PRELIMINARY REGULATIONS OF ESS CONNECTED TO KOREAN ISOLATED ISLAND POWER SYSTEM TO MINIMIZE THE CAPACITY OF ESS

JunBo SIM	HakJu LEE	YongSeung LEE	Il Keun Song	Joong Yeol Ahn
KEPRI, Korea	KEPRI, Korea	KEPRI, Korea	KEPRI, Korea	KEPRI, Korea
jbsim@kepco.co.kr	jureeya@kepco.co.kr	yslee88@kepco.co.kr	sk33@kepco.co.kr	hyahn@kepco.co.kr

ABSTRACT

In the islanding microgrids, there could occur a problem when ESS is operated in CVCF(Constant Voltage Constant Frequency) mode. In order for ESS to be operated in CVCF, it should have enough capacity to insure total demand required in the grid. If there is energy unbalance between supply and demand and the capacity of ESS is not enough to supply the power required from the loads, DGs instead of ESS need to support necessary power to maintain grid frequency constant. However, DGs cannot respond to frequency change due to constant frequency operation of ESS even it has frequency-power support functions. This makes microgrid power system reduce its efficiency and require enough capacity of ESS which can insure total demand of the grid. It causes lower economics problem. In order to help DGs or renewables respond to grid frequency change even in CVCF operation mode of ESS, ESS should have special function named 'Indirect voltage regulation' and presented in the paper.

This paper briefly introduces grid codes for DERs(Distributed Energy Resources) connected to 'stand-alone energy island' KEPCO is recently carrying out and presents necessity of indirect voltage control of ESS.

INTRODUCTION

Preliminary regulations for DERs

Only several countries have regulations for DERs connected to islanding microgrids even though they have that connected to bulk grids. Because the regulations should reflect characteristics of both transmission and distribution system, it could be quite stringent. In other words, requirements for DERs can be more various and complicated than DERs is connected to either transmission and distribution system. Regulations for DERs connected to islanding microgrid system issued as a grid code is rare and only some documents introduce functions necessary for DERs to help grid connection[1]. The guideline from IEC is also one of the references possible to refer to as regulations for DERs[2]. In compared with existing transmission or distribution grid codes, possibly required regulations are focused on control and operation functions to support grid frequency and voltage stability. The list of preliminary regulations for DERs in Korea are presented in table 1.

Table 1. The list of preliminary regulations for DERs

Regulations		Details
Frequency fluctuations		• Continuous operation • Frequency regulations
Voltage fluctuations		• Continuous operation • Switching operations
Frequency support		• f-P droop control • Virtual inertia response(for wind)
Voltage support		• Unbalanced voltage operation • Harmonic reduction • Q-V droop control or Voltage regulation
Power quality	Harmonics	• Current or Voltage harmonics • Inter-harmonics and higher frequency components • Converter switching harmonic limitation
	Flicker	• Long term flicker factor • Short term flicker factor
	DC current	• No DC current injection
Fault Ride Through		• Low voltage ride through • High voltage ride through • Dynamic reactive current support
Active power		• Power reduction • Ramp rate limitation • Power production constraint • Delta control(except for solar)
Reactive power		• reactive power capability • Set-point control • Power factor control
Protection system / Reconnection		• Anti-islanding • Re-synchronization and re-connection time • Islanding/non-islanding mode transaction • Rate of change of frequency relay • Black start function • Withstanding frequency/voltage deviations

Many of regulations for DERs are concerned with control functions differently from that for distribution system connection. Regulations for transmission system connection such as frequency support and black start are also shown. New functions like withstanding frequency/ voltage deviations and virtual inertia response are additionally considered. Some of these regulations in the list is going to be selected and required after detail evaluation and verification by analysis and reflection on reality.

Necessity of the proposed function of ESS

Some of the regulations require DERs, especially for wind turbine to help grid frequency regulation. And the wind turbines connected to the transmission or distribution system should be possible to reduce or increase their power according to the change of grid frequency as depicted in figure 1[3].

