

Voltage Control Method of Micro Hydropower Generators for Voltage Stabilization in Distribution Feeder with Renewable Energy Sources

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Abstract: This paper analyses the problem of voltage control by step voltage regulator (SVR) in the primary feeder with large-scaled PV systems, and presents operation ranges and the voltage control limit of micro hydropower generator (MHG) with power factor (PF) control function. In addition, this paper evaluates the voltage impact in primary feeders depending on voltage control modes of MHG, and then proposes an optimal voltage control algorithm. Furthermore, from the simulation results based on the proposed algorithm, it is verified that it can contribute to voltage stabilization in the distribution system with large-scaled PV systems.

Keywords: large scale PV system; micro hydropower generator; optimal voltage control; reactive power; voltage stabilization

1 INTRODUCTION

Recently, the government has started pushing a green growth policy as one of the next-generation industries, and also actively performing the demonstration project of 11% renewable sources among total energy by 2030. According to the activity plan of renewable energy sources, local governments and renewable energy producers are actively installing and operating large scale PV systems in the distribution system. However, when the PV systems were interconnected and operated in distribution systems, many problems related to power quality such as voltage fluctuation in distribution system have occurred [1-5]. Under these circumstances, the power company has installed SVR in order to keep voltages of customers within allowable voltage limits in distribution feeders with PV systems [6, 7]. In addition, the distributed generations, renewable energy sources, should be kept at more than 90% of PF in accordance with the grid interconnection codes, and in case of technically necessary, the upper and lower limits of PF should be controlled according to technical guideline of the power company, and also PF of the distributed generations must not become leading PF at the point of distribution system which is lagging PF at distributed generations [8, 9]. However, despite such voltage regulators and technical guidelines, there are many problems associated with the voltage fluctuation and power quality when large-scaled PV systems and MHGs are connected with the distribution system. Therefore, this paper analyses the problem of voltage control by SVR in primary feeders with large-scaled PV systems and presents operation range and control limit of MHG with PF control function. And also, this paper evaluates the voltage impact in primary feeders depending on voltage control modes of MHG and then proposes an optimal voltage control algorithm. Furthermore, from the simulation results based on the proposed method, it is verified that it is effective and practical to stabilization of customer voltages in distribution system with largescale PV systems.

2 CHARACTERISTICS OF VOLTAGE CONTROL OF DISTRIBUTED GENERATORS

2.1 Voltage Control of SVR

When large-scaled PV systems are operated in the distribution feeder (22,9 kV), voltages at customers violate

the allowable voltage limit due to the output of PV systems as shown in Fig. 1. To control the voltage, it is necessary to variate tap position of the pole transformer (P.tr). However, it is difficult to do it with the operation conditions of PV systems. Therefore, SVR is conventionally installed as one solution to overcome the voltage problem caused by PV systems. The operation type of SVR is categorized by LDC (line drop compensation) method, programed method and constant sending voltage method [10, 11]. In Korea, SVR generally adopts constant sending voltage method, but it is difficult to keep customer voltages within the allowable limits with load variation and feeder configuration [12].

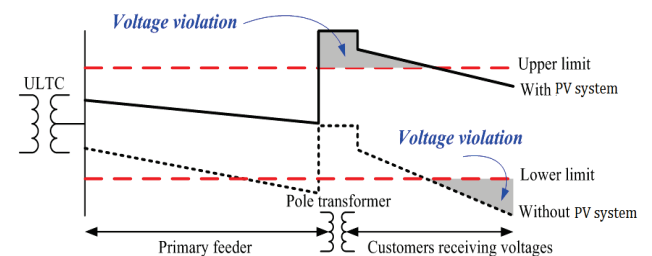


Figure 1 Customer voltage profile with operation of PV system

2.2 Voltage Control by PF Operation of MHG

2.2.1 PF Conditions of MHG

MHG needs to be kept at more than 90% of PF under the grid interconnection codes and also its PF does not need to become leading PF at point of distribution system which is identical with lagging PF at distributed generations. Therefore, a power company (KEPCO) usually sets operation condition of PF considering voltage characteristics in distribution feeders as shown in Tab. 1. In the case of A generator, its PF should be lower than 94% of leading, and in case of B generator, PF should be lower than 92% of leading depending on generator capacity [9].

