Autonomous decentralized control of off-grid DC micro-grid

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According to the basic idea of autonomous decentralized system, this paper divides the various units of off-grid DC micro-grid into different roles , and each roles are given specific control objectives and control strategy. In order to verify the effectiveness of the proposed off-grid DC micro-grid autonomous decentralized control strategy, this paper creates an off-grid DC micro-grid simulation model containing distributed generation, energy storage, and DC constant power load in PSCAD/EMTDC. Simulation results show that the strategy can respond quickly in the working condition of load fluctuations, energy storage reaches capacity limits, and distributed power source output fluctuation, thus enhance the stability and power supply quality of the system.

Keywords: Autonomous Decentralized Control; Off-grid DC Micro-grid; Role-Division; PSCAD/EMTDC.

1. Introduction

In the conventional DC micro grid control strategies, master-slave control and hierarchical control rely heavily on communication systems[1-3]. Although there are no requirements of communication, only local information, in peer-to-peer control, it is not easy to achieve coordinated control between various units, and there are higher requirements on the parameters of the system, which is not conducive to practical use[4-5].

Based on the study on the basic principles of autonomous decentralized control, the paper proposes an autonomous decentralized coordinated control strategy applying to off-grid DC micro-grid.

2. The Constitution and Operation Mode of dc Micro-Grid

2.1. *Micro-grid constitutes*

The typical structure of an off-grid DC micro-grid network is shown in Figure 1. We can classify the units into three self-node[6-8].
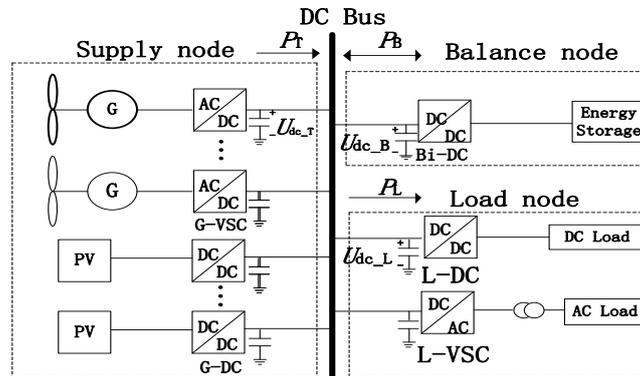
Fig. 1. Diagram of the traditional off-grid dc micro-grid.

(1)Balance node

The node can absorb power form micro-grid or output power to it ,in order to maintain the Voltage of the grid . Its control objective is to ensure a stable voltage on the DC bus.

(2)Power supply node

The node can only output power to micro-grid. Its control objectives are to maximize the output power.

(3)Load node

The node only absorbs power from micro-grid. Its control objective is to ensure the quality and continuity of load power supply as far as possible.

2.2. *Operation mode*

Off-grid DC micro-grid ,mainly relies on the balance node to maintain the power balance of the system[9-10].

$$P_B = P_L - P_T \tag{1}$$

Mode I:$P_L > P_T$, $P_B > 0$. Model II: $P_L = P_T$, $P_B = 0$. Model III:$P_L < P_T$, $P_B < 0$.

3. Autonomous Decentralized Strategy

Status signal and meaning shown in Table 1.

Table 1. Status signal and meaning.

symbol	meaning	Value explanation
B	Balance node state information	B=1 Energy storage device reached the storage limit B=0 Energy storage device proper function B=-1 Energy storage device reached lower limit
T	Supply node state information	T=1 MPPT control T=0 Constant voltage control
C	Load node state information	C=1 Have off-grid load C=0 Haven't off-grid load

3.1. *Control strategy of balance node*

The Balance node ADS control flow is shown in Figure 2. DC micro-grid balance node is mainly taken on by energy storage device, and the control strategy is shown in Figure 3.
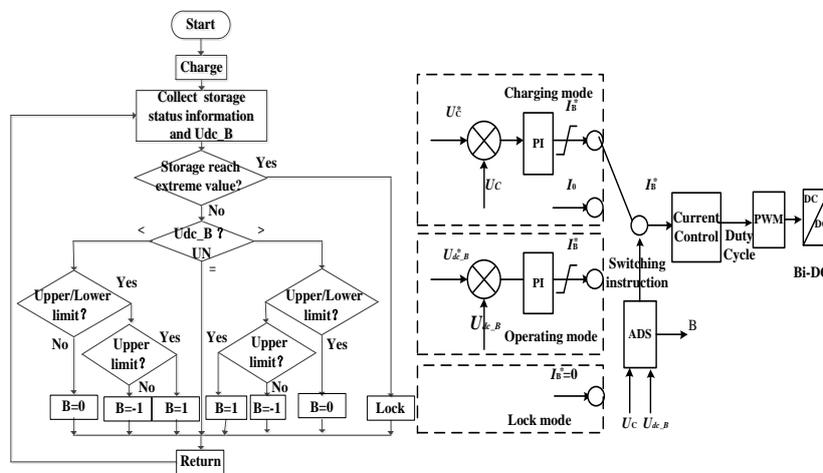

Fig. 2. ADS control flow chart of balancing bus.   Fig. 3. Control strategy diagram for Bi-DC.

