VOLTAGE AND FREQUENCY STABILITY ENHANCEMENT OF THE ISLANDED MICROGRID USING BATTERY ENERGY STORAGE

Changhee CHO Jin-Hong JEON Soonman KWON Kee-Young NAM Sungshin KIM
KERI–South Korea KERI–South Korea KERI–South Korea Halla E&E-South Korea Pusan Nat'l Univ.–South Korea
chcho@keri.re.kr jhjeon@keri.re.kr smk@keri.re.kr kynam@hallanup.com sskim@pusan.ac.kr

ABSTRACT

Microgrid is an aggregation of multiple micro-sources such as renewable resources, conventional generators and energy storages providing both electric power and thermal output. To the large scale power system, a microgrid is considered as a single controllable unit connected by a point of common coupling (PCC). In general, a microgrid operates in parallel with main grid. However there are cases when a microgrid operates in an islanded mode which means in a disconnected state from the main grid. Energy storage is essential for the maintaining the energy balance of the microgrid in islanded operation. In this paper, the voltage and the frequency stability of the islanded microgrid is treated. And impact of the energy storage on the stability of the islanded microgrid is also verified by the experimental cases. To show the experimental results, the microgrid test bed was built. Two test cases were performed to see the effectiveness of the energy storage in the voltage and frequency stability enhancement.

INTRODUCTION

Until recently, power quality of an islanded system is not getting much attention. Because it is considered as a trivial matter for minor users and the cost is too heavy to maintain the power quality in the islanded situation. As the microgrid grows in the future, the power quality issue in islanded system is expected not just a matter of minor peoples but the problems of the major public who are supplied by the microgrid distribution system. The microgrid is made up of large numbers of onsite distributed energy resources (DER) as well as electrical and thermal loads [1]. The Microgrid is expected to provide multiple benefits. It will improve the penetration ratio of the green energy so that it will help the environment by diminishing CO2 emission. It also improves the energy efficiency by the nature of onsite generation of DER without transmission loss. CHP system which recovers the waist heat is another factor for high efficiency [2][4]. Improvement of the reliability and power quality is the other benefit. By customizing the quality of power system to the customer's request, microgrid can provide more reliable and flexible power. The energy surety microgrid project for military bases is one example of this enhanced reliability of the microgrid [3]. Until now numerous researches of microgrid had been conducted and a number of major research projects are still underway around the world. Many demonstration facilities exists to test and verify the various feature of the microgrid [5][6].

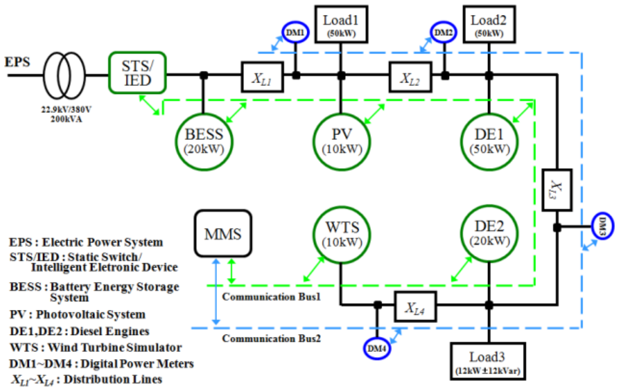
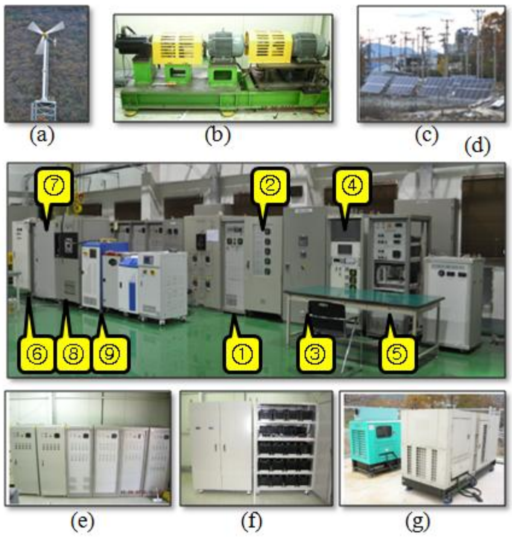