Table 1 PF allowable limit of distributed generator by KEPCO

Items	Capacity	PF allowable limits (based on the generator)
A generator	900 kW	lower than 94% of leading PF
B generator	1,500 kW	lower than 91% of leading PF

2.2.2 Operation Range of Reactive Power with PF Condition

According to the operation control range of PF to regulate voltage rising at PCC (point of common coupling), the actual output power of each MHG could be limited depending on rated capacity [13, 15]. A generator in Tab. 1 can operate rated power from 85% to 94% of leading PF as shown in Fig. 2, but B generator can operate 40% of rated power, approximately 600 kW, at lower than 91% of leading PF as shown in Fig. 3. Therefore, it is clear that output power of each generator is limited according to technical guidelines of PF operation condition and then the loss of power generation has occurred as shown in Tab. 2.

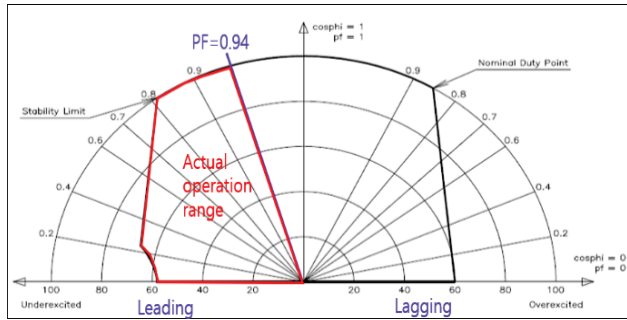


Figure 2 Operation range of PF at A generator

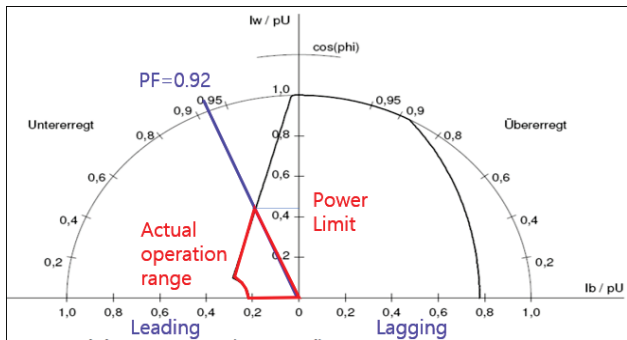


Figure 3 Operation range of PF at B generator

Table 2 Operation range of PF at each generator

Items	Capacity	PF allowable limit	Actual operation range
A generator	900 kW	up to 85% of leading PF	Rated power is available
B generator	1500 kW	up to 90% of leading PF	Rated power is not available

2.2.3 Characteristics of Voltage Control with PF Operation Condition

As described above, MHG usually performs operation range of PF according to technical guidelines of KEPCO to regulate voltage at PCC. Namely, each generator absorbs reactive power and reduces system voltage at PCC [14]. However, the operation condition of PF in each generator is usually applied regardless of the PV system or load variation in the distribution system. Fig. 4 shows voltage variation at PCC according to the operation condition of PF in each generator [16]. Voltage profile ① and ② in Fig. 4 indicate voltage profile in primary feeder with PV systems, and ③ and ④ are voltage profiles without PV systems, and also ② and ④ are voltage profiles with PF operation conditions of MHG. Since voltage profile in primary feeder with PV systems may be raised during the day as shown in

①, MHG can maintain customer voltage within allowable limit by reducing voltage at PCC with operation condition of PF as shown in ②. However, voltage profile in primary feeder with PV systems may be violated from the allowable limit during the night and heavy load of ③ by reducing voltage at PCC with operation condition of PF as shown in ④. Therefore, it is clear that operation condition of PF in each generator has a limitation of voltage control in distribution systems due to different one coping with the PV system or the load variation.

