Case study: Japan－U.S. Collaborative Smart Grid Demonstration Project in New Mexico

Part 2　Efforts in Albuquerque

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1.　Introduction

For the period between FY2009 and FY2014, the Japan – U.S. Collaborative Smart Grid Demonstration Project in New Mexico was implemented at two sites, Los Alamos and Albuquerque in New Mexico State in the United States as NEDO's first Overseas Smart Community Demonstration Project. Headed by NEDO, the project was accomplished by a collaboration of 19 Japanese companies, the State Government of New Mexico, electric utilities, research organizations, and other stakeholders demonstrate technologies that allow for large scale penetration of renewable energy in the future, and offering some important clues on the promotion of smart grid in both Japan and the U.S. in the course of this demonstrative experiment.

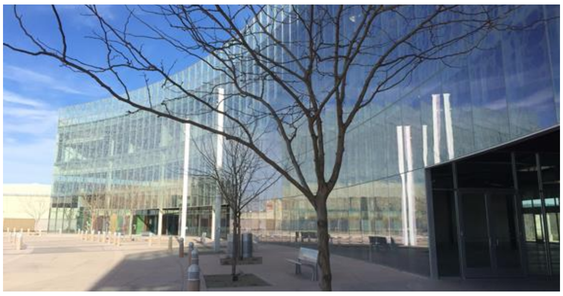
This Document is a case study focusing on the efforts deployed in Albuquerque and report on the suggestions made by this experience.

2.　Efforts in Albuquerque

In Albuquerque, an advanced microgrid consisting of Building Energy Management Systems (BEMSs) were constructed in a commercial building called the Aperture Center located at the Mesa Del Sol residential development. A research about how to operate the microgrid to optimize the facility's energy supply and possibly contribute to the operation of electric system has been conducted.

The BEMS constructed by Shimizu Corporation incorporate two control algorithms by Shimizu Corporation and Tokyo Gas, which are called here BEMS1 and BEMS2, respectively. Both BEMS algorithms controlled the same equipment and devices but had different purposes. In this case study, the major efforts made in the site of Albuquerque are described from the two BEMSs perspectives as follows:

- BEMS1: Contribution as microgrid as a whole to the operation of electric system
- BEMS2: Coordinated operation with other control system



Source: Photo taken by author

Figure 2　Aperture Center building at Mesa Del Sol

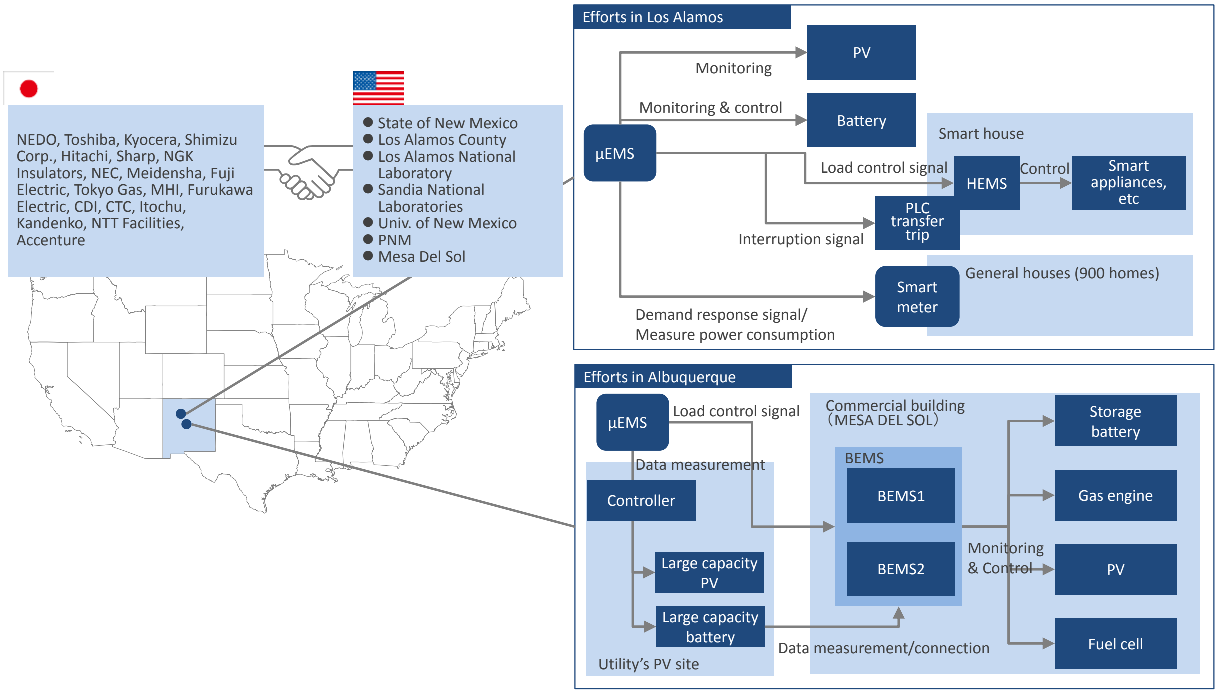


Figure 1　Whole picture of Japan-U.S. Collaborative Smart Grid Demonstration project in New Mexico

3. BEMS1 : Contribution to power system as a microgrid

3.1 System Overview

The first effort is the BEMS1 constructed in the Aperture Center at Mesa Del Sol by Shimizu Corporation. As shown in Figure 3, the system consists of the following DERs (Distributed Energy Resources): a gas-engine generator (240 kW), phosphoric-acid fuel cells (80 kW), a photovoltaic power generator (50 kW), storage batteries (160 kWh) managed by a Battery Energy Storage System (BESS), and an air-cooled refrigerator (70 USRT), an absorption type refrigerator (20 USRT), a water thermal storage tank (75 m^3) and a hot water thermal storage tank (110 m^3) as heat source systems. Controlled by the BEMS1, the equipment was configured to supply electric power and thermal energy to a commercial building.

