

Dynamic Performance and Effectiveness of Voltage Disturbances on the Improvement of Power Quality for Grid-Connected DFIG System Based Wind Turbines

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Abstract- Power quality (PQ) is renowned as any power problem manifested as a non-standard frequency, current & voltage that cause failure of end customer apparatus. The wind utilization, generation & its penetration in electrical grid are increasing widespread. One of the main problems in wind is the connection to the network. If the wind is inserted to grid generally controls the voltage disturbances on the system power quality, variation of voltage is the almost prevalent type of disturbance which affects stability and the quality of power for grid-connected wind energy system. This paper investigates the two widespread types of voltage variations like voltage sag and swell, which can occur when large amount of wind system is connected to grid. Also this article studies the response and performance at faults of a wind turbines inserted to distribution systems. In this work, a wind turbine with DFIG system is simulated by using MATLAB/Simulink program. The simulated model is subjected to disturbances which define as; voltages (sag and swell). The results of simulation show that, voltage sag & swell lead to mal-operation as well as shut-down of entire system, so, deteriorating the enhancement of power quality for the utility grid.

Keywords: Voltage disturbances, Wind turbines, Power quality problems, DFIG system.

I. INTRODUCTION

Traditionally, the electrical grid has been prepared to integrate different types of conventional generation plants such as: gas, hydro and nuclear etc., and with increased population and manufacturing development, there is more demand of energy. To confront this large and increasing energy demand, it becomes necessary for the possible sources embracing the renewable energy like wind system [1]. PQ is a big interest to the grid operators particularly when large wind is inserted to the electrical grid which, at rated frequency means to keep voltage/current waveforms is sinusoidal.

A wind farm is a set of wind turbines in the same site and used for the generation of wind system. Installing different turbines in groups at a location leads to large-

scale utilization of wind. This has operation, maintenance and economic features. Wind system is neat and abundant resource of energy; so, it plays a prevalent role in adding neat and non-polluting energy to the electrical grid.

Actually, wind system can effectively contend with other conventional resources of energy in the market [2]. Thus, as contend by Rini Ann Jerin and et al. [3], wind energy is starting to contend with other conventional resources of renewable energy. Utilize clean energy like wind using to generate electricity reduces the dependency on fossil fuels.

Power quality is one of the important roles in electrical system due to increasing penetration of renewable energy sources and it is extremely affected by the working of a transmission and distribution grid [4]. One of the modest techniques of a wind operation is to use the DFIG linked directly to the grid. The main issues of the power quality such as; voltage sag and swell in low voltage distribution systems & on the transmission side due to sensitive loads.

Thus, voltage at the point of common coupling (PCC) should be maintained within a specific limit to keep the power quality required by consumers [5]-[7].

II. DFIG TECHNOLOGY

Wind farm employ a doubly fed induction generator (DFIG) which consists of a wound rotor & an AC/DC/AC insulated-gate bipolar transistor based on pulse width modulation converter. The stator winding of DFIG is directly linked into the grid, while the rotor is fed at variable frequency across the power electronic converter model. The operation of DFIG is depend on the principle of induction generator. By regulating the converter's parameters, it is bearable to control the real and reactive power fed to the grid independently of the generators turning speed, giving it a distinct merit over other conventional power generators. The DFIG technology is usually used in wind turbines; this is an important wind conversion system having variable-speed ability. These machines are also famous as wound rotors or slip-ring IG [8], [9]. According to the application, DFIG is obtainable

in different ranges of power (1.5-6 MW). Fig. (1) shows schematic main parts of a DFIG-WT setup.

The wind turbine is a set of mechanical and electrical parts, the DFIG system, (RSC) rotor-side converter, DC-link, (GSC) grid-side converter and the control unit. The main task of the GSC is to regulate the bus voltage V_{dc} . The task of the RSC is to control the speed to realize power from the wind across an extent of wind speeds. There are many types of wind generator, but this paper focus about DFIG unit. Generally, features of the DFIG based wind turbine can be brief as follows: control of power factor can be executed at lower cost, improvement of PQ, reduced acoustic noise and another advantage of DFIG system has top performance through a voltage sag, disturbance situation & transient time [9],[10].

