CONTROL ALGORITHM OF DC MICROGRIDS BY USING VOLTAGE COMPENSATION TERM

Byoung-Sun Ko
Hanyang University – Korea
byoungnsun1@hanyang.ac.kr

Gi-Young Lee
Hanyang University – Korea
popple87@hanyang.ac.kr

Rae-Young Kim
Hanyang University – Korea
rykim@hanyang.ac.kr

Seok-Woong Kim
KEPCO – Korea
sw.kim@kepco.co.kr

Hyun-Min Kim
KEPCO – Korea
hm.kim@kepco.co.kr

Young-Pyo Cho
KEPCO – Korea
yp.zo@kepco.co.kr

Hong-Joo Kim
KEPCO – Korea
hongjoo.kim@kepco.co.kr

ABSTRACT

In this paper, the control algorithm of DC microgrid by using voltage compensation term is proposed for energy management and minimization of voltage variation. The droop control has a disadvantage in that it necessarily generates voltage variation and energy management is difficult. To solve these problems, the voltage compensation term through communication between different units is used as an index for energy status of DC microgrid. By setting the operation band and designing the droop gain and nominal voltage, energy management and minimization of voltage variation can be achieved.

INTRODUCTION

Recently, renewable energy sources(RES) such as photovoltaic panel(PV) and wind turbine are continuously increasing due to an increase in demand of digital load and limited energy source. However, the intermittent characteristic of RES deteriorates the stability of existing grid networks. As a result, studies on microgrid(MG) have been carried out to improve stability and overall efficiency through optimal power management. The MG can be classified into AC MG and DC MG in the connection method. DC MG has advantages of low loss and low cost because it does not require two-stage power conversion when coordinating the power generated by each sources[1].

It is necessary to maintain the output voltage of the DC MG within a certain range, and to manage the energy flow through proper output distribution. The droop control is a method of simulating the internal impedance of the ideal voltage source through droop gain. By applying droop control, it is possible to determine the load distribution while solving the circulating current.

However, inevitable voltage variation occurs, and optimized energy management is difficult due to constant droop gain.

The dc bus signaling(DBS) has been researched to solve the energy management problem of the droop control[2]. It is possible to solve power flow problem by dividing operation band according to the output voltage and defining power distribution ratio. However, the operation band transition performed by the magnitude of the output voltage cannot overcome the voltage variation problem of the droop control.

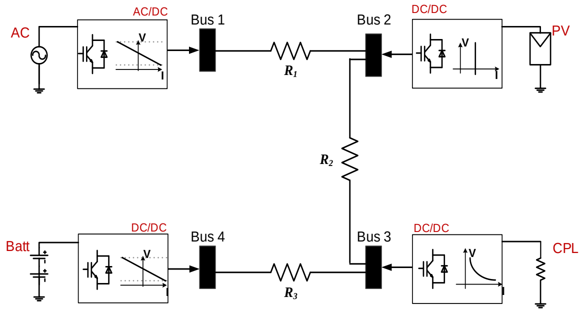

Fig. 1 Structure of DC MG

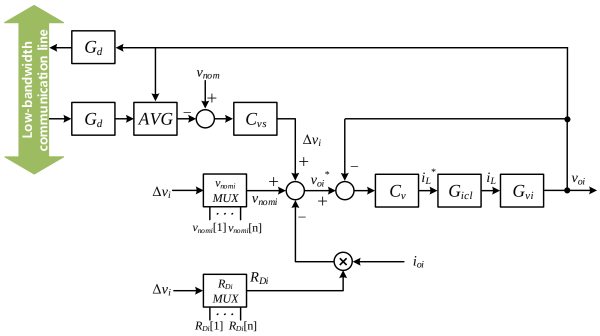

Fig. 2 Control block diagram of proposed method.

On the other hand, voltage shift methods based on average current or average voltage have been proposed to solve voltage variation of the droop control[3]. However, there is a disadvantage that energy management is difficult due to a constant droop gain.