The BEMS1 has two major capabilities: (1) control of DERs in the system when it is grid-connected so as to stabilize power flow at the point of common coupling (PCC) to any externally-set specific value (grid-connected mode); and (2) islanded operation of the building at times of grid outage, enabling switching between interconnected and islanded operation modes as needed without any instantaneous interruption (islanding mode).

Figure 4 shows the control logic under grid-connected mode. Here, the system was operated with optimal use of each DER, based on its performance characteristics by setting specific values in cascade to stabilize the power from PCC. The performance of BEMS1 during one day is shown in Figure 5. For two years, various demonstrative tests were conducted with real loads, followed by the adjustments of equipment to resolve operational issues that were encountered. As a result, the accuracy of power flow control at the PCC has been enhanced to approximately 2 kW of standard deviation of PCC power flow over the control target value.

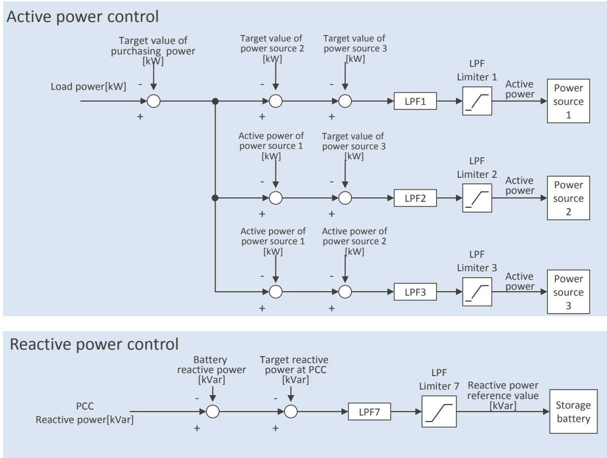


Figure 4 Control method for grid-connected mode

Islanding mode used an algorithm to supply power and heat for an entire commercial building when the circuit breaker at the PCC was open so that the building does not receive power supply from the grid. See Figure 6 for the logic.

