International Journal of Advance Research in Science and Engineering
Volume No. 11, Issue No. 04, April 2022
www.ijarse.com
IJARSE
ISSN 2319 - 8354

Short-Circuit Analysis of a Wind-Driven Induction Generator Connected to an Infinite Bus

Aminu Habibu Yakasai[1]Nasir Labaran Inuwa[2] Usman Ado[3]

ABSTRACT

A short-circuit current supplied by induction generators is becoming a matter of concern due to the increasing power share. Besides, in spite of that, the induction generator operation principle is analogous to the traditional synchronic generator, its excitation and thus, the short-circuit supply is widely dissimilar. Induction generators are mainly applied to produce electric energy through wind turbines. Several researches showing analytical studies have been published, but just a few experimental results have come out. This paper studied the operation and performance of an induction generator connected to a large grid system (an infinite bus), when short circuit fault occur. The operating condition of the generator was modeled mathematically, a short-circuit fault was supplied to the generator terminals and the developed model was simulated using MATLAB software and the various characteristics of the generator were obtained. The results show that wind turbine induction generator when short circuited leads to loss of power production and the failure disrupt the balance of power (active and reactive) as well as change in the power flow.

Index Terms—Short-circuit current, Induction generator, Infinite bus, Static synchronous compensator (STATCOM), Wind power plant(WPP)

1 INTRODUCTION

Recently, the energy and environmental crises have become one of the biggest issues around the world. In response to energy needs and environmental concerns, renewable technologies are considered the future energy technologies of choice. Renewable energy is harvested from nature, and it is clean and free. In the years to come, there will be more and more WPPs connected to the grid. With the goal of 20% wind penetration by 2030, the WPPs operation should be very well planned[1].Wind energy conversion has emerged as a viable alternative to meet the increased demand for energy resources in recent years. Broadly speaking, wind energy conversion systems can be classified in to variable speed and fixed speed devices. Variable speed systems employ an electronic interface for grid connection. Fixed speed systems commonly use squirrel cage induction generators which are directly connected to the grid. While the former is better suited for optimal energy extraction attractive option, the latter is simpler and cheaper and therefore, a considerable number of such systems are currently in operation. In fixed speed systems, induction generators are particularly favored owing to their lower cost and higher reliability[2]. Wind energy development is consumer and environment friendly, it requires shorter construction time compared to thermal, nuclear generation and is cost competitive. It becomes one of the most competitive sources of renewable energy. However, wind power has some disadvantages. For example, wind power is considered an intermittent power supply because wind does not blow 100% of the time.

Besides, the superior wind sites are usually located in remote areas; therefore, it may require substantial infrastructure improvement to deliver the wind- generated power to the load center. This work is to study the operation and performance of an induction generator connected to a large grid system (which can be considered as an infinite bus) through a long transmission line when short circuit fault occur (Short circuit current). The operating conditions of the generator are to be modeled mathematically and the developed model (simulink model) will be simulated using MATLAB software to obtain various characteristics of the generator.

In a previous research conducted on short-circuit currents supplied for induction generators four induction generators operating principles ranging from 5 to 10 kW where experimentally investigated: remnant magnetism excitation, capacitor excitation, dc rotor excitation of wounded rotor induction generator working as synchronic machine, and multiple feed induction generator, without power electronic interphase. Each machine was operated at as many operation schemes as possible. The test procedure consisted in the application of a sudden short circuit on to the machine terminals, while connected to the main supply by a non-rigid connection, being the machine adjusted for rated voltage and synchronic speed, recording short-circuit magnitudes by using a digital oscilloscope. The non-rigid connection (through a suitable current limiting resistance/inductance) is used in order to limit the main supply collaboration to short-circuit current. The research shows that induction machine short circuit contribution is closely related to excitation type and that the currently used initial and successive damped values represent an overestimation[8]. When an induction generator is connected to an infinite power net, the analysis becomes simple, since the voltage and frequency are determined by the driving network. However, an autonomous induction machine is able to generate electric power only if self-excitation occurs and it can be sustained. The main drawback of such generators however is its inherently poor voltage regulation, and it becomes necessary to have an appropriate voltage regulating scheme [16]. In a research conducted on Fuzzy Logic Improved Static Synchronous Compensator to Control Voltage of a Grid-connected Squirrel Cage Induction Generator, a new method was proposed for voltage control of a grid-connected squirrel cage induction generator. In this research, a compensator was used to control the reactive power and stabilize voltage fluctuations during a three-phase fault and generator isolation. Furthermore, a fuzzy controller was developed to ameliorate compensator's performance.