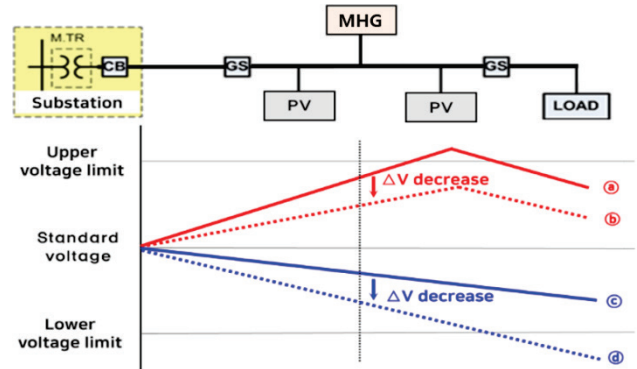


Figure 4 Voltage variation profile by PF operation range

3 OPTIMAL CONTROL METHOD OF MHG FOR VOLTAGE STABILIZATION IN DISTRIBUTION FEEDER

3.1 Characteristics of Optimal Voltage Control Mode

Generator voltage control modes of MHG installed and operated in Korea consist of control modes such as AVR and FCR and operation state mode such as OFF, PF and Var [15]. Tab. 3 shows voltage control modes for each MHG, which has different voltage control methods including AVR/OFF, AVR/ON and AVR/Var modes. Characteristics of each control mode are demonstrated as shown in Tab. 3.

Table 3 Voltage control mode of MHG

Power plant	Capacity / MW	Generator voltage / kV	Generator control mode
A	1000×3	3,3	AVR/OFF
B	1650×3	0,69	AVR/PF
C	1665×3	6,6	AVR/OFF
D	1250×4	0,69	AVR/PF
E	2500×2	3,3	AVR/OFF
F	947×3	0,69	AVR/PF
G	1500×2	3,3	AVR/OFF
H	1500×2	0,69	AVR/PF
I	1500×2	6,6	AVR/OFF
J	1500×2	3,3	AVR/OFF
K	1500×2	0,69	AVR/PF
L	660×4	0,48	AVR/VAR
M	1500×2	6,6	AVR/VAR
N	770×3	6,6	AVR/OFF

3.1.1 AVR Control Mode

AVR control mode is the most important mode of excitation system, which maintains a constant voltage of setting voltage regardless of voltage variation of PCC and output power of MHG.

3.1.2 Var Control Mode

Var control mode is to constantly control reactive power of MHG according to set value, and then the voltage of MHG may fluctuate with the voltage at PCC and output power of MHG. Fig. 5 shows characteristics of reactive power controlled step by step from leading PF operation to lag PF operation. It is known that the voltage of MHG is decreased with reactive power. Fig. 5a is a profile of reactive power ranging from 300 kVar to -100 kVar, and Fig. 5b is the voltage at PCC and voltage regulation of MHG according to reactive power variation.

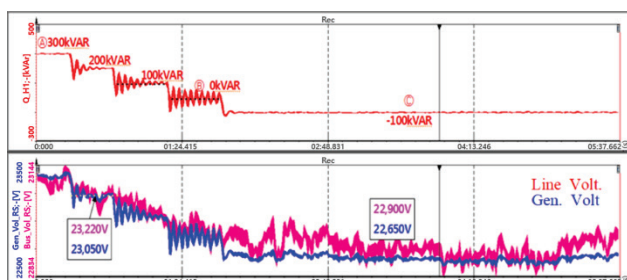


Figure 5 Voltage control characteristics in Var control mode

3.1.3 PF Control Mode

PF control mode is to constantly control PF of MHG according to set values, by adjusting active and reactive power. This mode is an operating method with set values of more than 90% of lagging PF under grid interconnection codes of distributed generators in KEPCO. Fig. 6 shows characteristics of reactive power and voltage of MHG according to step by step setting values of PF, where Fig. 6a is a profile of PF ranging from -0,99% to +0,95% and Fig. 6b is the characteristics of voltage regulation with the PF variation.

