Coordinated control of a hybrid wind farm with PMSG and FSIG during asymmetrical grid fault

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ABSTRACT

This paper investigates a coordinated control of a hybrid wind farm with permanent magnet synchronous generator (PMSG)-based and fixed-speed induction generator (FSIG)-based wind turbines during asymmetrical grid fault. According to the boundary conditions of asymmetrical grid fault, the coupling relationship between positive- and negative-sequence grid voltages is presented in detail. Furthermore, the impact of the operation and equivalent impedance of the hybrid wind farm on the grid voltage components during asymmetrical grid fault are analyzed. A coordinated low voltage ride through (LVRT) control strategy for a hybrid wind farm without communication equipments is then developed based on the impact analysis. The proposed strategy supports the grid voltage recovery with the reactive power provided from the PMSG systems. Meanwhile, by using the extra current capacity of the PMSG systems to provide the negative-sequence current, the negative-sequence grid voltage can be suppressed. As a result, performance and output power quality of the FSIG-based wind farm are both improved with the coordinated control of PMSG-based wind farm. Finally, the simulation results of a hybrid wind farm under different asymmetrical grid fault conditions and a phase-phase short circuit fault experimental results of laboratory-scale test rig both validate the proposed coordinated control strategy.

1. Introduction

With the large-scale development and exploitation of renewable energy source, wind power has shown a high penetration into the power system over the last decades [1–3]. Nowadays, fixed and variable speeds have become the two primary technologies for wind power generation. Compared with permanent magnet synchronous generator (PMSG) and doubly-fed induction generator (DFIG) systems, fixed-speed induction generator (FSIG) fails to fulfill some of the grid requirements for a fault ride-through [4,5]. During asymmetrical grid fault, a large amount of reactive power is consumed as the FSIG's rotor speed deviates from the synchronous speed, which may cause the tripping of the wind farm based on FSIG systems. Meanwhile, the negative-sequence component of grid voltage would further cause oscillations in electromechanical torque and output power of the FSIG-based wind farm. Consequently, how to improve the operation behavior of FSIG system during asymmetrical grid fault should be paid more attentions [6].

In order to enhance the low voltage ride through (LVRT) capability of the FSIG-based wind turbines, the applications of dynamic voltage restorer (DVR), static var compensator (SVC), StatCom and energy storage system (ESS) have been proposed respectively in [7–11]. Analytical and simulation results both indicate that StatCom has larger transient stability margin and greater performance than others during grid faults. In [12], a coordinated control of StatCom between positive- and negative-sequence grid voltages is proposed to improve the operation of FSIG-based wind farm during asymmetrical grid fault. In [13], a control structure integrated StatCom and ESS is proposed to enhance the LVRT capability of FSIG-based wind farm during the network disturbance. However, the installed capacity of StatCom cannot be determined accurately, which would further increase the cost of the whole system due to additional facility and over-compensation.

Recently, PMSG and DFIG systems have been installed alongside the FSIG-based wind farm [14–16], which can be used to optimize the performance of FSIG-based wind farm under non-ideal grid conditions. In [17], the operation of a wind energy conversion system containing both FSIG- and DFIG-based wind farms during network unbalance is investigated. Based on the detailed analysis about the natures of voltage dips in PMSG, DFIG and FSIG systems, Ref. [18] concluded that PMSG and DFIG systems both could be

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used to improve the stability of grid voltage and the operation of FSIG-based wind farm during grid voltage dips. For a large-scale hybrid wind farm, thousands of sensors and controllable devices would be difficult to efficiently operate due to the complex communication, computation and etc. As a consequence, the coordinated LVRT control among different distributed generators in the hybrid wind farm with FSIG and PMSG or DFIG becomes a new question to solve.

Aiming to realize the LVRT operation of a hybrid wind farm with DFIG and FSIG, an enhanced control strategy is further developed with the reactive power support provided by the DFIG systems in [19–22]. Considering the more flexible controllability of PMSG system, a controller for independently regulating the positive- and negative-sequence currents of PMSG converters was designed to improve the LVRT capability of the induction machines in [23]. However, such control method cannot realize the elimination of the negative-sequence grid voltage. A coordinated control strategy for a hybrid wind farm with PMSG and FSIG during unbalanced grid voltage was presented in [24]. By injecting the negative-sequence current at the point of common coupling, the negative-sequence grid voltage could be suppressed. However, the operation and control of a hybrid wind farm with PMSG and FSIG during asymmetrical grid fault, namely, severe unbalanced grid voltage condition, are not further investigated in this literature. On the other hand, according to the equivalent circuit when asymmetrical grid fault occurs, the positive-sequence grid voltage has a coupling relationship with the negative-sequence grid voltage as analyzed in [25]. Consequently, different voltage controls of the PMSG-based wind farm may have a great impact on the LVRT capability of the hybrid wind farm with PMSG and FSIG. However, there are few literatures to investigate the operation and coordinated voltage control of a hybrid wind farm with FSIG and PMSG during asymmetrical grid fault.

In this paper, a hybrid wind farm including a PMSG-based wind farm and a FSIG-based wind farm is considered as the investigated system. The main work and contribution of this paper contains that: (1) detailed analysis about the impact of operation and control of the PMSG-based wind farm and the equivalent impedance of the whole hybrid wind farm on the grid voltage components during asymmetrical grid fault; (2) a coordinated LVRT control strategy without communication equipment for a hybrid wind farm with PMSG and FSIG is developed based on the impact analysis. With the proposed coordinated control of PMSG converters, not only the hybrid wind farm can satisfy the grid codes for a fault ride-through but also the negative sequence grid voltage can be suppressed simultaneously. Due to the suppression of the negative-sequence voltage during asymmetrical grid fault, the output power quality of the FSIG-based wind farm would further be improved significantly.

This paper is organized as follows. The configuration and the operation of the investigated hybrid wind farm during asymmetrical grid fault are described in Section 2. Section 3 analyzes the coupling relationship between the positive- and negative-sequence components of grid voltage during asymmetrical grid faults. A coordinated LVRT control for the hybrid wind farm in Section 4 is followed by the simulation results for the asymmetrical grid fault in Section 5. Section 6 shows the verification for the proposed control strategy by experimental researches of a hybrid generators-based wind energy conversion system. The conclusion is drawn in Section 7.
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