in 2025. This breakdown contains 23% cost reduction of power generated from fossil fuel and 22% reduction by saving energy supply and demand.
The purpose of this study is to clarify the impact of massive PV penetration for the grid in Tarawa, the capital city of Kiribati. Moreover, we will also study for the introduction of an Energy Management System (EMS) to the grid of with the aim of improving economic efficiency while ensuring the reliability of the power supply by proactively using renewable energy and effectively using existing electric power generation facilities.

CURRENT ENERGY CIRCUMSTANCES IN KIRIBATI GRID

Demand as of 2014

Kiribati comprises 32 atolls and one island. The biggest is south Tarawa atoll, where Tarawa is located and centre of economy and politics of the country. About 50 thousand people reside in the atoll.
The Public Utilities Board (PUB), an organization under the Ministry of Public Works and Utilities (MPWU), is responsible for maintenance and operation for Kiribati's electric power industry.
Fig. 1 shows average daily load curves for weekdays and weekends of the main grid in south Tarawa atoll in 2014.

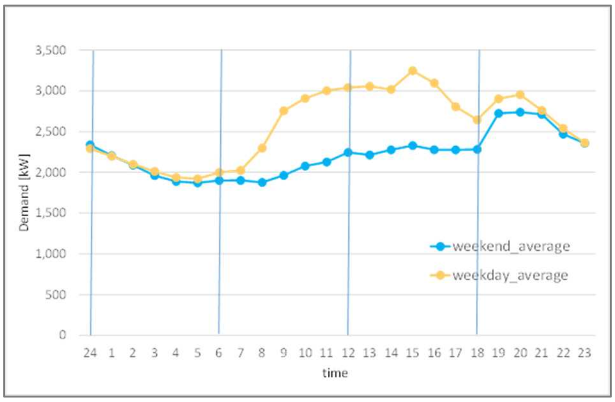

Fig. 1 Average daily load curves in Tarawa as of 2014

Peak demand hours exist during the daytime and night-time. The daytime peak lasts from 14:00 to 16:00 with demand at its highest at 15:00. The night-time peak lasts from 19:00 to 21:00 with demand at its highest at 20:00. Maximum demand in 2014 was recorded at 4.1 MW.

Grid in south Tarawa atoll

The total of four Diesel Generators (DGs) supply nearly all of PUB's power. The Betio site has one 1.25-MW generator, which was installed in 2004. The Bikenibeu site has three 1.4-MW DG, two of which were installed in 2002 and the third of which was installed in 2005.
In addition, PV power generation facilities are in operation after their introduction in 2015 - 400 kW at the Bikenibeu site purchased with funds from the Pacific Environment Community (PEC). In addition, 500 kW at the Bonriki site with funds from the UAE was in commissioning.
A single 11-kV bulk system supplies power to the main island of Tarawa. Fig. 2 shows a simplified diagram of the grid.

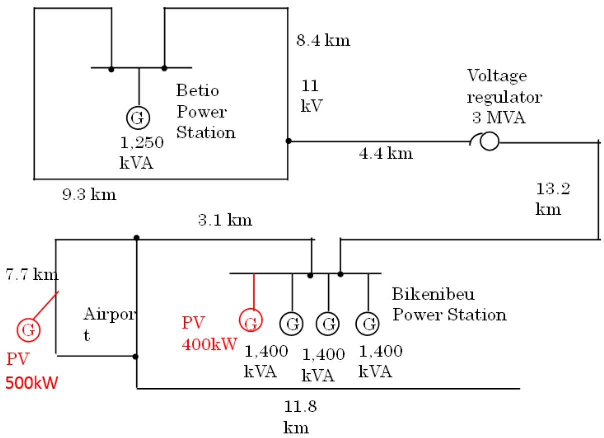

Fig. 2 Grid diagram in south Tarawa atoll as of 2014

Furthermore, a development institution planned to offer the fund for 0.5MW of PV to install in 2016.

