

Research on Optimal Control of AC-DC Hybrid Distribution Network

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Abstract. It is hard to optimize power flow and operating status of hybrid AC/DC distribution network with traditional control strategy, so this paper proposed a hierarchical control strategy with different voltage scales. In the first layer, different converter stations maintain stable operation of power system with different control strategy; In the second layer, when power fluctuations of system are large, converter stations change its operation mode to balance voltage fluctuation of DC side; In the third layer, energy optimal dispatch system calculate different converter stations' control reference to reduce power loss of system. When operation of system change, systems' stable operation is maintained by switching of control strategy in different layer. The simulation using Matlab/Simulink shows that this control strategy can reduce power loss and system can operate stably even in communication failure.

1. Introduction

With social progress and economic development, power load is growing rapidly, distributed generation is being paid more and more attention, besides, the user's power consumption has also changed greatly, the proportion of DC load is increasing largely. With the change of power supply mode and power consume mode, AC distribution network meet great challenge in access to distributed power and improve the power quality, so hybrid AC/DC distribution network is being paid more and more attention by experts and scholars [1]-[4].

To improve the reality of distribution network, experts try to connect different AC distribution network by flexible interconnected device(FID) and DC line, every area of the system can support power to each other by DC line. Besides, distribution generation, DC load and energy storage system can be connected to DC line. For the structure of hybrid AC/DC distribution network is much more complex, how to coordinate the control strategy of different converter stations is the key of system's stable operation.

In view of the above problems. A kind of control strategy was proposed to control AC voltage and frequency by converter station and energy storage system maintain the DC voltage within the allowable range by droop control, but this control strategy did not consider overcharge and discharge of energy storage systems [5]. Aim at the fluctuation of DC line voltage of hybrid AC/DC distribution network, feedforward controller and anti disturbance controller was adapted to balance it [6]. To reduce the impact of branch voltage fluctuation caused by distribution generation and electric vehicle,



the VSC of the branch which photovoltaic generation unit was connected into AC distribution network adapt AC voltage-power control [7]. A kind of control strategy of hybrid AC/DC distribution network based on back to back interconnected converter was proposed, it gives different converters control strategy depend on the power transmission between DC network and AC network, it also consider many kind of failure condition at the same time [8].

To optimize systems' operating status without need excessive communication requirements, this paper combine optimal scheduling with traditional control. When system operating normally, optimal scheduling system provide converter station with dispatch instruction to reduce its power loss; when dispatching system work abnormally, it change converters' mode to stable distribution network by detecting the voltage of each node.

2. Hybrid AC/DC Distribution Network's Structure

Nowadays, the development of AC and DC hybrid distribution network is in the initial stage, its topology is usually referred to traditional distribution network, this paper focuses on the topological structure of two-terminal. Connecting AC distribution network to DC distribution network by flexible interconnected device, energy storage system, photovoltaic power generation system and AC load are connected into DC areas by different flexible interconnected device, DC load and double fed induction generator(DFIG) are connected into AC areas. It can reduce the use of converter stations when more electric unit need to connected into it, besides, power support between AC areas and DC areas can be realized through effective control of flexible interconnect devices. Its topology shown in Fig. 1.

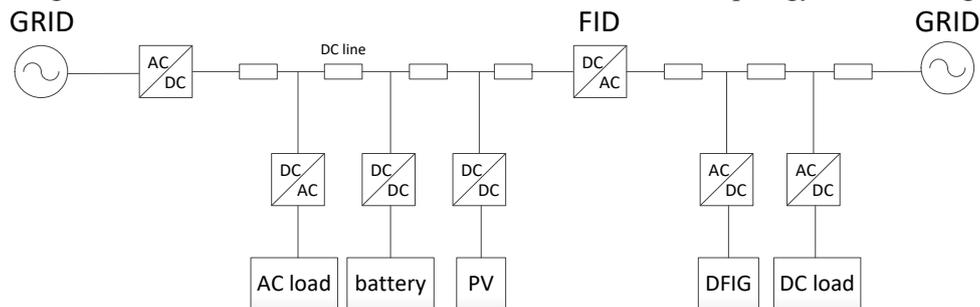


Figure 1. Topology of hybrid AC/DC distribution network.

3. Control Strategy

The hierarchical control proposed in this paper is divided into three layers according to DC side voltage. when the DC voltage deviation is within the allowable range, the main converter station and the minor converter station adopt different control strategies to provide voltage support for the DC side at the same time; when the DC voltage deviation become larger, energy storage system adopt droop control strategy to maintain the DC voltage; when systems operate stably, optimal scheduling system provide scheduling instruction for converter stations. Control strategy of each layers as follow.

