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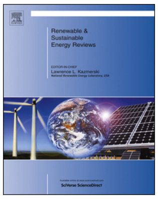

A review of low-voltage ride-through enhancement methods for permanent magnet synchronous generator based wind turbines

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ABSTRACT

Wind energy is rapidly growing in recent years. Among different types of wind turbines, due to several advantages, permanent magnet synchronous generator (PMSG) is attractive concept. Since the penetration level of wind power in the grid is increased, therefore, wind power can influence to the grid and vice versa. Some of the important problems in the grid are fault condition and voltage sags. These conditions may affect the operation of wind turbine. In order to enhance low voltage ride through (LVRT) capability in PMSG-based wind turbines, various approaches have been proposed in the last years. In this paper, the review and comparison of several LVRT capability enhancement methods is performed. The two foremost types of LVRT capability enhancement methods are external devices based methods and modified controller based methods. The main objectives of this paper are to introduce performances of different LVRT capability enhancement methods and use of some LVRT capability enhancement methods in PMSG based wind turbine which are applied in other kind of wind power generators. The external devices based methods can be effective but some of these methods are of significant cost. According to the literatures, modified controller based methods can reduce the LVRT capability enhancement cost. Several modified controller based methods have been proposed for LVRT capability enhancement. To compare the mentioned methods, several simulations are performed in MATLAB software. From the review of simulation results, series connection of FACTS devices and modification of back-to-back converter controllers are the highly efficient LVRT capability enhancement approaches.

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1. Introduction

During last decades, wind energy, as one of renewable energy sources, has grown rapidly in many countries [1–11]. According to the Global Wind Energy Council (GWEC) outlook 2012, the global cumulative installed wind power capacity reached to 282,430 MW in 2012 [12]. Also, the European wind energy association's 2020 “baseline” scenario assumes 581 TWh of wind energy being produced, meeting 15.7% of EU electricity demand, from a total installed capacity of 230 GW of wind power [13]. Therefore, the penetration level of wind power in power system will be extremely grown. Due to this high penetration level, it is important to analyze wind power's impacts on power grid and impacts of grid disturbances such as grid faults on wind farm generators [14,15].

There are three common types of typical generator systems used in wind farms [16]:

- Fixed-speed wind turbine system is composed of squirrel-cage induction generator (SCIG) directly connected to the grid and multistage gearbox to match the rotor speed with that of the wind turbine.
- Variable speed wind turbine system with a doubly fed induction generator (DFIG) where the stator winding is directly connected to the grid, but the rotor winding uses power electronic converter with partial power rating of about 30% of generator capacity, to connect to the grid [17].
- Variable speed wind turbine system with a direct-drive generator. In this type structure normally a synchronous generator and a full-scale power electronic converter are used. In comparison with other concepts, this type of structure do not need to multi-stage gearbox because a low-speed high-torque synchronous generator is used.

The last concept is more attractive when the permanent magnet synchronous generator (PMSG) is considered. The advantages of PMSG over other generators can be mentioned as follows [18]:

- Higher efficiency,
- No need to additional power supply for the field excitation,
- It has higher reliability because of the absence of slip rings and gearbox [19].

Furthermore, because of the developments in semiconductor switching devices and increased the reliability and efficiency, the use of PMSG-based wind turbine is rapidly growing. Recently, several companies in the world are manufacturing 2 MW PMSG-based wind turbine [20–22].

As mentioned above, one of the important problems that should be paid attention in the wind farms is the faults on grid side and its impacts on the wind farm generators. If the fault occurs in the grid and the supply voltage drops to lower levels, wind farm experiences a voltage sag condition, which may result in damage or bad effects on the grid after fault clearance [14]. In the past, wind farms could be disconnect from the grid, but now, the new grid codes, due to the high penetration level of wind farms, do not allow them to be disconnect when a grid fault occurs. A practical example of stability problem, created by disconnection of wind farm from grid, is the Western Europe outage on 4 November 2006, which caused losing 4892 MW of wind power generation [23]. Hence, according to the type of wind farm generators, some actions should be implemented to prevent disconnection of wind farms from the grid. Recovery of wind farms from various fault conditions in the grid is known as “fault ride-through” or “low voltage ride through (LVRT)” [24].

This paper reviews and compares the methods of LVRT in PMSG-based wind turbines and it is organized as follows. Section 2 shows a brief review of PMSG-based wind turbines concept. In Section 3, modern grid codes and some occurred problems in PMSG-based wind turbines are discussed. Section 4 reviews the LVRT methods in PMSG-based wind turbines. In Section 5, simulation results and comparisons of several methods are illustrated. Finally, in Section 6, conclusions are presented.

2. PMSG-based wind turbines concepts

In this section, the global structure of PMSG-based wind turbines is presented in two parts: mechanical wind turbine characteristics and modeling of PMSG, dc-link and grid. Fig. 1 shows PMSG-based wind power system.

2.1. Wind turbine characteristics

Mechanical output power of wind turbine is given by the following equation [25]:

$$P_m = 0.5\rho A v_w^3 C_p(\lambda,\beta) \tag{1}$$

where ρ is the air density, A is the blade swept area, v_w is the wind speed and the turbine power conversion coefficient $C_p(\lambda,\beta)$ is defined by the following equations:

$$C_p(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)\exp^{(-21/\lambda_i)} + 0.0068\lambda \tag{2}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{3}$$

As shown in (2) and (3), the power conversion coefficient is a function of the tip-speed ratio (λ), and also pitch angle (β) in a pitch-controlled wind turbine.

The tip-speed ratio depends on the rotational speed of the shaft (ω_m) and the wind speed as given below:

$$\lambda = \frac{R\omega_m}{v_w} \tag{4}$$

where R is the radius of blades.

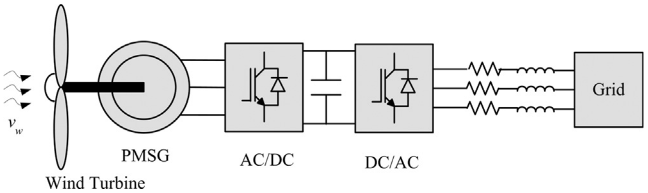

Fig. 1. PMSG based wind power system.