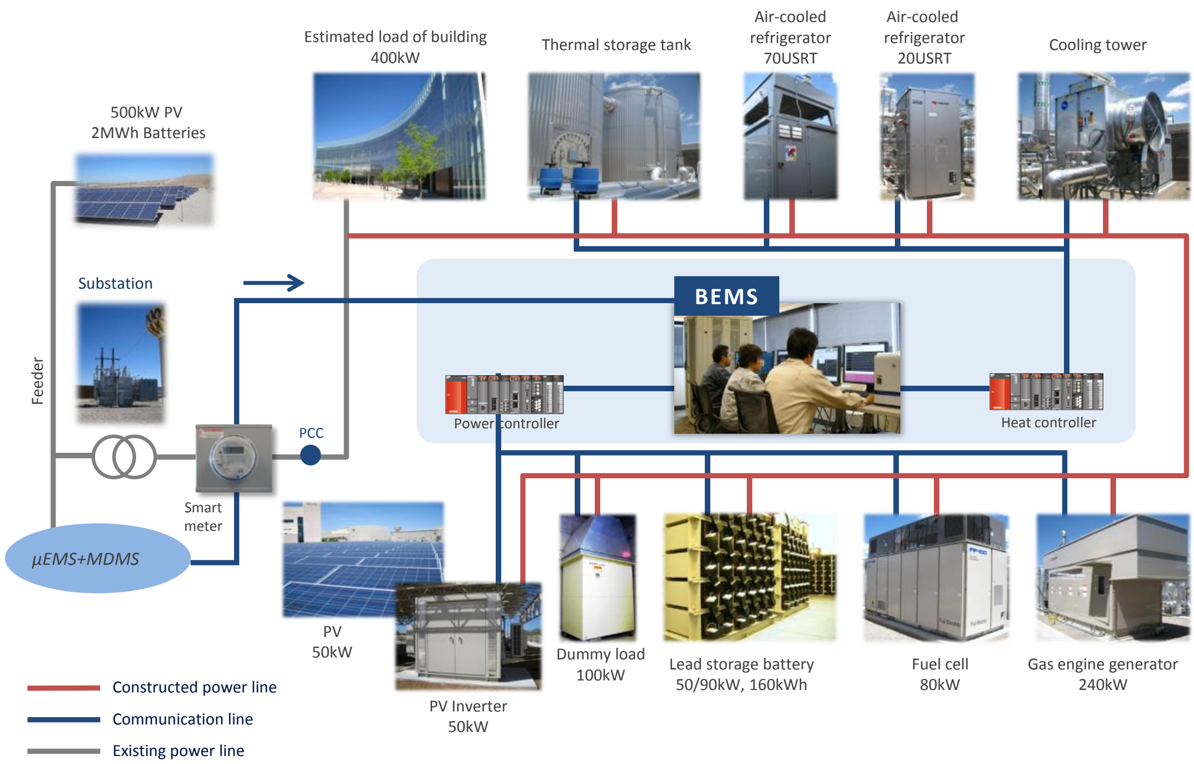


Figure 3 BEMS configuration

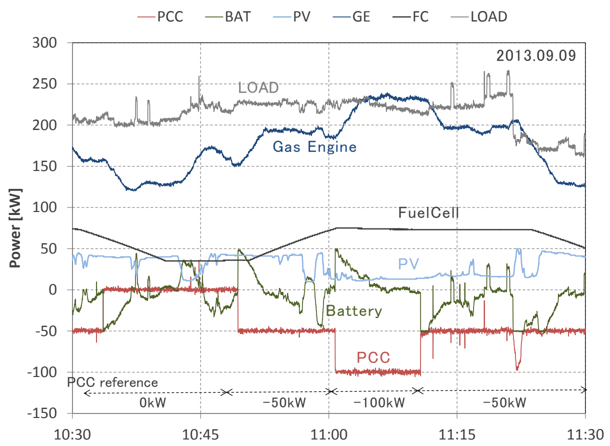


Figure 5 Performance results in grid-connected mode

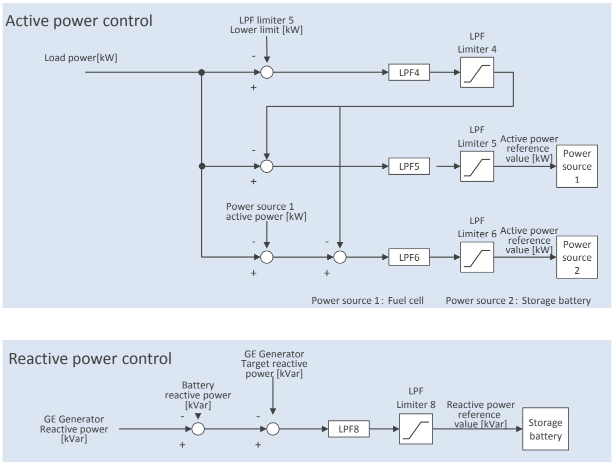


Figure 6 Control method for islanding mode

Figure 7 shows the demonstration result in Islanding mode. In islanding mode, voltage fluctuation achieved the target of 480V±10% for all operating hours, and frequency stayed in the target range of 60Hz±0.3Hz more than 98% of the time, resulting in the stable islanded operation while maintaining target power quality for long hours.

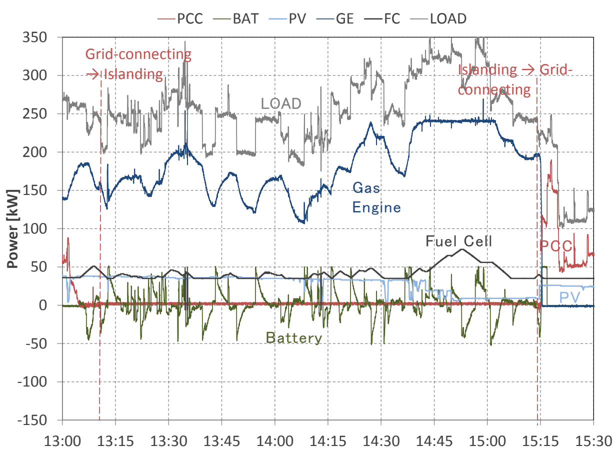


Figure 7 Performance results in Islanding mode

3.2 Key Findings – Lessons Learned

By the above-mentioned demonstration with BEMS1, it was confirmed that the microgrid had expected performance as Dr. Kimio Morino of Shimizu Corporation mentioned.

Comment by Dr. Kimio Morino

Engaging in the construction of demonstrative system for two years from 2010 and the demonstrative experiment for the following two years, the 9 Japanese companies participated in the demonstration project in Albuquerque were able to achieve their original aim with a great support by the U.S. counterpart.

At our company, we gained huge confidence as we could construct microgrid in the U.S. and successfully demonstrate various microgrid control technologies such as switching between islanding and grid-connected modes without any instantaneous interruption using BEMS, DR control in coordination with grid, power fluctuation compensation by use of refrigerator, etc.

The following four lessons have been learned from this experience:

Lesson (1): Microgrid that contributes to the operation of power system

First of all, the BEMS system developed here is able to contribute to the operation of power system on a microgrid-wide basis. When assuming a building as a microgrid, the power flow at PCC in the microgrid is controlled to become the pre-set target value in the grid-connected mode. In this demonstration, the target value at PCC could be changed on a minute-to-minute basis and DERs in the building were controlled to achieve the target value in accordance with the target value.

This means that the microgrid, when seen from the outside, can be treated as a controllable resource, with the DERs managing the target value and internal load fluctuations. In other words, the system that has been developed enabled the microgrid to respond to its load and also function as a virtual power plant (VPP). Mr. Jonathan Hawkins from the local utility PNM commented on how the demonstration experiment is significant for electric utilities.

Comment by Mr. Jonathan Hawkins

We were involved in the demonstration because we wanted to clarify how microgrid and electric utility relate to each other. It is important to deepen understanding of this system which is expected to prevail first and we have to find out how utilities can support microgrid and what kind of coordination would be needed between utilities and microgrid.

In this respect, we could learn a lot from the demonstrative experiment, and we would like to continue to further this research.

