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RESEARCH ARTICLE

OPEN-CIRCUIT FAULT DIAGNOSIS IN BACK-TO-BACK CONVERTERS OF PMSG DRIVES FOR WIND TURBINE SYSTEMS

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ABSTRACT

In order to increase the reliability and availability of wind turbines, condition monitoring and fault diagnosis are considered crucial means to achieve these goals. In this context, wind turbines based on permanent-magnet synchronous generators (PMSGs) with full-scale power converters are an emerging and promising technology. However, several statistical studies point out that power converters are a significant contributor to the overall failure rate of modern wind turbines. Accordingly, this paper presents a new and simple method for open-circuit faults diagnosis in full-scale back-to-back converters, applied in PMSG drives used for wind turbine systems. The three phase currents carry information about the faults and hence are used to diagnose the faults in the system. The three phase currents of the generator side and grid side converter are taken as the input for the fault detection. When the current value is zero it indicates that there is an open circuit fault in the particular phase. This concept is used to identify the faulty phase and the faulty switch. It is seen that the proposed method does not require any voltage and current sensors hence reducing the system complexity and the cost of the drive.

Key Words: Open Circuit Fault, Three Phase Currents, Back to Back Converter, PMSG.

INTRODUCTION

In today's scenario of increasing energy demands and environmental concern, it is necessary to analyse the different alternatives of energy. One such alternative is wind energy. Wind energy is one of the most talked-about alternative energy sources in the world today. The enormous potential of wind energy can meet the world energy demand many times. Wind energy is a totally renewable resource, unlike oil, coal and natural gas. Wind energy can be converted into electricity, directly using generators and inverters and converters. But the faults in the inverters and system complexity wind systems are the main barriers. The wind energy is the cleanest and sustainable energy, with long lifespan and a high reliability. Wind turbine systems using Permanent-Magnet Synchronous Generators have become very attractive during the last years because of their high efficiency, high power density, variable speed operation, reduced maintenance, and increased reliability. In order to allow the extraction of the maximum power from the wind and to improve the power quality injection to the grid, the wind turbine systems based on PMSGs are equipped with a conventional back-to-back power converter which present the interface between the generator and grid. The reliability of power semiconductors is one of the most important factors that will determine the reliability, the efficiency, and the cost of the wind drive system. These power converters are complex devices that are often exposed to high stresses, being therefore very prone to suffer critical failures.

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It is seen that faults related to the power converters are the most common in variable speed drive (Sethom and Ghedamsi, 2008), (Yang *et al*., 2011), (Yang *et al*., 2010). Power semiconductor failures are broadly classified as short circuit faults and open circuit faults. They are caused by high electrical or thermal stresses, gate driver failure, or wire disconnection. Short-circuit fault can be dangerous and requires safe and immediate shut down of the drive. Consequently in order to achieve fast fault detection, converter are equipped with appropriate protections and the short-circuit fault detection becomes a standard feature for electrical drives. In case of an open circuit fault, the shutdown of the drive may not be necessary. However, this fault is characterized by a current imbalance in both faulty and healthy phases which causes a pulsating torque. For grid-connected converter applications, such fault results in a non-sinusoidal grid current with a high total harmonic distortion and seriously decreases the grid power factor. Hence, the development of fault diagnostic methods has gain a lot of interest during the last years. Hence, the development of fault diagnostic methods has gain a lot of interest during the last years. The Park's Vector Approach was proposed in (Mendes *et al*., 1998) in voltage source inverter to find the faults. However, this method cannot be used to integrate into the drive controller because it requires very complex algorithms. The current space vector trajectory diameter can also be used for the localization of inverter power switch open-circuit faults (Peuget *et al*., 1998), (Trabelsi *et al*., 2010). But, this method is mot used because of disadvantages due to slow detection and problems under low-current values. Fast detection times can be achieved using voltage-based methods but it requires more voltage sensors (Ribeiro *et al*., 2003; An *et al*., 2010; An *et al*., 2011).

A recent approach proposes the use of a voltage observer which leads to use of less sensors (Freire *et al*., 2014).Fast fault detection by using a FPGA applied to a back-to-back converter was done in (Karimi *et al*., 2008), (Shahbazi *et al*., 2013). The similar method is applied to a three voltage- source inverter. However, the major drawback of this method is that at least two additional voltage sensors is required which will increase the drive complexity and the cost .As main drawbacks of the conventional methods they are computationally demanding and require the knowledge of the machine parameters. Hence in the proposed method the fault is diagnosed by using the available three phase currents. The method proves to be less complex and less expensive.