In this paper, the control algorithm of DC MG by using voltage compensation term is proposed to achieve energy management and minimize voltage variation. In the proposed method, the voltage compensation term was calculated by using the average voltage obtained from low bandwidth communication line(LBCL) and an

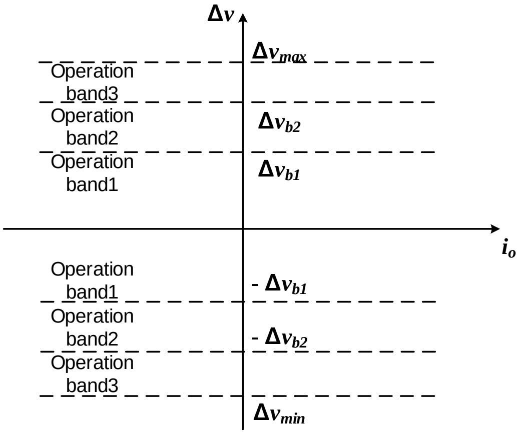

Fig. 3 Operation band of voltage compensation term

additional controller. The operation band is classified according to the magnitude of the voltage compensation term. By designing the droop gain and the nominal voltage according to each operation band, it is possible to compensate the voltage variation and to perform energy management. Analysis of the difference between the voltage compensation terms was carried out and the validity of the proposed method was verified by using PSCAD/EMTDC simulation.

VOLTAGE COMPENSATION

Fig. 1 shows an example of DC MG. It consists of the grid-tied AC/DC converter, an energy storage system(ESS)-coupled DC/DC converter, PV and a load. The proposed algorithm is applied to the AC/DC converter and the DC/DC converter to operate DC MG. Fig. 2 shows the control block diagram of the proposed algorithm. As can be seen from the figure, the average output voltage is calculated through LBCL and voltage compensation term is calculated by an additional controller. In the proposed control algorithm, the operation band is determined by dividing voltage compensation term. The voltage compensation term minimizes the voltage variation of the DC MG and at the same time changes the nominal voltage v_{nomi} and the droop gain R_{Di} of droop control through the multiplexer. These changes in v_{nomi} and R_{Di} implement energy management of the DC MG. Eq (1) shows the voltage reference value calculated by the proposed algorithm.

$$v_{oi}^{*} = v_{nomi} - R_{Di} i_{oi} + \Delta v_i \qquad (1)$$

<u>Definition of operation band</u>

Since the voltage compensation term is calculated from the average output voltage of each bus through LBCL, it represents the energy information of DC MG. As a result, the voltage compensation term is used as an index indicating the energy state of the DC MG.
Fig. 3 shows the operation band defined in the voltage compensation term. According to the value of voltage compensation term, it classified into operation band1, operation band2, and operation band3. The operation

Table I. System parameters		
Symbol	Quantity	Values
v_{nom}	Nominal voltage	120 V
v_{max}	Maximum voltage	126 V
v_{min}	Minimum voltage	114 V
R_1,R_2,R_3	Line impedance	0.1 Ω

Table II. Setpoints of the operation band			
Symbol	Value	Symbol	Value
Δv_{min}	-6 V	Δv_{max}	6 V
Δv_{b1}	3.6 V	Δv_{b2}	5.4 V

Table III. Nominal voltage and droop gain			
Grid-tied AC/DC converter			
Symbol	Value	Symbol	Value
$v_{nom1,3-1}$	124.8 V	$v_{nom1,3-2}$	115.2 V
$v_{nom1,2-1}$	122.4 V	$v_{nom1,2-2}$	117.6 V
$v_{nom1,1-1}$	120 V	$v_{nom1,1-2}$	120 V
$R_{D1,3-1}$	0.1 Ω	$R_{D1,3-2}$	0.09 Ω
$R_{D1,2-1}$	0.51 Ω	$R_{D1,2-2}$	0.45 Ω
$R_{D1,1-1}$	1.48 Ω	$R_{D1,1-2}$	1.4 Ω
ESS-coupled DC/DC converter			
Symbol	Value	Symbol	Value
$v_{nom2,3-1}$	116.8 V	$v_{nom2,3-2}$	124.9 V
$v_{nom2,2-1}$	117.7 V	$v_{nom2,2-2}$	121.2 V
$v_{nom2,1-1}$	120 V	$v_{nom2,1-2}$	120 V
$R_{D2,3-1}$	0.8 Ω	$R_{D2,3-2}$	0.8 Ω
$R_{D2,2-1}$	0.7 Ω	$R_{D2,2-2}$	0.6 Ω
$R_{D2,1-1}$	0.4 Ω	$R_{D2,1-2}$	0.61 Ω

band1 is a section where the energy balance of the DC MG is maintained. The load and RES operate without large output fluctuation, and the voltage of DC MG can be stably regulated through the charge and discharge of the droop control units. The operation band2 indicates the operation band1 outer section caused by instantaneous energy imbalance in the DC MG. In the operation band2, there is a larger output variation than operation band1, but it can be compensated through droop control units. Finally, the operation band3 refers to a case where a severe energy imbalance occurs in the DC MG. This is the section where the largest output and voltage fluctuation occurs when compared with the previous band. Examples are failure of RES or loads, islanding operation, and ESS failure. The DC MG system parameters are shown in table I and setpoint of the operation band are shown in the table II.

