Renewable and Sustainable Energy Reviews 56 (2016) 643–658

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A comprehensive review of low voltage ride through capability strategies for the wind energy conversion systems

Abdul Motin Howlader *, Tomonobu Senjyu

Faculty of Engineering, University of the Ryukyus, 1 Senbaru, Nishihara-cho, Nakagami, Okinawa 903-0213, Japan

A R T I C L E I N F O

Article history:
Received 5 August 2014
Received in revised form
4 September 2015
Accepted 30 November 2015

Keywords:
Wind energy conversion system
Low voltage ride through
Grid code
Energy storage
Chopper circuit

A B S T R A C T

Wind energy is an abundant source of the pollution free energy. The conventional fossil fuels such as coal, oil and gas are exhausting day by day and wind energy can be the alternative of fossil fuels. Wind energy conversion systems (WECSs) are very vulnerable to the disturbances, faults and low grid voltages. Therefore, modern WECSs are required and designed to the low voltage ride through (LVRT) capability in the line fault condition. There are several approaches to maintain the grid code requirements in the line fault condition. The aim of the paper is to overview some popular approaches of the LVRT capability enhancement in the line fault condition. The fault protection schemes are analyzed using different types of WECSs. The advantages and disadvantages are also analyzed in this paper. To protect the WECSs during the line fault condition, energy storage based approaches are proposed in many literatures but these approaches require an additional system cost. Therefore, some control approaches are proposed for the LVRT capability in literatures without energy storage system which can be reduced the system cost significantly. Among various types of control approaches, in recent, the chopper circuit based fault protection method is gaining interest for the simplicity and fault protection capability without energy storage system.

Contents

* Corresponding author.
E-mail address: motin@ieee.org (A.M. Howlader).

http://dx.doi.org/10.1016/j.rser.2015.11.073
1364-0321/

1. Introduction

The world recently passed 400 ppm of atmospheric CO_2 which is potentially enough to prompt a warming of two degrees Celsius. According to the report on BP Statistical Review of World Energy June 2015, world primary energy consumption grew by just 0.9% in 2014 but in 2013, it was around 2.0%. The conventional fossil fuels such as oil remains the world's leading fuel, at 32.6% of global energy consumption, natural gas accounted for 23.7% of primary energy consumption, and coal reached at the 30.0% share of global primary energy consumption. The unreliable nuclear power grew by an above average 1.8%, the second consecutive annual increase. Nuclear output accounted for 4.4% of global energy consumption which is the smallest share since 1984. Hydroelectric output reached 6.8% of global energy consumption. Renewable energy used in power generation increased by 16.3% and accounted for a record 6.0% of global power generation [1]. In order to meet the energy growing demands in a climate-constrained world entails a fundamental shift in how those energy services are transported. Renewable energy, coupled with energy efficiency measures, is central to achieving this objective [2].

There are several sources of renewable energy such as solar, wind, biomass, hydro, tidal, etc. Among the several renewable sources, wind energy is the fastest growing renewable energy [3–14]. In 2014, wind energy grew by more than 50 GW [2]. According to the report on World Wind Energy Association (WWEA), February 2015, total wind energy is close to 370 GW. The total market volume of wind capacity was 40% larger than in 2013, which is significantly bigger than in the previous record year 2012, when 44.6 GW were installed [2].

