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RESEARCH ARTICLE

Impact of an Unsymmetrical Fault on the Controller of the DFIG Wind Farm

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Abstract

Objectives: DFIG-based wind farms are predominant in their performance when compared to other types of generators. In the field study, due to transient events, converters at the machine side and grid side are affected. To protect the converters from an abnormal operation, overcurrent protective relays have to be designed and incorporated. Unsymmetrical fault analysis are help in the design of protective devise and speed sensors. **Methods:** DFIG-based wind systems are developed using the DIgSILENT power factory software and EMT simulations are executed during the unsymmetrical faults applied near the Machine Side Converter (MSC) and Grid Side Converter(GSC). **Findings:** During the simulation studies, various parameters are transient time, maximum current, steady-state, and voltage drop identified near the MSC and GSC. The short circuit parameters are attenuated during the unsymmetrical faults and the rotor maximum current increases by 2 to 3 times the rated current per unit, 40% to 50% voltage dip, and the current reach the steady state value after 1.213 sec during the fault. The parameters are affected more when a fault occurs near the GSC when compared to a fault near MSC. **Novelty:** These research findings will contribute to a better understanding and improvement of sensor sensitivity, as well as the development of control mechanisms, and protection tactics in designing more accurate and appropriate for DFIG-WT.

Keywords: DoublyFed Induction Generator; Machine Side Controller; Grid Side Controller; Unsymmetrical Fault; Sensor

1 Introduction

Energy consumption has increased significantly, as have environmental concerns. As a result, the globe is transitioning toward renewable energy resources and technologies since they are clean and cost nothing to operate. Wind energy is a renewable energy source. It should come as no surprise that wind farms will be used to generate the majority of power in the future. Among the various wind farms, a Doubly fed induction generator (DFIG) is predominant in all the accept [1]. According to IEC standards, Real-time events are measured at the grid-connected wind farms which help to understand the various cause of the events and its effect. The simulation model of the wind farm is also validated by comparison with the recorded events [2,3].MATLAB and Simulink were used to create a mathematical model of a wind turbine-based induction generator. An aerodynamic model, a wind turbine drive train based on two mass models, and an induction generator model comprise the developed model wind turbine. Based on electrical equations in Park's reference frame, the induction generator was created. The model is divided into electrical and mechanical subsystems. The suggested model of a wind turbine with a doubly-fed induction generation was subsequently evaluated in MATLAB software. The developed model is validated with real-time measurement data [4,5]. Although DFIG-based wind turbines have proved effective, there are still significant hurdles to overcome. Voltage imbalances with varying magnitudes are fairly typical in a highly competitive power system due to failures. [6]. Symmetrical and unsymmetrical faults provide a substantial flow of current to the rotor side of the DFIG, which is coupled via back-to-back converters; these high currents may damage the converters. To protect the DFIG and converter against transients and errors, a robust protection mechanism is required [7–10]. The disruption at the machine side converter (MSC) as well as the Grid side converter (GSC) during an appropriate malfunction is explored. However, symmetrical fault analysis is inadequate for the construction of predictive as well as preventive equipment [11]. The single line-to-ground fault behaviours of the DFIG wind turbine are analysed and crowbar protection is implemented to protect the wind machines from the high rotor current. But in this paper, only single-to-line fault is applied and various parameters are not found. Thus, the design of the protective equipment and sensors is complicated for the designer [12].

2 Methodology

2.1 Wind farm under study

The Pethappampatty Substation, located in Coimbatore District, TamilNadu, India is made up of 4 wind farm feeders, Pukkulam, SV Patty, Eluppanagaram, and Ponneri that are linked to the 33kV distribution system. The station was erected between 2010 and 2011. The variable speed DFIGs are installed at this wind farm. From May to June, power quality analyzers were placed at different sites around the Pethappampatty distribution systems. Three different power quality metres were deployed, and the Fluke 435 meter was put at the wind farm that was linked to the Pukkulam distribution system through power converters. The second Dranetz analyzer was placed at a feeder breaker at the Pukkulam substation. At the 110kV circuit breaker location, a power quality analyzer, HIOKI was installed. Figure 1 depicts the Negative sequence current under the transient category