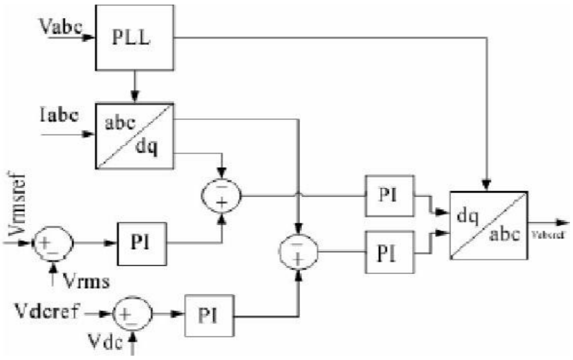

Figure 1 : Compensator Control Diagram

The above figure was the device used to compensate and control the voltage or power factor in the d-q coordinate. Accordingly, simulations were carried out in MATLAB/Simulink environment to confirm the abilities of new control scheme. The model aims to control the bus voltage via a compensator in an induction generator connected to the grid[4].

2. MATERIALS AND METHODS

This chapter describes the MATLAB modelling of the induction generator, wind turbine and the grid system. The complete model of a wind turbine with induction generator is constructed from a number of sub models, i.e. turbine, drive train, pitch controller, induction generator, rotor side and grid model and the system model will be adopted from MATLAB Simulink software. A general structure of the model is depicted in figure below.

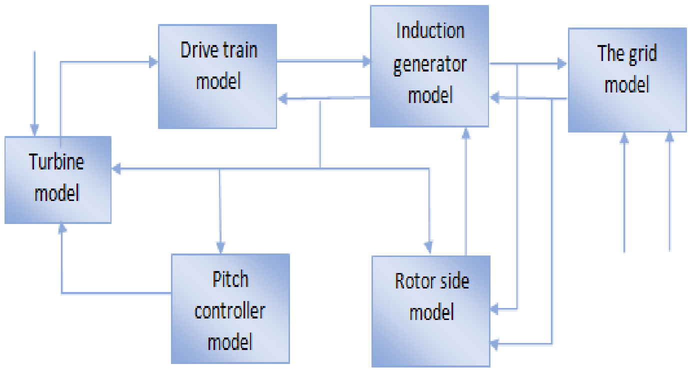

Figure 2: General block diagram of the model

The wind turbine and the induction generator (WTIG) are shown below. The stator winding is connected directly to the grid and the rotor is driven by the wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. In order to generate power the induction generator speed must be slightly above the synchronous speed. The reactive power absorbed by the induction generator is provided by the grid or by some devices like capacitor banks, SVC, STATCOM or synchronous condenser.

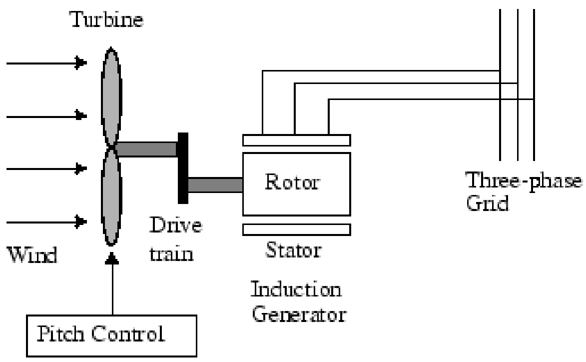

Figure 3: wind turbine (IG).