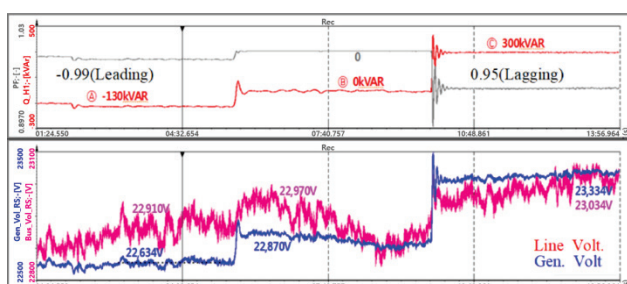


Figure 6 Voltage control characteristics in PF control mode

3.1.4 Optimal Control Mode

As described above, operation characteristics of the excitation system of MHG are being varied with control modes, and setting values of voltage control modes are different at each MHG. Also, to mitigate voltage variation at PCC when distributed generators are interconnected with a distribution system, leading PF operation of MHG is being required with the codes [9]. However, PF and Var modes of MHG is not enough to properly mitigate voltage variation at PCC because setting values of PF or Var are controlled with PV systems and load variations. If the voltage at PCC is higher than the allowable voltage limit, it can be reduced by leading the PF operation of MHG, but if it is lower than the limit, it can be further lowered and

then voltage problems of customers occur. However, AVR mode is the most effective one to mitigate voltage at PCC, which can constantly control voltage of generator with adjusting reactive power regardless of load and voltage variations.

3.2 Optimal Algorithm of Voltage Control for MHG

3.2.1 Characteristics of Existing Voltage Control Algorithm

As mentioned earlier, AVR mode among several voltage control modes is the proper control mode to mitigate voltage variation at PCC. However, this control mode also is not enough to properly mitigate voltage variation at PCC. If system voltage at PCC (V_L) is higher than the setting voltage (V_S), AVR mode is firstly to adjust voltage of MHG until the setting voltage after starting of generator, and to synchronize MHG at PCC with being compared to voltage at PCC (V_L) and then voltage of MHG (V_G) is constantly operated with variation of system voltage at PCC as shown in Fig. 7. Therefore, MHG may cause overvoltage at PCC according to its reverse power flow.

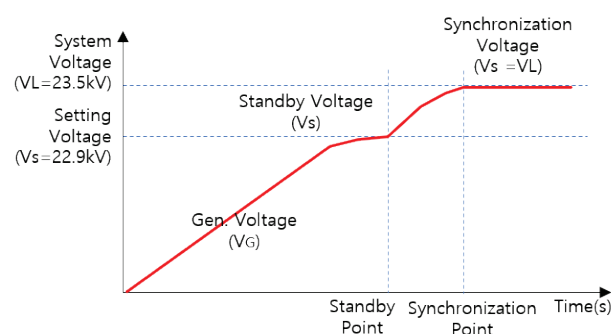


Figure 7 Concept of existing voltage control method

3.2.2 Optimal Algorithm of Voltage Control

Existing algorithm of voltage control is supposed to regulate voltage of MHG (V_{SET}) following the system voltage at PCC. The algorithm is not enough to properly mitigate voltage variation at PCC because voltage of MHG is normally determined according to voltage conditions at PCC with reverse power of PV systems and load variation. While voltage of MHG is synchronized and followed by variation of voltage at PCC, the proposed algorithm is scheduled to properly regulate the voltage of MHG (V_{SET}) at set point regardless of voltage variation at PCC by replacing setting value of exciter with setting voltage in order to stabilize system voltage at PCC as shown in Fig. 8.