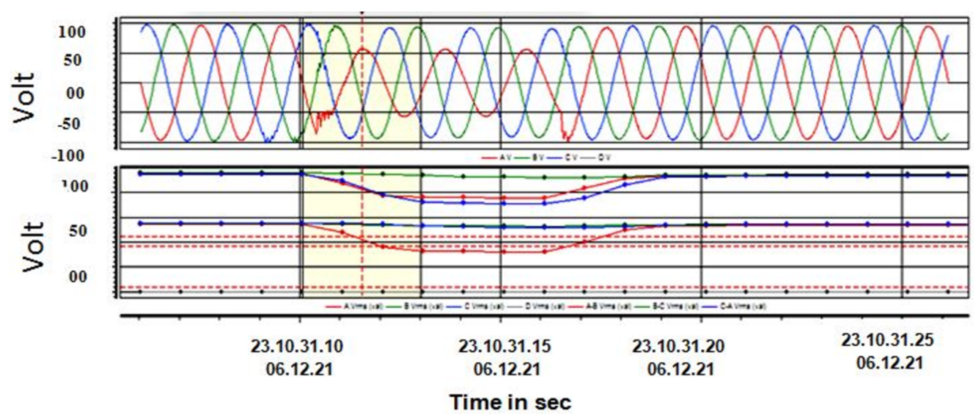

Fig 1. Negative sequence current under the transient category

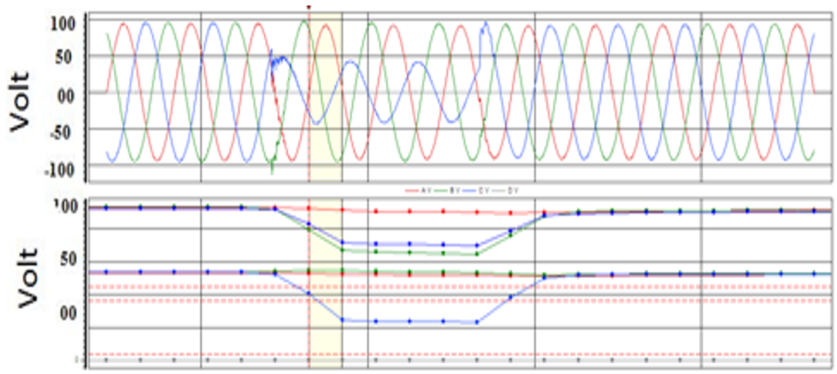

Fig 2. Negative sequence current under the transient category

2.2 Modelling of Doubly Fed Induction Generator

The DFIG-based wind electric system is the most widely utilized among all other wind-generating systems. It has the advantage of being able to control both active and reactive power independently[13]. DFIG WECS is made up of various components which include a generator, a turbine, an MSC, a GSC, a coupling transformer, and a DC voltage link as depicted in Figure 3.

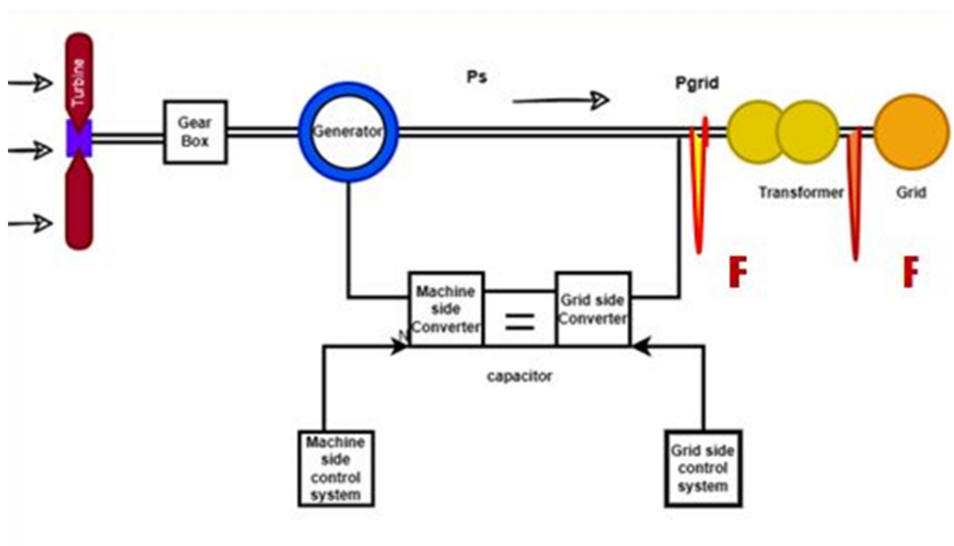

Fig 3. DFIG is connected to 50 Hz AC

In the DFIG-based WECS, an electrical supply is provided by a wound induction generator. The stator of the machine is connected to the network and the rotor is connected to the AC Circuits via back-to-back rectifier as well the transformer. The slip ring power of the rotor is pumped to the machine side converter and the grid side converter is synchronized to the utility grid through a transformer. The DC link connects the two converters back-to-back. The inductive generator may work in sub-synchronous, synchronous and super-synchronous settings since the power converter is reversible[14,15].