The (WTIG) consists of six 1.5-MW wind turbines which were connected to a 33-kV distribution system exports power to a 330-kV grid through a 25-km 33-kV feeder. The 9-MW wind turbine was simulated by three pairs of 1.5 MW wind-turbines. A wind turbine uses squirrel-cage induction generators (IG). The stator winding was connected directly to the 60 Hz grid and the rotor was driven by a variable-pitch wind turbine. The pitch angle was controlled in order to limit the generator output power at its nominal value for winds exceeding the nominal speed (9 m/s). In order to generate power the IG speed was slightly above the synchronous speed. The speed varies approximately between 1 pu at no load and 1.005 pu at full load. Each wind turbine has a protection system monitoring voltage, current and machine speed.

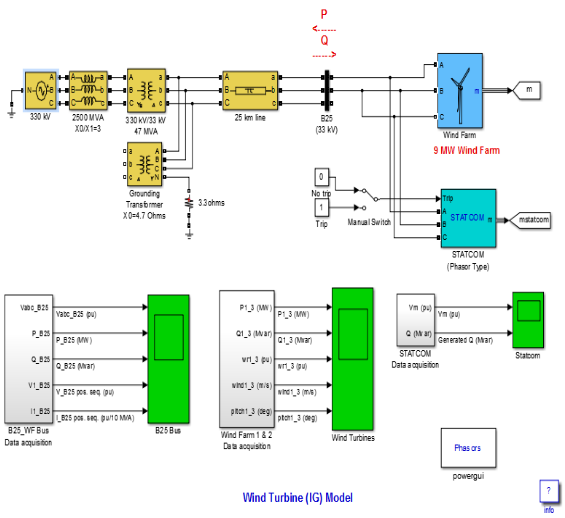

Figure 3: The (WTIG) model

Reactive power absorbed by the IGs was partly compensated by capacitor banks connected at each wind turbine low voltage bus (400 kvar for each pair of 1.5 MW turbines). The rest of the reactive power required to maintain the 33-kV voltage at bus B25 close to 1 pu was provided by a 3-Mvar STATCOM. Each wind turbine block represents two 1.5 MW turbines. The turbine mechanical power as function of turbine speed was displayed for wind speeds ranging from 4 m/s to 10 m/s. The nominal wind speed yielding the nominal mechanical power (1pu=3 MW) was 9 m/s. In this model, the system was observed during 20 s. This test procedure was done with the application of a sudden short circuit on to the induction generator terminals, while in grid connection, being the induction generator operating at rated voltage and asynchronous speed, the short-circuit magnitudes were recorded using a digital oscilloscope.

3. RESULTS AND DISCUSSION

The results obtain from the model oscilloscopes after running the simulation is shown in figure 4.0 which is a comparison of the results obtain with and without the application of short circuit fault. Figures below shows the scope monitoring active and reactive power, generator speed, wind speed and pitch angle for each turbine and the impact of the STATCOM on the voltage.

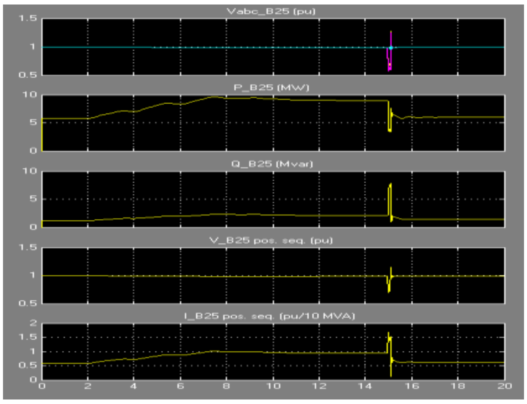

Figure 4.1(a) B25 Bus Characteristics without Short Circuit.