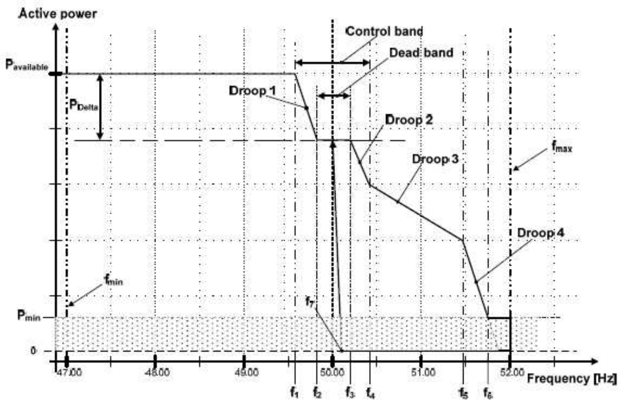

Figure 1. Frequency control requirement in Denmark

Most DERs to participate in frequency control use frequency error between reference signal and sensing frequency, then decide compensated power demand for frequency control as shown in figure 2[4].

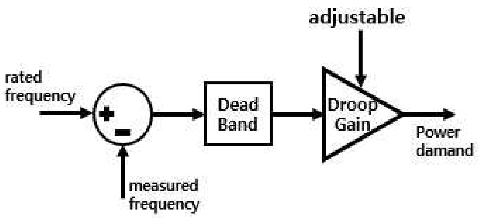

Figure 2. General frequency control algorithm of DERs

However, when microgrid is operated in CVCF mode by ESS, DERs cannot participate in frequency control and contributed to frequency regulation because its sensing frequency is constant at the rated frequency generated by ESS. Instead, grid voltage drops due to lacking of active power supply. This phenomenon occurs in every generating machine when ESS is operated as reference machine to regulate grid frequency and voltages. Figure 3 shows voltage drop phenomenon by lacking of active power supply in CVCF mode of ESS.

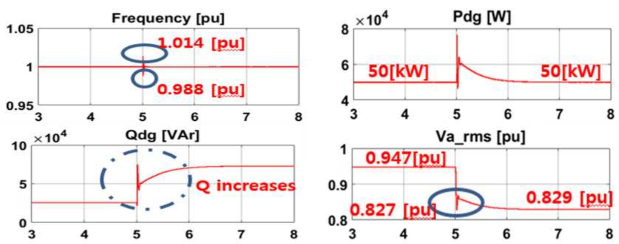

Figure 3. Frequency control problem of DERs during CVCF operation of ESS

When ESS and DGs are in the parallel operation, if there is energy unbalance between supply and demand, DGs cannot participate in droop control due to constant grid frequency and voltage drop is shown even though it tries to supply its reactive power to maintain grid voltage.

When CVCF operation is required, this makes microgrid system inefficient and the capacity of ESS quite high because ESS should endure all loads and losses to maintain grid frequency and voltages. Therefore, centralized controller can be adapted to observe the grid frequency and voltages and dispatch necessary compensating power to DERs by communication. Then, the capacity of ESS to maintain grid frequency and voltages can be reduced dividing its loads with installed DERs in the microgrid. However additional system needs more cost and it cannot be proper for low capacity and simple microgrid system by expensive expenses.

The proposed function of ESS makes DERs possible to participate in frequency control by itself.

A PROPOSED FUNCTION OF ESS

General control of ESS for CVCF operation

CVCF operation of ESS has been studied in several papers and can be divided by two representative control algorithms. One is constant frequency control of ESS using proportional resonance(PR) controller in stationary axis frame[5]. And the other one is to use PI controller in d-q axis frame. The second one is again divided by two control block, with/without inner current control loops. The CVCF control block in d-q axis frame without inner current control loops is as shown in Figure 4[6].

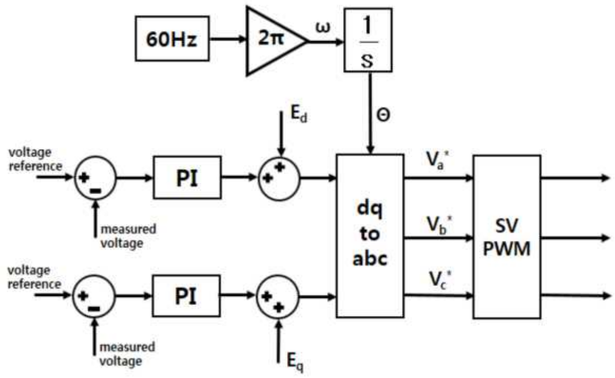

Figure 4. General control block of ESS for CVCF operation mode

The PI controller is used with voltage error as an input and voltage reference for PWM as an output. The reference voltage in d-q axis is transformed to abc frame reference voltage for PWM. The phase angle position used for d-q to abc axis transformation is the integration value of 60Hz. Here, the value of 60Hz is the constant frequency for CVCV operation of ESS. If the value of 60Hz is changed, grid frequency will also change. However, grid frequency does not change when there is no change in the integrated fixed frequency set-point.