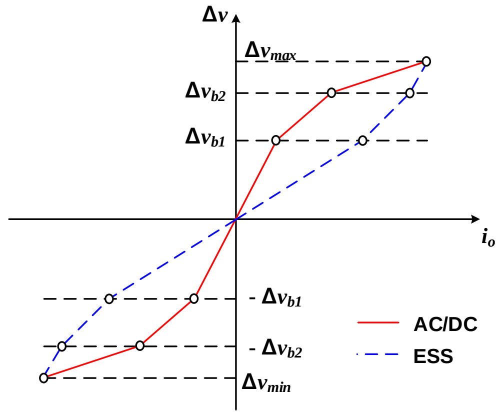

Fig. 4 Droop gains for each operation band

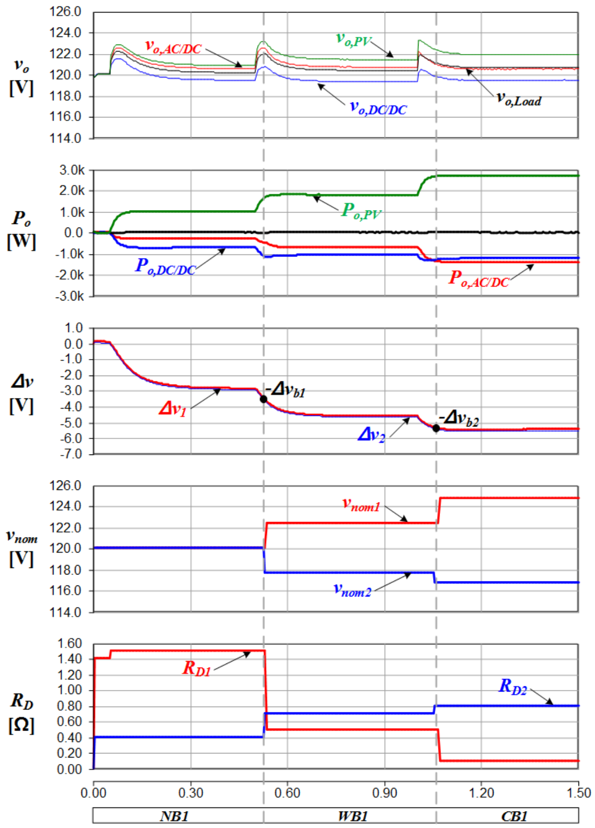

Fig. 5 Simulation results about PV output variation

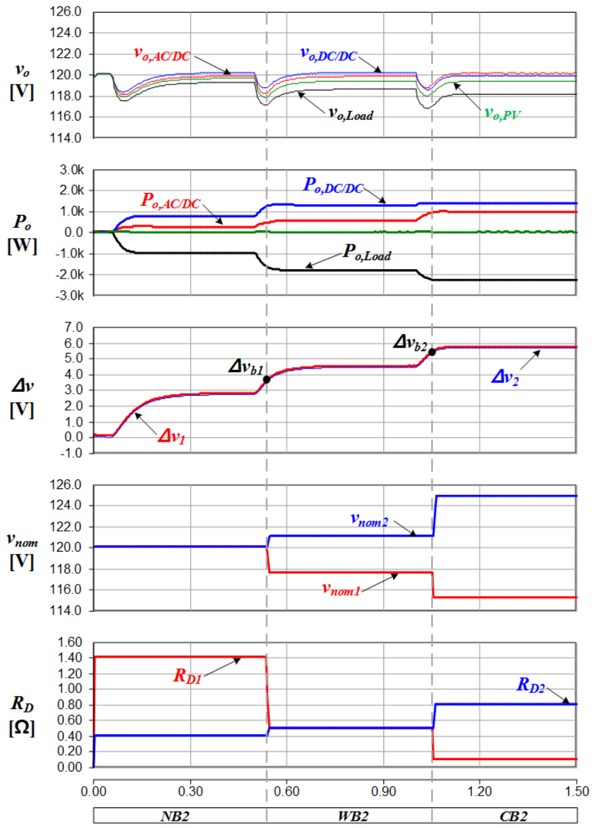

Fig. 6 Simulation results about load variation

Design of droop gain and nominal voltage

Fig. 4 shows the droop gain of the ESS-coupled DC/DC converter and grid-connected AC/DC converter designed for each operation band for energy management of the DC MG. In order to increase the utilization of energy produced from RES, the droop gains were designed.
In the operation band1, the AC/DC converter has a large droop gain, which minimize the energy flow between the ac-grid and the DC MG, while the DC/DC converter has a small droop gain.
In the case where the energy of the DC MG shows an unbalance state, the operation band will deviate from the operation band1. At this time, the voltage of the DC MG must be maintained by increasing the output of the AC/DC converter which is limited in the operation band1. As a result, the AC/DC converter has a small droop gain in the operation band 2 and 3. Conversely, in the case of DC/DC converters, excessive charge and discharge occur in the operation band 2 and 3, which may lead to overcharge and over-discharge, so the output must be restricted. Therefore, the droop gain of the DC/DC converters was set to a large value.
By designing the droop gain as described above, each converter can perform the scheduled output operation. In addition, calculation of nominal voltage is necessary to implement the output scheduling according to each operation band. It can be calculated by the droop gain and maximum output of each operation band. The designed droop gain and nominal voltage of converters are shown in table III.

SIMULATION RESULTS

PSCAD/EMTDC was used to verify the effectiveness of the proposed control algorithm by using voltage compensation term. The DC MG in fig 1 was simulated and the system parameters and setpoints for classification of the operation band in the Table I and II were used. In addition, the values of table III were used for the droop gain and nominal voltage of droop control for each operation band. The proposed algorithm was applied to grid-connected AC/DC converter and ESS-coupled DC/DC converter.
Fig. 5 shows the simulation results according to change of the PV generation. As shown in the figure, the output of PV changed to 1kW in 0.005 seconds. The voltage of the DC MG is increased by the amount of power generated by the PV, so that the voltage compensation term of AC/DC converter Δv_1 and the DC/DC converter Δv_2 is reduced to a negative value for maintaining the voltage of DC MG. Since Δv_1 and Δv_2 are larger than $-\Delta v_{b1}$(=-3.6V), it operates as the operation band1.