3.1. The first layer's control strategy

In the first layer, DC voltage deviation is small, the main converter adopt constant voltage control strategy, the minor converter adopt U-P droop control strategy, both of it support power for DC areas, besides the control parameters are provided by optimal power flow calculation. The voltage can be expressed as (1) and (2).

$$U - U_{opf} = -k_{up}(P_{VSC2} - P_{opf}) \quad (1)$$

$$k_{up} = \min \left\{ \frac{U_{\max} - U_{opf}}{P_{opf} - P_{\min}}, \frac{U_{opf} - U_{\min}}{P_{\max} - P_{opf}} \right\} \quad (2)$$

where U_{opf} and P_{opf} are the control parameter reference, U_{\max} , U_{\min} , P_{\max} , P_{\min} are critical point of mode switching, k_{up} is its drooping coefficient.

3.2. The second layer's control strategy

When the system is in poor operating condition, converter stations' voltage and power may exceed its critical value and change its control mode automatically, it is hard to maintain DC voltage in allowable range with only the main converter and minor converter. The energy storage systems will switch to droop control at this time to recover voltage to normal status. The voltage can be expressed as (3).

$$U_{Bi} = U_{Bi}^* - k_{Bi}(P_{Bi} - P_{Bi\text{ref}}) \quad (3)$$

where P_{Bi} and $P_{Bi\text{ref}}$ are power and its reference of battery, U_{Bi}^* is voltage's critical value, k_{Bi} is its drooping coefficient.

3.3. The third layer's control strategy

The third layer is energy optimization dispatch system, transfer the date collected or predicted to the optimal power flow calculation system, calculate and get the reference of control which will let the system in the optimal status. When the third layer work normally, it offers its calculation results to the lower layer.

In summary, the control strategy of this paper can be shown in Fig. 2

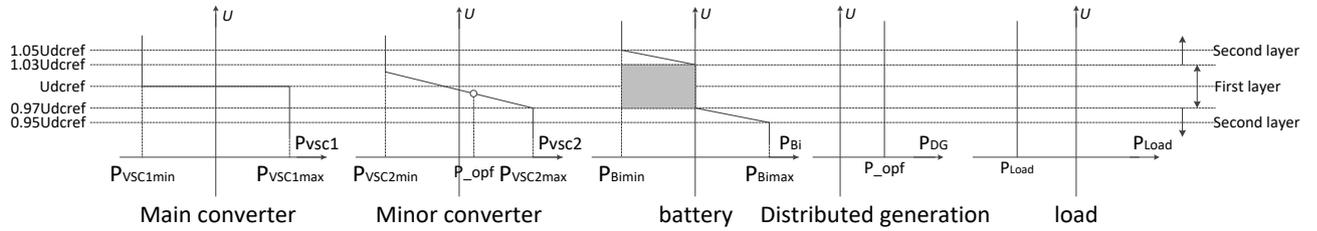


Figure 2. Proposed hierarchical control strategy

4. Energy Optimization Scheduling Model

The target of this control is to minimize the power loss of hybrid AC/DC distribution network and satisfy the constraint conditions at the same time, so objection function of system should include three part, minimize the power loss of line and converter and maximize distributed generation's power, so its objective function can be expressed as (4).

$$f_1(u, x) = \sum_{i=1}^{n_{DG}} (P_{DG_i_MPPT} - P_{DG_i}) + \sum_{i=1}^{n_{VSC}} P_{VSC_i} (1 - \eta_i) + P_{loss_line} \quad (4)$$

Where P_{DG_i} and $P_{DG_i_MPPT}$ are actual power and maximum power generation power of distribution generation; P_{VSC_i} is actual power of converter station, η_i is its efficiency; P_{loss_line} is the power loss of DC and AC transmission line

When hybrid AC/DC distribution network work stably, it should satisfy equality constraint and inequality constraint which can be expressed as follow formula

4.1. constraint of node power

$$P_{DG_i}^{DC} + P_{VSC_i}^{DC} - P_{L_i}^{DC} - U_i \sum_{j=1}^N (U_j - U_i) g_{ij} = 0 \quad (5)$$

$$P_{DG_i}^{AC} + P_{VSC_i}^{AC} - P_{L_i}^{AC} - U_i \sum_{j=1}^N U_j [G_{ij} \cos(\theta_i - \theta_j) + B_{ij} \sin(\theta_i - \theta_j)] = 0 \quad (6)$$

$$Q_{DG_i}^{AC} + Q_{VSC_i}^{AC} - Q_{L_i}^{AC} - U_i \sum_{j=1}^N U_j [G_{ij} \sin(\theta_i - \theta_j) - B_{ij} \cos(\theta_i - \theta_j)] = 0 \quad (7)$$

Where DG_i , VSC_i and L_i are distribution generation, converter station and load. DC and AC mean DC areas and AC areas.