2.3 Simulation model of DIFG in DIgSILENT

The simulations of structural elements such as aerodynamics and the control parts of the wind turbine, and converter side controllers, are developed and integrated using DIgSILENT software. The network architecture, as well as the electrical elements, are extracted from the built-in library in this research. A simulation layout has been developed with the in-built electrical components such as the busbar, transformer, lines and converters as shown in Figure 4.

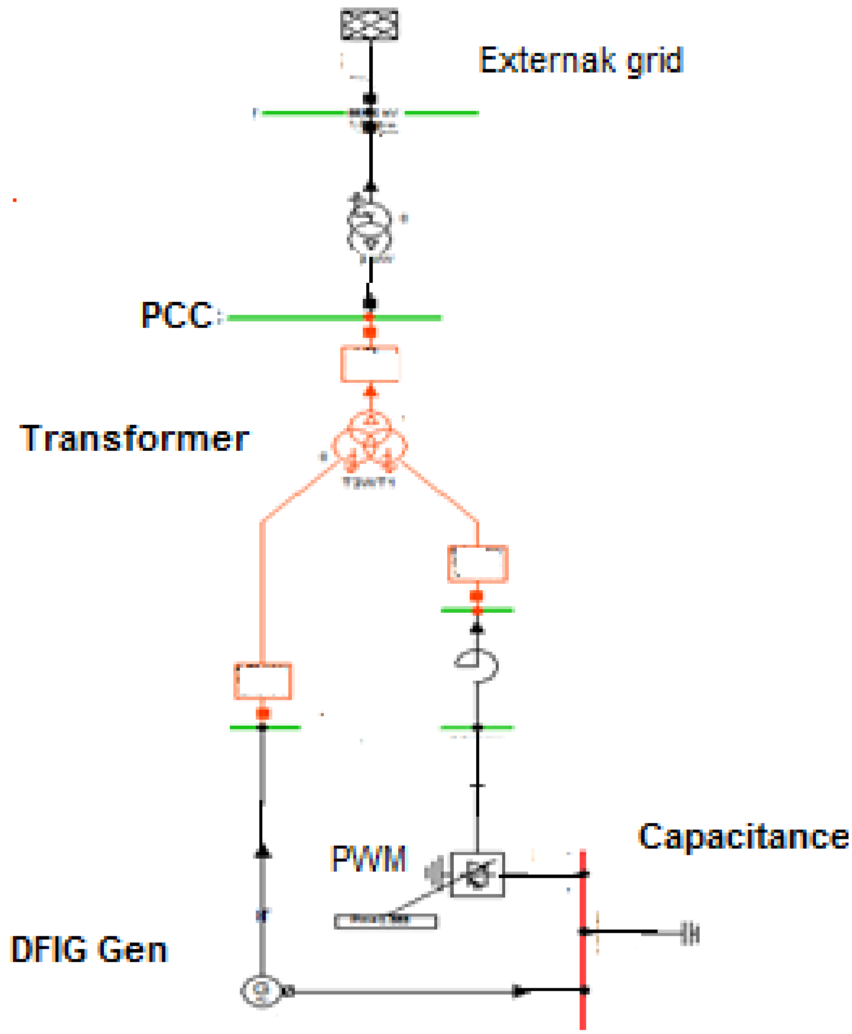

Fig 4. Simulation layout of the DFIG

3 Results and Discussion

The performance of grid-connected DFIG wind farms is studied during unsymmetrical faults such as single phase to ground, line to line, and double line to ground. For simulation operation, unsymmetrical short-circuit faults with a fault resistance value of 0.2ohm and a fault duration of 0.2sec are applied at MSC and GSC. Technological criteria must be adopted to fulfil the grid-code obligations. There are two requirements for grid code namely dynamic and static. At MSC and GSC, the static criteria comprise steady-state stability and power fluctuations. When the grid is disturbed, the dynamic grid code looks for the induction generator's anticipated reaction. Frequency, Power grid support capabilities, Voltage, Power factor regulation, FRT or LVRT capability are all dynamic criteria that determine the system's operational range. Hence the short circuit faults parameters namely transient time, maximum current, steady-state, and voltage sag or FRT values are measured for their impact at the GSC and MSC points[16–18].

