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A performance comparison of a nonlinear and a linear control for grid connected PMSG wind energy conversion system

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ABSTRACT

With the increased penetration of wind energy on modern power systems all over the world, the Wind Farm Systems (WFS) are today required to participate actively in electric network operation by an appropriate generation control strategy. This paper presents a comparative study of two control strategies for wind farm based on Permanent Magnet Synchronous Generator (PMSG) and interconnected to the distribution network. The 4 MW wind farm consists of 2 PMSGs based on 2 MW generators connected to a common DC-bus system. Each PMSG of the WFS is connected to the DC-bus through a rectifier, but the DC-bus is connected to the grid through only one inverter system. The proposed control laws are based on a sliding mode algorithm and classical Proportional Integral (PI) controllers to regulate both generator and grid-side converters. The control strategy combines a pitch control scheme and Maximum Power Point Tracking (MPPT) to maximize the total generated power of WFS. Furthermore, the aim of the control strategy is to maximize the extracted power with the lowest possible impact in the power network voltage and frequency for fault conditions as well as for normal working conditions. Finally, simulation results with Matlab/Simulink environment confirm that the proposed strategy has excellent performance.

Introduction

In recent years, owing to the increasing concern for the possible energy shortage and the environmental pollution, renewable energy has attracted great interests as it is a potential source for electricity generation with minimal environmental impact [1,2]. Besides, more and more importance is being attached to Wind Energy Conversion System (WECS) that is growing at a faster rate than any other source energy and it has gained vast populations in the past decade [3–6]. WECS can be divided into variable speed type and constant velocity type. Hence, for fixed velocity wind generation system, the generator is directly connected to the electric network, so the turbulence of the wind will result in power variations, and so affect the power quality in the grid system [7,8]. Although, for variable speed WECS, the generator is used with power electronic converter. Consequently, variable speed WECS offer several advantages over fixed velocity generation, such as MPPT control strategy, increased power capture, improved power quality, better efficiency and they can be controlled to reduce both mechanical stress and aerodynamic noise. For this reason, the variable speed wind turbine generator system is becoming the most important and fastest growing application of wind generation system [9–13]. In terms of the generators for WECS, several types of electric generators are used such as Doubly Fed Induction Generator (DFIG), Squirrel-Cage Induction Generator (SCIG), Synchronous Generator with external field excitation and Permanent Magnet Synchronous Generator (PMSG) with power electronic converter systems [14,15]. Recently, the use of the PMSG system is becoming more and more common for several reasons such as: lower operational noise is achieved, very high torque can be achieved at low speeds because PMSG is connected directly to the turbine without gearbox, external excitation current is not needed and no significant losses are generated in the rotor system. Hence, the efficiency of a PMSG based WECS has been assessed higher than other generators and it is an attractive choice for grid-connected variable-speed generation system [16–18].

Because of technology constraints, the size of individual variable-speed WECS is still limited. Accordingly, a Wind Farm System (WFS) is usually composed of a several individual Wind Turbine

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Generator (WTG) connected and operating simultaneously. In the case of WFS based on the PMSG, thanks to the advance of power electronic technology, decreasing equipment costs, the integration of WFS and the large scale exploration, the PMSG is interfaced to the grid with a full scale power converter and it is increasingly adapted due to full controllability of the system and its higher power density [18,19]. Furthermore, so as to adjust the rotational velocity to maximize the WTG output power from the fluctuating wind, variable speed operation of the system is required and, for various wind speeds, the wind Turbine Systems (WT) can be operate as close as possible to their optimal velocities to realize MPPT [6,20,21]. For this reason, control strategy for the WFS is used, and with the advance of power electronic technology, the Wind Farm Systems are at present required to participate actively in power network operation by appropriate generation control strategies [22,23]. Accordingly, several control schemes have been proposed. In addition, for each WT system, two controllers are used, one is the pitch controller for the pitch angle and the other one is the power controller regulating the output power [24–33].

With increasing penetration of WECS in electrical power systems, it is required that wind turbines stay connected to the electrical network and actively contribute to the system stability during after and grid faults. However, one of the main challenges for PMSG-based Wind Energy Conversion Systems is the Low Voltage Ride Through (LVRT) fulfillment, as demanded by grid connection requirements of different countries [34–36]. On the other hand, the full power converter wind turbine is the most flexible wind turbine system from an LVRT point of view, as the reactive and active power delivered to the grid system can be controlled significantly with the converters [37]. The techniques for LVRT capacity enhancement are summarized as in Fig. 1 [38]. So, fault ride through requirements have developed and converter protection schemes are proposed for several WECS. The applications of the solutions generally involve installing addition systems as the energy capacities of the ride-through device, such as a super capacitor, a chopper, an auxiliary converter. Several methods are proposed in literature for the LVRT improvement of WECS based PMSG such as [34–44]: over sizing of dc-link capacitors, pitch control device, dissipation of excess energy in dc crowbar, use of power quality conditioning systems, storage of surplus energy in the battery systems and fly-wheel devices, and appropriate control of full power converter.

