

Integration of wind Power Plant on Electrical grid based on PSS/E

S. Othman¹; H. M. Mahmud² S. A. Kotb³ and S. Sallam²

¹Faculty of Engineering, Al-Azhar University, Cairo, Egypt.

²Egyptian Electricity Hold Company, Cairo, Egypt.

³Egyptians Atomic Authority, Egyptian 2nd Research Reactor, Cairo, Egypt.

salah_sllm@yahoo.com

Abstract: The capacity of electrical power system in Egypt will increase rapidly in the coming twenty years. The conventional energy sources such as oil, natural gas, coal are finite and generate pollution. Alternatively, the renewable energy sources like wind, fuel cell, solar, biogas/biomass, tidal, geothermal, etc. are clean and abundantly available in nature. In the year 2030 will reach the generation of electricity from wind generation plants to about 20% of the electrical network loads according to the forecast of the Egyptian government. This paper concerned on PSS/E modeling of wind power generation of Doubly-fed Induction Generator (DFIG) type and their impact on issues of Egyptian electrical grid. Since Wind Turbine Generators (WTG) doesn't have the same characteristics as synchronous generators, the appropriate modeling of wind farms is requisite for transmission system operators to analyze the best options of transmission grid reinforcements as well as to evaluate the wind power impact on reliability and security of supply. In case of grid faults wind turbines have to supply a definite reactive power depending on the instantaneous voltage and to return quickly to normal operation.

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1. Introduction

The large scale development of wind turbines/farms becoming a significant part of the generation capacity in some area, which requires that the power system treats the wind turbines/farms like a power source, not only an energy source. The wind power penetration would result in variations of load flows in the interconnected systems, as well as re-dispatch of conventional power plants, which may cause the reduced reserve power capacity [1, 2]. Integration of large scale wind power may have severe impacts on the power system operation. Stable, reliable and economic operation of the power system under the massive integration of wind power is a big challenge to power system operators. The technical specifications, grid codes, for grid connection of wind turbines have been produced to specify the requirements that wind turbines must meet in order to be connected to the grid. Examples on such requirements include capabilities of contributing to frequency and voltage regulation by continuously controlling the active power and reactive power supplied to the power system, and the low voltage ride-through capability [3, 4, and 5]. This paper present the most significant characteristic and specific aspects of detailed DFIG modeling containing variable speed wind turbine units. A specific case study is analyzed in order to identify the main requirements for wind farm connection to the Egyptian electrical grid. This paper will not address the detailed mathematics

of PSS/E WTG user models which have been covered in many publications.

Not with standing the provisions of the Egyptian Transmission System Code (the Grid Code), this Wind Farm Grid Connection Code specifies the special requirements for the connection of Wind Farms to the High and Extra High Voltage transmission system (the Grid). The modelling approach of wind farms is based on Wind Grid Code Requirements. The aim of Wind Grid Code is to provide a self-contained description of the technical and operational requirements that are to be met by the developers and operators of Wind-Powered Generating Stations (WPGS) that wish to connect to the Egyptian electricity grid [4]. The Wind Code applies to all WPGSs that are or have applied to be connected to the transmission grid, with installed capacity of more than 7 GW until 2030. Developers of WPGSs intending to apply for connection to the transmission grid should be aware that they are required to provide Project Planning data at this level of detail at the time of filing the application in order for the TSO (Transmission system operator,) to carry out the relevant connection design and impact studies.

The Grid Operator is authorized to change one or more of the following requirements or to give further requirements, if it is necessary for a safety and stable operation of the Grid.

- In case of a deviation of the voltage ranges at the Grid Connection Point from its permissible voltage range, the Wind Farm shall be able to deliver Available Active Power according to wind conditions

when the voltage at the Grid Connection Point remains within the ranges from 0.9 to 1.1 per unit.. Any automatic disconnection of the Wind Farm from the Grid shall be prohibited due to the deviation within the voltage ranges, expressed by the voltage at the Grid Connection Point related to nominal voltage.

- In case of a deviation of the grid frequency from its permissible value, any automatic disconnection of the Wind Farm from the Grid shall be prohibited due to the deviation within the frequency range of 47.5 Hz until 51.5 Hz.