One point we should keep in mind is that the system has the ability to operate as a microgrid and as a VPP as well. However, the system for this demonstration has characteristics of contributing to the power system operation in the grid-connected mode and also shifting to the islanding mode without any instantaneous interruption at the time of power grid outage. Today, energy system resilience is an important consideration in the U.S. and Japan. It is significant that the system developed for the demonstration incorporated two features that support energy efficiency as well as resilience.

Mr. Manuel Barrera from Mesa Del Sol, developer of the demonstration site building, described his feelings about the microgrid and the demonstrative experiment.

Comment by Mr. Manuel Barrera

The demonstrative experiment was really a great experience for us to rediscover the value of microgrid. I believe a property value is improved with the microgrid and I am sure that even with a higher initial investment the long-term value of the property will be guaranteed.

As a developer, we would like to make an effective use of the results of this demonstration to continuously provide the customers who have interests in sustainability with our attractive service.

Currently, shared use of PV and storage battery at the community level is prohibited by regulation in New Mexico. However, the experiment this time demonstrated that such a scheme would be possible in an actual system. I am confident that the demonstrative experiment can be a supportive evidence to change the regulation.

The demonstration project was intended to technically verify the effectiveness of a building-scale microgrid. However, as pointed out by Mr. Barrera, it should be necessary to take an approach toward expansion of microgrid business based on the demonstration results (e.g. encouraging change in the policy and regulatory frameworks).

Lesson (2): Development of standards for grid connection of a microgrid

Microgrid as emerging technology is still in the evolution phase. There exist guidelines such as IEEE 1547.4 but the requirements on the connection between the electric system and microgrids are under debate. No standard on the grid connection of microgrid has been developed yet.

Under such circumstances, we still had to examine the requirements at the PCC. Mr. Jonathan Hawkins of PNM Resources looked back at that time and commented as follows:

Comment by Mr. Jonathan Hawkins

The U.S. electric utilities normally request compliance to IEEE 1547 for PCC, but it is very difficult to define the requirements for PCC for microgrid because it may shift into islanded operation mode. Because PNM wanted to clarify this point, they actively participated in the demonstration project from the beginning.

It was demonstrated that when under islanded operation mode, the microgrid has to disconnect itself from the grid at PCC to suspend power supply to the grid and also has to increase short-circuit capacity of the switch at PCC. I remember that we have carried out intensive studies to implement these functions which were very challenging that NEDO and all the companies involved faced tremendous difficulties.

As explained in the above comment, there was a high bar established in the introduction phase, but the project partners were able to meet these requirements and build the system which satisfied both the utility and the system developer to start the demonstration experiment and obtained fruitful results. IEEE 1547, the standard for grid connection of distributed generation in the U.S., is currently being revised and the discussions on the standard including the topic of microgrid are underway. The experience at the Aperture Center will be referenced for the future development of standards for the grid-connection of microgrid.

Lesson (3): Implications for the microgrid system design

The BEMS1 system developed for this demonstration is a hybrid system consisting of a number of energy resources with different features. There are various constraints in designing a hybrid system. The BEMS control system established in this demonstration project offers a suitable control method to implement optimum operation while overcoming the constraints.

The step response characteristics of DERs adopted in the demonstration project are shown in Table 1. Based on this table, it may seem critical to focus on the designing of the BESS with the fastest response. However, the cost of BESS is quite high, so it is desirable to minimize the capacity.

Amid discussions on a trade-off between cost and performance, the “Cascade Control System” has been implemented in the demonstration project. That is, the BESS can compensate power fluctuations that cannot be handled by other generation resources. The capacity requirement of costly BESS was minimized by using the BESS for only quick power deviations that could not be corrected by the other DERs.

Another important consideration was control of active power when there was not enough power for the microgrid. In the BEMS1 Cascade Control, active power of each DER was designed to be controlled based on real-time active power measurements. However, the load of the building–specifically, the elevators—became an issue. It was found that the power flow at PCC fluctuated largely because of the inrush current due to the operation of elevators.

Table 1 Response characteristics of DERs

DER	Response Time (Approximately)	Ramp Rate
Fuel cell	10min (40kW→80kW)	0.064kW/sec
Gas engine	5min 30sec (90kW→240kW)	0.45kW/sec
BESS	30msec (0kW→90kW)	3000kW/sec
Refrigerator	4min 30sec (30kW→70kW)	0.15kW/sec

To address this issue in the demonstration, a reactive power control function in addition to the active power control function was added to the BESS, improving the voltage performance.

In addition, there were various other lessons learned from the demonstrative experiment. Prof. Andrea Alberto Mammoli of the University of New Mexico talked about the significance of the project as follows:

Comment by Prof. Andrea Alberto Mammoli

A highly complicated system like microgrid is often quite difficult to explain only by the theory but can rather be understood by actually building and operating the real system.

For the aspects of microgrid design, maintenance and operation, we came up with quite many facts that we could only understand by actually doing it. In that sense, the demonstrative experiment has important implications and we have to make a further leap forward based on the knowledge obtained from the project this time.

Lesson (4): Capability of thermal load for the stabilization of power system

In this demonstration project, a refrigerator was used as thermal load to demonstrate the capability of thermal load for the stabilization of power system. By externally controlling the power consumption of this refrigerator, we were able to integrate the refrigerator into the microgrid as a demand response device.

