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A Novel Wind Turbine System Using NPC Topology- Back To Back Converter by Open-Switch Fault Detection Method

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ABSTRACT: In this paper using Back to back converters transfer power from permanent magnet synchronous generator to grid. A back to back converter with neutral point clamped topology is widely used. There are 12 switches is NPC(Neutral point clamped) topology. Open switch fault in NPC rectifier or back to back converter leads to distortion of input current. Open switch fault in NPC inverter of back to back converter leads to distortion of output current. An open switch fault causes a change in current pattern and can cause breakdown of other parts. Hence detection of open switch fault prevents the destruction of other components and improves reliability of the system.

KEYWORDS: Permanent magnet, NPC rectifier, NPC inverter and open switch fault.

I. INTRODUCTION

Most of the countries in the world use coal, oil, and natural gas to supply most of theirenergy needs. As world population continues to grow and the limited amounts of fossilfuels begin to diminish, it may not be possible to provide the amount of energy demandedby the world by only using fossils fuels. Burning fossil fuels to convert the energy alsocreates air, water, and soil pollution. In addition, it produces greenhouse gases which areresponsible for the global warming. There are plenty of ways to convert the energywithout fossil fuels like renewable energy. Renewable energy resources such as wind,solar, and hydropower offer clean alternatives to fossil fuels.Among them, the wind power is a cost-effective, efficient, and abundant source ofelectricity. For this reason, the wind industry has been growing rapidly in recent years to
reduce the global warming and the dependence on fossil fuels. Wind energy conversionsystem (WECS) is generally composed of a wind turbine, an electric generator, agenerator-side converter and a grid-side inverter. Different structures for a WECS can berealized to convert the wind energy at varying wind speeds to electric power. The most advanced generator type is the permanent magnet synchronous generator (PMSG) usedfor variable speed wind power generation systems.

Generally, power switch failures can be classified as short-switch fault and openswitchfault. Short-switch faults are produced by gate circuit degradation and AC overcurrent. A short-switch fault generates an unbalanced over current, which causes damagesin other important devices of the system. The unbalanced over voltage and over currentmay result in fatal accidents. Therefore, such a fault should be detected immediately toprotect expensive devices. There are several reasons that cause an open-switch fault. Theopen-switch faults are created by the disconnection of a wire from the switching devices
due to a thermal cycling or a gate driver failure. Open-switch faults may be caused byhigh collector current. Finally, the failure in gate driver circuits is one of the mostcommon causes of open-switch fault. Although open-switch faults do not cause the
shutdown of the entire system, the performance will be degraded. Also, the unbalancedoperation caused by the open-switch faults may generate secondary problems in thesystem. When any power switch presents state of failure in a generator-side converter orin a grid-side inverter, the other components of the system can be damaged. For thisreason, open-switch faults should be detected as soon as the fault occurs. It is veryimportant to identify the location of faulty

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switch properly. If any kinds of open-switchfaults occur either in a generator–side converter or in a grid-side inverter, the energysupplied to the grid will be reduced continuously.Diagnostic methods for the open-switch fault in an AC/DC PWM converter have beendeveloped with a special focus on condition monitoring [1]. The difference in detectionmethods between three-phase AC/DC PWM converter and inverter has been analyzed for
IGBT open-switch faults [2]. Based on these techniques, an alternative fault detectionmethod has been proposed for the PWM inverter. A new voltage-based approach withoutadditional sensors has been proposed for open-switch fault diagnosis in closed loopcontrolled PWM voltage source converter [3]. In this scheme, the information containedin the reference voltages which are available from the controller has been used asdetection variables. Four detection techniques using various voltage informations havebeen introduced for fault diagnosis in voltage-fed asynchronous machine drive systems[4]. Application of the fuzzy logic for a fault diagnosis of switching device in a voltagefedinduction motor was presented in [5].