Fig. 1 Structure of the microgrid pilot pant

MICROGRID PILOT PLANT

Fig. 1 shows the structure of the microgrid pilot plant. To test and verify the behavior of complex microgrid system, the microgrid pilot plant was developed in the laboratory [7][8].The pilot plant is a relative term meaning that the size is relatively smaller than the real microgrid. Although the generating units have conventional rotating generators such as diesel generators or CHP generators, most DER operates by the power electronics technology


(a) (b) (c) (d)

(e) (f) (g)

Fig. 2 Experimental setup of the microgrid

To evaluate the stability enhancement of the battery energy storage system (BESS), the microgrid pilot plant were used. Fig. 2 shows the experimental setup of the microgrid pilot plant. All control panels were installed inside of the laboratory building (d). The control panels consists of static switch ①, the distribution network simulator ②, control panel for the diesel generator1(DG1,50kW; ③), control panel for DG2 (20kW; ④), the BESS panel ⑤, the inverter for wind turbine ⑥, the control panel for MG set inverter ⑦, the control panel for the hybrid system ⑧, the photovoltaic inverter ⑨ and so forth. Some components are installed outside or in other building. They are the wind turbine (a), the MG set for wind turbine simulator (b), the photovoltaic panels (c), the loads simulator (e), the lead acid battery bank (f) and two diesel generators (g).

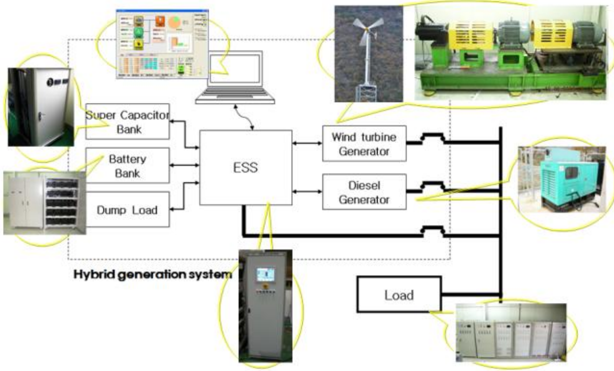
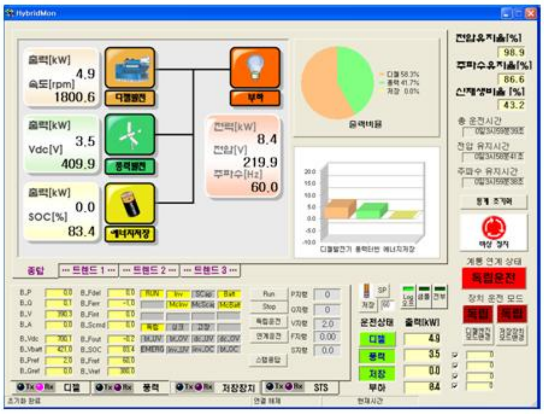


Fig. 3 Configuration of the islanded microgrid

ISLANDED MICROGRID

By using the combination of the microgrid pilot plant, the experimental setup of islanded microgrid was configured. Fig. 3 shows the configuration of the islanded microgrid. For the wind turbine generation, we had used WT simulator because it can provide consistent output even when wind does not blow. Diesel generator has the rated output of 20[kW]. It may change its operational mode freely and easily between the grid connected and the islanded mode. And it provides other generators with the references of the frequency and the voltage when it operates as islanded.


HybridMon

출력[kW] 4.9
속도[rpm] 1800.6

출력[kW] 3.5
Vdc[V] 409.9

출력[kW] 0.0
SOC[%] 83.4

전력[kW] 8.4
전압[V] 219.9
주파수[Hz] 60.0

전압유지율[%] 98.9
주파수유지율[%] 86.6
신재생비율[%] 43.2

Fig. 4 Central monitoring and control software

Fig. 4 shows the administrational program to control and monitor the microgrid system. It is connected to the controllers of WT simulator/diesel generator/energy storage by serial network. It plays a role of the operator interface which displays analog data/discrete status and it sends control gains/parameters to controllers.