Two categories of power converter structures are available nowadays. In one topology, the converter is composed of a generator side AC/DC rectifier, a dc link, and a DC/AC inverter. In the other structure, the converter is composed of a rectifier, a dc chopper, a dc link and a DC/AC inverter [39]. A chopper on the dc-link is used as a dc link over-voltage protection device [40,41] in which the control performance is simple and the total system charge is low.

The dc chopper can dissipate the unbalanced power between the PMSG and the electrical network when grid fault happens. An energy storage device is applied in Directly Driven PMSG in order to smooth out the output power fluctuations and accomplish the LVRT function [42]. A D module Filter was used in [43] to robustly estimate the grid voltage positive sequence for control in the case of asymmetric power grid voltage sags. A double Synchronous Reference Frame Vector Control (SRFVC) using Linear Quadratic Regulator (LQR) current controllers is proposed in [44], for the operation of a WECS based PMSG. The power converters totally decouple the PMSG from the electrical network, and therefore grid disturbances have no direct effect on the PMSG. Besides, the converters allow very flexible control of reactive and active power in cases of disturbed and normal grid conditions. Although, the above schemes need to install addition systems, which not only increase the converter size and device cost but also complicate the control strategies. Also, detecting the fundamental negative and positive sequence components of electrical network side currents and voltages with fast dynamic response and high precision is demanded to secure the control efficiency [45]. However, due to the lower voltage of DC bus there may cause a slight impact on the output power of PMSG, at the moment of the grid-side voltage increasing for recovery. The crowbar device is quit and not conducive to the system rapidly returned to normal during the fault recovery [46]. In addition, considering the worst scenario when the grid voltage drops to zero, the power rating of the chopper must be full scale (in MW category) [47]. Therefore, such a strategy can hardly satisfy the grid connection requirements. Also, one of the used solutions is the Active Power Filters (APF) [48]. Using APF has the benefit of reducing harmonics without active power consumption, although improving the efficiency of the electrical system. In addition to these tasks, the APF is used to achieve power conditioning tasks such as compensation of reactive power and load balancing [49–56]. Several studies were dedicated to the improvement of WECS performance with APF [57–63]. The basic diagram of the WECS based APF is illustrated in Fig. 2 [55–57]. The proposed configuration combines the advantages of WECS based PMSG and APF. The system consists of wind turbine which is connected to a PMSG, two back-to-back converters and a dc capacitor. Additionally, an auxiliary grid side converter (GSC) is connected in parallel with the main GSC. For normal working conditions of the power grid,

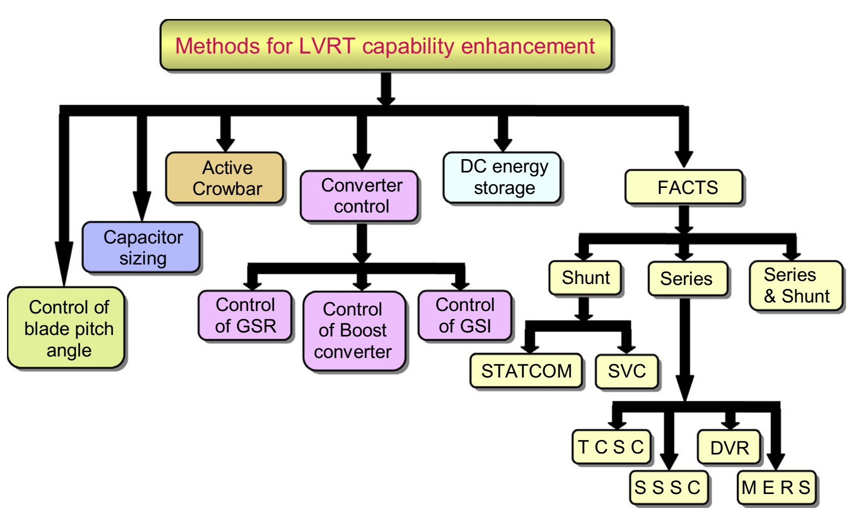

Fig. 1. Techniques for LVRT capability enhancement for WECS based PMSG.