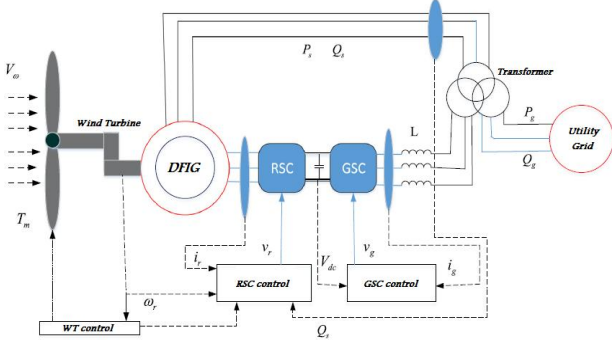


Fig. 1: Schematic main parts of a DFIG-WT setup

1. Turbine constant speed

For constant WT speed, the generator is inserted to the grid which stator is injected and will constantly operate at fixed speed anyhow rapidly the wind strikes. Fixed WT's speed is basically used induction generator for generation and it is stall regulated. The rotor windings three-phase is directly injected into the grid, while the stator supplies excitation to the machine. The shaft rotation speed can be studied in terms of frequency of electrical power supply (f) and pole-pairs (p) [11]-[13].

$$N_s = \frac{120 f}{p} \quad (1)$$

The second parameter used in the analysis of induction generator is the slip that is define as the difference among the synchronous speed & the rotor speed illustrated as a percentage of the synchronous speed which calculated as:

$$\text{Slip, } s = \frac{N_s - N_r}{N_s} \quad (2)$$

Two slip modes, (+ve) for motoring and (-ve) for generating. So, wind with induction generator can supply power to the grid when the speed, N_r overtakes the synchronous speed, N_s .

2. Turbine variable speed

The machine is allowed to be driven at varying speed with the wind. For this purpose a converter model is used to switch the AC to DC & finally to the grid, AC variable speed WTs can be stall, pitch regulated and active-stall types. In stall, the blades of the WT are sure fixed to the

hub at a particular angle and this technique is simple, cheap and robust. This can be carried out by varying the pitch of the blade or direction & changes its aerodynamic competence. Otherwise, in active-stall, the rotation of the rotor is executed by pitching the blades back to a deeper stall [12].

III. VOLTAGE VARIATIONS IN WIND POWER

The variations of voltage is directly associated to active and reactive power variations owing to the fluctuations in the WT due to wind and are described as the changes in the root mean square value of the supply voltage through a short time ranging among micro-seconds to few minutes [13]. For grid-connected wind, the parent variations of voltage can be in the forms such as: voltage sag or swell, transient, harmonics & short interruptions. Fig. (2) shows a grid-connected WT configuration.

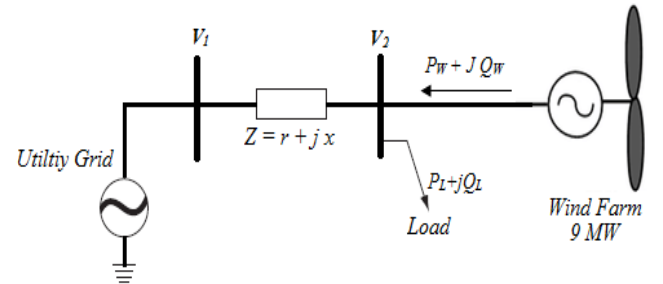


Fig. 2: A grid-connected WT representation

Apply Kirchoff's voltage law to Fig. 2 gives:

$$V_1 = V_2 + \sqrt{3} i(r + jx) \quad (3)$$

Where: V_1 : Grid voltage, V_2 : Voltage at the WT.

r : Resistance of the grid and x : Reactance of the grid.

