Droop Control Method Based on Generation Cost in DC Microgrid

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Abstract

This paper presents a linear droop control scheme based on the generation costs of DGs in an autonomous DC microgrid. Unlike the proportional power sharing of the conventional droop control, in the proposed control algorithm, the minimum output voltage range is adjusted and the droop coefficients are regulated according to the generation costs of DGs. As a result, the DGs with lower costs supplies more power in comparison with those with higher costs. Therefore, total generation cost of the system is reduced significantly. The proposed method is simple to implement and it does not require the centralized controller and communication links.

Key words – DC microgrids; Cost-based droop control; Economic operation; Cost function

1. Introduction

Microgrid consists of a number of renewable energy sources, storage devices and loads, and it can be categorized into AC or DC power grid [1]. However, DC microgrids have advantages over AC microgrids due to reduction of AC-DC or DC-AC conversion stages and absence of harmonics and reactive power problems. In addition, since the increasing penetration of dc power sources such as photovoltaics (PVs) as well as the development of dc loads such as LED or automobile electrical systems, DC microgrids have been focused on considerably in these days. Fig. 1 shows a typical DC microgrid configuration comprised of different types of power sources and loads.

In DC microgrids, the power sharing among power sources is important to guarantee safety and effective operation. To achieve the suitable power sharing, different approaches have been studied including master- slave control [2] and droop control and its variants [3], [4]. Among them, droop control has been widely used because of its simplicity and reliability. The droop control allows distributed generators (DGs) to share power proportionally according to their power ratings. Generally, the proportional relation works well in the system with similar characteristic generation units. However, in the microgrid where different types of sources exist as shown in Fig. 1, the droop control may make the uneconomical system operation.

To solve the economic-related problem, a linear cost-based droop control is presented in this paper. The proposed droop control method helps to reduce total generation cost (TGC) of the DC microgrid. The effectiveness of the proposed control method is verified by simulation.

2. Proposed control strategy

Generally, generation costs of DGs can be evaluated by using the maintenance cost, cost of power loss in DC-DC converters and fuel cost. These costs depend on the type of energy sources, DG's capacity and actual amount of power generation. Therefore, they cannot be represented by a unique function. Considering the DC microgrid in Fig. 1, the generation sources include PV which is non-dispatchable renewable source supported by energy storage system (DG1),

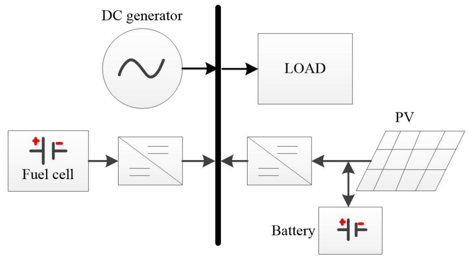

Fig. 1. Configuration of a DC microgrid

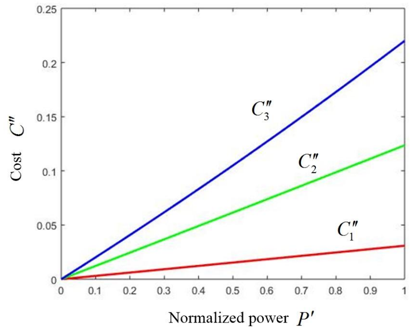

Fig. 2. Cost curve of DGs

fuel cell as dispatchable renewable source (DG2) and combustion engine (DG3).

The generation costs of the DGs are presented as the in the following [5]:

$$C_1(P_1) = 0.03(P_1 + 0.05 + 0.02P_1 + 0.01P_1^2)\ , \qquad (1)$$

$$C_2(P_2) = 0.12(P_2 + 0.05 + 0.02P_2 + 0.01P_2^2)\ , \qquad (2)$$

$$C_3(P_3) = 0.02P_3 + 0.01(4 + 18P_3 + 2P_3^2)\ , \qquad (3)$$

where C_i and P_i are generation cost and output power of *i-th* DG ($i = 1,2,3$).

In order to compare generation costs of different DGs without influence of DGs' power ratings, the cost function should be normalized with respect of the DG maximum power, $P_{max,i}$, according to (4):

$$C_i'(P_i) = \frac{C_i(P_i)}{P_{\max,i}};\ P_i' = \frac{P_i}{P_{\max,i}} \qquad (4)$$

In addition, from (1), (2) and (3), no load cost at $P_i = 0$ is always acquired in spite of the amount of power generated. Therefore, no load components should be removed as shown in (5) and the corresponding cost curves are plotted in Fig. 2.

$$C_i''(P_i) = C_i'(P_i) - C_i'(P_i = 0) \qquad (5)$$

In DC microgrid, the conventional droop control is presented in (6):

$$V_{ref,i} = V_{\max} - R_{d,i}P_i;\ R_{d,i} = \frac{V_{\max} - V_{\min}}{P_{\max,i}} \qquad (6)$$

where $V_{ref,i}$ is the reference voltage and $R_{d,i}$ is the droop coefficient of the *i-th* DG.