Measurement of the retention rate

The measurement of voltage and frequency were performed using the measurement technique of international standard for power power quality measurement method (IEC61400-4-30). Actual measurement was done by the power quality analyzer (PQA; WT3000). To calculate the retention rate of the voltage and the frequency, you have to distinguish a good from bad data. The suitability of data is decided by the criterion of Korean law regarding the electricity enterprises act. The criterion of maintaining the power quality is shown as table 1. The retention rate is calculated as the percentage of suitable data counts over an entire measurement counts.

Item	Nominal value	Permissive error
Voltage [V]	110	< ± 6
	220	< ± 13
	380	< ± 38
Frequency [Hz]	60	< ± 0.2

Table 1 The suitability criteria

Case 1 : varying wind + fixed load condition

Case 1 is a test case to check the stability of the voltage and the frequency under the condition of fluctuating WT output. For the experiment, the wind turbine simulator was programmed to produce variable output caused by severely varying wind. The output fluctuates from 1.6 [kW] minimum to 7.2[kW] maximum and the average of 4.9[kW]. The electrical load is fixed to 24[kW]. You can see that the output of diesel inversely proportional to the WT output. The proportion of the WT output to the total output is said to as the renewable ratio. It can be observed in Fig. 5, Fig. 7. The renewable ratio also fluctuates as WT output change and it has the minimum of 7.1[%], the maximum of 32.0[%] and the average of 21.9[%]. Figs. 5~6 and Figs. 7~8 are results of the uncontrolled and the BESS controlled respectively. Total measuring time is 4 minutes with the sampling of 50 msec. In other words, total 4800 samples were taken. Each sample is distinguished by the criterion. Consequently the retention rate of the voltage and the frequency are calculated. The measurement result is summarized in table 2. Because the criteria for the voltage is so wide, you can see the voltage retention rate is 100% regardless of control. However, the frequency retention rate of the BESS controlled shows better results more than 10% compare to the uncontrolled.

	Uncontrolled		BESS controlled	
Item	Voltage	Frequency	Voltage	Frequency
# of Measurement data	4800	4800	4800	4800
# of suitable data	4800	4000	4800	4558
Retention rate [%]	100.0	83.3	100.0	94.9

Table 2 The measurement result of the case 1

Case 2 : varying wind + varying load condition

Case 2 is more severe than case 1. In addition to fluctuating WT output, the electric load is also programmed to change with a variable pattern. You can see the diesel output is changing abruptly as load changes (Fig. 9, Fig. 11).Variation range of the load is from 4[kW] to 36[kW]. The measured value of renewable ratio varies between 8.5[%] to 100[%], and the average of 50.6[%]. The results of case 2 are shown in table 3. For the voltage, result is same as in case 1. The frequency retention rate is lowered as expected for both but proves the definite stability enhancement of the BESS controlled.

	Uncontrolled		BESS controlled	
Item	Voltage	Frequency	Voltage	Frequency
# of Measurement data	4800	4800	4800	4800
# of suitable data	4773	3535	4725	4155
Retention Rate [%]	99.4	73.6	99.0	86.6

Table 3 The measurement result of the case 2

CONCLUSION

This paper provides a brief review of the voltage and frequency stability issue of the microgrid in islanded operation. With the aid of stabilizing control in the developed energy storage, the voltage and the frequency stability of the islanded microgrid is comparably enhanced than the uncontrolled system. The developed battery energy storage and coordinated control system were verified by the two experimental cases. The experimental results show that the retention rate of the voltage and the frequency had risen up more than 10 percent under the condition of abrupt load change and severely fluctuating renewable output.

REFERENCES

[1] R.H.Lasseter, 2002, "MicroGrids", *Proceedings Power Eng. Soc. Winter Meeting*, vol.1, 305~308

[2] F. Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas, 2008, " Microgrids Management-Controls and Operation Aspects of Microgrids ", *IEEE Power and Energy Mag*, vol.6, 22-29

[3] M. R. Vallem, D. Jensen, J. Mitra, 2006, "Reliability Evaluation and Need Based Storage Assessment for Surety Microgrids ", *Proceedings North Amer. Power Symp.*, 29-33

[4] C. Xiarnay, H. Asano, S. Papathanassiou, G. Strbac, 2008, " Policymaking for microgrids ", *IEEE Power and Energy Mag.* vol. 6, 66~77

[5] M. Barnes, J. Kondoh, H. Asano, J. Oyarzabal, G. Ventakaramanan, R. Lasseter, N. Hatziargyriou, 2007, "Real-World MicroGrid-An Overview", *Proceedings IEEE Conf. on Syst. of Syst. Eng.*, 1-8

[6] F. Katiraei, M. R. Iravani, P. W. Lehn, 2005, "Micro-Grid Autonomous Operating During and Subsequent to Islanding Process", *IEEE Trans. Power Del.* vol. 20, 248-257.