3.2. *Control strategy of power supply node*

Supply node ADS control process is shown in Figure 4. Power supply nodes is undertaken mainly by various types of distributed generators. In this paper, we take solar power as an example, and the control strategy is shown in Figure 5.
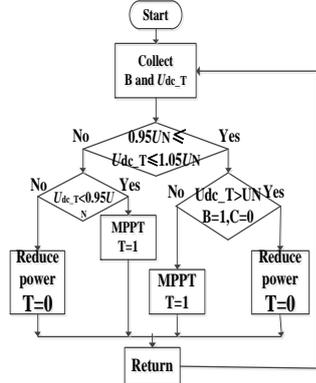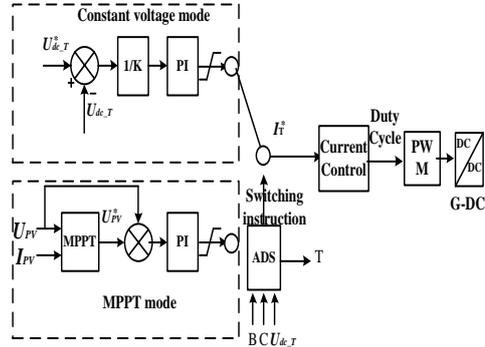
Fig. 4. ADS control flow chart of power bus   Fig. 5. Control strategy diagram for G-DC

3.3. *Control strategy of load node*

Load node ADS control process is shown in Figure 6. Load nodes in DC micro-grid consist of various types of AC and DC loads. This paper takes DC constant power load for example and the control strategy is shown in Figure 7.
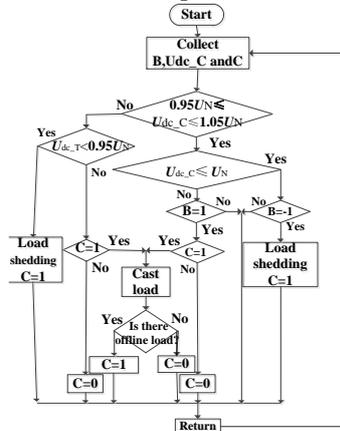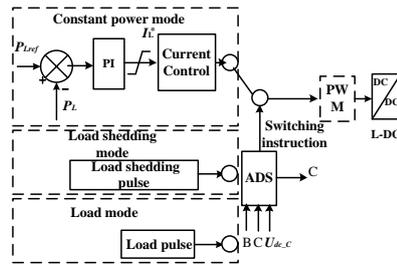

Fig. 6. ADS control flow chart of load bus   Fig. 7. Control strategy diagram for L-DC.

4. Simulation

In order to test and verify the effectiveness of the autonomous decentralized control strategy, we put up simulation system as   shown in Figure 8 in EMTDC/PSCAD. This system includes a permanent magnet synchronous wind power generator set and a photovoltaic cell, both of whose rated power are 5kW. We use super capacitor as the energy storage element, capacitance value C = 10F, the upper limit of voltage U_{Cmax}=90V, the lower limit of voltage U_{Cmin}=50V, the maximum output power is given by the Eq. (2) as below.

