Impact of Intermittent Misfire and Fire-through on the Performance of Full Converter Based WECS

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Abstract— **The integration of wind turbines into modern power grids has significantly increased during the last decade. The wind turbine equipped with full converter based wind energy Conversion System (FCWECS) represented about 20.3% of the worldwide total wind capacity in 2003. Since FCWECS is equipped with a voltage source inverter (VSI), it is vulnerable that misfire and fire-through may occur within the VSI switches. In this paper, impact of these switching malfunctions on FCWECS performance is investigated and discussed. Detailed simulations of the system under study are carried out using Matlab/Simulink to highlight the influence of these converter internal faults on PCC voltage, DC link voltage and shaft speed, as well as generator active and reactive power. Furthermore, compliance of the FCWECS with Spain fault ride through (FRT) grid codes is also investigated.**

Keywords- FCWECS, component, converter internal fault, misfir, fire-through and VSI.

I. INTRODUCTION

Wind energy is one of the most promising renewable energy sources in the world. Its capacity has reached 94 GW worldwide by the end of the year 2007 and it is expected to provide more than 10% of the global electricity in 2020 [1]. Full converter based wind energy conversion system (FCWECS) is a direct-driven wind turbine generator with full-scale converter which has the capability of working optimally and tracking the maximum power during variable wind speed conditions. In 2003, this type of wind turbine reached 20.3% of the total wind turbine installed globally [2]. The capability of the FCWECS to track maximum power relies on its converter configuration, which with proper controller could also contribute to deliver reactive power support during grid disturbance events as specified by most international grid code requirements. Since FCWECS utilizes IGBTs based voltage source inverter (VSI), it is vulnerable that switching malfunctions that are caused by misfire and fire-through may occur.

Misfire is the failure of a converter switch to take over conduction at the programmed conducting period while fire-through is the failure of a converter switch to block during a scheduled non-conducting period. These faults are caused by various malfunctions in the control and firing equipment [3]. Some of these converter faults are self-clearing if their causes are of transient nature. However these internal convert faults can still cause a major problem to the system particularly when they occur on inverter station rather than rectifier station [4]. The use of IGBT in FCWECS inverter is preferred due to its advantage which include high switching frequency in a typical range of 2-20 kHz compared to GTO switching frequency which does not exceed 1.0 kHz [5]. When gate-misfiring occurs on IGBT based converter station, it can cause catastrophic breakdown to the device, if the fault remains undetected [6]. Most of FCWECS studies are focused on the improvement of its fault ride through (FRT) capability during various grid faults such as in [7-10]. Although, there are a few studies regarding the effect of misfire and fire-through on HVDC performance such as [11] and fault diagnosis methods for both types of faults in variable speed based induction generator machines [12, 13], no attention has been given to investigate the impact of such faults on the overall performance of the full converter based WECS and its compliance to the recent developed grid codes. This paper investigates the impact of misfire and fire-through within VSI switches on the performance of FCWECS. Detailed simulations are performed to show impacts of these faults on the performance of generator and distribution system. The FCWECS fault ride through (FRT) compliance with Spain grid codes is also investigated.

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II. SYSTEM UNDER STUDY

The FCWECS configuration used in this study consists of a synchronous generator connected to a diode rectifier, DC-DC IGBT-based PWM boost converter and a DC/AC IGBT-based PWM voltage source inverter (VSI) as shown in Fig. 1. This configuration enables the turbine to take part in the power control [14]. When the speed of synchronous generator changes, the voltage at the DC side of the rectifier will change accordingly and the chopper will adapt this change to the voltage across the DC link [15]. The system under study shown in Fig. 2 consists of a single 2 MW FCWECS connected to the AC grid at a point of common coupling (PCC) through Y/Δ step up transformer. The typical configuration of the VSI used in FCWECS is shown in Fig. 3.

