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Fault Diagnosis and Fault-Tolerant Control of Wind Turbines via sliding mode control

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Abstract

The proposed method describes adaptive fault estimation algorithm smc is proposed to enhance the rapidity and accuracy performance of fault estimation. In particular, an electrical fault scenario, the DFTG winding short circuit fault, is considered due to its high occurrence rates. Based on the fault estimation information, a fault compensator is designed based on fault information provided by the fault diagnosis scheme to guarantee the stability of the system. This adaptive fault estimation algorithm is proposed to enhance the rapidity and accuracy performance of fault estimation. In particular, an electrical fault scenario, the DFTG winding short circuit fault, is considered due to its high occurrence rates. Based on the fault estimation information, a fault compensator is designed based on fault information provided by the fault diagnosis scheme to guarantee the stability of the system, and it incorporates with a traditional controller to provide an online fault compensation of winding short circuit faults.

1. INTRODUCTION

Fault tolerant control of wind turbine systems is an emerging field of research [1-5]. Energy demand thrusts manufacturers to produce larger wind turbines and move to offshore implementation. Besides, high maintenance costs and more electricity production share force them to design reliable and robust systems. O ne of major studies to make this structures more reliable is to employ fault tolerant controllers (FTCs). FTCs can be divided into two groups: passive and active [6]. In passive FTC, often a robust scheme is proposed to preserve stability in presence of a number of faults. The performance degradation even in non-faulty condition is the major drawback of this method. Active FTC, uses a FDI system to detect and tolerate the fault possibly with some degradation of performance. Many studies have been devoted to multivariable Hw design for wind turbines such as [8-10]. In these papers mostly proposed controller has high order and also the control signal limitations are not considered in implementation. In [7] sensor FDI output is employed to control a DC motor. This FDI scheme uses a sliding mode observer to reconstruct the sensor fault. This method is utilized in this work, too. A low order controller based on Hw method is designed to regulate wind turbine outputs in presence of severe wind disturbances. Controller is composed of a set of integrators and a static output feedback gain which is designed such that the Hw norm of output to disturbances is smaller than a predetermined bound. The proposed method describes adaptive fault estimation algorithm smc is proposed to enhance the rapidity and accuracy performance of fault estimation. In particular, an electrical fault scenario, the DFTG winding short circuit fault, is considered due to its high occurrence rates. Based on the fault estimation information, a fault compensator is designed based on fault information provided by the fault diagnosis scheme to guarantee the stability of the system. This bound is chosen such that acceptable performance is achieved while control signal is remained in feasible range. The suitability of proposed method is shown through extensive simulations.

II.DOUBLY-FED INDUCTION GENERATOR

(DFIG) Wind turbines can either operate at fixed speed or variable speed. For a fixed speed wind turbine the generator is directly connected to the electrical grid. For a variable speed wind turbine the generator is controlled by power electronic equipment. There are several reasons for using variable-speed operation of wind turbines; among those are possibilities to reduce stresses of the mechanical structure, acoustic noise reduction and the possibility to control active and reactive power. Most of the major wind turbine manufactures are developing new larger wind turbines in the 3-to-5-MW range. These large wind turbines are all based on variable-speed operation with pitch control using a direct driven synchronous generator (without gearbox) or a doubly-fed induction generator (DFIG). The Doubly-Fed Induction Generator (DFIG) is an induction generator with both stator and rotor windings as shown in fig. 2. The DFIG is nowadays widely used in variable-speed wind energy applications with a static converter connected between the stator and rotor. Currently, this topology occupies close to 50% of the wind energy market

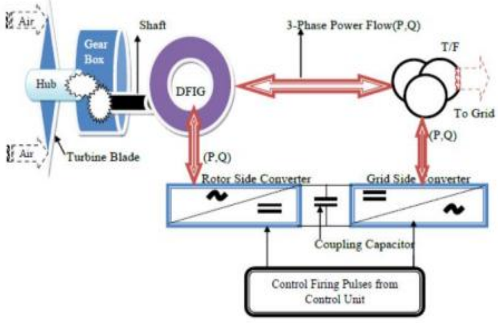

Fig. 1 Doubly-Fed Induction Generator (DFIG)

So with the advancement in the thyristor converter the turbines can be used to generator power at variable speed. In the control system converter- inverter circuit is use to control the magnitude, phase and frequency. There are different ways to control the inverter and converter output power like:- • Back-to back PWM converter in the rotor circuit of DFIG. • DC link chokes were used but they are expensive and required an extra commutation circuit for operating at synchronous speed and this result in the poor performance. • In order to overcome this drawback, Pulse Width Modulation (PWM) converter in asynchronous wound rotor induction generator also known as DFIG is used. It has low distortion of rotor, stator and supply current and hence the lesser cost of the inverter. It can cover a wide operation range from sub-synchronous to supersynchronous speed operating with the flow in both directions

III.SYSTEM MODELING

The winding short circuit fault, especially within stator windings, is one of the most common faults in electric machines including DFIGs. This fault may occur within one phase or sometimes in several phases simultaneously.