$$E_{\max} = \frac{1}{2}C(U_{C\max}{}^2 - U_{C\min}{}^2) \tag{2}$$

We can know that when $E_{\max}$ = 28kJ, loads L_1, L_2, L_3 are all constant load, and the capacities are respectively 4kW, 2kW, 4kW. Among them L1 is precedence over L_2 and L_3, L_2 and L_3 have the same priority. Direct-current generator rated voltage UN = 400V. Next we give three operating modes in off-grid mode, and the simulation result of DC micro-grid with autonomous decentralized control is shown in Figure 9. We can learn from Figure 9 that in the initial state of the simulation (0-2s), the power output P_T of the supply node is 10kW, and the system runs at the maximum power mode. When the output power P_B of the balance node is 0kW, SOC initial value is 70%. Constant power load L_1, L_2, L_3 all access to the system, the total load of the system P_L is 10kW, and the system voltage U_{dc} stable is kept at 1 pu.
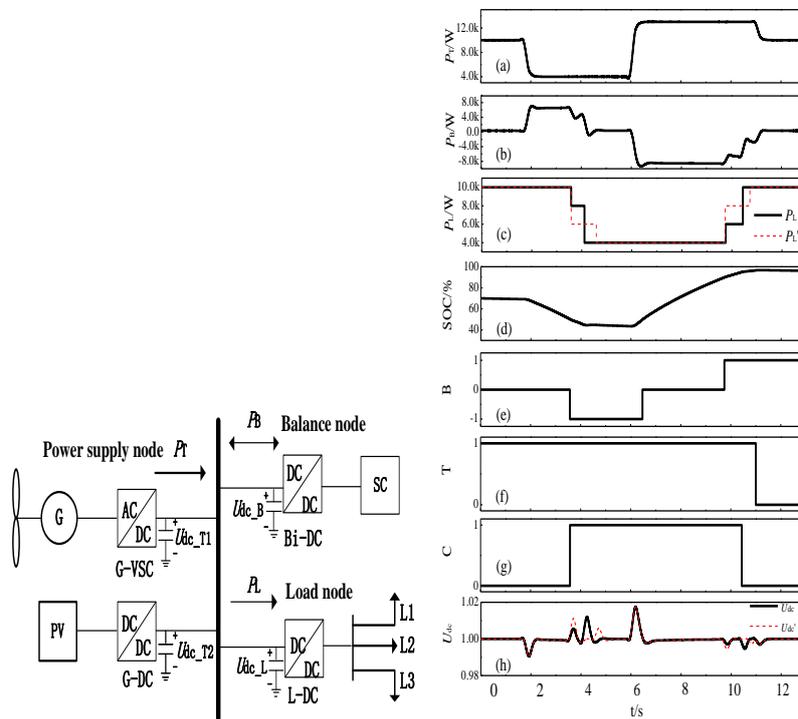

Fig. 8. Simulated system diagram of dc micro-grid.   Fig. 9. Off-grid dc micro-grid performances.

Mode I(2-4s): At 2s, power supply node output power P_T decreases to 4kW. The balance node output power to compensate for the power shortage, P_B is 6kW, and the SOC begin to decrease, as is shown in Figure 9(a),(b),(d).At 3.5s, SOC of the balance node drops to 50%, load L_2 is removed, Since at this time P_T

is less than P_L, the balance node kept on outputting power, SOC% drops below 50%, as shown in Figure 9(c),(d). At 4s, load L_3 is cut, only with the most important load L_1 left. At this moment P_T is equal to P_L; The output power P_B of the balance node is 0kW, as is shown in Figure 9(a)-(c), and the system enters into model II.

Model II(4-6s): In model II, P_T equals to P_L. P_B is 0kW, and SOC remains unchanged, as is shown in Figure 9

Model III(6-11s): At 6s, P_T increases to 12kW. At this time P_T is more than P_L. The balance node absorbs power, and P_B is -8kW, SOC% began to rise, and the system enters into mode III. At about 10s ,SOC% rises to 90%,as shown in Figure 9(a)-(d). load L_2 accesses to the system, At this time P_T is still more than P_L, the balance nodes continues to absorb power, and SOC continues to rise, as shown in Figure 9(a)-(d). At about 10.5s, load L_3 accesses to system. At this time all system loads access to the system with no offline load, as shown in Figure 9(c). Since at this moment is still greater than the P_L , SOC% continues to rise. At 11s the power supply node makes drop power control in order to maintain the system voltage stability, as is shown in Figure 9(a).

Figure 9 (c), (h) use the dashed line to show that, when the loads have the same priority, a large load switching simulation diagram should be selected first. Figure 9(h) shows that ,in the three off-grid modes, with the change of power supply node and the load node, balance nodes continue to adjust its output power, hence maintaining the system DC voltage between 0.98 ~ 1.02pu, which ensures the stability of the system.

5. Conclusion

The advantages of this control strategy lie in:

(1)In the autonomous decentralized control strategy, each element is independent and only obtains a small amount of system status information to complete the grid-connected and off-grid control, which greatly improves the system scalability and fault tolerance.

(2)Data fields and radio communication make each node take appropriate action, we can get the system running status, predict its own operation impact on system, reduce the impact on the system by selecting the optimal mode of operation .

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