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Research paper

Grid Synchronization and Control of a Doubly Fed Induction Generator (DFIG) Wind Turbine using Unified Power Flow Controller (UPFC)

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Abstract

Nowadays, wind energy conversion system (WECS) development becomes a necessity on a modern power system. Abundancy of these sources with the proper site selection, the WECS serves as an alternative source but with intermittency issues. In the case of connecting wind farms to the power system network, since regions with wind energy potential are not necessarily close to consumers, voltage stability and reactive power control are the most important issues. Using Flexible AC Transmission System (FACTS) devices are considered in order to maintain stability and provide the reactive power requirement of the grid and transfer the maximum power extracted from wind turbine to consumers. In this study, a wind farm used Doubly Fed Induction Generator (DFIG) modeled in MATLAB and synchronized to grid. Then, stability assessment is made for four different grid fault cases and each case is studied with and without Unified Power Follow Controller (UPFC) in the power network. Results are shown, after applying UPFC voltage transients where fault are decreased, wind turbine reactive power demand is eliminated, and wind turbine is able to provide a constant reactive power close to its nominal value.

Keywords: *Wind Energy, renewable, FACTS devices, UPFC, MATLAB*

1. Introduction

With the increase of wind power on some parts of the world, the problem of stability on these sources becomes a vital issue. When the wind sources were integrated with non-conventional plants such as coal, hydro and steam, voltage and reliability issues were the major concerns [1-4].
The introduction of the DFIG can address the problems of grid stability issues. It can control both the real and reactive powers from the stator and rotor respectively. It is also widely used in the wind power industry. The following are the advantages of using DFIG's:

- produces greater energy;
- a reduction of mechanical loads and a simpler pitch control;
- an extensive controllability of both active and reactive powers; and
- power output will have less oscillations.

2. Problem Statement

One of the basic requirements for WECS to continue its uninterruptible operation is to follow the requirements of the grid code. Based from standards, the voltage violations must be limited to a plus/minus 5% of the rated voltage. Stability issues is also one of the dilemma experienced by WECS especially when it is on dynamic operation such as fault on the system. If a fault occurs, the problem of the critical time of operation of breakers, transients, and stability concerns must be given such importance. Otherwise, the arcing produced from the breakers can damage adjacent substations and can cascade to other electrical apparatus. Synchronous Condensers or shunt capacitors can compensate the loss of reactive power especially when DFIG's are interconnected in the power system [5,6]. In some isolated systems such as micro grids, capacitor banks were used as a solution to the problem of instability. Majority of the loads connected on the modern power system are inductive, which means a mismatch on the generation of reactive power can lead to larger oscillations in the terminal voltage especially in the case of micro grids. Therefore, it will produce under voltage or sag on the system if reactive control is not provided in which can damage the consumer loads such as computers and can deteriorate its performance. Thus, WECS needs appropriate control on the reactive power and must be maintained within specified limits based on standards.

3. Aims of the Research

There are many types of power flow controllers in the literature that provides real and reactive flows and dependent on its connection. FACTS devices or (flexible AC transmission systems) are devices that controls the power flow in a transmission line and the common types are STATCOM (static synchronous controller) and UPFC (unified power flow controller). The unified power flow controller unlike other FACTS devices has the ability to control both active and reactive powers of the line, which in return can compensate the correct parameters for the terminal voltage and its corresponding angle. The models of the UPFC as well as the

DFIG was modelled initially in Matlab. Both parameters are modelled in its stable conditions until a fault occurs which causes the dynamic state.

Thus, the problem to be solved in this study is to investigate the effect of the UPFC to a sample WECS under different wind velocity changes and fault conditions. Specifically, it address the following problems:

1. To simulate and model of a grid connected variable speed DFIG wind turbine.
2. voltage stability and reactive power compensation of a wind turbine during variable wind speeds, a fault in the grid, voltage sag and a sudden change of load in power grid.

4. Materials and methods

The methodology of this research is shown on Figure 1. The model blocks is being simulated using the SimPowerSystems. The SimPower systems is a simulation tool which can be build using control blocks and uses the Simulink technology in Matlab. It is used by any course disciplines such as mechanical, control, thermal and circuit analysis. The Simulink uses the Matlab as its computation engine which the model can use control boxes. Every control boxes has different control block algorithm which can be edited for research purposes. The block algorithm uses different equations which is considered as the mathematical model of every component in the power system network. Thus, modelling is essential in the first part of the study especially on the design of the wind farm and protection blocks.