When the wind turbine generates the power desired to meet the load demand and no current drawn from grid. At this status, V_1 must be equal to V_2 according to eq. (3). So, when the WT produces more power than demanded, then, V_1 will be less than V_2 . Similarly, when the WT creates lower power than demanded, then, the difference among the load and turbines generated power shall be supplied to the grid, the current drawn will pass through the impedance, thus, grid voltage shall be greater than at the PCC. So, the short circuit power (S_{sc}) in the wind connected point can be computed as follows:

$$S_{sc} = \frac{V_s^2}{z} \quad (4)$$

Where: Z , Impedance of the grid ($Z = r + jx$).

Short circuit power in eq. (4) that illustrates the fault level at the wind which is proportional inversely to the impedance between the source & the load. Then, a small value of impedance will results in high fault level making the grid robust while, large value will results in low fault level, the short circuit ratio and the grid be considered as weak. It is noticed that, in case of a weak grid, there is a high flair of voltage differences because an abrupt change in the power output of the wind will makes a current flow during the impedance. Voltage variations at the point of interconnection for the WT ΔV can be represented in

of motor as shown in Fig. 5-c decreases gradually as soon as the protection unit drives the factory. Fig. 5-d depicts the WT maintains on real power generating at 1.85MW. So, at B25, 1.35MW real power is transmitted to the grid after the factory has tripped as shown in Fig. 5-e.

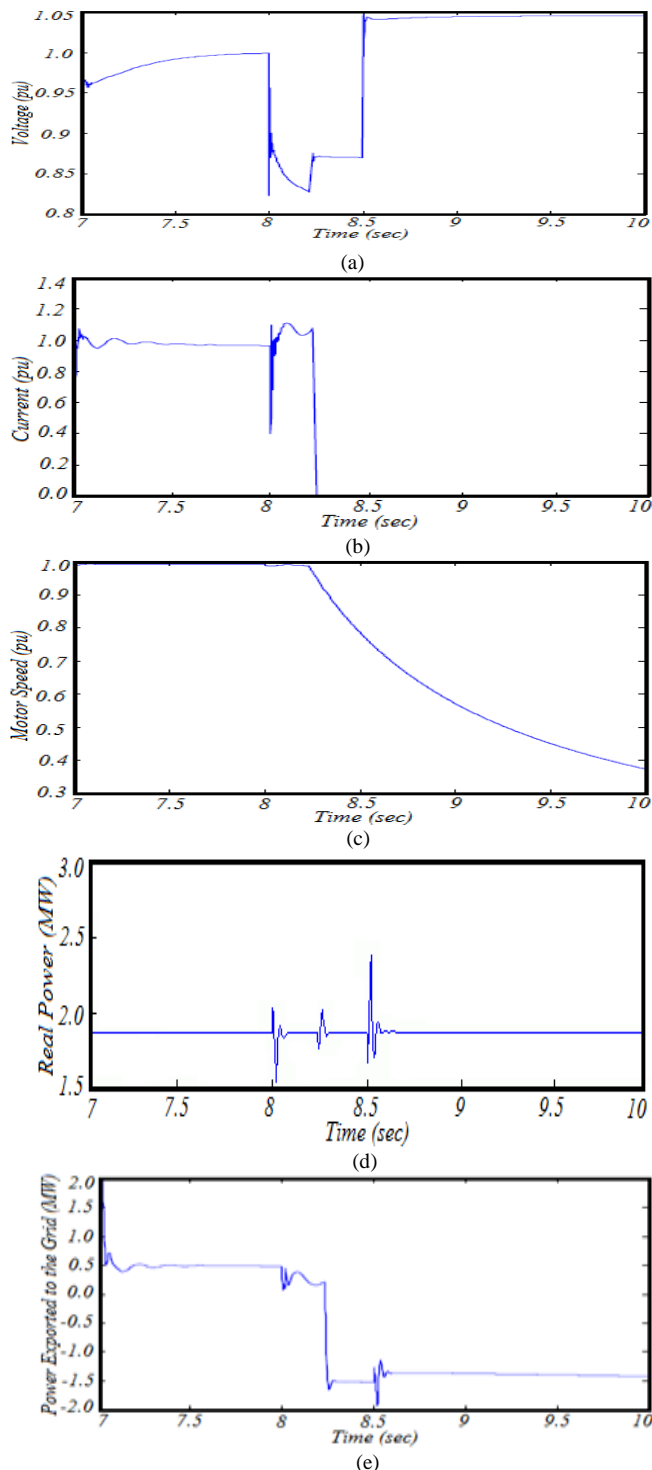


Fig. 5: Voltage sag based VAR regulation mode

Case study (2): Effect of voltage swell

In this case, a 0.2pu voltage swell lasting 0.52s is set to the 120kV utility grid to occur at the simulation time of 8s and the WT control adjusts to VAR regulation mode.