In this work, we denote the former case: the single-phase fault. In this section, we aim to develop a mathematical model of DFIG with respect to the single-phase short circuit fault within stator windings. When a short circuit fault occurs, the stator windings currents become asymmetrical, and an obvious increase can be observed in the current of the faulted phase. This is because the effective impedance of the faulted phase is reduced by the short circuit.

The modeling strategy is to consider the short circuit loops as some additional circuits placed in parallel to the original winding circuits of DFIG, and then represent the electrical and magnetic relationships among all these circuits by using circuit theory. The sequence component decomposition is a widely used technique dealing with the structural asymmetry problems of the electric machines [18, 19]. In this section, a common sinusoidal signal decomposition technique is introduced.

By using this technique, the single-phase fault model proposed is transformed into a state-space model representation and the fault is formulated into an additive fault current.

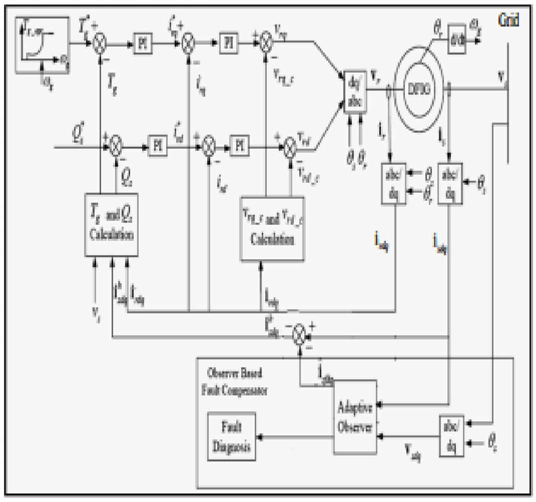

Fig 2 closed-loop control with the fault compensator

IV.CONTROL STRATEGY

Sliding mode control design procedure:

The method of control is divided into two steps the first is determine the voltage value at which the system operates with its maximum of power, and then the second is to operate the system with this voltage value that gives the maximum power

Step 1

In this part of the work, the main objective is to construct a MPP voltage-reference generator that meets the MPP. Specifically, this generator is expected to compute on-line the optimal voltage value VMPP so that, if the voltage Vp is made equal to VMPP then, maximal power is captured. In fact this method does not require irradiation measurement

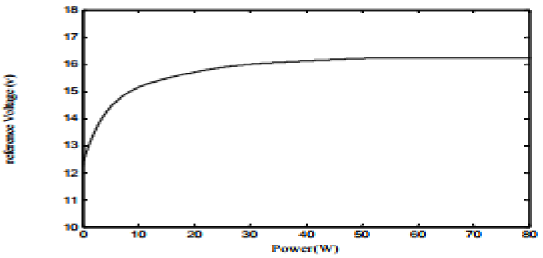

Fig 3 Optimal power-voltage characteristic

The figure 3 present the curve of optimal power voltage characteristic obtained from the polynomial interpolation. involves the maximum of extractable power, a number of such couples for different irradiation values have been collected and then interpolated to get the suitable function (VMPP= F(PMPP)). This function is created using Matlab Fitting Curve Toolbox. In this work several test has been done using different type of function such as, Fourier, Gaussian, rational, and the polynomial function like the work of Abderrahim. Finely we deduce that the power function fits more the Atersa model. The constructed function is denoted as :

$F(x)= a\, x^{b} + c$

Step 2: After determined the Vref the implemented (SMC) algorithm calculate the difference between the acquired PV voltage and the Vref and then, via the boost converter force the PVG to operate at the reference voltage value (Vref) and therefore at the maximum power zone.