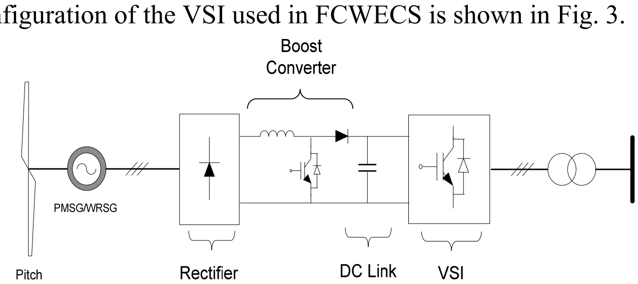

Figure 1. Typical configuration of FCWECS

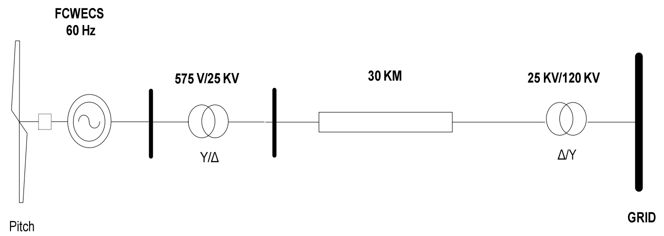

Figure 2. System under study

The grid is represented by an ideal 3-phase voltage source of constant frequency and is connected to the wind turbine through a 30 km transmission line. The reactive power produced by the wind turbine is regulated at 0 Mvar at normal operating conditions. For an average wind speed of 15 m/s that is used in this study, the turbine output power is 1.0 pu and the generator speed is 1.2 pu.

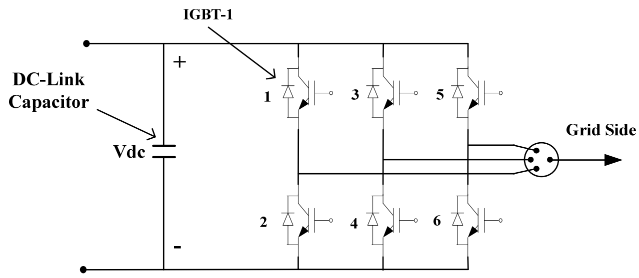

Figure 3. VSI model of FCWECS

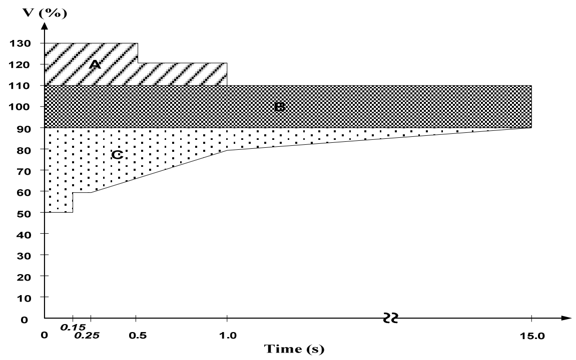

Figure 4. Fault-Ride-Through of Spain grid code [16]

One parameter that has been given special attention in most of the worldwide recent grid codes is the voltage profile at the PCC where the wind turbine is required to withstand certain level of voltage sag or swell for certain duration during grid disturbance events. This requirement is known as fault ride through (FRT). Several studies can be found in the literatures regarding the compliance of wind energy conversion systems (WECS) with various grid codes during grid disturbance events such as [17, 18]. In this paper, the FCWECS compliance with the FRT of Spain (shown in Fig. 4 [19]) under misfire and fire-through of the VSI switches is investigated. Fig. 4 shows the FRT of Spain grid code which is divided into three main blocks. "A" block is representing the high voltage ride through (HVRT) of Spain grid code. The maximum allowable high voltage in the vicinity at the PCC is 130% that lasts for duration of 0.5 s from the instant of fault occurrence. After that the maximum voltage is reduced to 120% for the next 0.5 s. All high voltage profiles above "A" block will lead to the disconnection of wind turbine generator (WTG) from the system. The normal condition of this grid code is laid on "B" block. All voltage profiles within this block range (90% to 110%) are classified as a normal condition. The low voltage ride through (LVRT) is limited in "C" block. The minimum voltage drop allowed in this grid code is 50% that lasts for 0.15 s from the instant of fault occurrence and then increased to 60% for 0.1 s. The low voltage restriction then ramps up to 80% at 1 s and reaches the normal condition in 15 s from the instant of fault occurrence. Similar to the HVRT, any voltage level at the PCC below the levels constrained by the "C" block will lead to the disconnection of WTG from the system.

