Open-circuit fault detection method for Grid-side Three-level NPC Inverter

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Abstract*—Reliability of power electronics is one most critical challenge to face in order to improve the reliability of wind turbine system (WTS). As the power of the wind turbine is increasing, different topologies of power converters are developed for wind turbine applications. The three-level Neutral-Point Clamped (NPC) converter is widely used in WTS, since it has many advantages like a large output capacity, high output voltage and low current Total Harmonic Distortion (THD). However, the topology of these converters has a large number of switches which are fragile components. Open circuit is one of the most common failures in these converters and causes considerable economic damage in wind power systems. This paper presents an open-circuit fault diagnosis method for a three-level NPC inverters based on current and charge distortion in the output of the inverter. The operation of the NPC inverter under normal and open-circuit fault are analyzed. Simulations results of the converter control and the fault diagnosis method are presented and discussed.

Keywords*—power electronics; reliability ; fault detection ; NPC converter.

I. Introduction

The last decade has been marked by increasing global awareness about global warming and the need to reduce carbon emissions. As a result, the demand for renewable energies, especially electricity production from wind turbine energy sources, continues to grow exponentially [1]. The large integration of wind power into the electric grid makes improving reliability of wind turbine system an important issue. Power converters are one of the most fragile components of the wind power systems, and improving their reliability is a key issue to ensure better reliability of wind power systems and competitiveness in the power generation market [2,8]. Multi-level converters offer the possibility to reach very high power levels and a remarkable energy quality at its output. NPCs are the most likely candidates to replace Voltage Source Converters (VSCs) in the structure of wind power systems [3,4,17]. However, these converters have a large number of power switches, which makes their reliability an issue of concern for researchers and industry. Power switches are considered the main cause of failure in power conversion systems due to their fragility [6,7]. The detection of short circuits is generally ensured by the new generation of drivers. Open circuit detection in converters remains an important research topic for improving the reliability of power converters [9,10]. In this paper, we present our work on open circuit fault detection in NPC three-level converters. The method is based on detecting and locating faulty switches by analyzing the distortions caused by these faults on the converter output currents and charges.

In section II, the wind turbine system based on a back to back NPC converter will be described. In section III, the analysis of NPC converter under normal, fault conditions and an open-circuit fault detection method are presented. In section IV, the simulations results will be exposed. Finally, the conclusions are presented in section V.

II. Wind Turbine System

The configuration system for grid connected PMSG wind turbine proposed in this paper is shown in Fig 1. The WTS is composed by five parts: wind turbine, permanent magnet synchronous generator (PMSG) , three-levels generator-side converter NPC , three-levels grid-side NPC inverter.

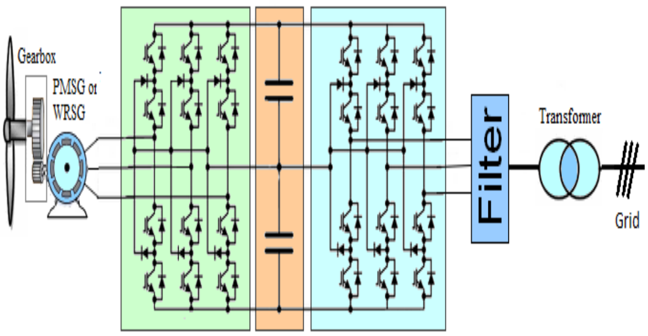

Fig. 1. Wind turbine system based on back-to-back NPC converter

Wind turbine converts wind kinetic energy to mechanical energy. The PMSG converts rotational mechanical energy into electrical energy. The generator side converter is used to ensure the extraction of the maximum power from PMSG and to converter the Ac voltage to Dc voltage.

The grid side inverter connects the dc-link to the grid; his principal role is converting the Dc voltage of the bus-side to Ac voltage on the grid. Moreover the grid-side converter is mainly used to control the Dc-link voltage and to control the active power and reactive power delivered to the grid [11,12].