In the operation band1, the nominal voltage and the droop gain of the AC/DC converter are set to $v_{nom1,1-1}$ and $R_{D1,1-1}$, which listed in table III. The nominal voltage and droop gain of DC/DC converter also set to $v_{nom2,1-1}$ and $R_{D2,1-1}$. Each converter performs output scheduling according to the designed nominal voltage and droop gain. The output of PV is 1kW, and the outputs of AC/DC converter and DC/DC converter are 0.27kW and 0.72kW, respectively. The power generation amount of PV increases to about 1.8kW in 0.5 seconds, and Δv_1 and Δv_2 exist in a range between $-\Delta v_{b1}$ and $-\Delta v_{b2}$. Accordingly, it operates with the operation band2. In the operation band2, the nominal

voltage and the droop gain of the AC/DC converter and DC/DC converter are changed to $v_{nom,2-1}$ and $R_{D,2-1}$. In the case of the DC/DC converter, the increase in the output variation is small because the droop gain is increased. Conversely, in AC/DC converters, the increase in output variation is large due to the reduced droop gain. The outputs of AC/DC converter and DC/DC converter are 0.7kW and 1.07kW, respectively.
The outputs of PV is increased to 2.7kW in 1 seconds, and the operation band transition is occur. In the operation band3, the nominal voltage and the droop gain of the AC/DC converter and DC/DC converter are changed. At this time, the outputs of each converter are 1.4kW and 1.2 kW, respectively.
It can be confirmed that the value of the voltage compensation term varies according to the output of PV and the output scheduling is performed by changing the nominal voltage and the droop gain according to the operation band. Also, the voltage of DC MG is maintained within v_{max}, v_{min} in table I.
Fig. 6 shows the simulation results for load variation. As can be seen in the figure, the load changes at 1kW, 1.8kW, and 2.3kW at 0.05 second, 0.5 second, and 1 second, respectively. The voltage compensation terms increase in the positive direction to maintain the DC MG voltage.
As in the case of the PV output variation, the operation band is determined through the voltage compensation term, and output scheduling is performed by varying the nominal voltage and the droop gain in each operation band. Also, it can be confirmed that the DC MG maintains at about 120V under all load conditions.

CONCLUSION

In this paper, the control algorithm of DC MG by using the voltage compensation term was proposed to minimize voltage variation and achieve energy management of DC MG. The voltage compensation term reflects the energy state of the DC MG. Therefore, it can be used to indicate the operation band.
The design of the nominal voltage and the droop gain in each operation band was performed and the effectiveness of the proposed algorithm was verified by simulation of various loads and generation situations through PSCAD/EMTDC.

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