The simulation results of wind farm in VAR regulation mode are shown in Fig. (6) at 9m/s constant wind speed. Notice that, from Fig. 6 (a-e) a voltage swell for period of 0.52s exceeding the threshold limit trips the factory 0.22s after it is measured, the speed of motor starts decreasing gradually.

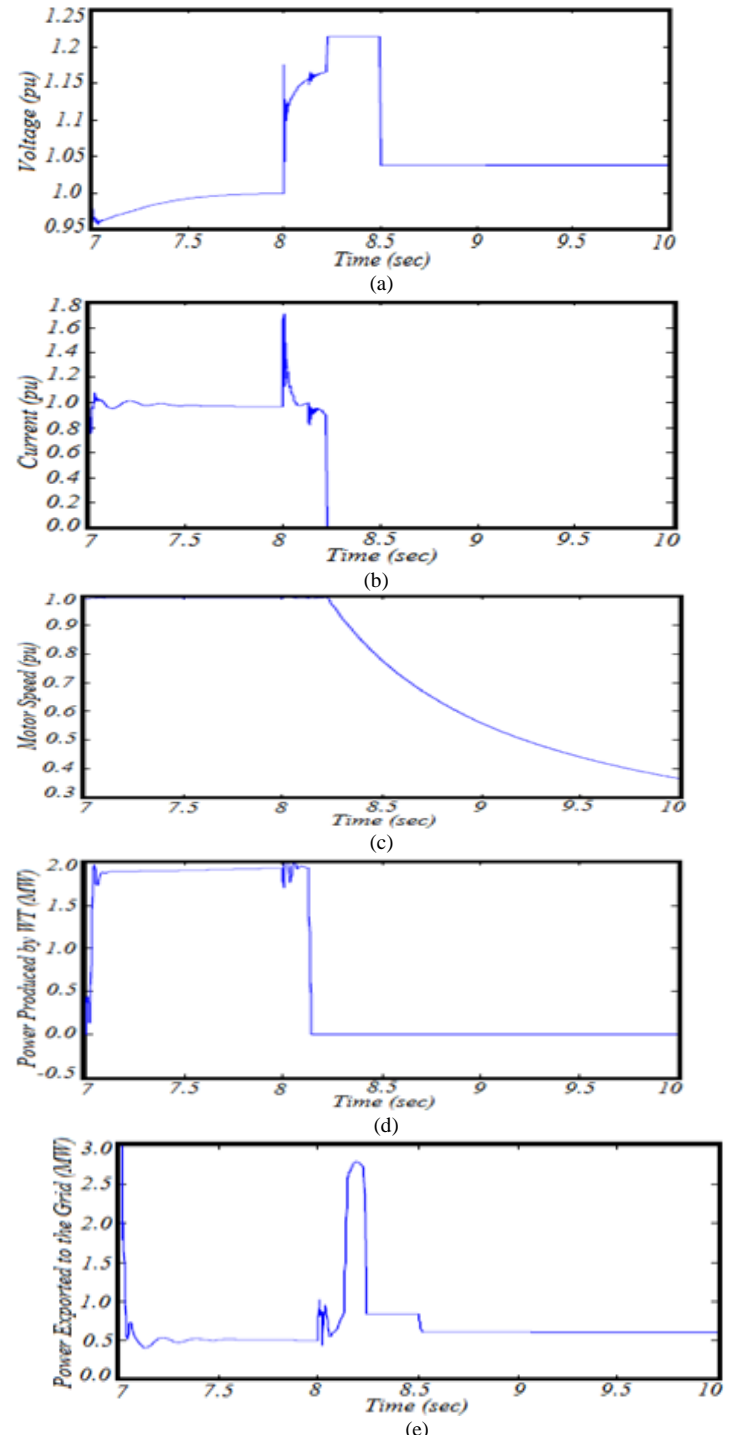


Fig. 6: Voltage swell based VAR regulation mode

Case study (3): WT response to variation in wind speed

Initially, it is adjust at 8 m/s as well at $t=5s$ and increases suddenly to 14 m/s. The performance of a wind farm in voltage regulation mode depicts the waveforms inserted