4.2. constraint of node voltage

$$U_{i\min} \leq U_i \leq U_{i\max} \quad (8)$$

where U_i , $U_{i\min}$ and $U_{i\max}$ are node voltage and its limit.

4.3. constraint of transmission line power

$$P_{ij\min}^{DC} \leq P_{ij}^{DC} \leq P_{ij\max}^{DC} \quad (9)$$

$$S_{ij\min}^{AC} \leq S_{ij}^{AC} \leq S_{ij\max}^{AC} \quad (10)$$

where P_{ij} , $P_{ij\min}$ and $P_{ij\max}$ are actual power of transmission line and its limit; S_{ij} , $S_{ij\min}$ and $S_{ij\max}$ are apparent power of transmission line and its limit.

4.4. constraint of converter station

$$P_{VSCi\min} < P_{VSCi} < P_{VSCi\max} \quad (11)$$

$$\sqrt{P_{VSCi}^2 + Q_{VSCi}^2} < S_{VSCi} \quad (12)$$

where P_{VSCi} and Q_{VSCi} are actual power and reactive power of converter station, $P_{VSCi\min}$, $P_{VSCi\max}$ and S_{VSCi} are its limit.

5. Simulation Analysis

To verify the effectiveness of the hierarchical control strategy in this paper, building the simulation model shown in Fig. 1 with Matlab/Simulink, where the DC bus voltage is 20Kv, DC voltage bus voltage is 6Kv. The following gives the system operating status when power fluctuate, its operating conditions change as follows and the status of system shown in Fig. 3

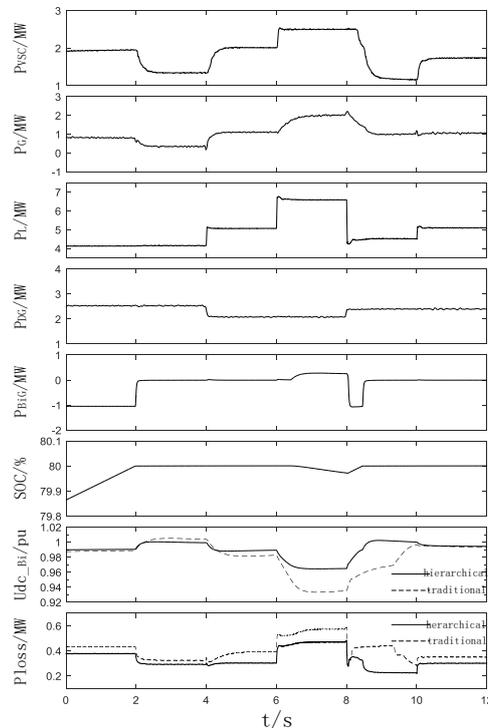


Figure 3. System operation performance

In Initial state, power of PV and DFIG are 1.5Mw and 1.1Mw, load L1, L2 and L3 are 2Mw, 1Mw and 1Mw, state of charge of energy storage system is 79.86%, its voltage deviation is small; At the 2s, SOC reach 80%, battery stop charging; At the 4s, energy scheduling system hitch, besides, PV's

power reduce to 1Mw, load L2 increase to 2Mw, it lead to drastic decrease of DC voltage; At the 6s, load L1 increase to 3.5Mw, the main converter station's power reach its upper limit and switch its control strategy to current limiting mode which will lead to drastic decrease of DC voltage. when the DC voltage deviation reach its lower limit, the systems will switch to the second layer. At the 8s, load L1 reduce to 1Mw, load L3 increase to 1.5Mw and power of DFIG increase to 1.5Mw, the demand of DC load is reduced at that time, so the DC voltage increase; At the 10s, the scheduling system return to normal.

6. Conclusion

This paper presents the hybrid AC/DC distribution network's structure and its hierarchical control strategy, establish an optimal scheduling model which aims at minimal power loss. It can be known through simulation verification that this paper's control strategy can reduce power loss and ensure the stable operation of the system with no need for high communication quality; when system's power fluctuates, minor converter change its power under droop control, reduce the pressure of the main converter station.

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