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Crowbar Protection Scheme for Fault Ride Through in a Doubly-fed Induction Generator

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Abstract: This study focusses on using a crowbar protection scheme to overcome the symmetrical voltage dips in a doubly fed induction generator (DFIG). The crowbar protection scheme is integrated into the wind energy conversion system of the DFIG. The implementation of this scheme provides automated fault ride-through during sudden transients which may otherwise lead to over current faults. The increased use of renewable sources for electricity generation leads to a reduction in pollution which directly benefits the environment. Sustained usage of renewable resources will be beneficial for the environment.

Key words: Doubly fed induction generator, dynamic crowbar protection, environment, fault ride through, pollution, symmetrical voltage dips.

Introduction

Due to global warming caused by the combustion of non-renewable energy sources, the increasing cost of conventional power sources like oil and gas is pushing the world to move away from such processes of electrical power generation and ideating toward renewable ways of electricity generation. The exponential rise in the need for renewable energy calls for extensive research and advancement in the domain of power electronic converter control.

Among the existing renewable energy technologies, the wind energy conversion system (WECS) established on a doubly-fed induction generator (DFIG) is extremely significant because of the increased flexibility of power capture. The grid integration of such WECS is, anyhow, a major obstacle since the direct interconnection of the stator side with the grid makes it vulnerable to loss of control while the system experiences voltage dips (Abu-Rub et al., 2014). Moreover, factors such as irregular wind characteristics result in the violation of the grid codes and can also lead to frequent failure occurrences in wind farms. Under these circumstances, the integrated power system performance is compromised. Thus, precautionary measures are extremely important.

The implementation and analysis of certain algorithms and neural networks have proved to maximise the power generation magnitudes and efficiency of the systems (Banerjee et al., 2019; Kumar et al., 2022). However, they have led to increased complexity of control. In such a scenario, it becomes important to have robust protection schemes for overcoming sudden faults.

Doubly-fed Induction Generator (DFIG)

The doubly fed induction generator (DFIG) comprises an induction generator consisting of a slip ring which is commonly utilised in wind turbines due to

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the additional benefits offered. A DFIG can generate power at synchronous, sub-synchronous as well as super-synchronous speeds (Chhabra et al., 2022). In comparison to conventional wind turbines, the DFIG offers a versatile extent of the speed limit for wind turbine operation. The induction generator of DFIG is grid-connected to the rotor mains as well as the stator terminals through a partially rated variable frequency AC/DC/AC converter (Ahyaten et al., 2020; Bejaoui et al., 2014). It can be implemented in several different topologies including some recent prototypes called "two-lead" and "three-lead" connections which also provide a basis for simplified operation (Banerjee et al., 2020).

In the presence of irregular wind speeds, the wind turbine output fluctuates. Hence, variable-speed wind turbines are more suited to capture optimum power. This fact has resulted in the widespread adoption of wind energy conversion systems based on variable-speed wind turbines. To integrate the variable wind turbine output with the power grid, doubly fed induction generators are utilized because of benefits such as the absence of large capacitive banks, active and reactive power control, and improved power quality (Chen et al., 2011; Sathiyanarayanan et al., 2014). An appropriate representation of the integration model involving the utility of DFIG in the Wind Energy Conversion system can be seen in Figure 1.

Symmetrical Voltage Dips – A drop of voltage for a short duration in one or more phases is called a voltage dip. When the voltages of all the phases are uniformly decreased, then these voltage dips are known to be balanced or symmetrical dips. On the other hand, non-uniform dips in voltages are known as asymmetrical or unbalanced. These dips in voltage are generally caused by short-duration over-currents, inrush currents, transformer energising caused by three-phase to-ground short- circuits or motor group start-ups (Abad et al., 2011; Xu et al., 2018).

Voltage dips can be categorised as total and partial voltage dips. In the partial voltage dips, the rotor is considered open-circuited, thus leading to a fall in voltage levels below the rated value but positive in magnitude. Whereas, the total voltage dips experience a complete fall in voltage with respect to the rated value (Makhoba et al., 2020)

An extreme voltage dip produces currents that surpass the upper limit of the rotor converter, thus affecting the control scheme as well as the safety of the converter. On the other hand, when the voltage dip is moderate or minute, there is a natural presence of negative fluxes which result in the generation of certain oscillations in the electromagnetic torque, but the converter stays intact and can independently control the rotor current.