3.1 Single phase to ground fault

The LV side of the transformer near MSC is subjected to a single phase to ground fault, while the HV side of the transformer near GSC is examined. The simulation is executed for 3 sec. At 0.8 sec, the fault is applied and cleared at 1 sec. The performance of the DFIG wind farm during the fault is shown in Figure 5 (a) and (b). Figure 5 (a) depicts the generator rotor current and bus bar voltage at LV being disturbed due to the fault, which is protected by the MSC. The second simulation is again run for the same duration and fault intervals. The fault is applied at the HV side near the GSC for 2 seconds. The simulation results namely generator rotor current and voltage at the fault busbar are shown in Figure 5 (c) and (d). Figure 5 (c), shows the oscillation of rotor current during the fault interval with a maximum overshoot value of 2.379 p.u. and attains the steady state current of 0.89 p.u. Figure 5 (c), also shows the transient value of 1.031 sec and a voltage dip of 1.177 p.u.is shown in Figure 5 (d). It is noted that the generator rotor current oscillates and voltage sags at the grid busbar near GSC while MSC remains robust.

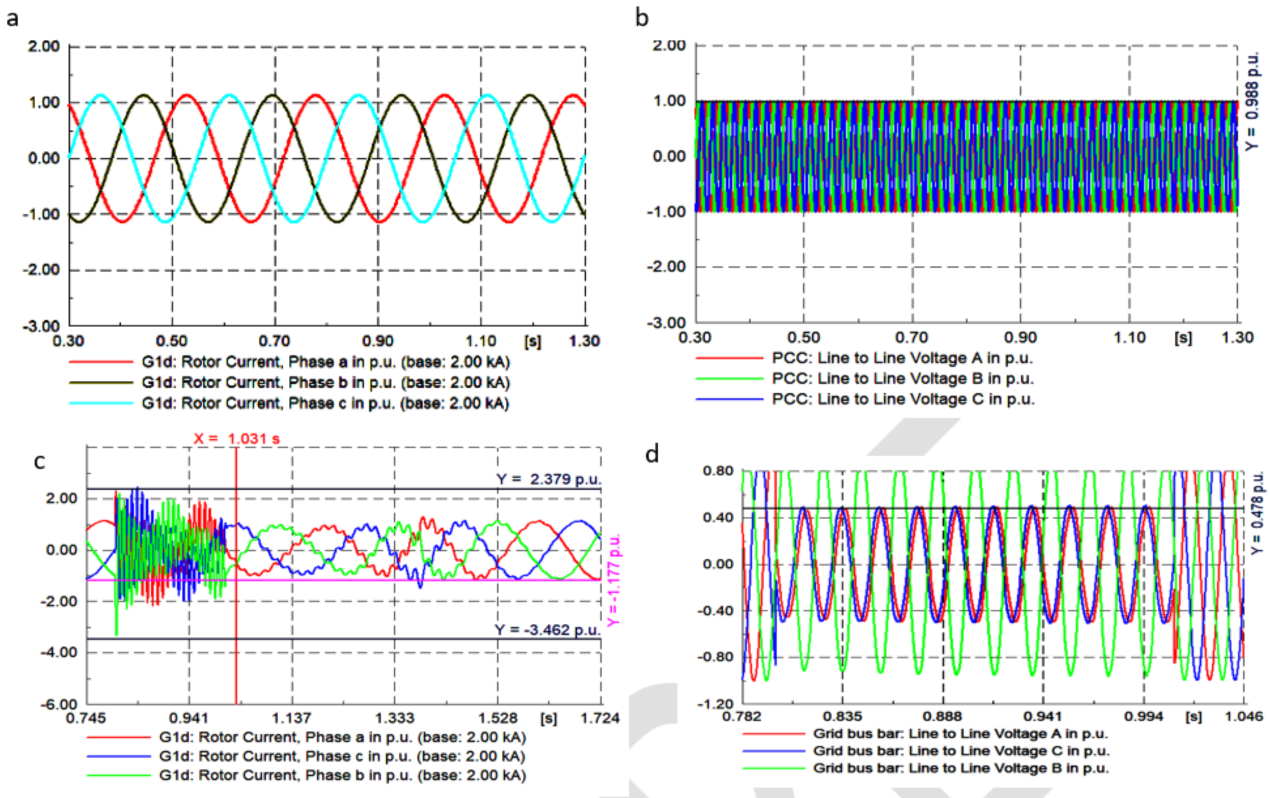

Fig 5. Simulation outcomes (a,c) transient time, maximum current and steady-state current (b,d) voltage drop when an unsymmetrical short-circuit occurs at MSC and GSC

3.2 Line-to-Line Fault

The performance of the DFIG wind farm is analyzed during the Line to Line (LL) fault. During the simulation period of 3 seconds, an LL fault is applied near the MSC for a duration of 0.8 seconds to 1 second with a fault resistance of 0.2. Figure 6 (a), shows that the attained maximum current value is 2.556 p.u and it reaches the steady state value of 1.110 p.u at 1.877 sec. Figure 6 (a) also shows the transient time value of 1.026sec during the short circuit interval and Figure 6 (b), shows the voltage dip of 0.856 p.u of the DFIG wind machine during the LL fault. To analyze the GSC, once again the simulation is executed, with the same duration and fault interval, which is applied near the HV side of the transformer. Figure 6 (c), shows that the short circuit rotor current has reached the maximum value of 2. 875p.u and attained the steady state value of 1.199p.u at 1.992sec. During the unsymmetrical short-circuit fault, the simulated transient current duration is 1.034 seconds, as shown in Figure 6 (c). Figure 6 (d) depicts that the voltage sag of 0.592 p.u occurs during the fault interval.