Figure represents the diagram on how the power flows were controlled on a DFIG For the case of the rotor power (P_r), it is always a fraction of P_s (stator power) when the absolute value of the slip is lower than 1. When the speed is greater than the synchronous speed, the stator power is considered positive. However, when the speed is lower than synchronous speed, the stator speed is considered positive. If the stator power is transferred to the DC bus capacitor, it will rise the DC voltage which constitutes to an upper speed synchronous operation. When the stator speed is taken out of the DC bus capacitor and gives the DC voltage a lower value, the state is said to be a sub synchronous speed operation. C_{grid} (grid controller) is used to generate or absorb the power P_{gc} (grid electrical output) in order to keep the DC voltage constant. The value of the AC/DC/AC converter P_{gc} is equal to P_r in the steady state and the speed of the turbine is generated by the C_{rotor} [3,7].

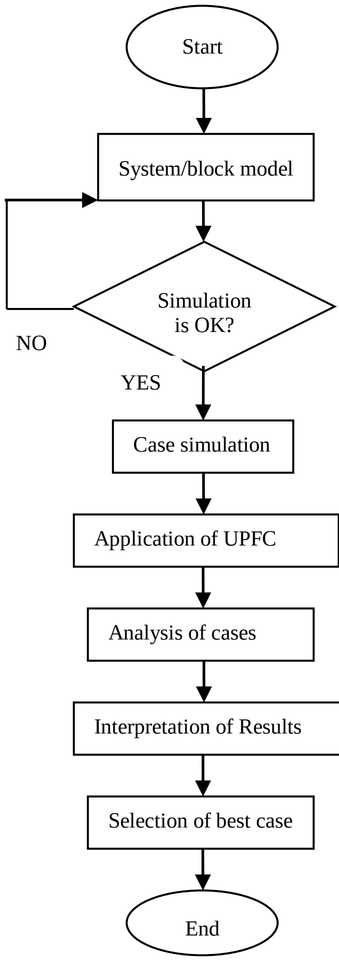


Figure 1: Flowchart of the study

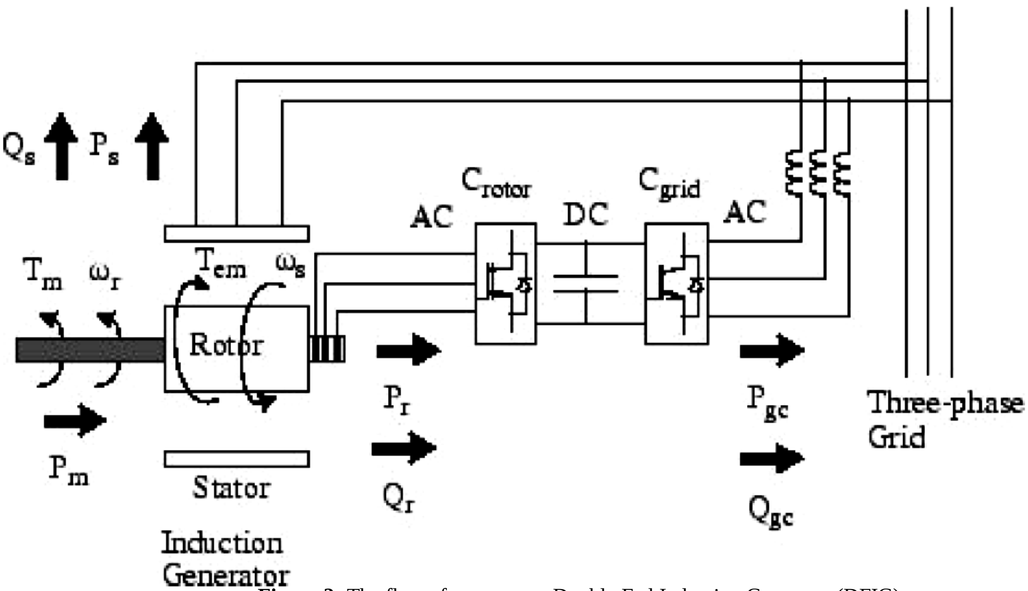


Figure 2: The flow of power on a Doubly Fed Induction Generator (DFIG)