The overall control performance is enhanced with the integration of refrigerator as a demand response device. In this manner, the power consumption can be controlled up to a certain level; therefore, the required capacity and cost of the BESS could be minimized. Figure 8 shows the data of BESS' reduced capacity resulted from the integration of the refrigerator. In this case, a 30% reduction in the BESS capacity was achieved.

The quality of service provided by the refrigerator is an important constraint. The refrigerator was not introduced in the system to assist with the operation of electric power system, but rather to maintain temperature in the building within a target range. If this function of refrigerator is hindered, a trade-off between contribution to the operation of power system and maintaining service quality must occur.

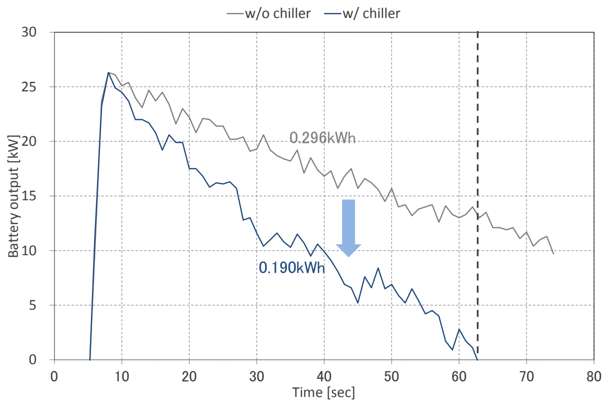


Figure 8 Effect of BESS capacity reduction due to integration of refrigerator to BEMS

In this regard, there were interesting findings. Figure 9 indicates the measurement value of the refrigerator's temperature regulation when integrated into BEMS1. The results indicate that neither TCOP (operational efficiency) nor cold water outlet temperature were significantly affected. In general, thermal energy has a long time constant. That is why a refrigerator can be integrated to a power system as a controlled device without losing service quality. It is highly desirable to make the best possible use of operational flexibility provided by thermal management devices.

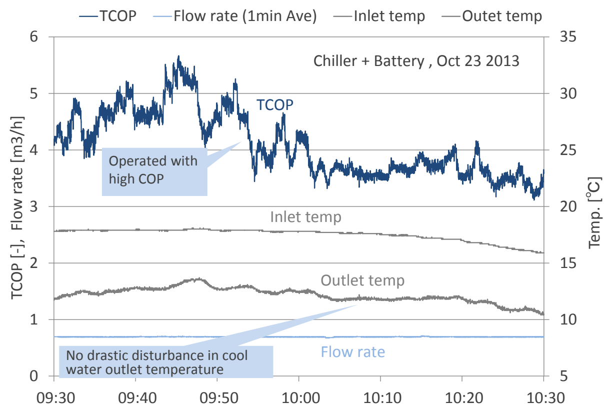


Figure 9 TCOP and cold water outlet temperature of the refrigerator which is integrated and controlled

4. BEMS2: Coordinated operation with other control system

4.1 System Overview

The second effort is the BEMS project led by Tokyo Gas, which was also constructed in the Aperture Center at Mesa Del Sol. BEMS1 of Shimizu Corporation and BEMS2 of Tokyo Gas are different systems implemented in the same hardware.

The configuration of the entire BEMS2 control system is shown in Figure 10 and Figure 11, and consisted of the same DERs as Shimizu's BEMS1 with a gas engine, fuel cell, PV, batteries and thermal source system. There were also two operation modes of (1) grid-connected mode and (2) islanding mode in this Tokyo Gas' BEMS2, the same two modes implemented in BEMS1. However, Tokyo Gas took the approach to place particular importance on supporting the operation of a large-scale PV plant (500 kW) and the large-scale energy storage (lead batteries, 500 kW/500 kWh) owned and operated by the electric power company (PNM). The large-scale PV plant and battery is located approximately 2 km from the Mesa Del Sol site, and are electrically connected to the same feeder as the Aperture Center building and BEMS.

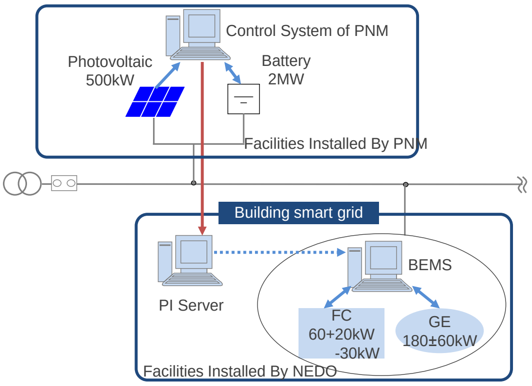


Figure 10 BEMS2 Configuration – Interconnected Operation-

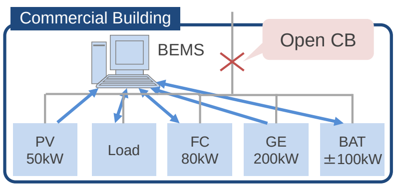


Figure 11 BEMS2 Configuration – Interconnected Operation-

For grid-connected mode, the BEMS2 of Tokyo Gas was controlled to operate in conjunction with the utility-owned PV plant and energy storage system. In Shimizu's BEMS1, on the other hand, operated in conjunction with the small-scale PV and small-scale energy storage within the microgrid during grid-connected mode.

The large energy storage system (battery) was installed by PNM on the grid side to compensate the PV plant fluctuations. However, as previously mentioned, storage batteries are expensive.