Current power quality

We surveyed the power frequency of the grid in 2015 with 0.9MW of PV operating. Fig. 3 shows output of the 0.4MW-PV funded by PEC, which recorded Sep. 19th in 2015.

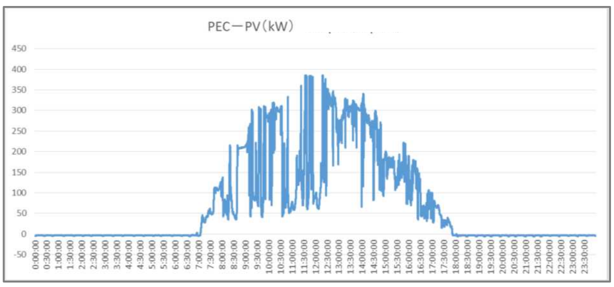

Fig.3 Output record of PV funded by PEC

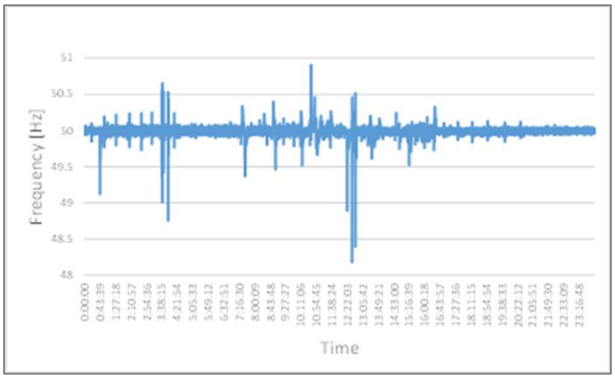

Fig. 4 South Tarawa Grid frequency fluctuation

The frequency fluctuated somewhat during the study period, but stayed completely within the range of 50±2Hz, where three standard deviations (99.7%) were equal to 0.26 Hz. This can be explained in large part by the fact that the generators ran without governors and the supply-demand balance was regulated automatically. In addition, the rare times the fluctuation was pronounced were likely due to lack of skill in changing the number of generators in operation. These results also show that PV fluctuation did not cause any stability during the study period in 2015 after 0.9 MW of PV power was connected to the grid.

SIMULATION ON GRID OPERATION

We surveyed how PUB operated the grid and DGs. The Bikenibeu Power Station had an operation system in which the number of DG in operation is automatically controlled according to the reserve capacity of the operational DG. This system also balances the output of DGs in operation. We simulated the operation pattern in case 0.9 MW of PV operating fully.

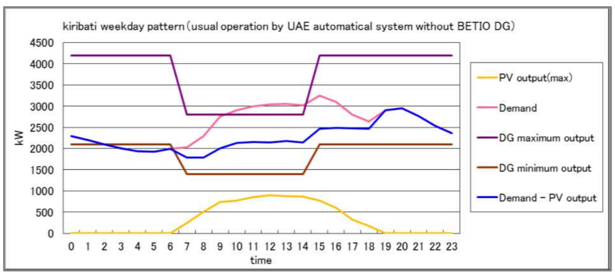

Fig. 5 Simulation result of grid operation in weekday pattern (PV 0.9MW)

Fig. 5 also shows that under the existing system DG supply capacity would be insufficient if PV output decreased suddenly around 12:00 when demand is high, which could lead to a power outage. It means there was a potential risk of outage although it did not happen during the study period.
If more PV is installed without any countermeasures in this grid, the risk of blackout would increase.

PROPOSED COUNTERMEASURE

Image of the countermeasure using EMS

Aforementioned, it would increase the risk of blackout after installed 0.5MW of PV in current situation. Therefore, we will implement a feasibility study with installing EMS as solution. Fig. 6 shows an image of the countermeasure using EMS.