[7] J.-Y. Kim, J.-H. Jeon, S.-K. Kim, C. Cho, J. H. Park, H.-M. Kim, K.-Y. Nam, 2010, "Cooperative Control Strategy of Energy Storage System and Microsources for Stabilizing the Microgrid during Islanded Operation ", *IEEE Trans. Power Electron.*, vol. 25, 3037-3048

[8] C. Cho, S. -K. Kim, J. -H. Jeon, S. Kim, 2011, "New Ideas for a Soft Synchronizer Applied to CHP Cogeneration", *IEEE Trans. Power Del.*, vol. 26, 11-21

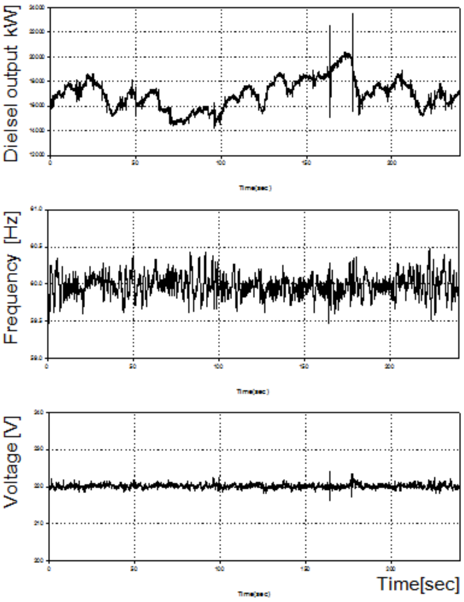


Fig. 5 Measurement of PQA (Case1-Uncontrolled)

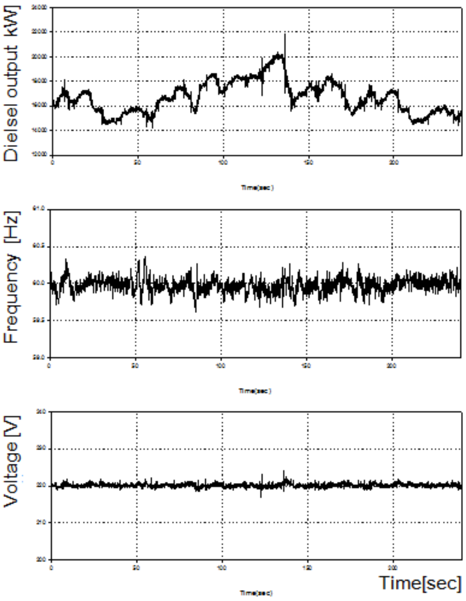


Fig. 7 Measurement of PQA (Case1 - BESS controlled)

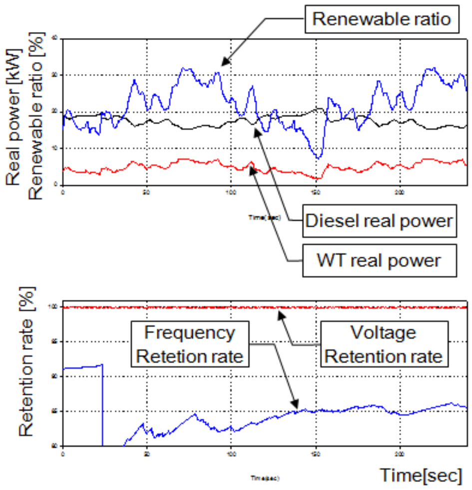


Fig. 6 PC monitoring (Case1-Uncontrolled)