III. Simulation Results

In this paper, both misfire and fire-through are applied at t= 1.0 s and allowed to last for 0.2 s. Both faults are applied on IGBT-1 of the FCWECS' inverter shown in Fig. 3.

A. *Misfire Fault*

According to the simulations results of this paper, during misfire fault, the generated active and reactive powers will experience overshooting at the instants of fault occurrence and clearance as shown in Figs. 5 and 6, respectively. The shaft speed will also oscillate slightly following the application of misfire fault as shown in Fig. 7.

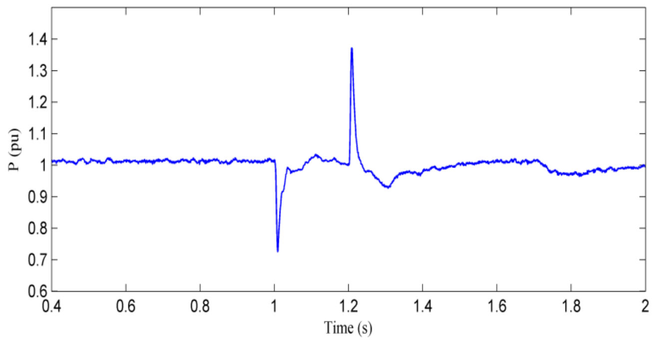

Figure 5. Active power responses during misfire fault

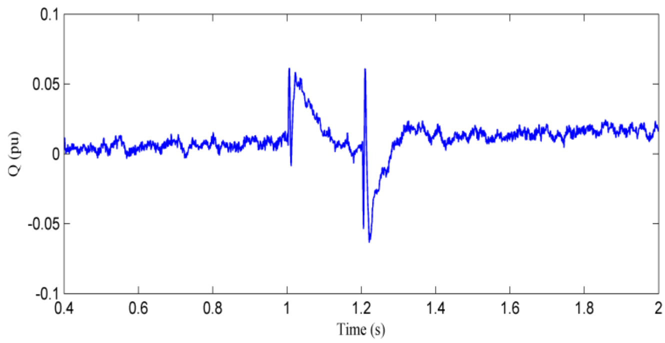

Figure 6. Reactive power responses during misfire fault

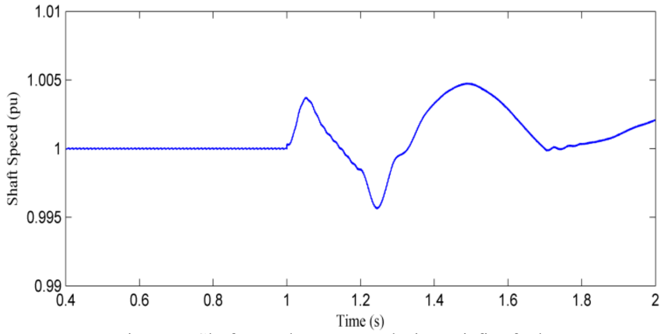

Figure 7. Shaft speed responses during misfire fault

One of the important parameters of the converter that is interfaced with the grid is the voltage across the DC link. As shown in Fig. 8, voltage across the DC link exhibits significant oscillations once the misfire is applied at t= 1.0 s. The maximum overshoot however, remains within the safety margin of 1.25 pu as specified in [20].