Therefore, the proposed algorithm of optimal voltage control is as follows.

[Step 1] Build up voltage of MHG (V_G) with initial set value (V_{pre}) of exciter from starting point to standby point in Fig. 8.

[Step 2] Control voltage of MHG by synchronizer from standby point to synchronization point, which is constantly followed by system voltage of PCC (V_L) regardless of system voltage variation.

[Step 3] Replace setting value of excitation controller with setting voltage (V_{SET}) if output of MHG is more than scheduled value from synchronization point to set point

and then regulate the voltage of MHG to setting voltage with exciter control.

[Step 4] Regulate voltage of MHG within capability curve of output power, which is operated between OEL (over excitation limit) and UEL (under excitation limit).

[Step 5] Even if MHG violates capability curve of output power, the voltage of MHG is maintained with limited conditions.

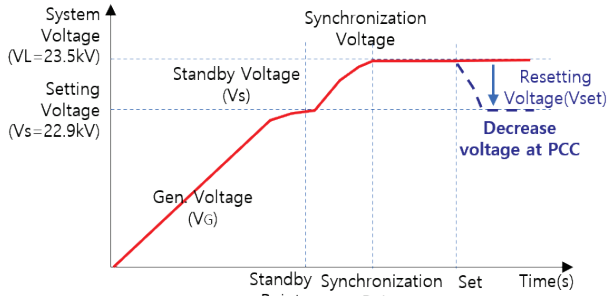


Figure 8 Concept of optimal voltage control method

Optimal algorithm of voltage control is demonstrated as shown in Fig. 9.