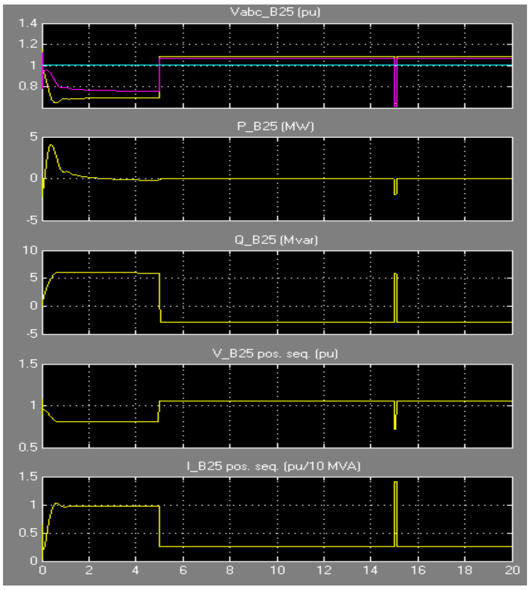

Figure 4.1 (b) B25 Bus Characteristics with Short Circuit faults

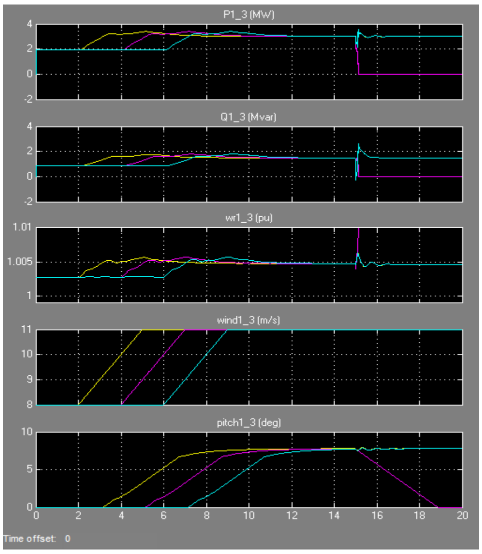

Figure Error! No text of specified style in document.**.2(a) Wind Turbines Characteristics without Short Circuit**

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ISSN 2319 - 8354

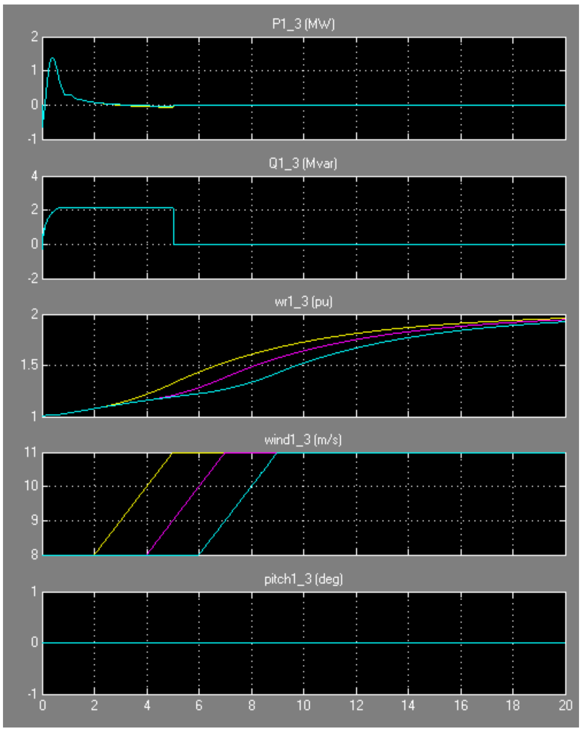

Figure 4.2 (b) Wind Turbines Characteristics with Short Circuit faults.