to simulation. At $t=5s$, the active power generated starts increasing simply with each other with the turbine speed to arrive its rated value of 9MW in about 15s. During this time period the turbine speed increases among 0.82pu to 1.24pu. The pitch angle is (0) deg., the turbine working point follows the red curve of the wind characteristics up to point D as depicted in Fig. (7). The DFIG is controlled to follow the curve (ABCD) in wind characteristics. Turbine speed optimization is obtained at points (B&C). In this study, the rotor is operate at sub-synchronous for speeds less than 10m/s and it is operating at a super-synchronous for higher speeds of the wind. The output power of the turbine is presented for different speeds ranging among 5m/s to 16.2m/s.

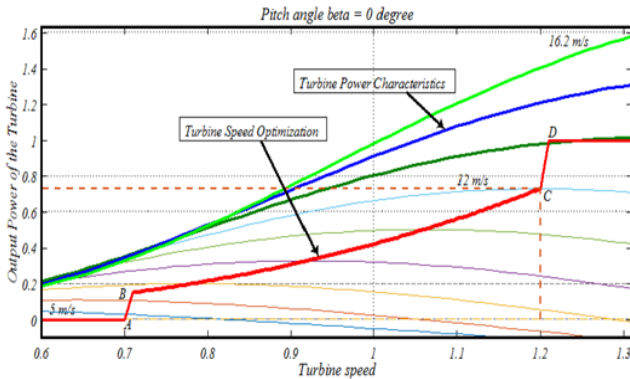


Fig. 7: Wind characteristics based DFIG

Also, observe that, voltage & reactive power generated that is controlled to maintain a one pu voltage. The wind absorbs 0.7 MVAR to control voltage at one pu. If you change the mode to VAR regulation based on the reactive power generated Q_{ref} regulate to zero, the voltage will increases to 1.3 pu if the WT produces its nominal power at unity power factor. Fig. (8) illustrates the wind farm waveforms based on VAR regulation mode.

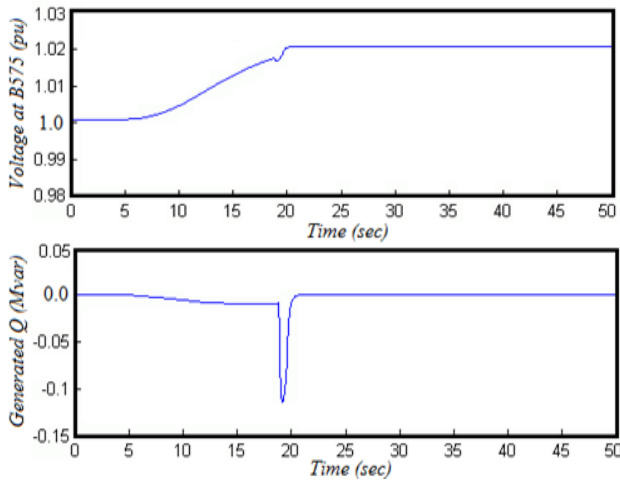


Fig. 8: Waveforms based VAR regulation mode

Case study (4): Effect of a single fault

In this scenario, observe the effect of a single phase fault happen on 25kV system that applied at $t=5s$ on phase (A)

at B25. If the VAR regulation mode is applied with Q_{ref} regulate to 0, the voltage falls to 0.74 pu and the under-voltage trips the WF. Observe that, the turbine speed will increase. At $t=40s$ the pitch angle initiates to increase to limit the speed. Fig. (9) depicts the simulation results of wind farm waveforms during fault at B25 based on VAR regulation mode.

