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Fault ride-through enhancement of fixed speed wind turbine using bridge-type fault current limiter

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Abstract

The interaction between wind energy turbines and the grid results in two main problems, increasing the short-circuit level and reducing the Fault Ride-Through (FRT) capability during faults. The objective of this paper is to solve these problems, for fixed speed Wind Energy Systems (WECS), utilizing the bridge-type Fault Current Limiter (FCL) with a discharging resistor. A simple cascaded control system is proposed for the FCL to regulate the terminal voltage of the generator and limit the current. The system is simulated on PSCAD/EMTDC software to evaluate the dynamic performance of the proposed WECS compensated by FCL. The simulation results show the potentials of the FCL as a simple and effective method for solving grid interconnection problems of WECS.

Keywords: Fault current limiter (FCL); Fault ride-through (FRT); Voltage regulation; Wind energy conversion systems

1. Introduction

Year after year, the world fossil fuel reserve decreases and clean renewable energy resources are being enormously installed around the world. Wind energy is one of these resources that is widely mounted worldwide due to its reliability and cost effectiveness. The interconnection of the wind farms to the electricity grid may cause stability problems. Moreover, reducing the short circuit current and increasing FRT capability of wind farms are the most important issues. Several solution techniques are investigated in the literature (Firouzi and Gharehpetian, 2013).

Traditionally, the WECS are classified to two main types, namely fixed speed and variable speed. Recently, variable speed wind turbines are mostly used due to their efficiency, improved power quality, and independent control of active and reactive power (Ali, 2012). However, fixed speed WECS were vastly installed over the past-years worldwide, representing a large installed capacity. Since directly connected squirrel cage induction generators, used with fixed

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speed wind turbines, have a lifetime over twenty years, it is essential to study and ameliorate their performance (Ali and Wu, 2010).

Many techniques are proposed to improve the FRT of wind farms such as the pitch control, the shunt, and series compensation. The shunt compensation based techniques include STATic synchronous COMpensator (STATCOM) (Awad et al., 2014; Molinas et al., 2008), Static Var Compensator (SVC) (Molinas et al., 2008), and Thyristor Switched Capacitor (TSC) (Ren et al., 2012). The series compensation based techniques incorporate Dynamic Voltage Restorer (DVR) (Ramirez et al., 2011; Leon et al., 2011), Series Dynamic Braking Resistor (SDBR) (Causebrook et al., 2007), Magnetic Energy Recovery Switch (MERS) (Wiik et al., 2009a), and FCL. Although the pitch control offers the lowest cost solution to improve the LVRT, its dynamic response is low (Rashid and Ali, 2014). The STATCOM and SVC have the capability to enhance the transient stability margin by controlling the reactive power after fault occurrence, however, the mechanical stress increases (Ramirez et al., 2011). The TSC generates no harmonics but the reactive power cannot be varied continuously (Tayyebifar et al., 2014). The DVR is a good solution to improve power quality and isolate the grid faults from the WECS on the account of its bulk size and complex control (Hussein and Ali, 2014). The SDBR has a high reliability, enhances transient stability and needs low maintenance. The main disadvantage of the SDBR is that it allows a sudden rise of fault current instantaneously (Rashid and Ali, 2014; Causebrook et al., 2007). To reduce the switching losses, the MERS is proposed which has a compact size, however, it injects harmonics (Wiik et al., 2009b). The FCL offers an effective and simple solution to enhance the FRT of a WECS. In addition, the FCL is compact in size and limits the instantaneous rise of fault current (Rashid and Ali, 2014; Chen et al., 2013).

This paper presents a simple control system for the bridge-type FCL with a discharging resistor to enhance the FRT capability of a fixed speed WECS.

2. Fault current limiters

There are many types of the FCLs which can be summarized as follows:

1. Superconducting FCL depends on utilizing a superconducting element that has low impedance during normal operation and high impedance when the current rises suddenly. Cooling equipment is needed to control the temperature of the superconducting element for proper operation which increases the cost of this type of FCL (Sheng et al., 2012; de Sousa et al., 2012).
2. Solid-state FCL is based on semiconductor devices which are controlled to inject certain impedance in series with the feeder to limit the fault current. Although this type of FCL is easy to control, it experiences many technical challenges (Abramovitz and Smedley, 2012; Corzine and Ashton, 2012).
3. Saturable core FCL where a dc current saturates the iron core which isolates the secondary side impedance, during normal operation. During faults, the high ac current drives the core out of saturation, inserting the secondary side impedance to the power line. This technology needs bulky devices due to the need for many iron cores (Chen et al., 2013; Cvoric et al., 2009; Abbott et al., 2006).

3. Bridge-type fault current limiter

The non-superconducting bridge-type FCL has been proposed because of its simple control and reduced cost compared to the other types (Hagh and Abapour, 2009; Min et al., 2008). It consists of a diode bridge and a dc reactor L_d as shown in Fig. 1 (Ise et al., 2001). In addition, a resistor in parallel with a semiconductor switch is connected in series with the dc reactor to control the level of the fault current by controlling the dc reactor current.

The FCL is connected between the WECS and the grid through open secondary windings of an insertion transformer where the primary windings are star connected to the bridge-type FCL. During normal operation, the semiconductor switch is turned-on to bypass the discharging resistor. Hence, the impedance seen from open-winding side of the transformer is the smallest and is governed by the equivalent impedance of the transformer. As a result, the dc reactor current i_d is proportional to the generated current from the WECS and within normal values. During grid fault, the dc current value rises suddenly above its limit value. Once the fault is detected, the control circuit turns-off the semiconductor switch to insert the discharging resistor into the feeder between the WECS and the grid. By controlling the switching times of the semiconductor switch, the current level of the wind generator is controlled to be within the limit values (Firouzi and Gharehpetian, 2013).