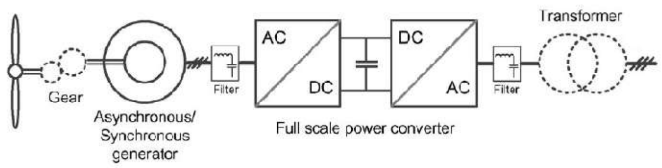

Fig. 1. General diagram of wind turbine system

Proposed Work

Block Diagram

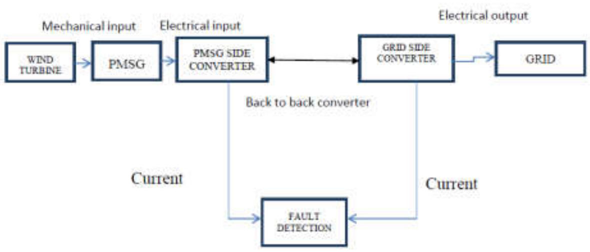

Fig. 2. Block diagram of the proposed method

Back To Back Converters

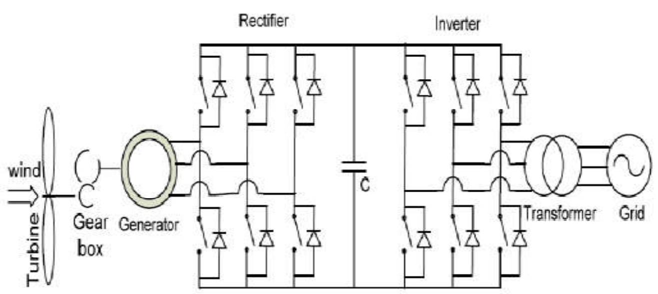

Fig. 3. Circuit diagram of back to back converter

The controlled rectifier and controlled inverter based converter is called back to back converter consisting of two conventional pulse width modulated (PWM) voltage source inverters (VSIs). It differs from the diode rectifier based converter for the rectification stage, where the diode rectifier with chopper circuit is replaced by controlled rectifier. The controlled rectifier gives the bidirectional power flow capability, which is not possible in the diode rectifier based power conditioning system.

Moreover, the controlled rectifier strongly reduces the input current harmonics and harmonic losses. The grid side converter enables to control the active and reactive power flow to the grid and keeps the DC-link voltage constant, improving the output power quality by reducing total harmonic distortion (THD). The generator side converter works as a driver, controlling the magnetisation demand and the desired rotor speed of the generator. The decoupling capacitor between grid side converter and generator side converter provides independent control capability of the two converters. Therefore, converter voltage level is also in the range of 380–690 V due to the low generator voltage rating and the use of two level converter topology. In order to integrate the wind turbine with local medium voltage grid a step-up transformer is normally installed inside the nacelle of the wind turbine.

Proposed Method

The proposed system in fig 2 consists of the PMSG based wind turbine system based on back to back converters. The gate signals for the generator side converter are generated by the PWM generators by using output of the PMSG and the PI controllers. The generator side converter and the grid side converters are connected through a DC link capacitance. The input to the grid side converter switches are given by the current control subsystem. A load is connected in between the load and the grid. The current for the load is provided by the PMSG initially and if in any case the current is not sufficient then the current is drawn from the grid. A grid is connected at the end with the circuit. A 110 volt grid is considered. The other subsystems consist of demultiplexer, subsystem to find if open circuit fault exists in the switches which consists of comparator and subsystem to find the faulty switch. The output of demultiplexer is filtered using a second order filter. The input current value to the comparator is compared with the constant value 1 and -1. If there is any open circuit fault then the current value is zero. Hence only if the current is not equal to zero the output is obtained.

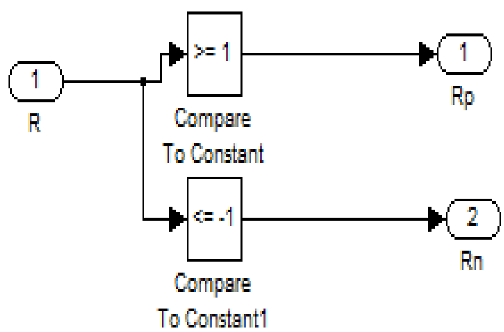

Fig. 4. Simulink model to find open circuit fault

In the subsystem for the detection of the faulty switch the input to the subsystem is any other value except 1 if there is no fault and the input will be zero in case of any fault. The sample and hold block is connected to each input. The sample and hold block gives output 1 if the condition is true and zero if the condition is false. The switches are multiplied with a gain which has value of the corresponding switch. The sum of all the gains is added and subtracted from the constant value of 21. If there is a fault in any switch then the corresponding number will be the output.