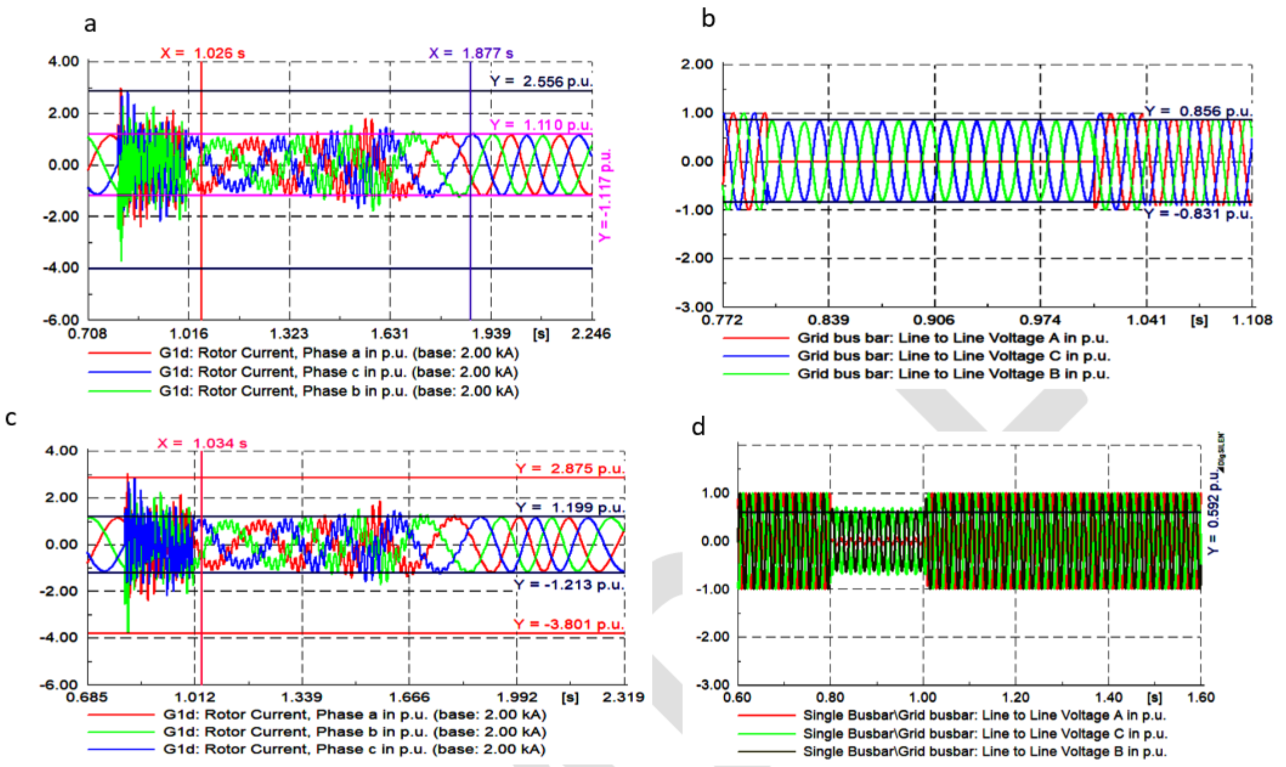

Fig 6. Simulation results in (a,c) transient time, maximum current and steady-state current (b,d) voltage drop due to unsymmetrical short-circuit occurring at MSC and GSC

3.3 Double line to ground fault

The double line to ground (LLG) fault, like other faults, is studied using the same simulation process. The maximum rotor current value was found to be 2.458 p.u as shown in Figure 7 (a), and it achieves a steady state value of 1.180 p.u. From Figure 7 (a), it is observed that the transient current exists for a time duration of 1.056sec and Figure 7 (b) shows the voltage dip of 0.799p.u during the LLG fault. To analyse the GSC's performance, a simulation is run in the same way as the MSC, with the same duration at the HV side of the transformer. Figure 7 (c), illustrates that a maximum short-circuit rotor current of 2.979 p.u and a settling time value is 1.213 p.u. are observed. When an unsymmetric short-circuit defect disruption occurs at the GSC, the estimated transient period for a wind energy transformation network depending on DFIG is 1.046 seconds, as illustrated in Figure 7 (c). During the fault interval, the voltage sag was 0.413 .u, as seen in Figure 7 (d). Table 1 shows the measured results of unsymmetrical faults.

Table 1. Unsymmetrical short circuit simulation results of MSC and GSC

S.No	Types of faults	Transient time sec	Maximum current p.u	Steady-state current p.u	Voltage drop p.u
Machine side controller	LG	0	0	0	0
	LL	1.026	2.556	1.110	0.856
	LLG	1.056	2.458	1.180	0.799
Grid side controller	LG	1.031	2.379	1.177	0.478
	LL	1.034	2.875	1.199	0.592
	LLG	1.046	2.979	1.213	0.413

The rotor current oscillates at 2 to 3.5 times the rated current value during an unsymmetrical fault, and once the fault is rectified, the current returns to its steady-state level in 1.03s to 1.082s. Short-circuit properties of the GSC (transient time,