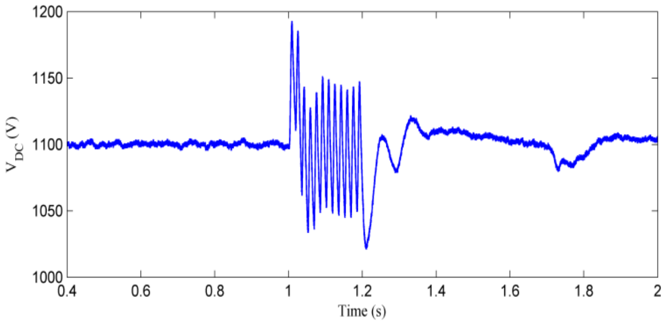

Figure 8. DC link voltage response during misfire fault

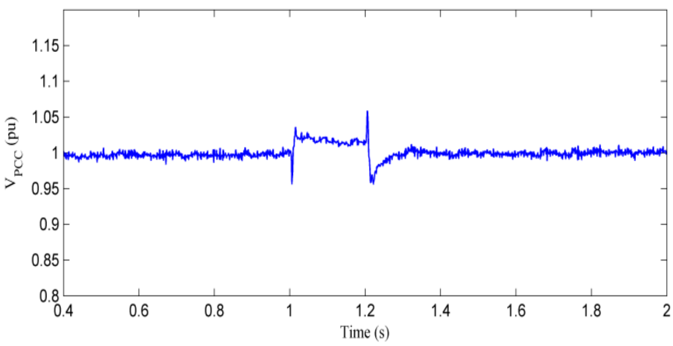

Figure 9. Voltage response at PCC during misfire fault

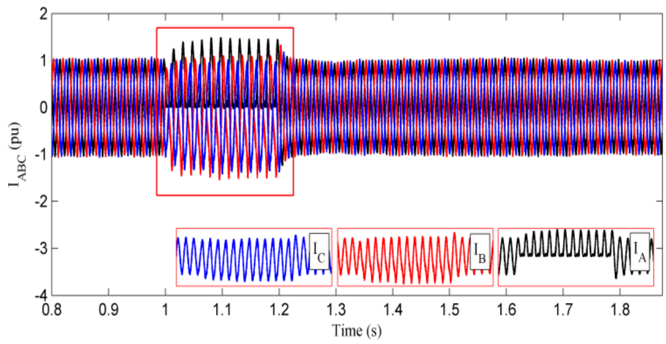

Figure 10. VSI current waveform during misfire fault

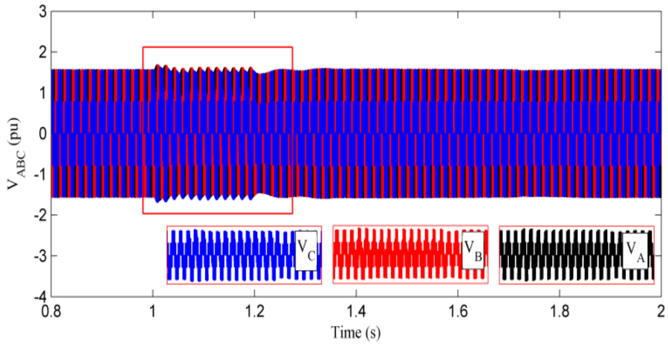

Figure 11. VSI voltage waveform during misfire fault

Voltage at the PCC under misfire condition is shown in Fig. 9, which reveals that the voltage is not influenced significantly, and therefore it is still complying with the FRT of the Spain grid code (Fig. 4). Both grid inverter current and voltage are also influenced insignificantly as shown in Figs. 10 and 11, respectively.

B. Fire-through Fault

The impact of fire-through on FCWECS performance is worse than misfire as shown in Figs. 12 through 18. When the fire-through is applied at t= 1.0s, the generated active power drops significantly and the generator acts as a motor at the instant of fault clearance. In practical situation, both generator and converter protection devices will be energized to isolate them from the grid to avoid such undesirable conditions. After fault clearance, the generated tends to produce more active power than its pre-determined nominal value; this may be attributed to the inability of the VSI's switching or control system to retain its default setting.