The symmetrical voltage dips consequences in balanced voltage dips on the DFIG terminals. Hence, the control at the time of symmetrical voltage dips can allot exclusive emphasis on the natural flux decay. During the voltage dips, the Rotor Side Converter (RSC) experiences maximum output voltage which causes the

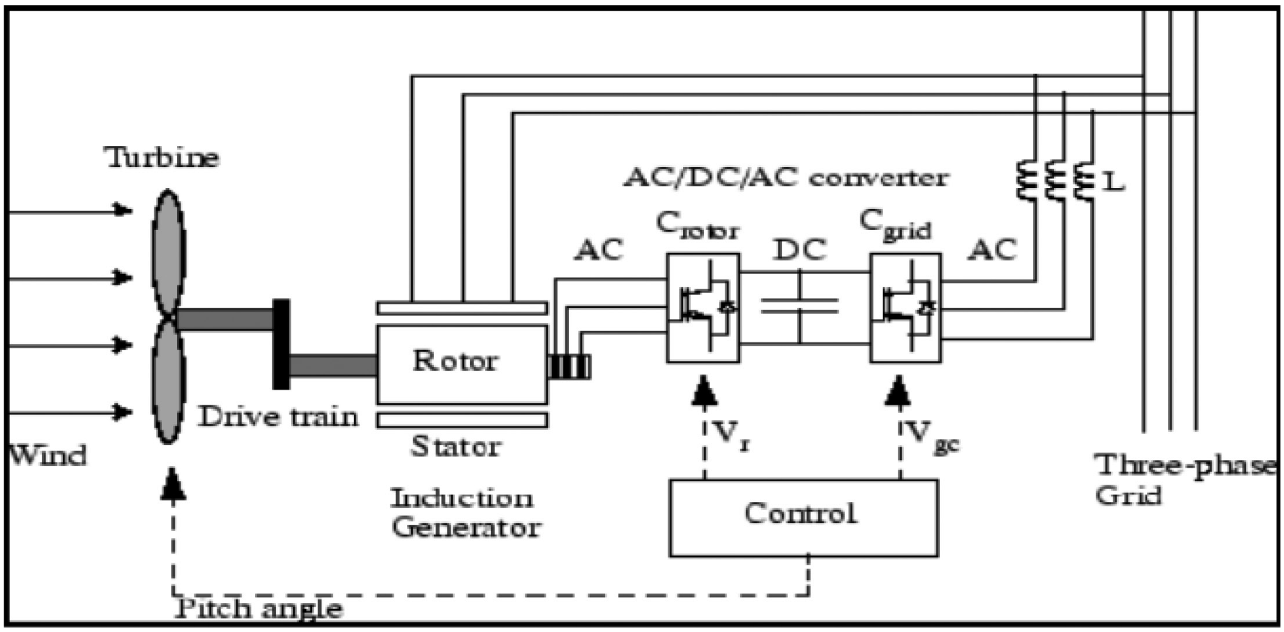

Figure 1: System design representation of DFIG.

saturation of the RSC and further results in the loss of rotor current control.

Project Equipment

Crowbar protection is a frequently utilised DFIG protection technique to overcome transients during prominent voltagedips. The crowbar protection system, as illustrated in Figure 2, contains a shunt resistor which is connected to the rotor circuit terminals via a DC rectifier. A switch is utilised to operate the system, such thatin the case of faults the crowbar mechanism is turned on while the RSC is isolated (open-circuited), thus diverting each of the transients to the crowbar which protects the Back to Back converter (Anaya-Lara et al., 2014; Yang et al., 2008).

The crowbar protection mechanism can be simply activated or deactivated by the identification of the fault severity on the basis of dc-link voltage (V_{dc}) or rotor voltage (V_r), and rotor current (I_r) magnitudes. When the magnitudes of such parameters surpass the thresholds, the crowbar protection system is engaged. Moreover, to avoid the unnecessary activation of the crowbar protection mechanism, hysteresis can be included in the switching time of the relaying apparatus (Yang et al., 2012).

Results and Discussion

A symmetrical voltage dip is introduced in the generator after 3 seconds and the same is cleared after 4 seconds.