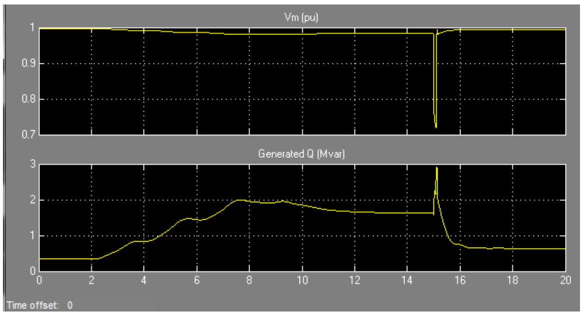

Figure 4.3 (a) STATCOM Characteristics without Short Circuit

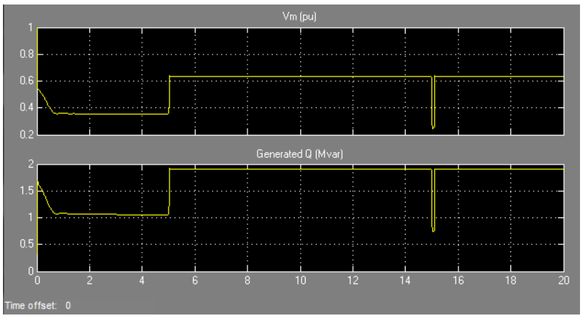

Figure 4.3 (b) STATCOM Characteristics with Short Circuit faults

This study investigated the effect of short circuit current on a wind turbine induction generator connected to an infinite bus i.e. in grid connection, with similar induction generator without the short circuit fault.

Figure 4.1(a), 4.2(b) and 4.3 (a) shows the simulation results of the wind turbine IG without short circuit fault; the scope monitoring active and reactive power, generator speed, wind speed and pitch angle for each turbine. For each pair of turbine the generated active power starts increasing smoothly (together with the wind speed) to reach its rated value of 3 MW in approximately 8s. Over that time frame the turbine speed increased from 1.0028 pu to 1.0047 pu. Initially, the pitch angle of the turbine blades was zero degree. When the output power exceeds 3 MW, the pitch angle increased from 0 deg to 8 deg which bring the output power back to its nominal value. It was observe that the absorbed reactive power increases as the generated active power increases. At nominal power, each pair of wind turbine absorbs 1.47 Mvar. For a 11m/s wind speed, the total exported power measured at the B25 bus was 9 MW and the STATCOM maintains the voltage at 0.984 pu by generating 1.62 Mvar (see "B25 Bus" and "STATCOM" scopes).

Figure 4.1(b), 4.2(b) and 4.2(c) shows the simulation results of the wind turbine IG with short circuit fault; the scope monitoring active and reactive power, generator speed, wind speed and pitch angle for each turbine. For each pair of turbine the generated active power drops to zero (with the wind speed at its nominal value) to which it's reach a value of 0 MW in approximately 1s. Over that time frame the turbine speed increased from 1.0028 pu to 1.0047 pu. Initially, the pitch angle of the turbine blades was zero degree. When the output power drops to 0 MW the pitch angle remains at 0 deg. It was observe that the absorbed reactive power decreases as the generated active power decreases. At 0 MW power, each pair of wind turbine absorbs -3.5 Mvar. For a 11m/s wind speed, the total exported power measured at the B25 bus was 0 MW and the STATCOM maintains the voltage at 0.6 pu by generating 1.98 Mvar (see "B25 Bus" and "STATCOM" scopes).

4. CONCLUSION AND RECOMMENDATION

The attention has continued to grow as the demands on reducing polluting emissions have increased. With the development of wind turbine technology, large scale wind farms of hundreds MW level are being developed in many countries. These modern wind farms are usually connected to the power grid. This research describes a simple approach to analyze and understand the behavior of a wind turbine induction generator grid connected with short circuit current fault. The research adopted a simple MATLAB/ SIMULINK WTIG model. From the comparisons made between the simulation results with the SCC and without SCC; it was observed that the WTIG power system is perfectly significant and the system stability is largely associated with power system faults in a network or the generator such as tripping of transmission lines, voltage sag, loss of production capacity (generator unit failure) and short circuits. These failures disrupt the balance of power (active and reactive) and change the power flow. Though the capacity of the operating generators may be adequate, large voltage drops occur suddenly.

This work can be improved or advanced SCC modeling for other types of WPP, evaluate the short-circuit (SC) current contribution of different WTGs into the transmission network under various fault conditions and SCC differences between different types of wind turbine generators (WTGs) and conventional generating units can be used in future to improve the stability and dynamic performance of grid connected induction generator.

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