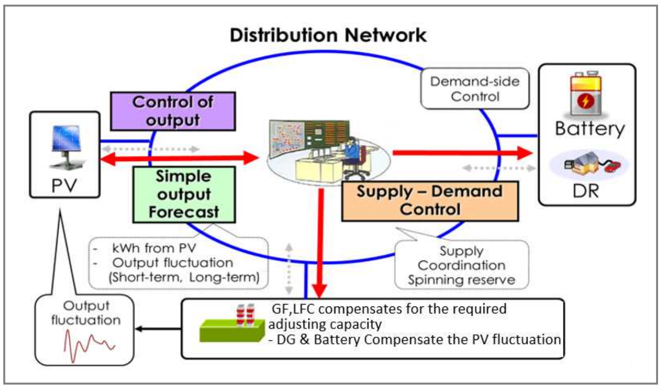

Fig. 6. Illustration of the countermeasure using EMS

SYSTEM OVERVIEW

Basic Functions of the EMS

The EMS proposed in this study will have the following functions based on the assumption that a total of 1,400 kW of PV power will be introduced:

- Automatic, efficient operation (maintaining operation of at least 50% load) of existing Diesel Generators units while using the PV output forecast system
- Introduction of storage batteries (520 kW, 2,000 kWh) to respond to sudden PV output fluctuations
- Regulation of PV output only when the storage batteries are not able to handle the surplus

Conceptual Diagram of the System

Fig. 7 is a conceptual diagram of the proposed system. An EMS that can control the power generation system on the entire South Tarawa Grid will be introduced such that it includes the operation control system for the Bikenibeu Power Station installed with assistance from the UAE. The control logic of EMS must be updated whenever new power sources are added, but in principle EMS is a scalable system.

EMS, which is the main facility in the Project, is expected to be installed in the CONTROL ROOM and MASTER ROOM of the Bikenibeu Power Station. The study team's proposal includes the introduction of storage batteries, but those, too, are expected to be installed on the property of the Bikenibeu Power Station. A temporary location has been determined for PV power that may be provided with WB assistance because the site has not been confirmed yet.

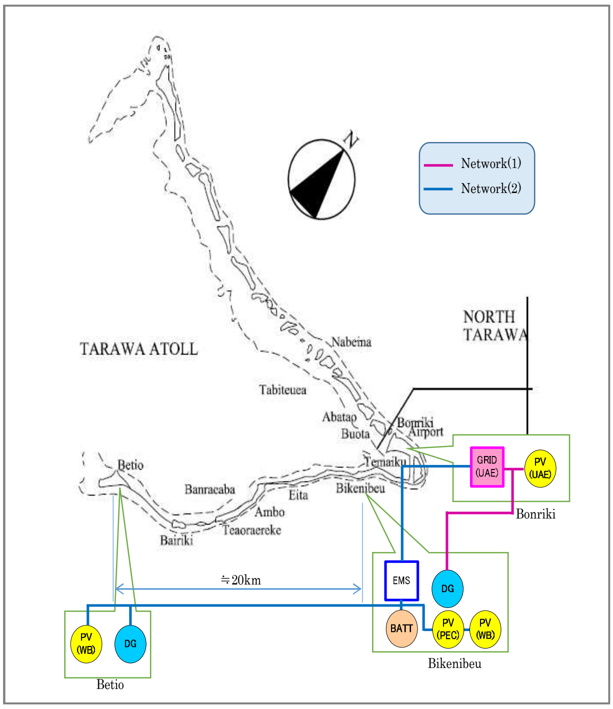

Fig. 7. Conceptual Diagram of the System

ENERGY MANAGEMENT SYSTEM CAPACITY

The system will enable comprehensive, economical operation by control through storage batteries, PV power regulation and the like as necessary while controlling Diesel Generators output and sequencing at both the Bikenibeu Power Station and the Betio Power Station.

・A function to control the output and sequencing of Diesel Generators at both Bikenibeu and Betio

・A function to control the charging and discharging of storage batteries

・A function to control the regulation/deregulation of PV power

・A function to project PV power generation and output in simple terms (with all-weather cameras, etc.)