In this paper, a three-level -NPC inverter is used, these inverters are usually used in medium voltage drives because of the reduction of switching losses due to a lower dv/dt, and their ability to share the blocking voltage between the two switches connected in series, thus supporting high voltages [3]. In this paper, we adopt a space-vector modulation strategy to control generator and grid side converters [11].

III. NPC OPERATION AND FAULT DETECTION METHOD

A. *NPC under normal conditions*

The operating principle of each of the NPC converter arms can be summed up in three switching states which make possible to connect the three phases to the three Dc-bus points P, O, N. As illustrated in Fig 2, the state P consists of connecting the phase to the positive point of the continuous bus, the state N consists of connecting the phase to the negative point of the continuous bus and the state O consists of connecting the phase to the neutral point of the continuous bus [13,14]. Table.1 shows us the different possible switching combinations and theirs associated Dc-bus voltage levels [5]. The desired output current is obtained via the different switching combinations.

Table 1. Switch State and output voltage in NPC inverter

Switching State	Semiconductor Switching State				Output Voltage
	S_{x1}	S_{x2}	S_{x3}	S_{x4}	
P	ON	ON	OFF	OFF	$V_{dc}/2$
O	OFF	ON	ON	OFF	0
N	OFF	OFF	ON	ON	$-V_{dc}/2$

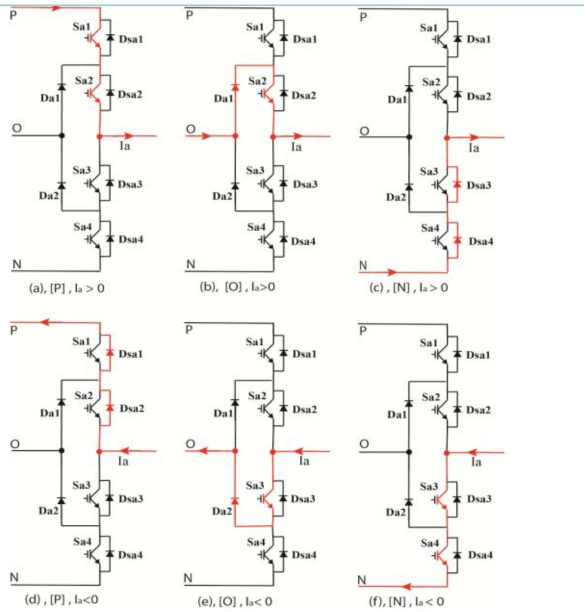

Fig. 2. Current flows according to switching state and current direction in a NPC inverter.

B. *NPC Under fault operation*

The output current of converters is related to the switching state of the power switches, as studied in the previous section. The fault of one of the switches inevitably leads to a distorted output current [15]. In the case of an open circuit fault in one of the switches, the faulty switch remains in an open state and cannot be closed. Therefore, depending on the position of the faulty switch, the output current will have distortions either on its negative or positive sinusoidal alternation.

In the following an analysis of the different open-circuit scenarios in the NPC inverter switches, and the repercussions of these faults on the output inverter current. Due to the symmetrical structure of the NPC converter, only the case of fault in the phase A (S_{a1}, S_{a2}, S_{a3}, S_{a4}) will be studied.

Open-circuit fault in S_{a1}

Unlike normal operating conditions where the switching state P consists of connecting the phase to the positive point of the Dc-bus via switches S_{a1} and S_{a2}. Figure 3 show that in the case of open-circuit fault in switch S_{a1}, the phase cannot be connected to the positive point of the Dc-bus, so it will cause distortions on the positive output current of phase A. The O and N switching states are not affected in this case, so the operation will remain the same as the case without faults for both switching states.

