Study on Structure and Control Strategy of Hybrid AC / DC Power Grid

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Abstract. Hybrid AC/DC power grid is the development direction and inevitable choice of the future power transmission and distribution network along with the high proportion penetration of distribution generation (DG). The design principle of hybrid AC/DC power grid structure is studied and a novel hybrid AC/DC power grid network structure which combined power electronic transformer (PET) with traditional transformer was proposed to reach the goal of flexible regulation under stable operating conditions. The corresponding control strategy of the proposed grid was designed based on the master-slave control and peer-to-peer control. The correctness of the proposed hybrid AC/DC power grid and the rationality of the control strategies are verified according to the simulation under the PSCAD/EMTDC simulation environment.

1. Introduction
In order to effectively deal with the increasingly serious environmental pollution and fossil energy exhaustion problem, research to improve the penetration of distributed generation (DG) in the power grid under multi types power mode and load side diversity condition has been carried out.

The large scale access to distributed generation (DG), mainly include wind power and photovoltaic generation, has changed the single characteristic of the traditional grid power supply mode. The traditional distribution network, with the main features of unidirectional power flow and the radiant network, will face enormous challenges with the development of loads diversity and the high demand for power quality [1]. The construction of hybrid AC/DC power grid with sub-units of micro-grid and active power distribution network based on the traditional power grid is the future development direction of transmission and distribution network.

Hybrid AC/DC power grid has both the advantages of AC power grid and DC power grid, mainly including: 1) Bidirectional power flow of AC DC subsystem and provide the power support to each other. 2) The operation of subsystems can be flexibly switched in both grid and island conditions. 3) The power electronic transformer is reduced while the efficiency of the system is improved; 4) Flexible system control can improve the reliability of power supply. Therefore, hybrid AC DC power grid becomes the inevitable choice for intelligent development of transmission and distribution network in the future.
The research on hybrid AC/DC power system mainly focuses on topology design, operation control strategy, fault protection and stability analysis. Reference [2] mainly describes several designing principle of distribution network according to the partition and hierarchy principles, while consider resource utilization maximization, energy complementary, energy storage and reactive power compensation. The corresponding power control strategy is comprehensively expounded in three components, which include AC subsystem, DC subsystem and interlinking converter. The state-of-the-art power control strategies of AC and DC subsystem are classified and summarized, hierarchical control is more popular in all of the control, which can not only sharing the load current, but also providing virtual inertia for the system. The harmonic current of VSC under unbalanced condition is theoretically analyzed [4], methods to separate positive and negative sequence components of grid voltage are summed up. Finally, protection and control strategy of grid are proposed. Reference [5] mainly focus on the stability analysis of Micro-grid, the impedance model of Micro-grid is established under synchronous dq coordinate system, and the Nyquist stability criterion is used to analyze the stability of the system. Some other methods of stability study have been proposed, mainly including small signal analysis and analysis of frequency stability in frequency domain [6].

A novel hybrid AC/DC power grid network topology incorporate power electronic transformer and conventional transformer was proposed in this paper. The control strategies of proposed hybrid AC/DC power system are mainly discussed master-slave and peer-to-peer control. Finally, the validity of proposed topology and control strategies are verified using PSCAD/EMTDC simulation.

2. Structure of hybrid AC/DC power grid

2.1. Principles of the Structure Design
Hybrid AC/DC power grid, which has both the advantages of AC power grid and DC power grid, is the state-of-the-art construction of transmission and distribution network in the future. The construction of hybrid AC/DC power grid must comply with four principles [7].

The principle of partition: The type of power supply and the network architecture are rationally designed according to the capacity of the load and the future development plan to reduce network loss and improve the transmission efficiency.

The principle of hierarchy: Bus voltage level in the power grid and the capacity of equipment are reasonably designed according to the type of power supply and the network of architecture.

Energy complementation and maximization utilization: Coordination and complementation of distributed power and traditional power supply. The use of energy storage device to suppress the fluctuation of distributed power, and improve the penetration of power quality: Reactive power compensator device is reasonably designed to optimize the operation of the system and improve the power quality of the load side.

2.2. Typical Hybrid AC/DC Power Grid
Hybrid AC/DC power grid is mainly composed of AC subsystem, DC subsystem and interconnected converter. Two typical system patterns are given in [3]. One is that the AC subsystem and DC subsystem are basically independent of each other, and are interconnected only through the high voltage side or the low voltage side of AC bus. The other is the multi-terminal interconnection of the AC/DC subsystem. The practical applications of hybrid AC/DC power grid are generally one of these two patterns or combination.

2.3. The Proposed Hybrid AC/DC Power Grid Structure
As an “energy router” for hybrid AC/DC power grid, the application of power electronic transformer improves the flexibility of system control, but reduce the reliability of system operation. A novel hybrid AC/DC power grid network topology incorporate and traditional transformer was proposed later.
Vigorous development of flexible HVDC in China, the interconnected and mutual supply of hybrid AC/DC power grid is realized through flexible HVDC. The proposed hybrid AC/DC power grid network structure is shown in Fig. 1.