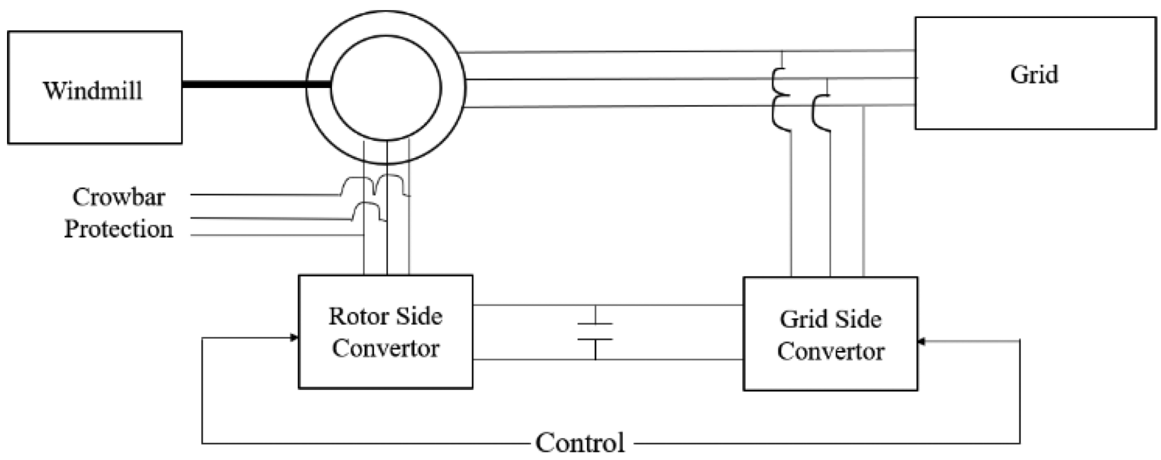

Figure 2: Block diagram of crowbar protection integrated wind energy conversion system.

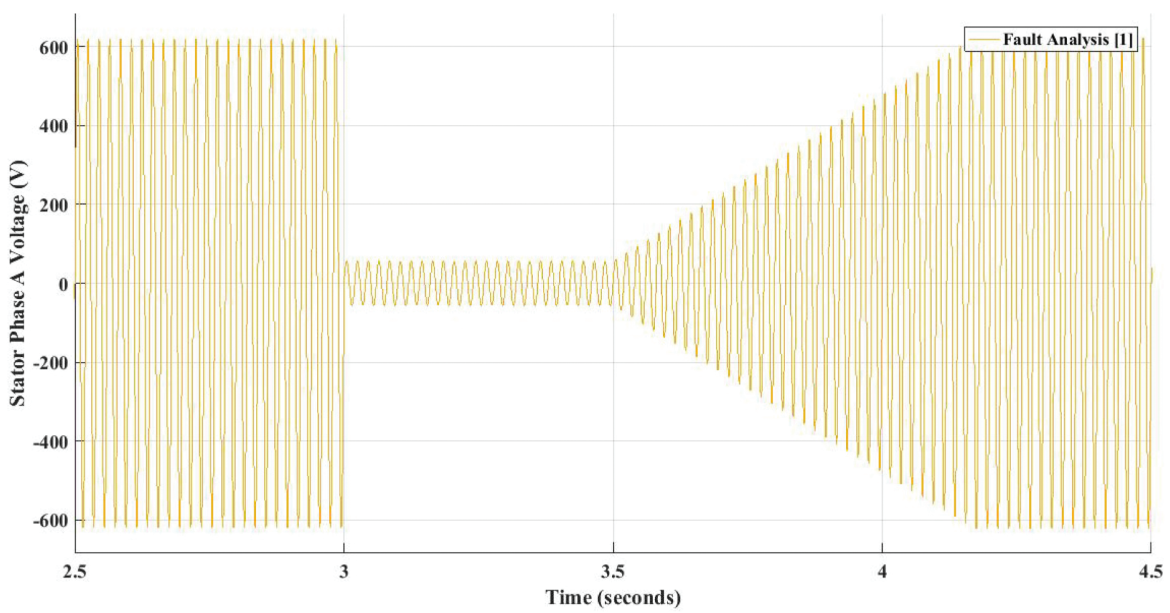

Figure 3: Stator phase A voltage versus time.

The graphs of the actuating quantities are illustrated below in Figures 3-5.

Figure 3 illustrates the phase A stator voltage magnitude during the period of the voltage dip. It can be observed that the voltage during the fault is reduced.

Figure 4 illustrates the flux linkage during the period of the voltage dip. During the fault, the flux has been reduced by the affirmative action of the crowbar. This has mitigated the possibility of damage to the machine.

Figure 5 illustrates that as soon as there is a voltage dip, the crowbar protection is actuated.

Conclusion

The project is oriented towards the improvisation of the wind energy conversion system based on doubly-fed induction generator was implemented with the help of system protection techniques. The utilised