A survey was done on the existing methods of fault diagnosis and protection of IGBT
[6]. A real-time diagnosis for multiple open-switch faults in voltage-fed PWM motordrives was proposed in [7, 8]. Open-switch fault diagnosis of AC/DC PWM converter hasbecome essential in wind turbine applications, not only to avoid secondary fault in theAC/DC PWM converter but also to improve the stability and reliability of entire system.A diagnostic method for multiple open-switch faults in the two converters of a PMSGdrive has been proposed for wind turbine applications [9]. A diagnostic method for adoubly-fed wind power converter in microgrid system has been presented [10], which isbased on the investigation of the characteristics of current signals. A systemreconfiguration topology was designed for the microgrid system to keep a doubly-fedinduction generator continue running after the open-switch faults. A fault diagnosismethod based on the analysis of the load currents in voltage source inverters wasproposed [11], which was an extension of the normalized dc components method. Bycombining the normalized dc components with additional diagnostic variables, thecertainty of the diagnoses under transients and light loads has been markedly improved.Since the performance and reliability of the system are degraded due to the openswitchfault, a fault tolerant control method is needed to solve this problem. A faultdiagnostic method and fault tolerant topology have been proposed for the generator–sideconverter [12] to minimize the unbalance of AC input current and the ripple voltage in theDC-link of three-phase AC/DC PWM converter. Fault detection and isolation on a PWMinverter using the knowledge based model were investigated [13]. This scheme was basedon the analysis of the current vector trajectory and instantaneous frequency in faulty modeand validated through the simulations and experiments. Some diagnostic methods use thefuzzy theory and model reference adaptive system [14]. In this study, the simulations andexperiments were carried out for a digitally controlled permanent magnet synchronousmotor drive system to show the effectiveness and simplicity. A fault diagnostic techniqueto detect the fault type and fault location in multilevel inverter has been also proposed andvalidated [15]. A novel fast diagnostic method for open-switch faults in inverters withoutsensors has been proposed [16] to improve the reliability of the system. This scheme isachieved by the analysis using switching function model of inverter under both healthyand faulty conditions.

II. PROPOSED FAULT DETECTION METHOD

A flow chart of the proposed fault detection algorithm is presented in Figure 1. In theproposed fault detection algorithm, three-phase voltages Va, Vb, and Vc are calculated atfirst by using the DC link voltage and switching times from the space vector PWMscheme.

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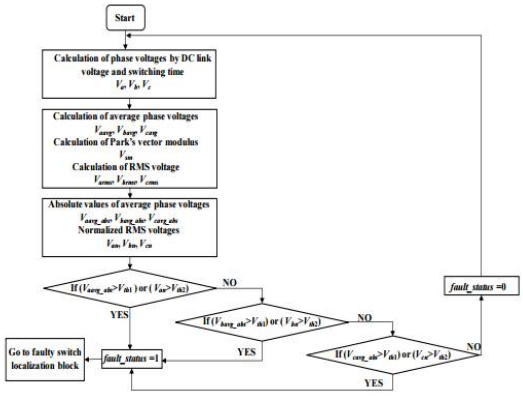

Fig. 1 Flow Chart of the Proposed Open-Switch Fault DetectionAlgorithm

From these values, the absolute values of average three-phase voltages Vaavg_abs,Vbavg_abs, and Vcavg_abs and the normalized three-phase RMS voltages Van, Vbn, and Vcn arecalculated by using three-phase RMS voltages and Park's vector modulus. The switchingpattern in the symmetrical space vector PWM scheme is shown in Figure 2.

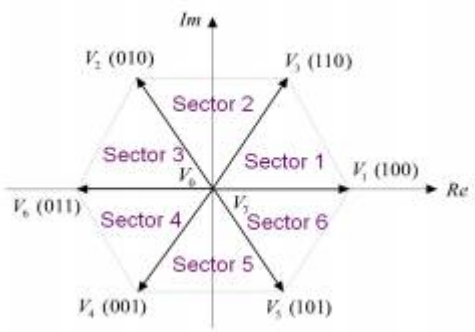

Fig. 2 The Symmetrical Space Vector PWM Scheme

III. COMPARISON OF TOLERANCE CONTROLS

In this section, the characteristics of tolerance controls introducedin Section IV, are analyzed and compared in the simulationresults. The simulation circuit is the same as that shownin Fig. 1. For the analysis of the input current ripple, dc-linkvoltage ripple, and switch losses, simulation parameters are asfollows: the rated power is 1.5 kW, the grid line-to-line voltage is127 Vrms, the grid frequency is 60 Hz, the L-filter value is 1 mH,the dc-link voltage is 200 V, the dc-link capacitor is 1100 μF,the load is 33.3 Ω, the switching frequency is 10 kHz, and thecontrol period is 100 us. The parameters of the insulated gatebipolar mode transistor (IGBT) module 4MBI300VG-120R-50from Fuji Electric were used in the simulation.

Three tolerancecontrols restore the distorted input currents after 0.5 s as shownin Fig. 13; however, each tolerance control has a different polevoltage and current ripple is also different. R2LS-TC makes thepole voltage of three-phase as two levels (Vdc/2 and −Vdc/2)as shown in Fig. 13(a). The a-phase pole voltage has two levelsin Sectors II and V, and, in the rest of the Sector, the a-phasepole voltage is clamped as Vdc/2 and −Vdc/2 when 3LSO-TCis applied. The b- and c-phase pole voltages maintain the threelevels as shown in Fig. 13(b). OP2LS-TC makes the a-phasepole voltage as two levels in all the Sectors. The b- and c-phases
have three-level pole voltages as shown in Fig. 13(c).Fig. 14 shows the expanded current waveforms of tolerancecontrols. R2LS-TC increases the ripple of three-phase currentsin Sectors II–V as shown in Fig. 14(b) owing to

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the 2-LSM.3LSO-TC has current ripple in Sector II–V that is smaller thanthat of R2LS-TC; nevertheless, the current ripple in Sectors Iand IV increases compared with that of R2LS-TC.