The demonstration was intended to demonstrate that the capacity of the large batteries could be reduced by coordinating the PV smoothing control with a gas engine and fuel cell using BEMS2. This experimental demonstration was implemented by Tokyo Gas and Sandia National Laboratories with the cooperation of Shimizu Corporation, Toshiba and PNM.

The control logic of this BEMS2 is shown in Figure 12. In this scheme, the output fluctuations of the PV plant is compensated by two generation sources of gas engine and fuel cell, and the difference in the output of PV plant and gas engine is compensated by the large storage batteries installed on the grid side.

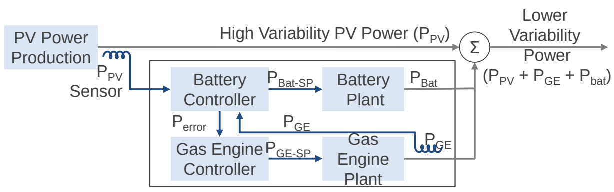


Figure 12 Coordinated Control of gas engine and battery

The result of the demonstration with Coordinated Control is shown in Figure 13. The experiment demonstrated that, in this case, the capacity of storage battery required to perform PV output smoothing can be lowered by approximately 14% with Coordinated Control compared to the case without Coordinated Control.

However, it must be noted that there factors such as communication delay can affect control performance. In the verification based on actual data (see Figure 14), it was indicated that the Coordinated Control has the potential to reduce battery capacity by up to 17.7% with a lower communication delay.

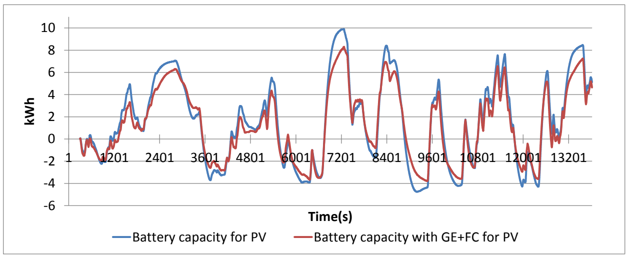


Figure 14 Verification of battery capacity reducing effect based on actual data

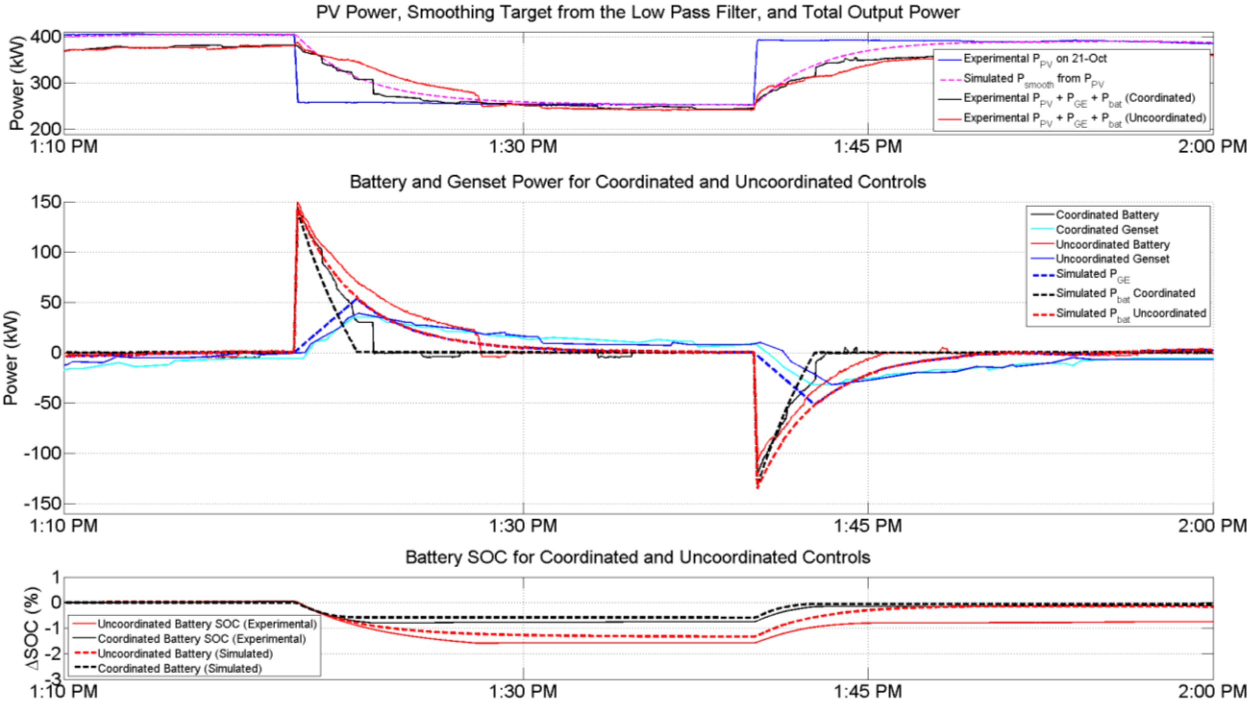


Figure 13　Performance of Coordinated Control

For the islanding mode, devices to be controlled are basically the same as in the case of Shimizu BEMS1, but the concept of control is different. As shown in the control logic in Figure 15, in the Tokyo Gas BEMS2, the gas engine was considered as the main energy resource within the island. In other words, it is basically the gas engine that takes charge of absorbing load fluctuations when in the islanding mode.