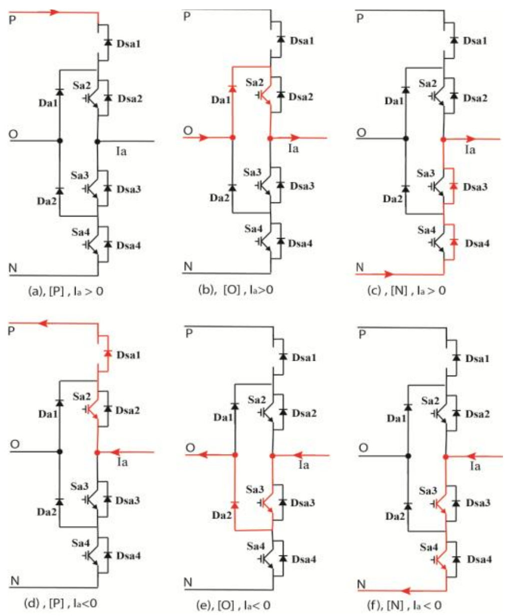

Fig. 3. Current flows according to switching state and current direction in a NPC inverter under S_{a1} fault conditions.

Open-circuit fault in S_{a2}

As illustrated in Fig.4, the case of an open circuit fault in switch S_{a2}, the phase cannot be connected to either the positive point of the Dc-bus or the neutral point of the Dc-bus. The only possibility of connection is via the diodes D_{Sa1} and D_{Sa2} when the current is negative. The fault in switch S_{a2} will cause the suppression of the positive part of the sinusoidal alternation of the phase current A.

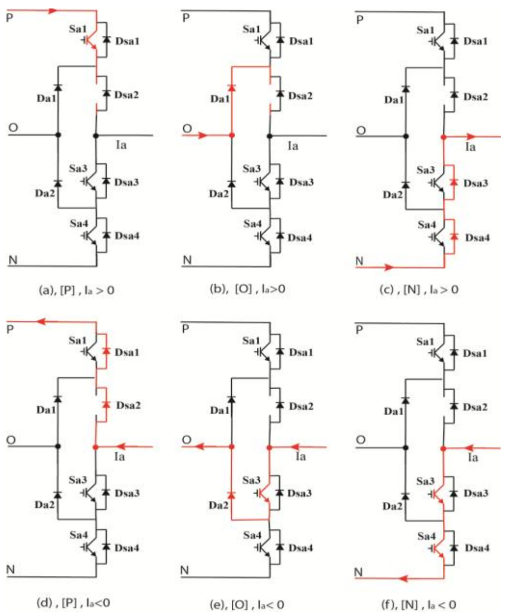

Fig. 4. Current flows according to switching state and current direction in a NPC inverter under S_{a2} fault conditions.

Open-circuit fault in S_{a3}

An open circuit fault in any of the switches on the bottom of the NPC converter will cause distortions in the negative part of the output current. In the case of a fault in switch S_{a3}, the O and N switching states are not applicable. Therefore, the fault in switch S_{a3} will cause the suppression of the negative part of the sinusoidal alternation of the phase current A.

Open-circuit fault in S_{a4}

Switching state N is not possible in case of fault in switch S_{a4}. This will cause distortions on the negative part of output current of phase A. Switching states O and P are not affected in this case, so the operation will remain the same as the fault-free case for both switching states.

C. Open-circuit diagnosis method

The fault detection in the NPC inverter, as mentioned in the previous section, leaves distortions on the output current form. The analysis of the current form allows us to detect and localize the faulty switch [16]. The proposed fault detection method is illustrated in Fig.5. It is based on the calculation and comparison of the charges passing through each phase to determine which leg and switch is open-circuited. For each phase, the positive and negative charges are calculated and compared:

$$Q_{Xp} = \int I_{Xp} \, .dt \quad (1)$$

$$Q_{Xn} = \int I_{Xn} .dt \quad (2)$$

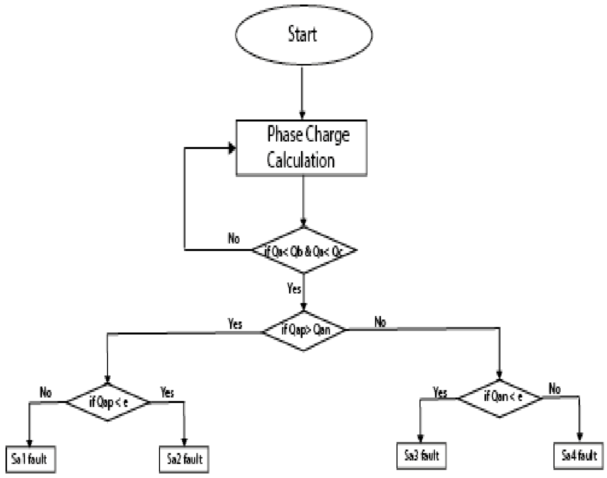

Fig. 5. Structure of the proposed defect detection method in case of faults in the phase A.

IV. Simulation Results

The control and the method of detection of defects are evaluated via the simulations of system under the software Matlab. The results of the proposed method are exposed in the Fig. 6 to 11. Fig.9 shows, the curve of charges under the conditions of normal operation, the Fig.6 illustrates the output current of converter without defects. It can be observed that the outputs three phase currents of the three-level NPC inverter are sinusoidal under a normal condition.

The reaction of system in case of open circuit in the switch S_{a1} is illustrated on Fig.7 where we notice a distortion at the output current at t= 0.25s. After this moment, the detection signal indicate that phase A is detected as faulty. Fig.10 shows us the calculation of charge and the effect of this defect on the curve of charge, the charge $Q_{\_A\_p}$ is at the smallest value. In the case of an open circuit at the switch S_{a2}, Fig.8 and Fig.11 show respectively the shape of the current and the charge before and after defect. It can be observed that the outputs three phase currents of the three-level NPC inverter are sinusoidal under a normal condition.

Distortions are noticed after fault simulated in the S_{a2} switch, the charge $Q_{\_A\_p}$ will be at its lowest value. The detection signal indicate that switch S_{a2} in phase a is detected as faulty.