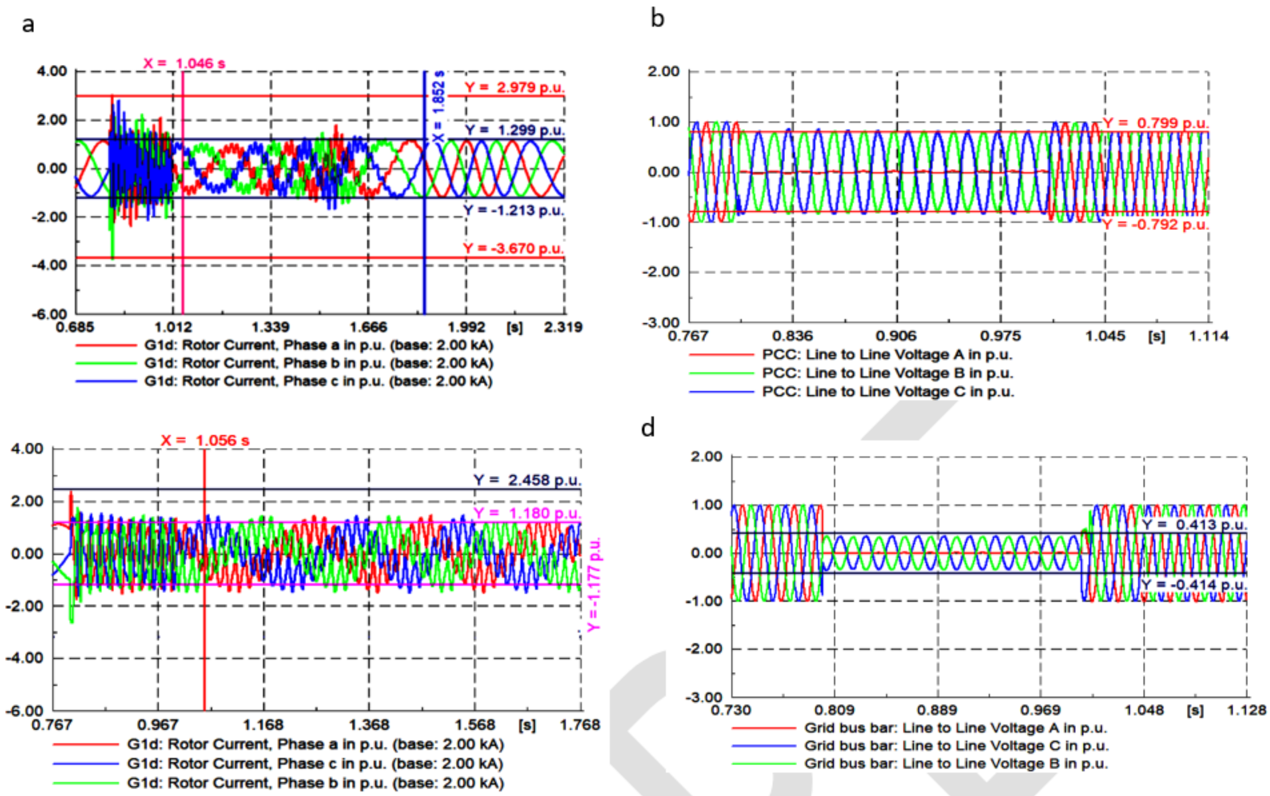

Fig 7. Simulation results in (a,c) transient time, maximum current and steady-state current (b,d) voltage drop due to symmetrical short-circuit occurring at MSC and GSC

maximum current, steady-state, voltage drop) be susceptible to fault clustering, while the MSC is found to be more resistant. The analysis of measurement and simulation data helps to determine whether DFIG is prone to network failures. The authors simulated and identified the parameters only for a symmetrical fault alone which won't be helpful for the design to design the protective devices and sensors. In this paper [11] only single to-ground fault alone was analysed and crowbar protection was implemented to protect the converters from high currents. But, double line to ground fault, Line to line fault are not analysed and their parameters were also not identified. In this research work, the developed model is validated and unsymmetrical fault analysis with its various parameters is identified.

These results demonstrate that the GSC and MSC have differing predictability during unsymmetrical short-circuit failure circumstances. The modelling observations give reliable fault detection results when the system's stability and optimization performance are examined. These research findings will contribute to a better understanding and improvement of sensor sensitivity, as well as the development of control mechanisms, and protection tactics in designing more accurate and appropriate DFIG-WT.

4 Conclusion