Wind energy is a natural gifted source of green energy. But wind power suffers in many ways. One of the major problem is line fault for the wind energy conversion system (WECS). For that reason, the WECS is needed and designed to the low voltage ride through (LVRT) capability in the system fault condition. The LVRT is also known as the fault ride through (FRT) which has become an important aspect of the wind turbine control system. The term LVRT reflects the ability of a wind turbine (or in reality a wind farm) to remain connected to the grid throughout a short mains voltage drop (a brownout) or a mains failure (a blackout). During the fault time, when the voltage of the power grid is dropped, it is important that a wind farm stay online in order to prevent major blackouts. Especially, when the major power of an area is depended on the wind farm. It is not only necessary that the farm stays online but also it is equally crucial that the wind farm works actively to compensate for the faulty grid condition. On the other hand, in the fault condition, there is a huge deviation of the DC-link voltage of the WECS. To protect the important devices of the WECS, it is necessary to handle the fault situation. The LVRT capability of a wind farm should be satisfied for meeting the grid code requirements which are defined by grid operators. The capability of meeting these demands is significant for the wind turbine or the wind farm which is allowed to be connected to the grid. As mentioned that the LVRT-demands are individually specified by the grid operators and might therefore vary from operator to operator and from country to country [15]. On the other hand, wind turbines have different generator technologies, structures, and control strategies, they behave in a different way during the grid fault condition, and hence require different methods to improve LVRT capability. Depending on the rotational speed, wind turbines can be fixed speed or variable speed. Nowadays, there are three most frequently used types of wind turbine generator systems in the industry, i.e. fixed speed wind turbines (FSWTs) using Squirrel Cage Induction Generator (SCIG), and variable speed wind turbines (VSWTs) using Doubly Fed Induction Generator (DFIG) and Permanent Magnet Synchronous Generator (PMSG).

This paper proposed a comprehensive review of LVRT methodologies for the different types of WECSs. In Ref. [16], a review of the LVRT for DFIG based WECS has been proposed. A review of LVRT for the PMSG based WECS is analysis in Ref. [17]. Ref. [18] has been proposed LVRT methodologies for the WECS running in isolated micro-grid and effects. Various approaches have been proposed for the LVRT capability of the WECS in recent year. The flexible AC transmission system (FACTS) devices such as static var compensator (SVC) and static synchronous compensator (STATCOM), and STATCOM with energy storage device have been proposed to enhance the LVRT capability for the FSWTs and VSWTs. The energy storage systems (ESSs) with power electronics devices have also been proposed in some literatures to improve the LVRT capability for FSWTs and VSWTs. But installation and maintenance costs of the FACTS and ESS devices are very high. Therefore, there are some methods have been proposed for the LVRT capability without FACTS and ESS devices of the WECSs. These methods are highly cost effective for the wind farms. Each method has some advantages and disadvantages which are also discussed in this paper. Operating principles of different LVRT capability methods are reviewed in this paper. Simulation results of different LVRT capability methods are also analyzed in this paper.

2. Wind energy conversion system

The system diagrams of the VSWTs and FSWTs are shown Fig. 1. Fig. 1(a), the configuration of the PMSG based WECS is shown, using a back-to-back full-scale PWM voltage source converter connected to the grid. The system configuration of the DFIG based wind turbine is shown Fig. 1(b). In this configuration, the three-phase rotor winding is connected to the generator-side converter while the three-phase stator winding is directly connected to the power grid. The system diagram of the SCIG based wind turbine is shown Fig. 1(c). A capacitor bank is connected to the terminal of the SCIG for providing reactive power compensation at the steady state operation. The value of capacitor bank is chosen so that power factor of the SCIG based WECS during the rated operation becomes unity. The soft starter is a simple and cheap power electric component, used in the SCIG wind turbine for connection or disconnection the generator to the grid. Three phase ground fault location and the fault protection scheme using chopper circuit (Fig. 1(a), (b)) and STATCOM (Fig. 1(c)) are also indicated Fig. 1.

2.1. Wind turbine model

The mathematical expressions of the wind turbine output power P_w and the wind turbine torque T_w (i.e. input torque to the PMSG) are written as follows [19]:

$$P_w = \frac{1}{2}\rho\pi R_o^2 V_w^3 C_p(\lambda, \beta) \quad (1)$$

$$T_w = \frac{1}{2}\rho\pi R_o^3 V_w^2 C_p(\lambda, \beta)/\lambda \quad (2)$$