Proposed control of ESS for CVCF operation

In order for DERs or DGs to participate in frequency control and support supply-demand balance in the grid, reference frequency of ESS needs to be changed responding to grid voltage changes. If there is no accident in the grid and grid voltage drops when measured current is controlled at the rated current, it means supply and demand are different. Then, ESS needs to its reference frequency and DERs or DGs should respond to the grid frequency changes. When constant frequency control of ESS using proportional resonance(PR) controller is implemented in the grid, special control algorithm may be necessary. However, if vector in the d-q axis frames proposed control for IVR(Indirect Voltage Regulation) can be possibly implemented using control blocks as shown in Figure 5.

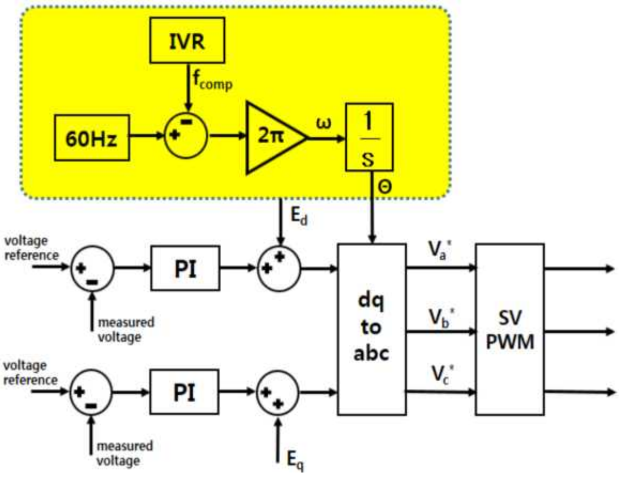

Figure 5. Proposed control blocks of ESS for CVCF operation mode

The control blocks in the yellow field of figure 5 indicates the compensating method of IVR in the d-q axis frames. Other two methods can be possible according to the compensating parameter and gain of IVR as figure 6.

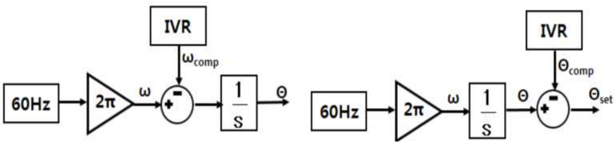

Figure 6. Proposed compensation blocks for CVCF operation mode

Internal control blocks of IVR is as depicted in figure 7. The error between the minimum value among three pre-calculated grid voltage and rated voltage or different reference voltage is used as an input of PID controller with filters through a dead band block. Then, the final value for the compensation can be decided. If the compensating parameters are changed like figure 6, the gain and filters of PID should be changed properly.

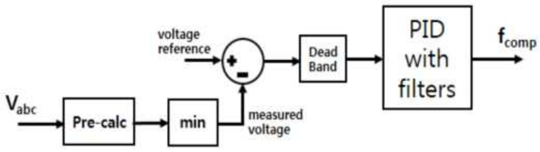

Figure 7. Internal control block of Indirect Voltage Regulation(IVR)

SIMULATION AND ANALYSIS

In order to analyse CVCF operation of ESS and verify indirect voltage regulation, MATLAB/SIMULINK was used. The designed power system consists of two diesels of 300kW, one DER of 500kW, one ESS of 500kW, and three lumped loads of 250kW, 300kW, 500kW. the designed power system is as shown in figure 8.

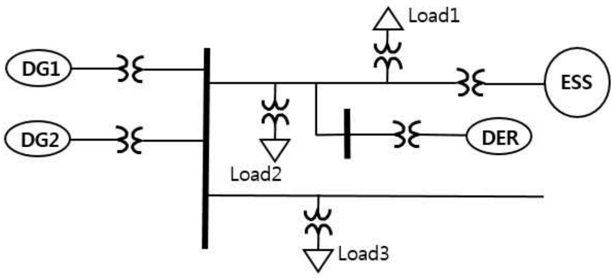

Figure 8. Simple configuration of simulation model to verify Indirect Voltage Regulation

The purposes of the simulation are to show how DGs and DER respond to the changes of loads and generation and to verify IVR is necessary when CVCF operation of ESS. The simulation has two cases; without and with IVR function of ESS under the condition of what DGs and DER have power-frequency droop algorithm.