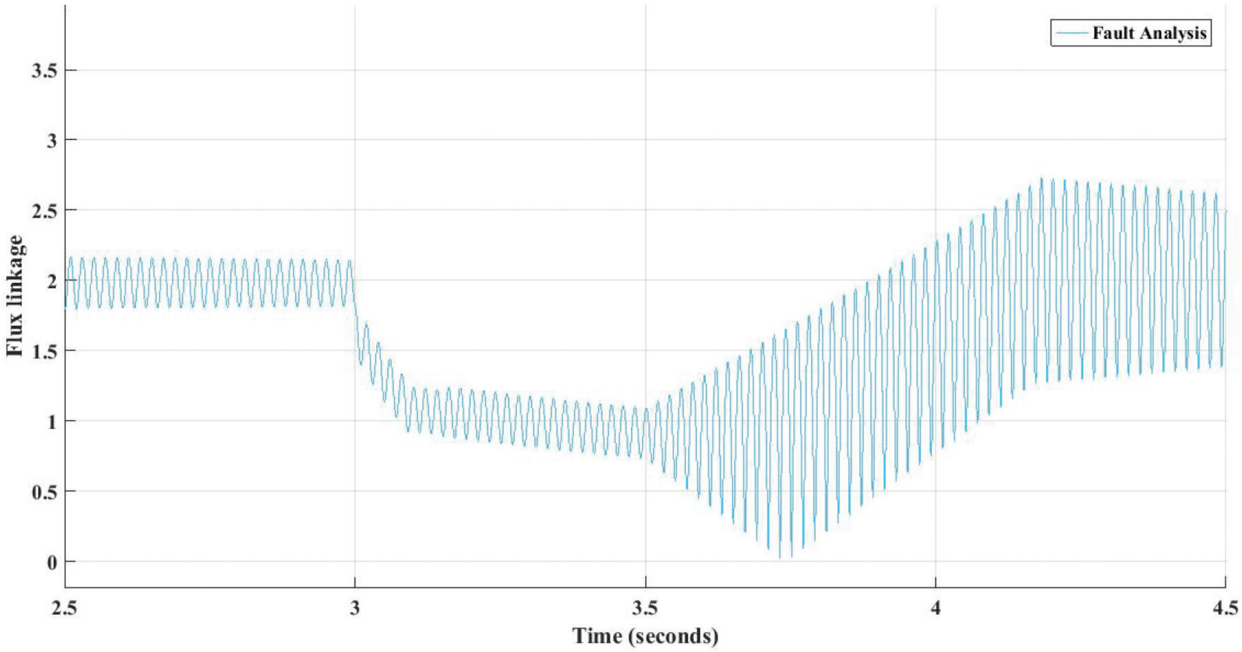

Figure 4: Flux linkage versus time.

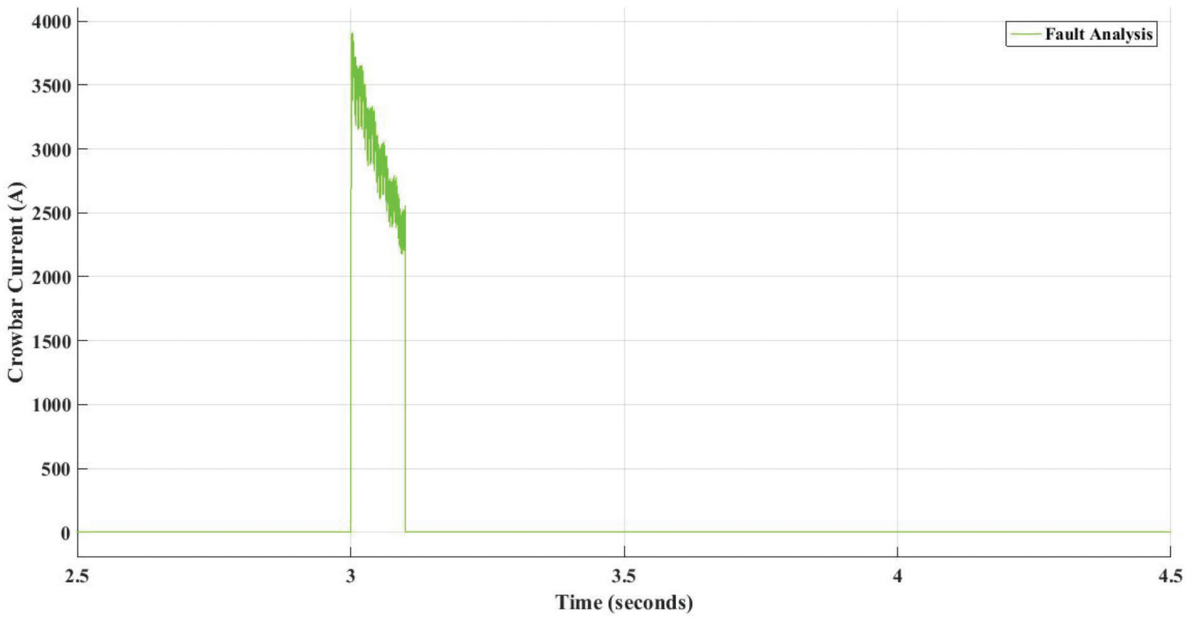

Figure 5: Crowbar current versus time.

simulation model ensured the robustness of the system by controlling vital parameters. Thus, the analysis of the control parameters associated with the DFIG was considered for developing an efficient and effective future prospect in the domain of renewable energy power generation.

The faults associated with the power generation system lead to unpredictable voltage dips which results in the loading of the circuit. Therefore, to maintain the physical integrity of the power generation system a protection technique named as crowbar protection technique was implemented on the rotor side controller.

Therefore, the aim and objective of maximising the power generation magnitudes and protecting the system against fault consequences were fulfilled.

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