According to conventional droop control, the output power is shared proportionally according to the power ratings of DGs.

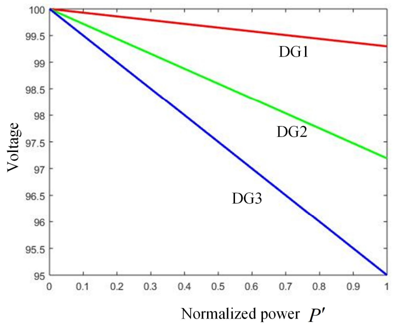

Fig. 3. Linear cost based droop lines

In order to hit the mark of reducing TGC of the considered microgrid, a linear cost based droop control method is proposed. Illustrative expression for the method is shown in (7) and (8):

$$V_{ref,i} = V_{\max} - \gamma_i P_i ; \gamma_i = \frac{V_{\max} - V^*_{\min,i}}{P_{\max,i}} \qquad (7)$$

$$V^*_{\min,i} = V_{\max} - \frac{V_{\max} - V_{\min}}{\max\left(\left\{C''_{\max,1}, C''_{\max,2}, \ldots, C''_{\max,n}\right\}\right)} C''_{\max,i} \qquad (8)$$

where $V^*_{min,i}$ is the allowable modified minimum voltage of *i-th* DG based on the maximum cost $C''_{max,i}$. $C''_{max,i}$ can be calculated according to (5) in case $P_i = P_{max,i}$. The droop scheme in (7) is obviously similar to the conventional scheme in (6). The difference is the minimum voltage set-point which is defined based on cost function as (8). Consequently, the droop gain γ_i changes correspondingly. The proposed control scheme ensures that the lower cost DGs produce more power so that the TGC decreases. Fig. 3 shows the droop lines of DGs when the proposed linear cost-based droop control is applied.

3. Simulation results

Effectiveness in reducing TGC of the proposed scheme is evaluated by simulation which is carried out for the microgrid in Fig. 1. In the simulation, the maximum voltage is 100 V, the power ratings of power sources are equal to 1kW and the line resistances are equal to 0.1Ω. In the simulation, three different load conditions are considered to investigate the performance from the light load to the heavy load states. Accordingly, the resitive loads including10Ω, 30Ω and 40Ω are connected to the microgrid, respectively.

The conventional droop scheme is implemented and the simulation results are shown in Fig. 4. As can be seen from Fig. 4, three DGs share the amount of power in proportional to their ratings because of the conventional droop control algorithm. Total generation cost with three load coditions is 0.16, 0.20 and 0.23 of cost unit, in turn.

Fig. 5 shows the simulation results by applying the proposed cost-based droop scheme. From Fig. 5, the DG1 containing PV and energy storage generates the highest amount of power because of the lowest generation cost. Meanwhile, DG3 which is DC generator supplies the smallest power due to the highest generation cost. The total generation cost in different load states is 0.13, 0.15 and 0.18 of cost unit, which reduces 18% ~ 25% total cost in comparison with that in conventional droop control method.

4. Conclusion

In this paper, a linear generation cost-based droop control scheme for autonomous DC microgrid is proposed. According

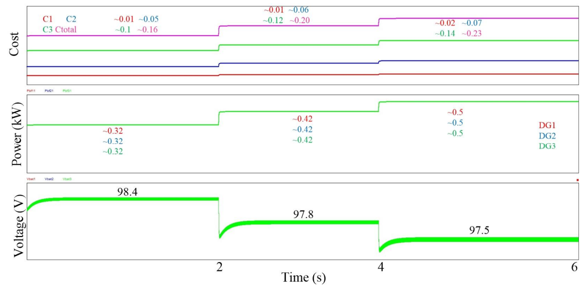

Fig. 4. Conventional droop control

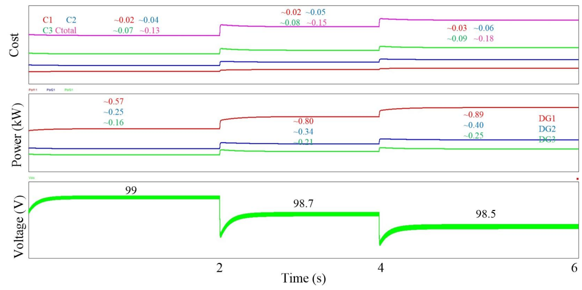

Fig. 5. Proposed cost-based droop control

to the proposed control method, the minimum voltage level of each DG is adjusted based on its generation cost. Consequently, the droop coefficient is regulated to change the output power corresponding to the generation cost. That means the DG with more expensive generation cost has to share lower amount of power and vice versa. As a result, total generation cost of DC grid is decreased. The performance of the proposed control method is verified by simulation, and the efficiency of the control strategy is proven in generation cost reduction.

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