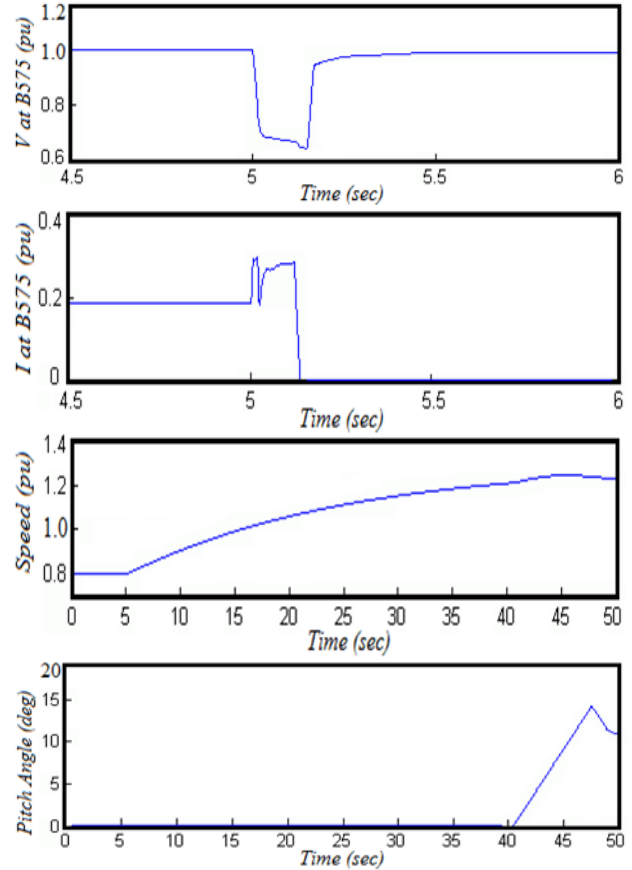


Fig. 9: Simulation results during fault based VAR regulation mode

CONCLUSION

This study presents the effectiveness of disturbances such as: voltage sags and swells for the grid-connected doubly fed induction machine (DFIG) based wind farm. The simulation results illustrates, the main effects of voltage sag encompass isolation of sensitive loads, loss of data, fail functions and system shutdown. Voltage swell can leads to isolation of equipment, reduced life and discomfort tripping. Grid-connected DFIG based wind farm is expected to respond with specific grid codes, known as; (power quality, voltage, active and reactive power control), low voltage ride through (LVRT) at the point of interconnection with the electrical grid. Wind energy based LVRT capability can withstand disturbance on the transmission line. In another meaning, it will rest injected to the grid during electrical disturbances.

APPENDIX

The system parameters applied are given as follows:

Grid Voltage:

3-phase, 25 kV, 60 Hz.

Generator Parameters:

Power rated: 6*1.5 MW at 0.92 PF, 575 V, 60 Hz.

Stator resistance & reactance = $R_s = 0.014$ and $L_s = 0.2$ pu

Rotor resistance & reactance = $R_r = 0.01$ and $L_r = 0.16$ pu

Magnetizing inductance $L_m = 5$ pu

Parameters of WT

Nominal mechanical power: 6*1.5MW

Controller gain of pitch angle $[K_p] = 500$ with (deg) = 45

Converter parameters:

Maximum power = 0.52 pu

Grid-side $[L \ R] = [0.15 \ 0.15/100]$ pu

IGBT with 3 arms, 6 pulse and sample time 5 μ s.

Nominal DC-bus voltage = 1200 V

Nominal DC-bus capacitor = $6*10000e^{-6}$ F

Control Parameters:

Reference voltage $V_{ref} = 1$ pu

Gains of grid voltage $[K_p \ K_i] = [1.32 \ 300]$

Generated reactive power Q_{ref} (pu) = 0 pu

Gains of reactive power $[K_p \ K_i] = [0.1 \ 5]$

Load Parameters:

Plant with induction machine load 1.68 MW at 0.94 PF, 2300 V, 60 Hz with resistive load = 200 Kw

Load = 500 kW inserted on the 575 V bus.

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