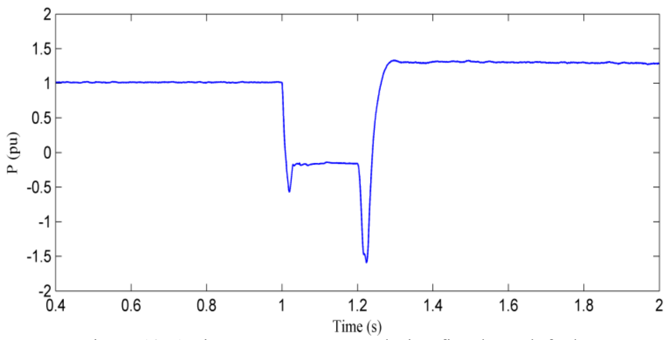

Figure 12. Active power responses during fire-through fault

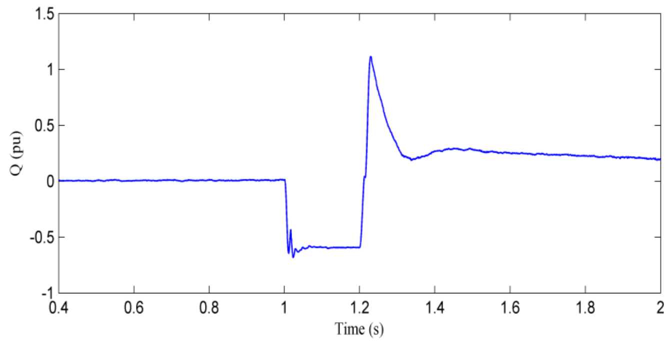

Figure 13. Reactive power responses during fire-through fault

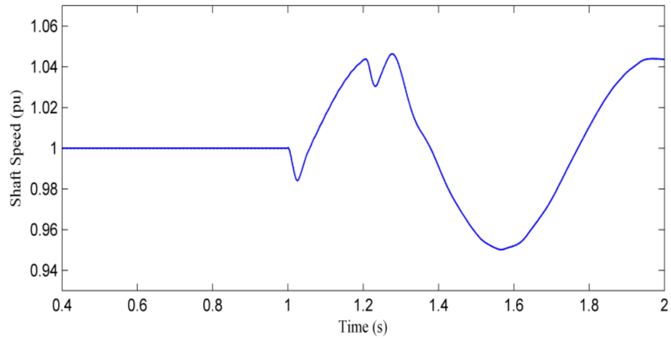

Figure 14. Shaft speed responses during fire-through fault

When fire-through occurs, the FCWECS tends to absorb excessive amount of reactive power from the grid as shown in Fig. 13 and the shaft speed will oscillate between positive and negative levels as shown in Fig. 14.