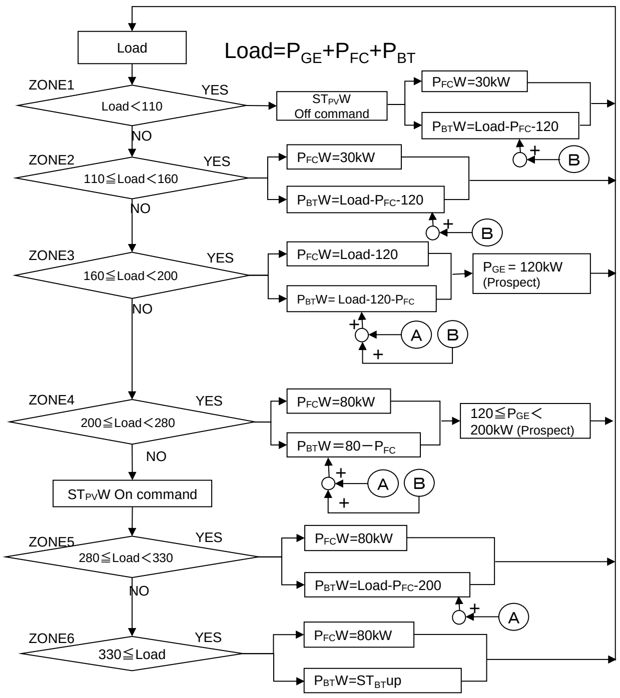


Figure 15　Logic of islanding operation of Tokyo Gas' BEMS2

The results of experimental demonstration with BEMS2 in islanding operation mode are shown in Figures 16. It is indicated that the power supply remained stable because of the distributed energy resources such as gas engine even when the load changed drastically.

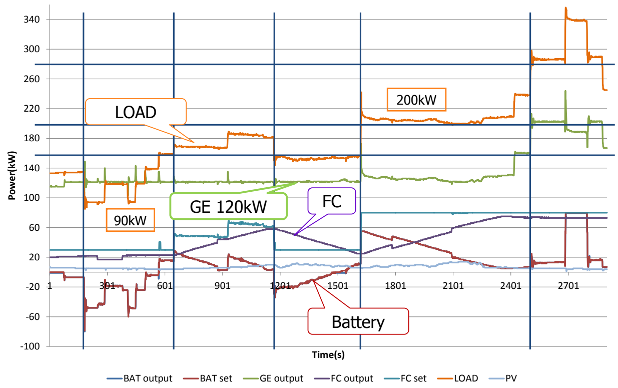


Figure 16　Results of islanding operation of Tokyo Gas' BEMS2

4.2 Key Findings – Lessons Learned

Three important lessons can be drawn from the BEMS2 demonstrations, as described below:

Lesson (1): Knowledge obtained from collaborative research

The approach based on BEMS2 which Tokyo Gas developed in cooperation with Sandia National Laboratories and PNM allowed coordination between the microgrid of the building in Mesa Del Sol and PNM's large scale PV and storage system. This was the first experience for microgrid community to integrate and operate the respective system of Japan and the U.S. Dr. Abraham Elis of Sandia National Laboratories spoke about the significance of this experience below. Collaborative efforts in the project deepened mutual understanding of technology challenges, and promoted a shared vision for future developments. This type of demonstration involving actual hardware and collaboration among customers, equipment manufacturers, researchers and utilities greatly contributes to the future development of smart grid.

Comment by Dr. Abraham Ellis

The collaborative research with the stakeholders in Japan and in New Mexico has been very important for Sandia National Laboratories and contributed to a very successful project.

The fact that various stakeholders in Japan and the U.S. conducted a research collaboratively, shared a vision and discovered areas where they could work together was an important contribution to the future cooperation between the two countries in this field.

Microgrid is the technology that facilitates modernization of electric system by enabling efficiency improvement, maximum use of renewable energy and resilient energy supply.

We would like to further promote the research based on the fruitful results of this research project.

It was demonstrated in this collaborative research that a number of distributed generators in different sites could be controlled for a single common purpose. The demonstration experiment was successfully completed in this regard, but there were also challenges that surfaced only after carrying out the experiment. Dr. Abraham Ellis from Sandia National Laboratories reflected on an important lesson learned for future consideration on communication-related requirements.

Comment by Dr. Abraham Ellis

The Prosperity Site (PNM's large PV-storage demonstration) and the Aperture Center in Mesa Del Sol are physically separated, so the key issue was the requirement for remote communication. We were also interested in whether the electric utility can control the distributed generations on demand side. The two systems were not designed to interoperate, and enabling full communication for control purposes was a challenge.

We have to consider how the communication interfaces should be standardized in the future.

Although the simulated reduction in storage battery capacity was 17.7% as previously described, the performance of actually built system resulted in less than 17.7% due to communication delay, etc. As Prof. Andrea Albert Mammoli commented, there are many factors that we found only after we actually implemented the demonstration experiment. The experiments produced the expected results, but also produced new lessons learned for all of us.

Lesson (2): Demonstrated performance of gas engine to contribute to the grid operation

Through this BEMS2-based approach which Tokyo Gas developed in cooperation with Sandia National Laboratories and PNM, it was verified that CHP systems such as a gas engine and fuel cell are highly effective for the local compensation of variable energy sources including PV. By operating DERs at partial load, there will be a margin for the adjustment. If we can control this margin in an appropriate manner, we can reduce the control actions that the power system is required to perform, thereby contributing to the proper operation of power system. Dr. Takao Shinji of Tokyo Gas, who led the project, described his experience with the experiment as follows:

Comment by Dr. Takao Shinji

I am satisfied with this experimental demonstration because the expected results have been verified.