Figure 1. Structure of hybrid AC/DC power grid

Power electronic transformer is a novel substation with flexible control, which can realize various functions such as electrical isolation, voltage transformation and reactive power compensation. In this paper, the power electronic transformer unified as Fle-Sub. In Fig. 1, Fle-Sub1 and Fle-Sub2 realize AC/DC/DC/AC three voltage transformation, also provide AC 380V, DC 20kV, DC 750V voltage interface. Fle-Sub1 and Fle-Sub2 interconnect through 20kV HVDC transmission, and connect to the regional power grid through 10kV AC bus bar. Fle-Sub1 operates in parallel with the traditional transformer substation through bus connection switch.

The advantages of proposed hybrid AC/DC power grid is as follows:
- The system operation reliability is improved by the parallel operation of interconnected converter and tradition transformer. More other functions can realized through the flexible control of the Fle-Sub compare to the traditional transformer substation.
- Regional hybrid AC/DC power grid interconnect and mutual supply through flexible HVDC. Easy to build in practical application.
- Multi voltage level interface is provided for flexible access of different types power supply and meet the diversity needs of the load in the future.

3. Coordinated control strategy of the proposed hybrid AC/DC power grid

On the basis of ensuring the stable operation of the system, the purpose of system control strategies is to reduce system loss, improve power supply quality of system, satisfy the demand of flexible control in load side and improve the permeability of distribution generation [5-8].

The coordination control strategies of hybrid AC/DC power grid can divide into three kinds based on the speed of communication, which include high speed communication control, low speed communication control and control without communication [9-10]. Maser-slave control [11] and peer-to-peer control [12] are applied into the proposed hybrid AC/DC power grid to achieve the purpose mentioned above.

The master-slave control structure of the proposed hybrid AC/DC power grid in this paper as show in Fig. 2. The front-end input level of Fle-Sub1 and Fle-Sub2 use the master-slave control strategy, the former uses the fixed DC voltage and reactive power control to ensure the voltage stability of 20kV DC system, while the latter uses the PQ control strategy to control the power flow between the system and the power grid. Medium voltage DC conversion level uses the open loop control strategy to provide the 750V DC voltage interface for DC load. The invert output level of the Fle-Sub1 and Fle-Sub2 choice the control strategy according to the load power model, that is to say we can choose the V/F or Droop control strategy when the load side is isolated island, while we can choice the PQ control strategy when the load side connect to the grid, and the control strategies switch between the mentioned above two control model according to the detection signal of the load. Traditional transformer parallel operate with the Fle-Sub1 through the bus bar connection switch, and the control...
model of the invert output side of Fle-Sub1 choice the PQ control strategy when the bus bar connection switch is open state.

The peer-to-peer control strategy refers to apply DC droop control to ensure the stability of 20kV DC system, which reduce the dependence of the 20kV DC system on the Fle-Sub1. The peer-to-peer control structure of the system same as Fig. 2, with the exception of the 20kV DC interface control strategy.

Figure 2. The control structure diagram of the proposed hybrid AC/DC power grid under master-slave control mode.

4. Simulation result
Build the simulation in the following several operation mode of the proposed hybrid AC/DC power grid in PSCAD/EMTDC to verify rationality of the topology and correctness of the control strategies.

4.1. Master-Slave Control Operation Mode
The front-end level of Fle-Sub1 use the DC link control and the reference of DC voltage change from 20kV to 21kV in 0.45 second, while the front-end level of Fle-Sub2 use the PQ control and the reference of active power change from 2MW to 2.5 MW in 0.3 second. The control strategy of the invert output level in Fle-Sub1 change from VF control to PQ control when the 0.4kV bus bar connection switch close in 0.3 second, the reference of active power change from 1MW to 1.2MW in 0.6 second. The waveforms of the simulation under above mentioned operating mode are show in Fig. 3.
Figure 3. Simulation waveform under the master-slave control mode

4.2. Peer-to-Peer Control Operation Mode

Master-slave control relay on the fast communication system, while peer-to-peer control can realize without communication system, and the redundancy of the system is improved under peer-to-peer control strategy.

The front-end level of Fle-Sub1 and Fle-Sub2 use droop control to keep the voltage of 20kV DC system stable under peer-to-peer control strategy. Different droop coefficients are used in the simulation. The invert level of Fle-Sub1 use VF control and the bus bar connection switch keep open state. The waveform of the simulation under above mentioned operating mode is show in Fig. 4.
5. Conclusion
A novel hybrid AC/DC power grid is proposed in this paper. Coordination control strategies of the system are designed, which mainly based on master-slave control and peer-to-peer control strategy. The simulation results are consistent with the theoretical analysis. The stability and reliability of the proposed system need to be further verified.

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