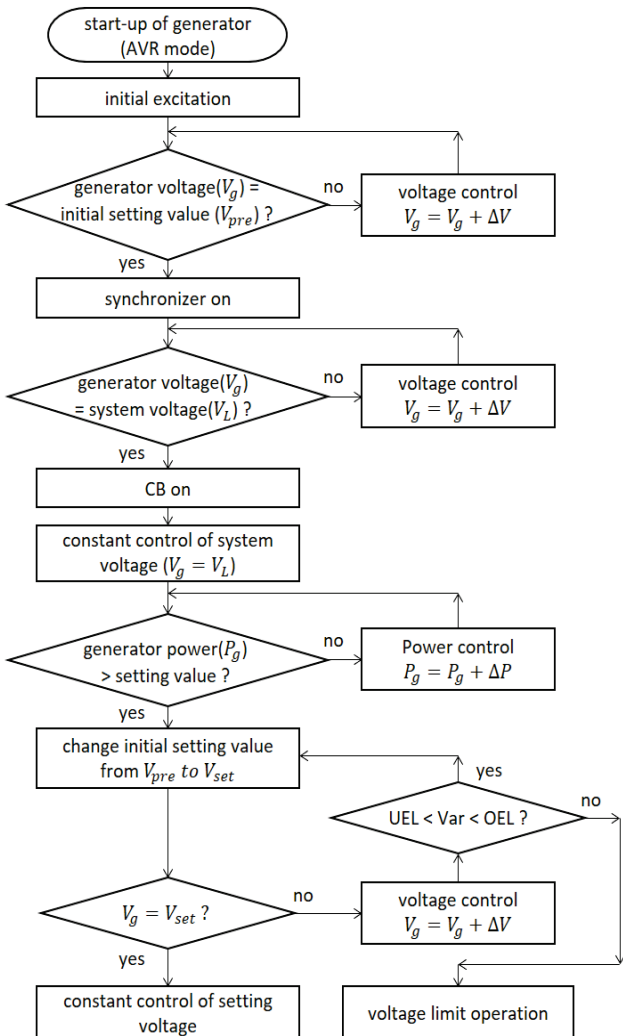


Figure 9 Optimal voltage control algorithm of MHG

4 CASE STUDIES

4.1 Verification of Optimal Algorithm by Excitation System Simulator

The proposed optimal algorithm of voltage control is implemented at existing simulator of the excitation system called RTS-7000, and its performance characteristics are demonstrated in Fig. 10. Fig. 10 shows the case where system voltage at PCC is higher than setting voltage of MHG, which is characteristic of field voltage, field current, reactive power and voltage variation at MHG. Where, ① of Fig. 10 shows synchronization point and ② is optimal voltage control point. And also "Section I" of Fig. 10 is a section whose rated voltage of MHG is determined by field voltage and current after start-up and "Section II" is a section in which voltage of MHG is increased by supplying reactive power to follow system voltage at PCC after synchronization of MHG. Furthermore, "Section III" is a section whose rated voltage of MHG is maintained by absorbing reactive power with optimal voltage control if system voltage in the PCC is higher than one of MHG. Therefore, it is found that the proposed method is useful for voltage control in the distribution feeder.

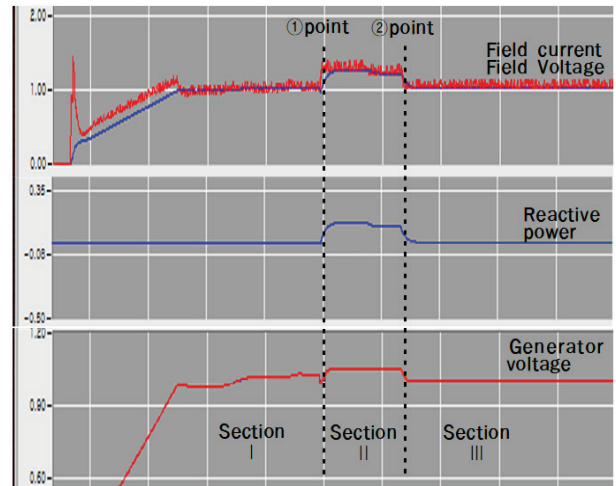


Figure 10 Voltage profile in case of higher system

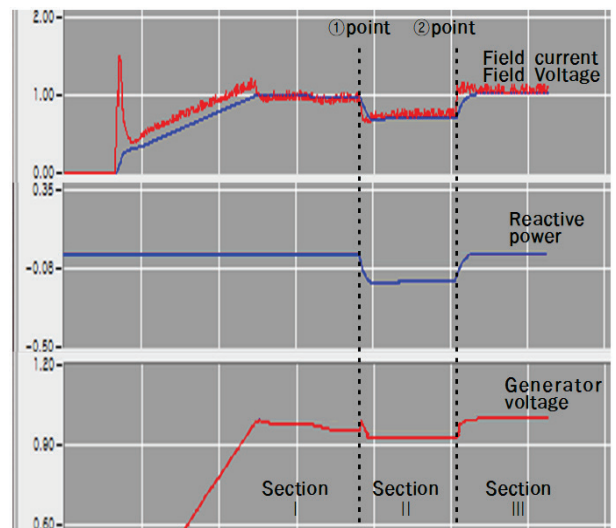


Figure 11 Voltage profile in case of lower system voltage than setting voltage of MHG

Fig. 11 shows the case where system voltage at PCC is lower than setting voltage of MHG. Field current and

active power is controlled based on the optimal algorithm, and then system voltage at PCC can be maintained within allowable limit in section III as shown in Fig. 11. Therefore, it is known that the proposed voltage control algorithm of MHG is useful for voltage control in distribution system.

4.2 Control Characteristics of Optimal Algorithm in Real System

4.2.1 Simulation Condition

Fig. 12 shows configuration of $Y D/L$ (distribution line) in $H S/S$ (substation) which is interconnected with large scale PV systems and MHG, as shown in Tab. 4. Specifically, the total length of D/L is as long as 40,5 km, and 1,8 MW of MHG is located at 13,2 km from S/S . And also, total of 6,3 MW of PV systems are installed through the D/L . Furthermore, a range of daily load profile is from 3,7 MW at off-peak load to 9,8 MW at peak load. Also, the voltage of the distribution feeder can be significantly maintained higher than nominal voltage when large scale PV systems are operated.