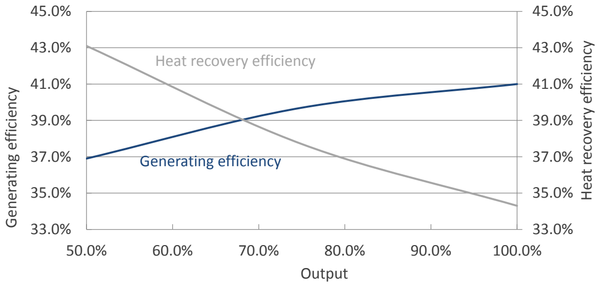
It has an important implication in terms of the proven universality of this solution that it was demonstrated here in New Mexico with the assistance of Sandia National Laboratories and PNM that gas engine, fuel cell and other power generation devices for customers can contribute to stabilizing power system without losing the original function as power-generating equipment.

In general, energy storage as a solution for high penetration of PVs will be introduced in order to stabilize power system as a new function. On the other hand, this demonstration shows that gas engines and fuel cells that have been already introduced by customer could also be used for the stabilization of power system. If these existing CHP systems can be used not only as the original power-generating facility but also as the contributing factor to the power system operation, the effectiveness of DERs can be further enhanced.

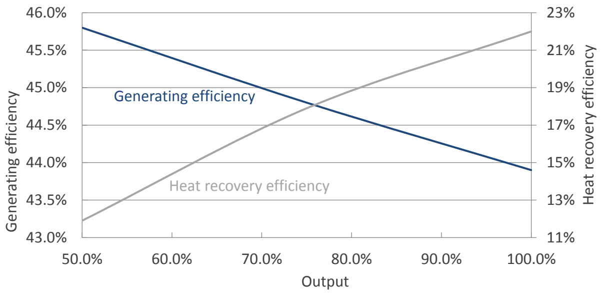
It should be noted here that the generation efficiency of gas engine and fuel cell would drop if they contribute to power grid operation. If there is a substantial decline in the generation efficiency because of the partial load operation, the contribution to power grid operation may be limited by cost considerations. Figure 17 shows the characteristics of partial load operation of gas engine and fuel cell. In partial load operation, gas engines have the characteristic that generation efficiency decreases but heat recovery efficiency increases. For fuel cell, its heat recovery efficiency drops but the generation efficiency improves. That is to say, partial load operation may not have a significant impact on the overall efficiency of an entire system. From these features, there is ample room for us to study on the contribution of gas engines and fuel cells to power system operation so as to realize the overall optimization of power system operation.

Lesson (3): Possible islanding operation mainly by gas engine

Arguments on islanding operation of microgrid often focus on energy storage including batteries because of their excellent responsiveness. For BEMS1 of Shimizu, the method of islanding operation has been established to fully utilize the batteries.
For BEMS2 of Tokyo Gas, on the other hand, the method of islanding operation has been established based on gas engine instead of utilizing the high capability of energy storage. Compared to batteries, gas engine's responsiveness is not quick (measured by the ramp rate of the DER). However, the demonstration presented the possibility using a gas engine for power management of microgrid in islanding state.



(a) Gas Engine



(b) Fuel Cell

Figure 17 Characteristics of the partial load operations of gas engine and fuel cell

When designing a microgrid, whether to have an integrated system including energy storage or to make a simple CHP-based system largely depends on the decision made by the entity who adopts the equipment. However, as mentioned above, the two experimental demonstrations conducted in Albuquerque showcase two viable technical solutions.

5. Acknowledgment

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This Case Study was commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

6. Reference

[1] *NEDO, "Report on Japan-US Collaborative Smart Grid Demonstration Project, Smart Building Demonstration in Albuquerque," NEDO FY 2010 – FY 2013 Project Report, 2014. (in Japanese)*

[2] *Use Case- "BEMS Control of DERs and HVAC Equipment in a Commercial Building Which Enables Islanding Operation and Demand Response", posted on the EPRI Smart Grid Use Case Repository. June, 17, 2011.*

[3] *Atsushi Denda; Outline of the Albuquerque smart grid project for commercial buildings -Japan-US collaborative smart grid project in New Mexico- , IRED2014, Nov. 18. 2014.*

[4] *Kimio Morino; Demonstration of the Smart Grid at a Commercial Building in City of Albuquerque, IRED2014, Nov. 18. 2014.*

[5] *J. Johnson, K. Morino, A. Denda, J. Hawkins, B. Arellano, T. Ogata, T. Shinji, M. Tadokoro, A. Ellis, "Experimental Comparison of PV-Smoothing Controllers using Distributed Generators", Sandia Report SAND2014-1546, 2014*

[6] *A. Ellis and D. Schoenwald, "PV Output Smoothing with Energy Storage," Proceedings of the 38th IEEE Photovoltaic Specialists Conference, Austin, TX, 3–8 June 8, 2012.*

[7] *J. Johnson, A. Ellis, A. Denda, K. Morino, T. Shinji, T. Ogata, M. Tadokoro, "PV Output Smoothing using a Battery and Natural Gas Engine-Generator," 39th IEEE Photovoltaic Specialists Conference, Tampa Bay, Florida, 16-21 Jun, 2013.*

[8] *Interviews with stakeholders by author*