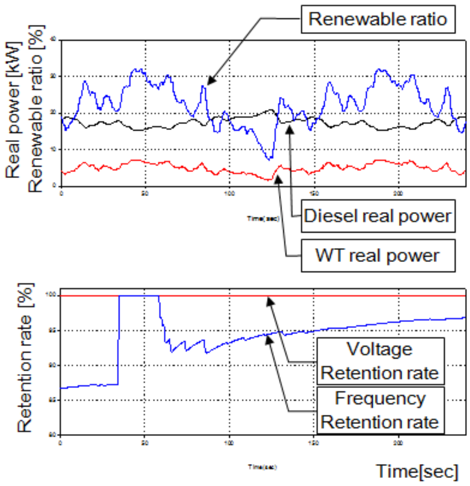


Fig. 8 PC monitoring (Case1-BESS controlled)

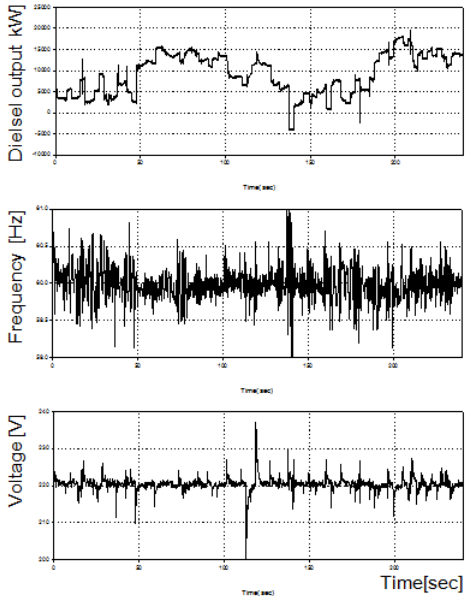


Fig. 9 Measurement of PQA (Case2-Uncontrolled)

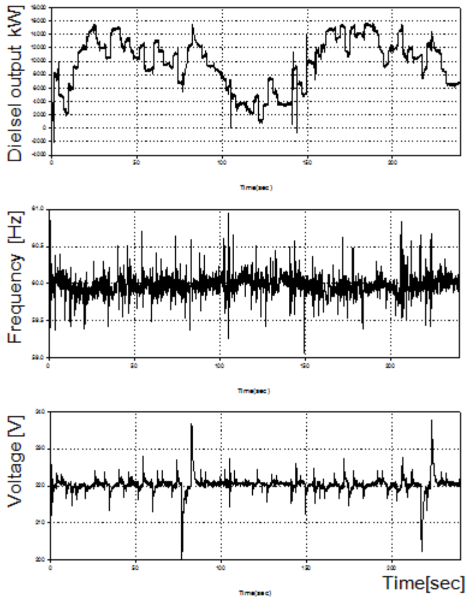


Fig. 11 Measurement of PQA(Case2-BESS controlled)

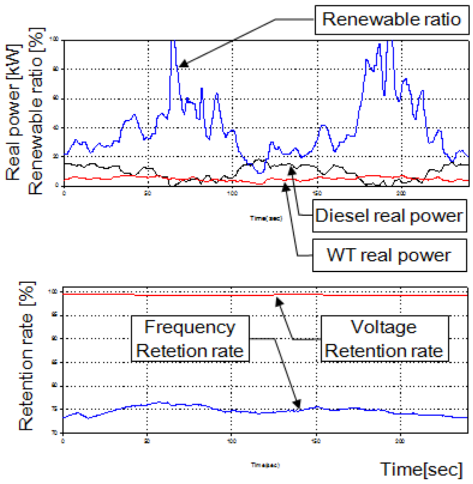


Fig. 10 PC monitoring (Case2-Uncontrolled)

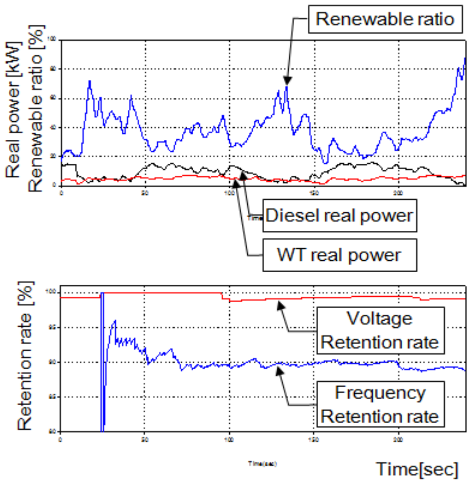


Fig. 12 PC monitoring (Case 2-BESS controlled)