$S=e= V_p-V_{ref}$

$$u = \frac{1}{2}(1 + Sign(S))$$

$$u = \begin{cases} 1 & S > 0 \\ 0 & S < 0 \end{cases}$$

V.SIMULATION RESULTS

In this subsection, as a first step, we aim to analyze the behavior of the fault currents (Ifd and Ifq), which has different signatures for three different fault positions (phase 'a', 'b', or 'c'). Those analysis results are crucial to be used later for the fault position diagnosis. For that purpose, a short circuit fault is introduced into stator phase 'a', 'b' and 'c', respectively, and for each case the simulations results are presented in Figure 3

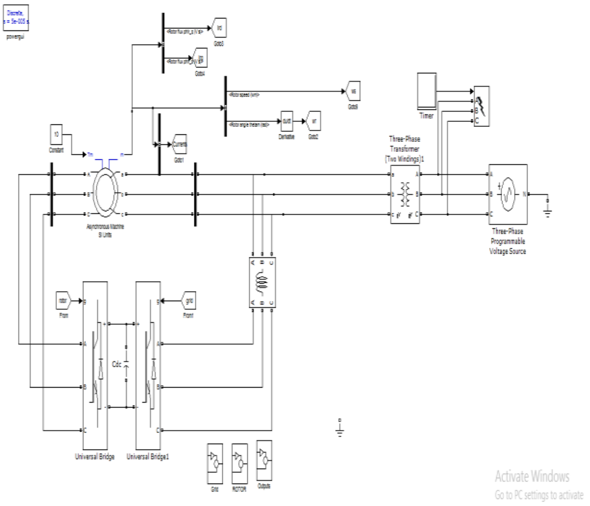

Fig.4 Simulink model of proposed system

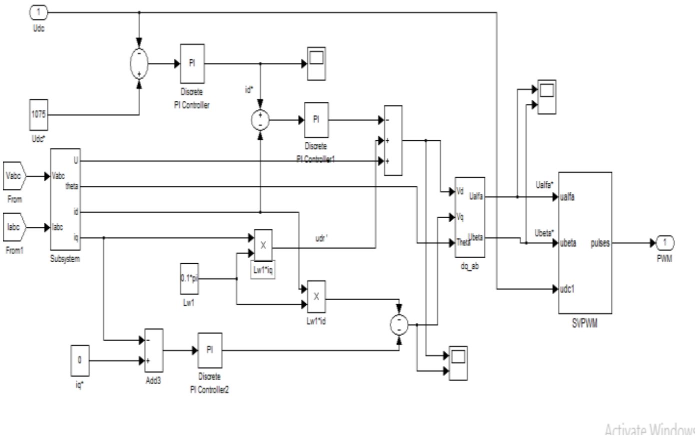

Fig.5 control diagram of proposed model

It can be noticed that the phase angle of I fdq IS III accordance with the physical position of the faulted phase, hence it can be used to indicate the fault position. In other words, when a fault occurs in any phase, it will be reflected in the corresponding positions as indicated in Figure 4. This result is important as it will be employed later for the fault diagnosis. The adaptive observer algorithms proposed in above sections are simulated in order to analyze and evaluate the estimation and diagnosis of a single-phase short circuit applied to a stator winding. The simulation studies are carried out in the Matlab/Simulink environment. Before presenting the main results of faults estimation, it is crucial to mention that, the observer is activated at t=2sec after the DFIG reaching the steady state, and thereafter a short circuit fault is applied to stator phase 'a' at t=2,5se

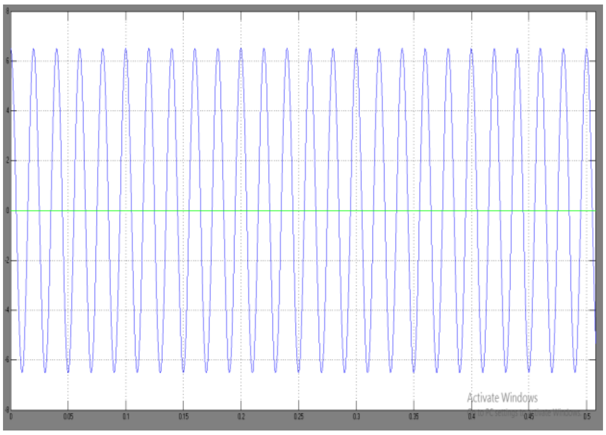

Fig.6 Fault in stator phase 'a'