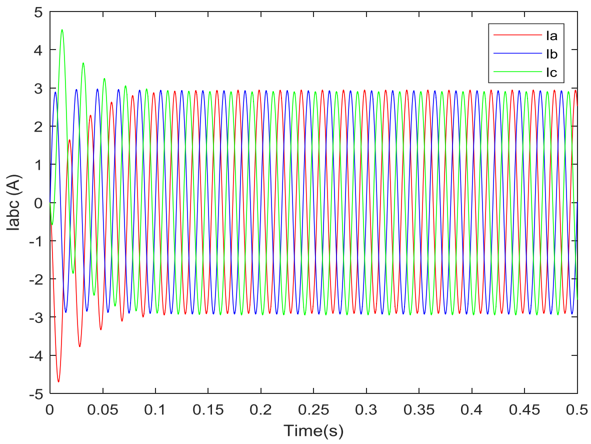

Fig. 6. Three phase currents under normal

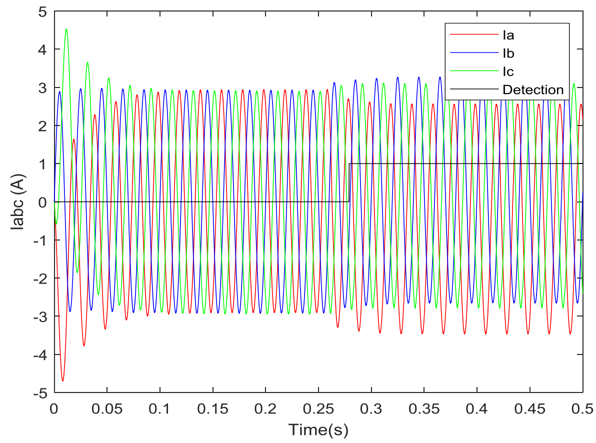

Fig. 7. Three phase currents in case of an open-circuit in Sa1

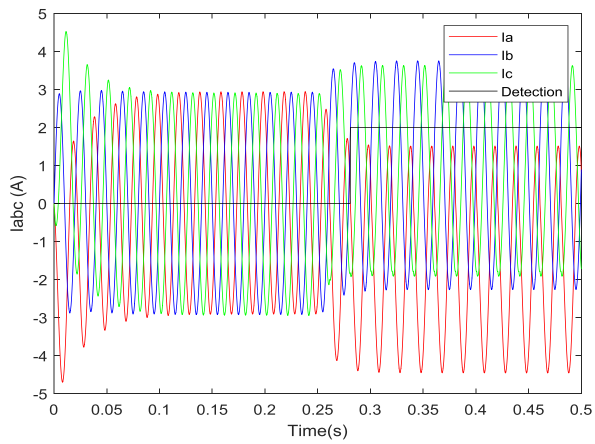

Fig. 8. Three phase currents in case of an open-circuit in Sa2

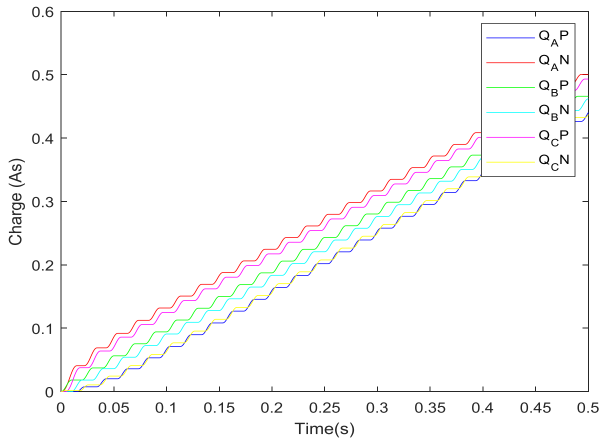

Fig. 9. Phase charges in normal conditions

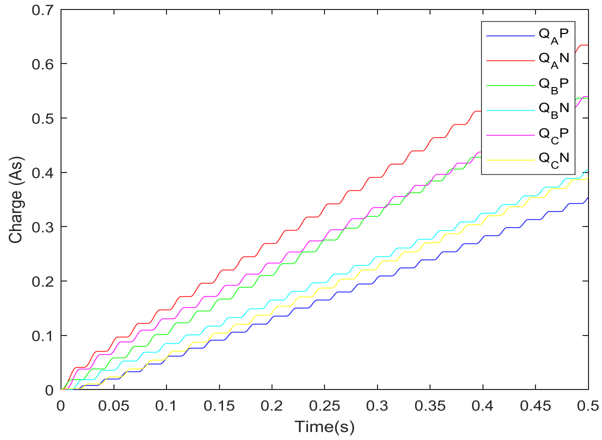

Fig. 10. Phase charges in case of an open-circuit fault in Sa1

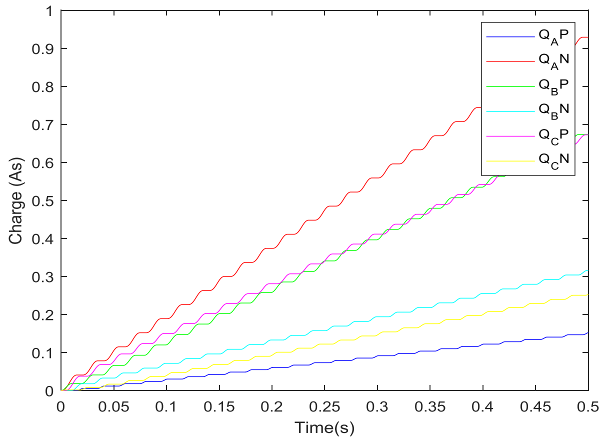

Fig. 11. Phase charges in case of an open-circuit fault in Sa2

V. CONCLUSION

The paper is part of work to improve the reliability of wind power systems; the method developed allows a rapid detection of open circuit fault in multilevel converters NPCs. The method is based on the fault signature on the output currents and charges of the converter. The simulations results show the effectiveness of the detection method. From the results obtained, it can be concluded that the proposed fault detection method for the NPC inverter is interesting. Based on the promising results presented in this paper, future work will focus on fault tolerant control.

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