Without Indirect Voltage Regulation

Scenarios to be implemented are as below:

- Base load of 500kW
- Additional load of 300kW at 4s
- Additional load of 400kW at 6s

Without IVR, it is expected for the power system to be collapsed due to the unbalance of supply and demand. In the simulation, ESS cannot maintain the grid voltages to the rated level and the power goes to the breakdown. Figure 9 shows unstable grid voltages.

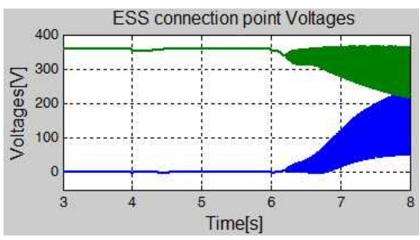

Figure 9. Voltages at PCC of ESS

When loads increases, DER and DGs do not increase their power as in figure 10, because grid frequency does not change by constant frequency control of ESS as in figure 11.

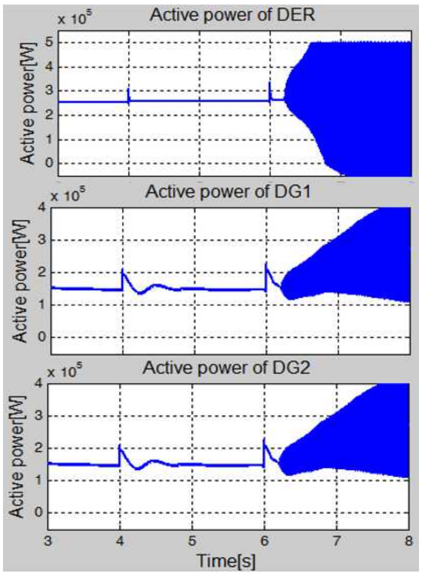

Figure 10. DER and DGs responses

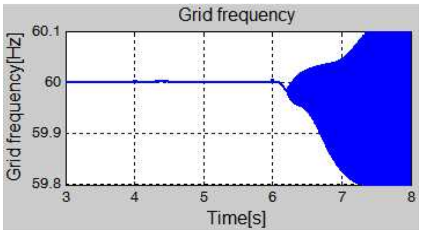

Figure 11. Grid frequency

Therefore, ESS should endure the increased load to maintain grid voltage reduced by lack of active power component. At 4s, the active power of ESS increases as 300kW to maintain it voltage level. However, its capacity cannot satisfy the lacking power at 6s and the power system goes to unstable states as in figure 12.

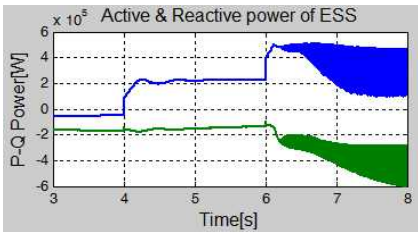

Figure 12. Active and reactive power of ESS

With Indirect Voltage Regulation

Scenarios to verify IVR has been changed to clearly show the effect as below:

- Base load of 500kW
- Additional load of 700kW at 4s
- Rejection of DG2 at 6s

As soon as load increase at 4s and rejection of DG2 at 6s, IVR works and grid frequency goes down by designed gains as in figure 13.

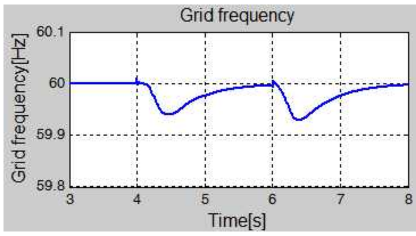

Figure 13. Grid frequency

Then, DER and DGs respond to share the increased load by its droop rates.

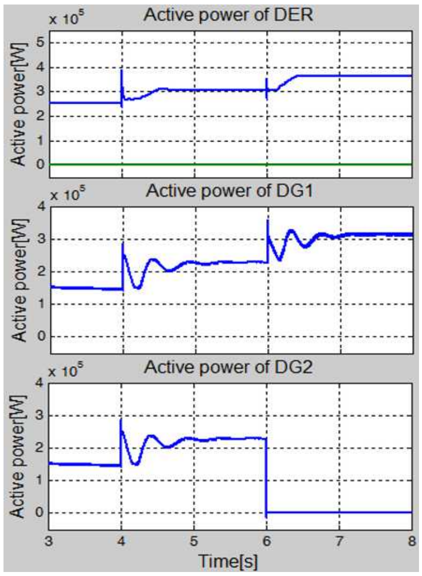

Figure 14. DER and DGs responses

Of course, ESS also respond to the change of load at 4s and rejection of DG2 at 6s as depicted in figure 15.