The prognosis and immediate detection of converter (GSC or MSC) breakdowns are one of the most promising techniques to regulate and optimize the durability and functioning expenses of WECSs. To sustain the specified capability of the doubly-fed inductive network, a sensor-based method can be employed to suppress disturbance and establish improved suitable systems for overcoming short-circuit fault scenarios. Before designing these sensor-based options, it is important to understand the fault ride-through disturbance parameters and the constraints of the wind energy transition platform's numerous variables and regulators.

An analysis of real-time measurement data at the wind farm is done, which helps to initiate a simulation study on the parameter controller under unsymmetrical short-circuit disorder. The DFIG wind electric system was developed using DIgSILENT software and various parameters are simulated during the fault period at the sensitive points. The simulation parameter results indicate that the rotor maximum current increases by 2 to 3 times the rated current, 40% to 50% voltage dip, and the current reaches the steady state value after 1.213 sec during the fault. As a result, during unsymmetrical faults, MSC outperforms GSC. Finally, this study lays the groundwork for future research on unsymmetrical short-circuit faults with the goal of better understanding the unsymmetrical fault situation of each system variable, the resiliency of the fault point, and the sensor rating limit. It will aid in meeting early peak demand by reducing security threats and system outages. The outcomes of these simulations may be utilized to develop a prevention or regulation plan for an energy-producing network that has been disturbed. The model is validated with the simulation and real time data, therefore model can be used for optimally turning of PI controller at the machine and grid side converters to improve the low voltage ride through capability.

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