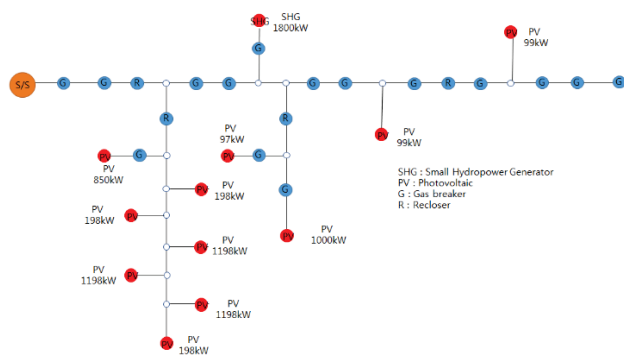


Figure 12 Real distribution system with PV systems

Table 4 Parameters of distribution line

Items	Contents
Main Feeder Length	40,5 km
Location Of MHG	13,2 km
Total Capacity Of PV Systems	6,333 MW
Capacity Of MHG	1,8 MW
Peak Load	9,8 MW
Off-Peak Load	3,7 MW

4.2.2 Control Characteristics of Optimal Algorithm

Based on the proposed optimal voltage control algorithm of MHG, voltage characteristics at PCC are demonstrated in Fig. 13.

Fig. 13a shows characteristics of the reactive power variation and Fig. 13b shows characteristics of voltage variation at MHG on condition that system voltage at PCC is 23,2 kV. Reactive power of generator is controlled from 17 kVar to -60 kVar by resetting the generator voltage to 23 kV through the proposed optimal control algorithm of MHG. It is found that the system voltage at PCC is decreased to 23 kV. Therefore, it is clear that the proposed optimum voltage control method can constantly control voltage at PCC of MHG, and it can contribute to voltage stabilization of the distribution system even though a large scale PV system is operated.

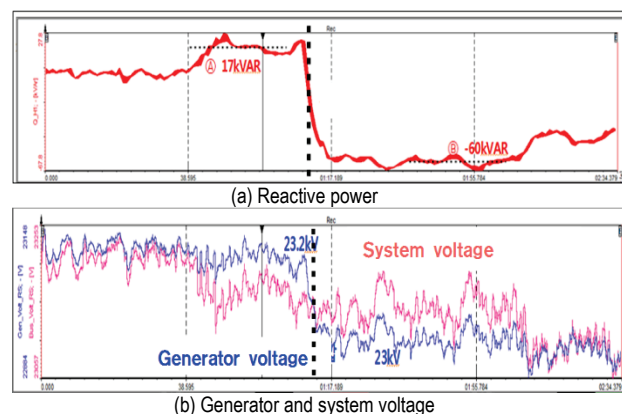


Figure 13 Characteristics of reactive power and system voltage

5 CONCLUSION

This paper proposes an optimal method of voltage control for MHG to overcome issues of voltage control in distribution feeders with large scale PV systems. In addition, this paper implements an excitation system simulator based on the proposed optimal control algorithm. From the proposed algorithm and simulator, it is confirmed that the system voltage is constantly maintained to setting voltage by controlling field current and reactive power if the system voltage at PCC is higher than setting voltage of MHG. Therefore, it is clear that optimal voltage control algorithm proposed in this paper can constantly control voltage at PCC even if large-scaled PV system is interconnected with distribution feeders, and the algorithm can contribute voltage stabilization of distribution systems. In the future, evaluation of hosting capacity for PV system is required depending on location of PCC and capacity of MHG based on the proposed voltage control method of MHG.

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