Simulation Results

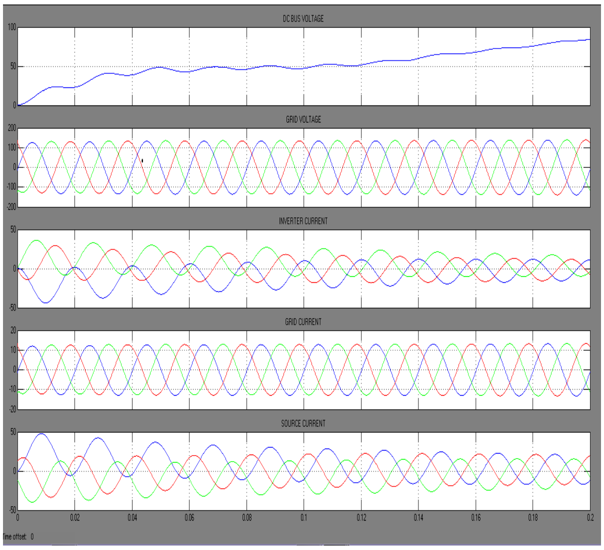

Fig. 5. Output of the PMSG based wind turbine system using back to back converters

Fig 5 is the output of the proposed method. The DC bus voltage, the grid voltage, the grid current, the inverter current and the load current are measured in the scope. The voltage of the grid is considered to be 110 V. from the graph it can be inferred that the generator supplies the current to the load and whenever the requirement of the load is not satisfied then the grid supplies the remaining needed current.

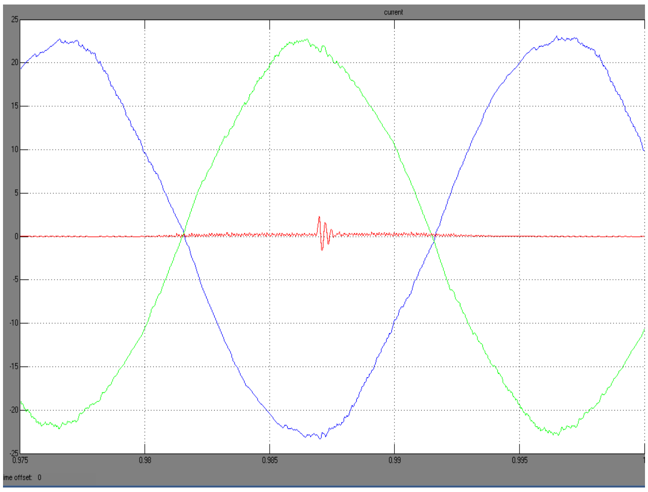

Fig 6. Output with fault in a switch

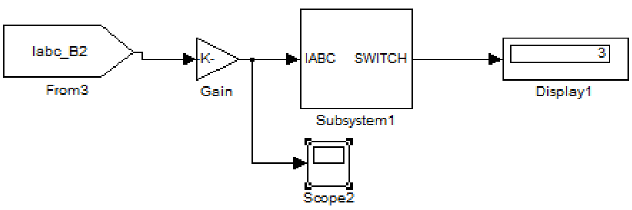

Fig. 7. Display of the faulty switch

Fig 6 represents the three phase current waveform when there is open circuit fault in one of the phases of the three phase current. The faulty phase does not have a perfect sine wave and hence the faulty phase can be found out. Fig 7 is the display of the faulty switch. A novel algorithm for real-time diagnostics of multiple power switches open-circuit faults in the back-to-back converter of a PMSG drive, has been proposed in this project. The fault diagnosis method needs just input variables that are already available from the main control of the wind turbine system, avoiding the use of extra hardware solutions and the increasing of the system complexity and costs. Regarding the fault localization, when the detection is achieved, the faulty IGBT identification is accomplished based on the currents. The fault detection method is experimentally validated in order to verify the theoretical approaches and simulation results. The obtained results show a reliable performance of the proposed algorithm under all the considered operating conditions. The method allows us to effectively detect and localize open-circuit faults both in the generator-side and in the grid-side converters. The proposed method utilizes the known current values from the inverter and the converter side to find the faults as the currents carries the information about the faults. It is seen the proposed method is less complex and does not need any additional use of sensors and hence reducing the system complexity and the cost.

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