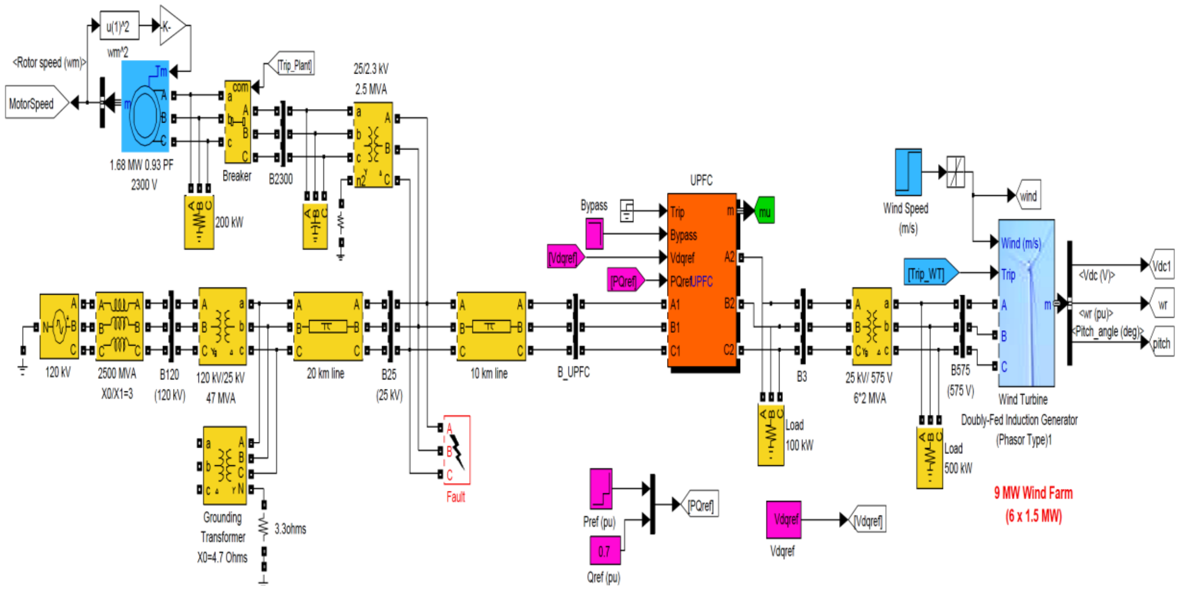
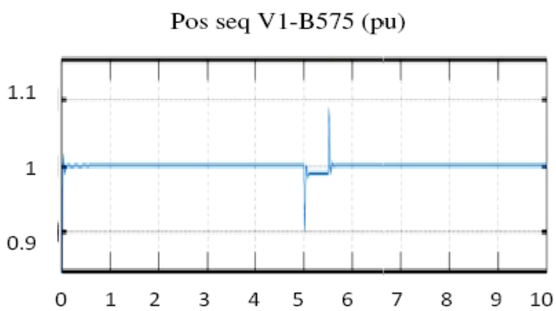


Figure 3: Test system model diagram

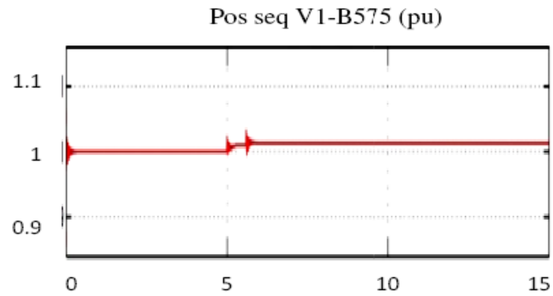
5. Results and Discussion

The power system on Figure 3 composed of a wind farm with a 9 megawatt installed capacity that contains six 1.5 megawatt wind turbines which is driven by DFIG generators connected to a 25KV distribution system. It distributes power to a 120KV grid through a 40 kilometer, 25 KV transmission line. A 2300V, 2-MVA plant consisting of a motor load with a power factor of 0.93 and real power of 1.63 megawatts and of a 400-kilowatt resistive load is connected on the same feeder at B25 busbar. Both the wind turbine and the motor load have a protection system monitoring voltage, current and machine speed. Taking note of the DC link voltage is also observed. The AC/DC/AC IGBT-based PWM converter and a wound rotor induction motor was use to model the DFIG. The rotor is fed at a variable frequency with the aid of a AC/DC/AC conversion and the stator is directly connected to the 60 Hz supply. The mechanical stresses in the turbine such as wind gust was minimized using the DFIG technology which gives the system a maximum harness of the wind by optimizing the turbine speed. Represented on Figures 4 and 5, the impact of the fault in terms of a voltage sag was observed in the 120KV source system.. First, in the wind speed step block which got disabled by changing the final value from 24 to 8 m/s. Then in the 120-kV voltage source 0.15 PU voltage drop lasting 0.5 s is programmed to occur at t = 5 s to simulate the voltage sag.



(a)

Figure 4. Wind output voltage for simulation 1



(b)

Figure 5: Wind output voltage for simulation 2

6. Conclusion

Wind farms are disconnected to the grid when it is not providing the necessary reactive power. It is a requirement that to control the reactive power so that it can give sufficient power during normal state and support during dynamic state or faults. Unlike synchronous generators, it has the self-recovery capability that when the system becomes weaker due to high penetration of DG such as WECS.

In this research, the wind turbine was modeled and synchronized to the power grid. The type of wind turbines used in this study was DFIG which required reactive power compensation during grid side disturbances. Effects of UPFC were studied with the wind velocity changes conditions, load compensation, sample fault on the line and voltage sag on the system. The operation of DFIG and its control with and without UPFC were discussed. First a wind turbine in a direct connection to the grid was simulated and the corresponding results had been displayed. Then, the system was studied in the presence of UPFC and the reactive power compensation as well as voltage stability improvement was shown. Here the researchers also studied the protection system in consideration which gave a wind turbine trip's signal to the system when there were several conditions on the system.

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