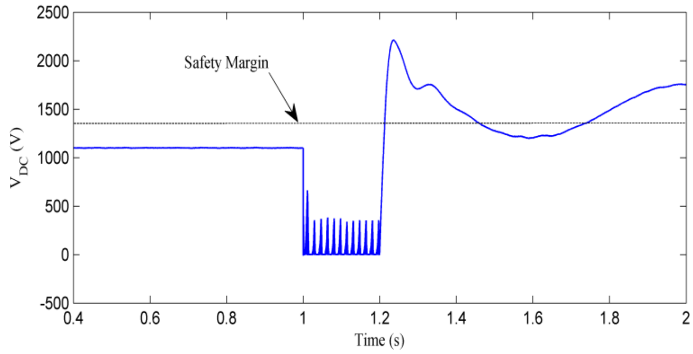

Figure 15. DC link voltage response during fire-through fault

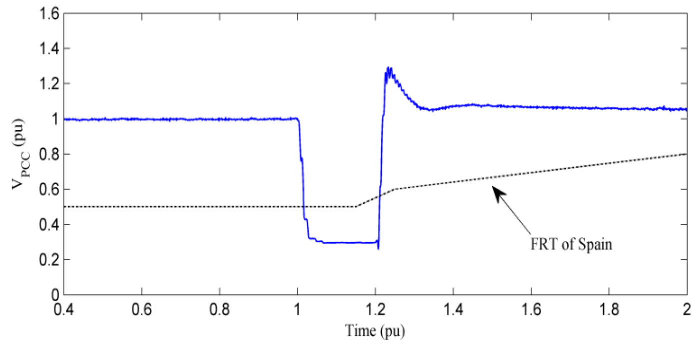

Figure 16. Voltage response at PCC during fire-through fault

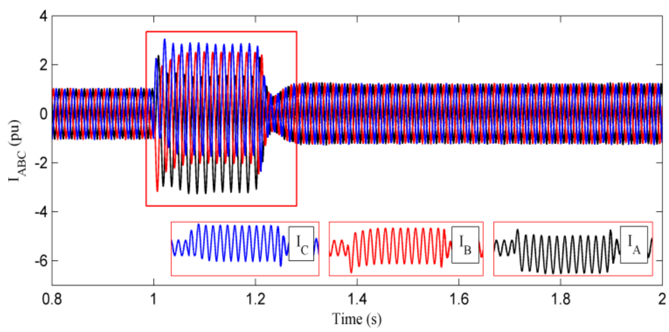

Figure 17. VSI current waveform during fire-through fault

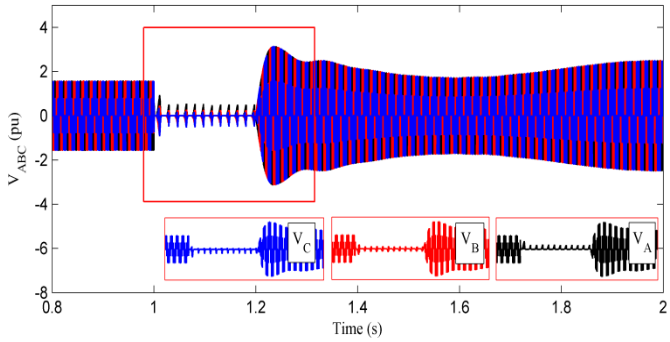

Figure 18. VSI voltage waveform during fire-through fault

Fig. 15 shows that the voltage across the DC link capacitor drops to zero level once the fire-through is applied. A significant drop of the DC link voltage can lead to a failure of the generator control or to excess switching currents, which could lead to a damage of the power electronic modules [21]. Once the fault is cleared at 1.2s, the voltage tends to oscillate with a maximum overshooting of 2250 V that violates the safety margin specified in [20]. The increase of the DC link voltage can also cause overloading of the DC link capacitor, which can lead to hardware damages and loss of grid control capabilities [21]. Consequently, inverter protection system must be activated to block the inverter operation in this case.

The voltage at the PCC will experience voltage sag of 0.8 pu and it will violate the LVRT of Spain FRT grid codes used in this study as shown in Fig. 16. This will call for the disconnection of the WTG from the grid.

Fig. 17 shows that the grid inverter currents are doubled during the fire-through fault. Following Ref. [20] which specifies the maximum allowable grid inverter current to be $2I_{Rated}$, the inverter protection must operate to isolate the inverter and protect the switches from the excess currents. Grid inverter voltage will also significantly drop during the fire-through fault as shown in Fig. 18.

IV. CONCLUSION

Impacts of misfire and fire-through on FCWECS performance are presented. Simulation results show that misfire has insignificant impact on the overall performance of the FCWECS. However, in fire-through case, all system parameters such as the voltage at PCC, the voltage across the DC link capacitor and the inverter switches currents will violate the specified safety margins. Generator active power drops significantly to a level beyond zero and the machine behaves as a motor. The machine requires substantial reactive power support from the grid during such fault. This will call for an appropriate FCWECS protection scheme to isolate the WECS to avoid any possible damages. This study is considerably important for the design of proper protection system to avoid the severe consequences due to voltage source inverter switching malfunctions such as misfire and fire-through.

APPENDIX

PARAMETERS OF FCWECS

Rated Power	2.0 MW
Stator Voltage	575 V
Frequency	60 Hz
R_S	0.006 pu
V_{DC}	1100 V

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