・A function to create demand in simple terms (based on statistics from the previous day, week, etc.)

・A function to make comprehensive decisions on the aforementioned control and data, and plan and perform operations economically

・A function for remotely monitoring onsite data from Japan

Adding Facilities to Existing Diesel Power Generation Facilities

The following additional facilities are required to control the operation of DGs units using EMS:

・Facilities to gather DGs output data, and send/enter it into EMSz

・Facilities to receive orders from EMS and control the output and sequencing of DGs

Adding Facilities to PV Power Generation Facilities

As with DGs units, PV units also require the following additional facilities:

・Facilities to send/enter PV output data into EMS

・Facilities to receive orders from EMS and control PV output

・All-weather cameras to forecast PV output and facilities to send data to EMS

The PV power generation forecast system relies on all-weather cameras to forecast anywhere from 30 minutes to as long as several hours into the future. However, the key criteria in this system's simplified PV output forecasting will be the consistency or inconsistency of weather. Under conditions where PV output can be guaranteed (when the weather is consistent), there is no need to consider surplus capacity in response to actual demand; PV output can be anticipated, and the number of DGs in operation can be reduced and operated at the most efficient points possible. When PV output cannot be guaranteed (when the weather is inconsistent), Diesel Generators will be started and operated to guarantee reserve capacity.

RESULT OF THE CASE STUDY IN KIRIBATI

Simulation results

We simulated the operation pattern with EMS that operating 1.4 MW of PV and storage batteries. Fig. 8 shows the simulation results for weekday demand. This figure shows that storage batteries can compensate for the PV fluctuation. Furthermore, this figure also shows that an EMS with storage batteries can ensure the reliability of the power supply by proactively using PV and using existing DGs effectively, because the "DG (Diesel Generator) 100% output" value is bigger than the "Demand with margin" value at all times.

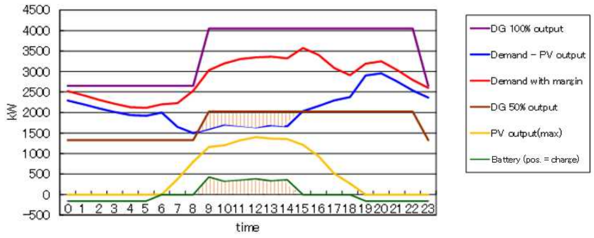

Fig. 8 Simulation results for weekday demand using EMS with batteries (PV 1.4MW)

Chart 1 shows the results of the study. EMS that operating 0.9 MW of PV can mitigate the need for PV output suppression. In case installed 1.4 MW of PV, EMS can reduce the consumption of fuel. Furthermore, installing EMS and storage battery capacity of 520 kW and 2,000 kWh enables us not only to maintain supply reliability but also to reduce fuel costs by increasing the operation efficiency of the DGs.

CONCLUSION

In this paper, we figured out existing 0.9 MW of PV would cause the problem such as degradation of power quality and blackout at worst to the grid in Tarawa, where there was the concrete plan to install more PV (0.5MW). On top of this, we figured out that installation of EMS could solve the following problems occurring:

- Blackout caused by the fluctuation of PV output
- Damage of Diesel engines and low fuel efficiency due to low-load operation.

Moreover, Battery installation could avoid the suppression of the output from PV to be installed in future.

Chart 1. Results of the study

	Current situation	Case 1	Case 2	Case 3
Capacity of PV installed	0.9MW		1.4MW	
Control system	-	EMS	EMS	EMS
Storage batteries	None	None	None	0.52Mw, 2.0MWh
Outages due to PV fluctuation	None	None	None	None
Diesel generator operation rate less than 50%	None	None	None	None
Suppression rate of PV output per year	None	None	21%	9%
Reduction of CO^2 emissions per year	-	455 t	810 t	1068 t
Reduction in fuel[*1] per year	-	168kl	299kl	394kl