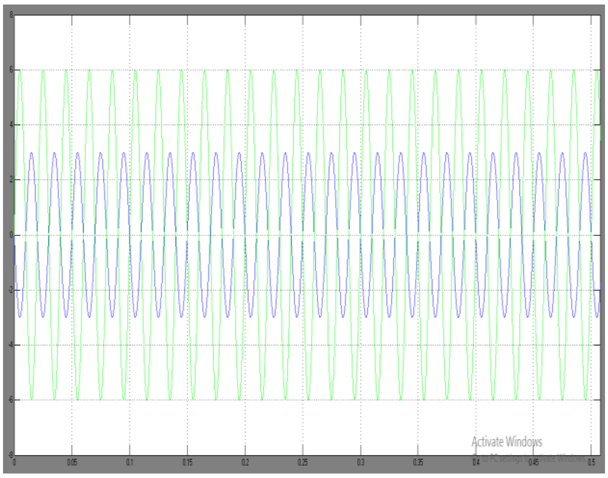

Fig.7 Fault in stator Phase b

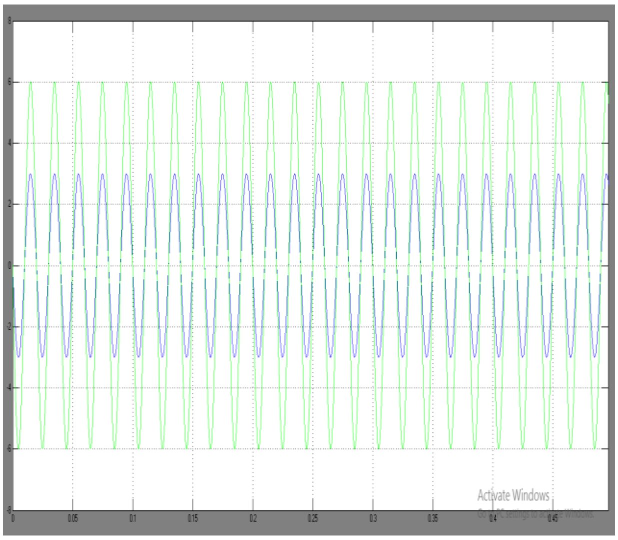

Fig.8 fault in stator phase c

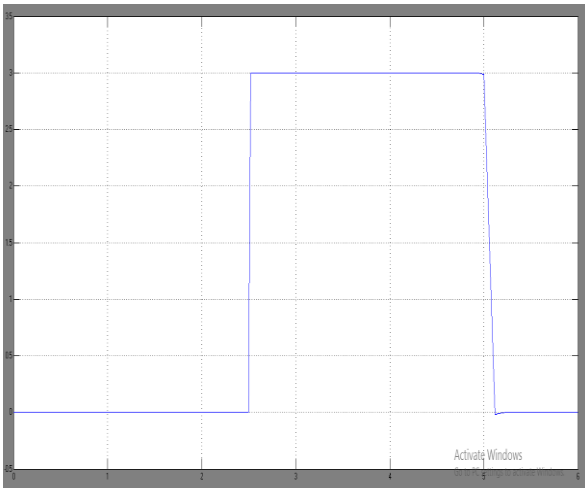

Fig. 9 : Ifd+ estimation using conventional adaptive observer

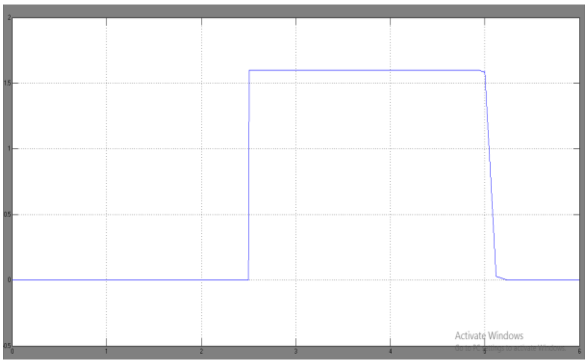

Fig.10: Ifq+ estimation using conventional adaptive observer

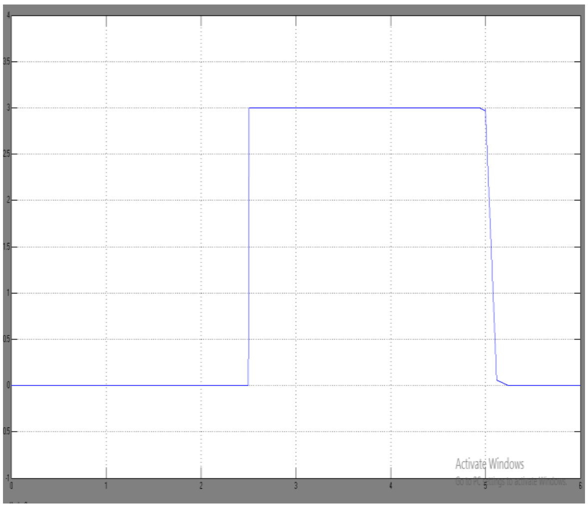

Fig.11: I fd - estimation using conventional adaptive observer

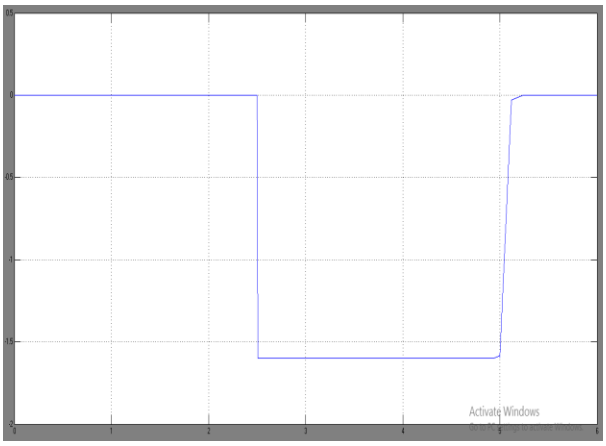

Fig.12: I fq - estimation using conventional adaptive observer

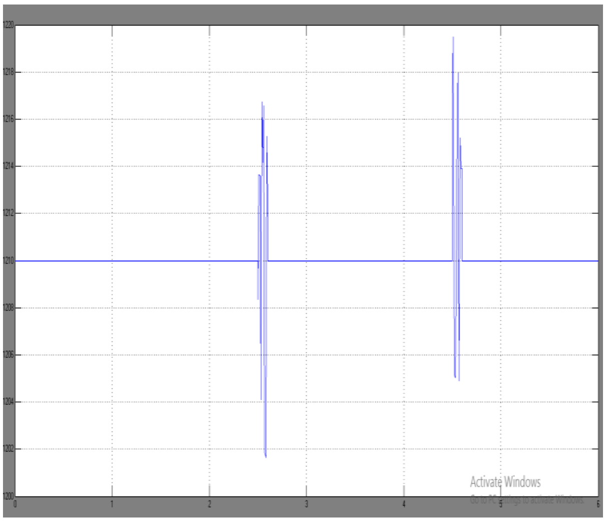

Fig. 13: Active power compensation

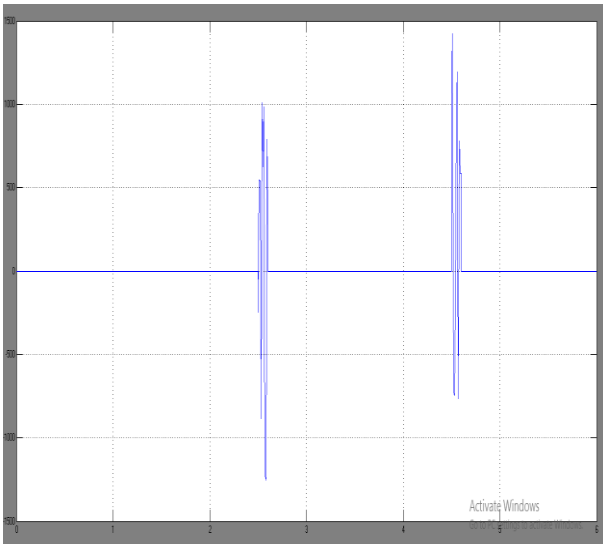

Fig. 14: Reactive power compensation

VI.CONCLUSION

an adaptive observer technique for a model-based fault diagnosis was developed in order to improve the reliability of DFIG stator windings short circuit fault within wind turbine systems. Then, an active fault tolerant scheme was synthesized based the fault information provided by the fault diagnosis scheme. For this purpose, a fault compensator was designed, and then used to correct the current measurements and reference signals. This fault compensator was validated on a closed-loop sliding mode controlled DFIG wind turbine system, and the simulation results showed that it can highly reduce the oscillations in the electromagnetic torque, output power and other output electrical quantities aroused by winding short circuit faults.

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