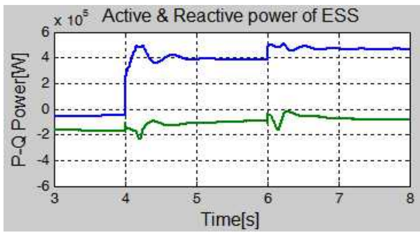

Figure 15. Active and reactive power of ESS

As a result, grid voltage can be maintained and the power system stays in the stable region as in figure 16.

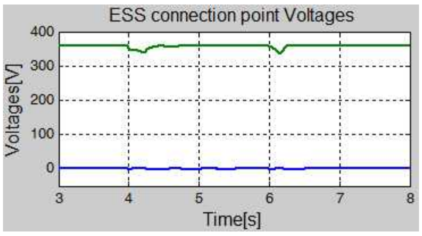

Figure 16. Voltages at PCC of ESS

CONCLUSION

Because DERs or DGs cannot recognize and respond to the grid frequency and participate in frequency control due to the constant grid frequency when CVCF operation mode of ESS is implemented, special algorithm for DERs or DGs to support frequency control of ESS. If supply and demand are unbalance and the capacity of ESS is lacking, grid voltage sags occurs. Then, we can use this phenomenon and possibly change reference frequency of ESS operating in CVCF mode. This means we can change grid frequency using the voltage sags and make DERs and DGs participate in frequency control with the temporary grid frequency change. This is possible on the DERs' side like P-v droop control as required by SIWG(Smart Inverter Working Group) in U.S[7]. However, most DERs and DGs do not have P-v droop control function and it would be hard to modify pre-installed DERs and DGs of islanding power system under the plan. Therefore, ESS needs to have IVR function in order to help DERs participate in the frequency control. Here, the trigger signal to make IVR work is very important because IVR can be unnecessary response in normal operation. Therefore, the IVR should work with following two conditions.

- Positive and negative maximum of active current with grid voltage drop
- Polar limits of SOC inside DOD with grid voltage drop

In this paper, IVR function of ESS is proposed and verified by simulation. The developed IVR function of ESS will be implemented in the field test in the future and be required as an essential control algorithm of ESS after verification of its validation.

Acknowledgments

This work was supported by Korea Electric Power Research Institute(KEPRI) belonging to Korea Electric Power Corporation(KEPCO) for the project No. R16DA06.

REFERENCES

[1] E.M.G. Rodrigues, G.J. Osorio, R. Godina, A.W.Bizuayehu, J.M. Lujano-Rojas and J.P.S. Catalao, 2016, "Grid Code Reinforcements for Deeper Renewable Generation in Insular Energy Systems", *Renewable and sustainable energy reviews 53*, 163-177, Elsevier Ltd.

[2] IEC TC8, 2016, "IEC/TS 62786: Distributed Energy Resources connection with the grid", *IEC/TS 62786 Ed.1.*

[3] Energinet.dk, "Technical regulation 3.2.5 for wind power plants with a power output greater than 11kW", *Document no.55986/10, Technical Regulation 3.2.5.*

[4] Sylvain Baudoin, Ionel Vechiu and Haritza Camblong, 2012, "A review of voltage and frequency control for islanded microgrid", *ICSTCC, 16th International Conference on, IEEE.*

[5] Juan C. Vasquez, Josep M. Guerrero, Mehdi Savaghebi, Joaquin Eloy-Garcia and Remus Teodorescu, 2011, "Modelling, Analysis, and Design of Stationary Reference Frame Droop Controlled Parallel Three-Phase Voltage Source Inverters", *Power Electronics and ECCE Asia, 2011 IEEE 8th International Conference on.*

[6] Woo-Hyun Hwang, Sang-Kyu Kim, Jung-Ho Lee, Woo-Kyu Chae, Je-Ho Lee, Hyun-Jun Lee and Jae-Eon Kim, 2014, "Autonomous Micro-grid Design for Supplying Electricity in Carbon-Free Island", *Journal of Electrical Engineering and Technology Vol. 9, 742-748.*

[7] Pacific Gas and Electric Company, 2015, "Generating facility Interconnections", Electric rule No. 21, San Francisco, California.