The dc-link voltage and the neutral-point voltage(top- and bottom voltages) when each tolerance control isapplied at unity power factor. Among the three tolerance controls,R2LS-TC has smallest ripple in the neutral-point voltage.The neutral-point voltages of 3LSO-TC and OP2LS-TC containlarger ripple. Therefore, the dc-link voltage also has ripple becauseit is affected by the ripple of the neutral-point voltages.Table VI lists the magnitudes of the dc-link voltage and theneutral-point voltage ripple (Vdc,ripple , Vneu,ripple), here thepower factor is unity according to various power levels (Load =27, 33, and 66 Ω). As a result, R2LS-TC is advantageous in theripple of the dc-link voltage and the neutral-point voltage.

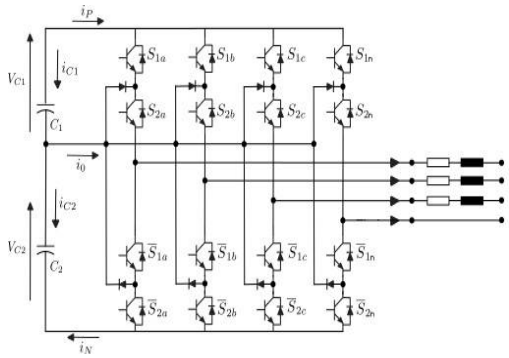

Fig. 3 Proposed Circuit Diagram

Switching State	Device Switching Status (Phase A)				Inverter Terminal Voltage V_{AZ}
	S_1	S_2	S_3	S_4	
P	On	On	Off	Off	E
O	Off	On	On	Off	0
N	Off	Off	On	On	$-E$

