

Resilient Secondary Control for Distributed DCMG Considering FDI Attacks and Electricity Price

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ABSTRACT

This paper proposes a resilient secondary control for a distributed DC microgrid (DCMG) to achieve the power balance and voltage regulation even under false data injection (FDI) attacks and electricity price change. A distributed power management based on the droop control method is proposed to optimize the supplied and consumed powers under electricity price change. In addition, to enhance the reliability of the DCMG system, a compensation term is integrated to the secondary control, which effectively eliminates the negative effect of FDI attacks. Several simulations are conducted to verify the effectiveness of the proposed scheme under various scenarios.

1. Introduction

Recently, the microgrid which composes the utility grid, load, energy storage systems, and renewable energy sources such as solar or wind power sources, has played a crucial role in achieving a balance between the energy development and environmental protection. Generally, the microgrid system is separated into the DC microgrid (DCMG) and the AC microgrid (ACMG). Compared with ACMG, DCMG has the following advantages: high system efficiency, simple controller without harmonics, frequency, and reactive power. As a result, the DCMG system has grasped more and more attention from researchers.

According to the communication perspective, the control scheme of the DCMG system is classified into the centralized control, decentralized control, and distributed control. The centralized control faces many drawbacks related to the computational burden and single point failure due to the central controller. In contrast, the decentralized method provides high flexibility and easy scalability without any digital communication link (DCL) and the central controller. However, it is more challenging to maintain the stabilization of the entire DCMG system under uncertain conditions due to the lack of exchange information among power agents. To overcome this weakness, the distributed control is considered as an effective solution by combining the advantages as well as decreasing the disadvantages of the above control schemes.

Generally, the droop method is employed in the distributed DCMG system to coordinate the power among power agents and regulate the DC bus voltage (DCV, V_{DC}). However, the negative effects such as cyber attacks should be carefully considered to improve the reliability of the DCMG system. In addition, it is necessary to propose an optimal power management to minimize electricity costs under electricity price change.

In this paper, a distributed secondary control based on $V-P$ droop curve is presented to achieve high efficiency and stability for the DCMG system under various conditions. The proposed scheme not only controls the V_{DC} at the nominal value (V_{DC}^{nom}) under

false data injection (FDI) attacks but also optimizes the power management under electricity price uncertainty. Simulation results are introduced to demonstrate the feasibility and reliability of the proposed control scheme.

2. Proposed Control Scheme

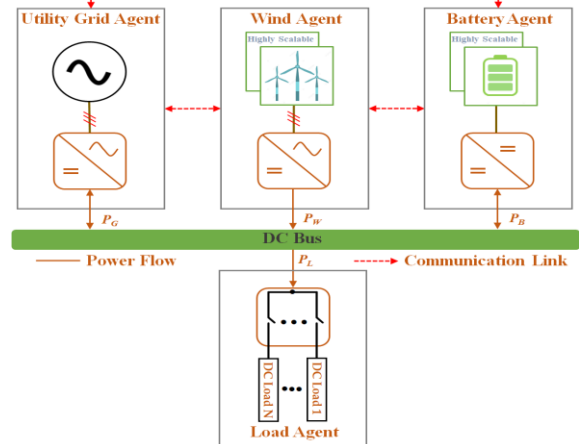


Fig. 1 Configuration of the proposed distributed DCMG.

Fig. 1 shows the configuration of a distributed DCMG which consists of the utility grid agent, wind turbine agent, battery agent, and load agent. In this distributed DCMG system, DCLs are assigned to transfer information of distributed secondary control output value by transmitting power agents. The distributed secondary control output value of each agent i (u_i) is determined as follow:

$$\dot{u}_i = -(e_i / T_{i,1}) + \Delta_i - \omega_i^z \quad (1)$$

where $T_{i,1}$, ω_i^z , e_i , Δ_i are the first auxiliary gain, FDI attack signal, combination error, and compensation term of the agent i . In this paper, Δ_i which is utilized to eliminate the FDI attack can be obtained as

$$\dot{\Delta}_i = -e_i / T_{i,2} \quad (2)$$

where $T_{i,2}$ is the second auxiliary gain of the agent i . The combination error of agent i is calculated as

$$e_i = e_i^v + e_i^u \quad (3)$$

$$e_i^v = V_{DC}^{nom} - V_{DC} \quad (4)$$

$$e_i^u = u_i - u_j \quad (5)$$

where e_i^v is the error between V_{DC}^{nom} and V_{DC} , while e_i^u is the error between the secondary control output of the power agent i (u_i) and the power agent j (u_j) that is sent to the power agent i via DCL, respectively. Fig. 2 describes the block diagram of the proposed control scheme in detail. The secondary controller is used to guarantee the DCV at the nominal value

even under FDI attacks while the primary controller is utilized to ensure the power balance based on the $V-P$ droop curves.