Fig. 4 Modes of Operation

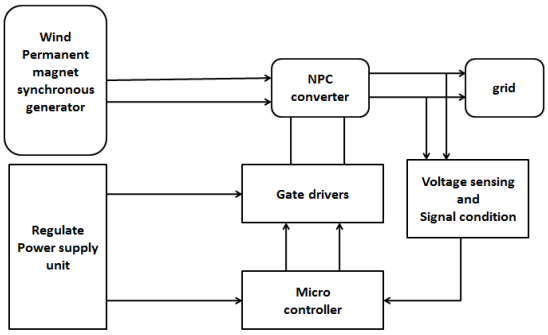

Fig. 5 Proposed Block Diagram

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IV. RESULTS

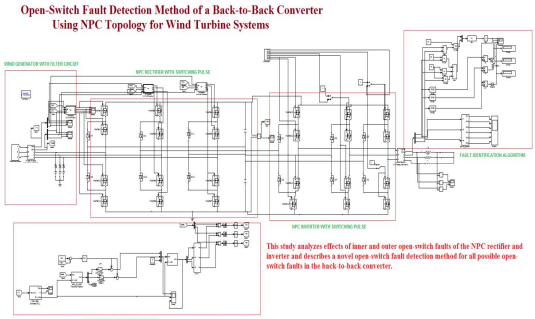

Fig. 6 Proposed Simulink Diagram

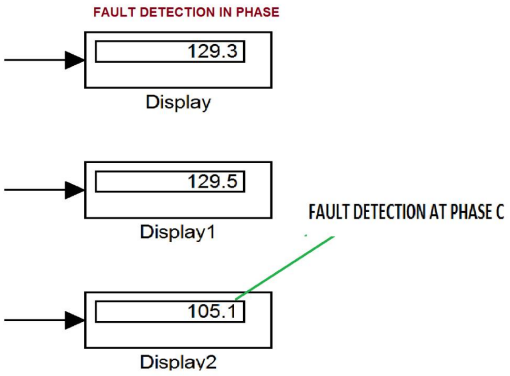

Fig. 7 Fault Detection

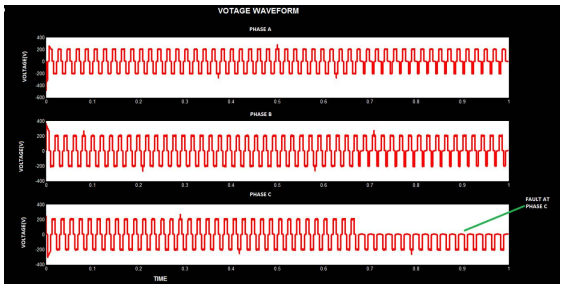

Fig. 8 Output Voltage

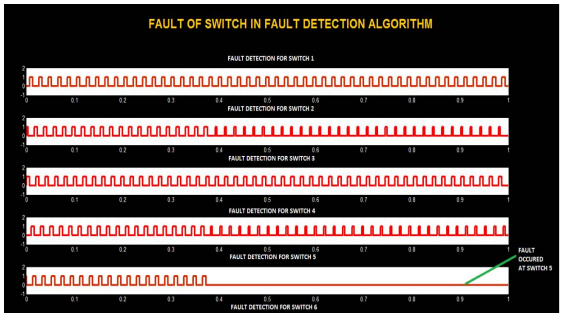

Fig. 9 Fault of Switch in Fault Detection Algorithm

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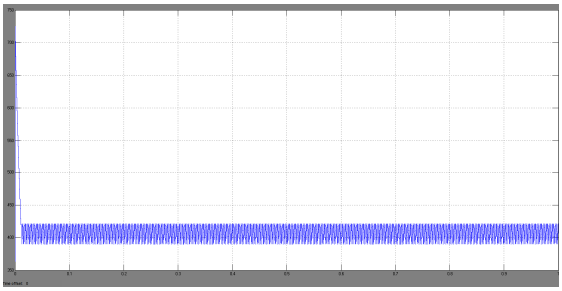

Fig. 10 Output for DC link Voltage

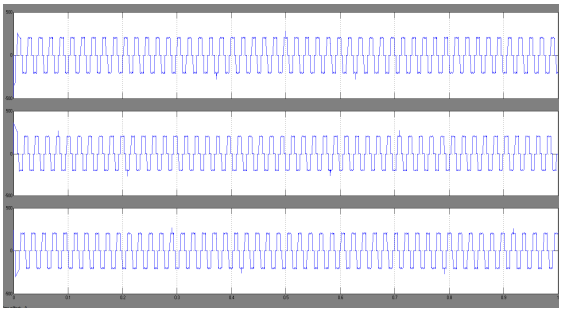

Fig. 11 Output Voltage

Since the microcontroller is a digital device , it is mandatory to supply +5V DC supply.The supply from the battery or the AC supply are to be regulated to +5V DC in order to feed the microcontroller.

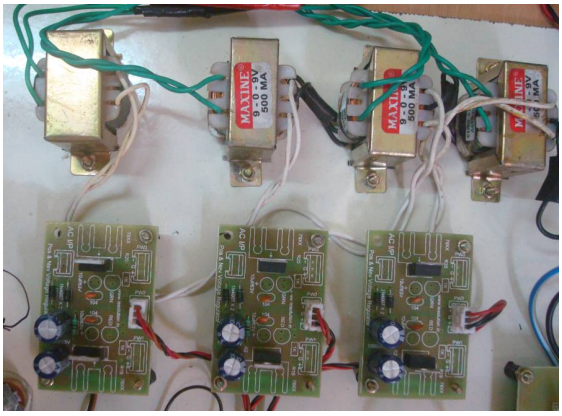

Fig. 12 Proposed Hardware

V. CONCLUSION

This paper proposed a three-level switching-oriented (3LSO)tolerance control for the T-type rectifier and analyzed the characteristicof the tolerance control by comparing it with that ofthe two tolerance controls. The introduced tolerance controlswere described in terms of the space vector and characteristicswere identified by using simulation and experimental results.Additionally, to evaluate these controls, following three factorswere considered: the current THD, dc-link voltage ripple, andefficiency. From analyzed results, we arrived at the followingconclusion:

R2LS-TC: This control guarantees the lower dc-link voltageripple compared to the other tolerance controls (3LSO-TC andOP2LS-TC). In Sectors that operate as the convectional threelevelswitching method, the neutral-point voltagebalancing controlcan be conducted; however, it causes the current THD andefficiency to be high and low.

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3LSO-TC: This control guarantees higher efficiency. Still thecurrent THD and the dc-link voltage ripple increase. Additionally,the changed small vectors from infeasible vectors due to theopen-switch fault are not used for the neutral-point voltage balancingcontrol; however, the changed vectors for neutral-pointvoltage balancing control in opposite Sectors can be used tothe neutral-point voltage balancing control (the small vectors,which is the opposite type, in the opposite sectors guarantee theneutral-point balance). These vectors for neutral-point voltagebalancing control are decided depending on the position of theopen-switch fault; therefore, the neutral-point voltage balancingcontrol in 3LSO-TC has a limitation.

Consequently, these tolerance controls have different advantages,and they should be selected by considering the specificrequirements of applications using the T-type rectifier.

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