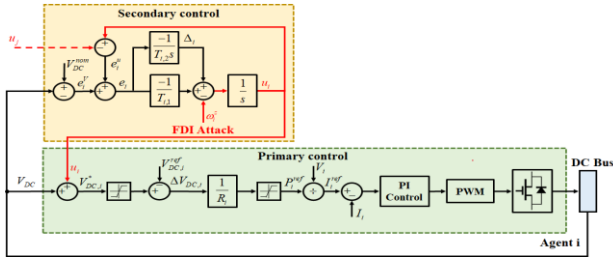


Fig. 2 Block diagram of the proposed control scheme.

To achieve optimal power management both in the grid-connected and islanded modes in the distributed DCMG, the $V-P$ droop curves of each power agent are presented in Fig. 3. The $V-P$ droop curves are determined based on the relationship of the low voltage level ($V_{DC,i}^{*,L}$), the high voltage level ($V_{DC,i}^{*,H}$), the maximum consumed power ($P_i^{C,max}$), the maximum supplied power ($P_i^{S,max}$), and droop characteristics (R_i) of each power agent. In the islanded mode, the battery or wind turbine agent regulates the DCV at the nominal value based on the load demand. When the load demand is higher than the sum of wind turbine power and maximum battery discharging power, the load shedding is activated to prevent the system collapse. In the grid-connected mode, the utility grid agent regulates the DCV based on the electricity price condition. Under high electricity price, the utility grid automatically changes its $V-P$ droop curve from ① to ② to optimize the utility costs. In this case, the utility grid agent prioritizes absorbing the power from the DC bus as much as possible.

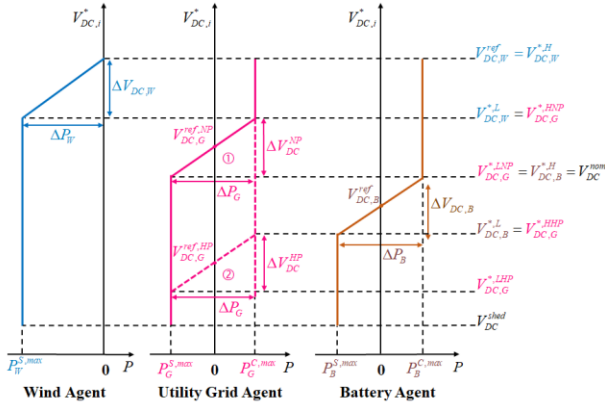


Fig. 3 $V-P$ droop curves for distributed power management.

3. Simulation Results

In order to verify the effectiveness of the proposed distributed control scheme, the simulations based on the PSIM software are conducted under uncertain conditions. Fig. 4 shows the system responses under various conditions. It is assumed that the DCMG system starts with the islanded mode and the generated wind power is less than the sum of the load power and the maximum battery charging power. In this situation, the battery agent regulates the DCV at the nominal value by the charging mode, while the wind turbine agent is in the maximum power

point tracking mode. When FDI attacks occur in both the battery and wind turbine agent at $t = 0.8s$, the negative impacts of FDI attacks are mitigated by the compensation term to maintain the voltage restoration and power balance for the distributed DCMG system. As the utility grid agent is recovered at $t = 1.2s$ with the normal electricity price condition, it causes the battery agent to operate at the maximum charging mode, and the DCV is controlled by the utility grid by converter mode. At $t = 2.0s$, FDI attack happens in the utility grid agent, the overall system stabilization is still ensured. When the electricity price is changed from normal to high at $t = 2.8s$, the battery operation is switched to discharging mode. As a result, the utility grid agent absorbs power from the DC bus via inverter mode. As FDI attack signals are increased in both the utility grid, wind turbine, and battery agents at $t = 3.5s$, the distributed DCMG system still guarantees the voltage and power stabilization by the proposed control scheme.

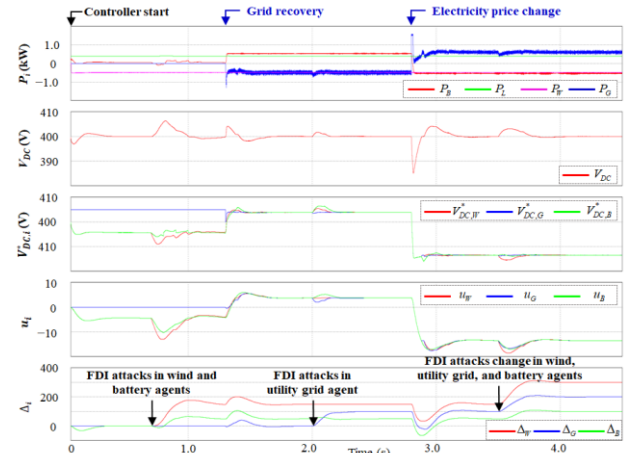


Fig. 4 System responses under various conditions.

4. Conclusion

This paper has presented a distributed resilient secondary control to achieve the optimal power management in case of electricity price change and voltage restoration for the DCMG system under FDI attacks. The reliability and feasibility of the proposed scheme have been validated by the simulation results under various conditions.

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References

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