- Voltage unbalance is defined as the deviation between the highest and lowest line voltage divided by the average line voltage of three phases. Wind Farms shall be able to withstand voltage unbalance not exceeding 3%.

- The voltage fluctuations in a Wind Farm can occur because of the switching operations (capacitor banks, wind turbine generator start/stop), inrush currents during wind turbine generator starting etc. The maximum voltage fluctuation is 5% from the voltage nominal value.

- The wind turbine generators of the Wind Farm shall only connect to the Grid (start-up), if the frequency and the voltage at the Grid Connection

Point are within the following limits: Frequency: $48 \text{ Hz} \leq f \leq 50.2 \text{ Hz}$ and Voltage allowed $0.95 \text{ per unit} \leq U \leq 1.05 \text{ per unit}$. [6]

2. Egyptian Electrical National Grid

The Egyptian Electrical National Grid (EENG) in Egypt is divided into five geographical regions, namely, Alexandria, Delta, Cairo, Canal, and Upper Egypt. The Egyptian Electricity transmission system is composed of 500 kv, 400 kv, 220 kv, 132 kv, and 66 kv levels [7]. A proposal of wind power plant will be located in the Canal Zone. Figure (2) shows the section from the Canal Zone which contain the wind power plant.

3. Wind turbine model

The DFIG wind turbine generator model is defined in Behnke [8]. The complete WTG model is divided into four functional blocks, as indicated in Figure (1). This paper is primarily concerned with the dynamic interactions of the wind turbine and electrical grid under transient fault.

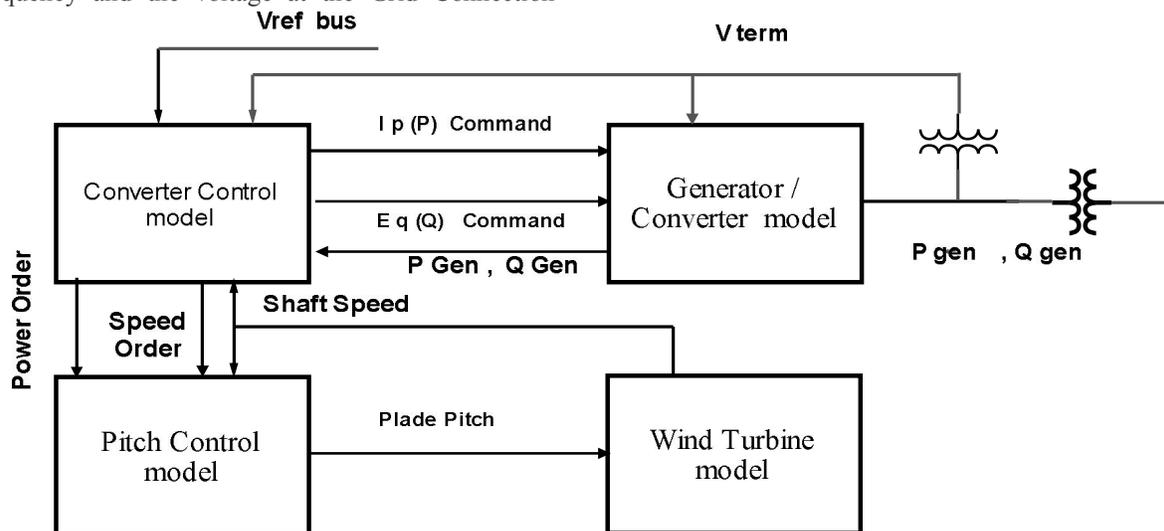


Fig.1. WTG dynamic model connectivity, from [8].

The power system modeling including wind turbines for steady state analysis in PSS/E version33 is fairly simple, as shown in figure (2). Each individual wind turbine generator (WTG) is connected to a 690V bus and the WTGs are connected to the wind farm internal network through their 0.69/35 kV step-up transformers. The internal network is organized in eight rows or sections with five WTGs in each section. Within these rows, the wind turbines are connected through 35kV underground cables of different lengths

and capacities depending on the location of each unit and the distance to the 35kV collector bus. The load flow solution provides the initial conditions for subsequent dynamic simulations. The maximum and minimum limits of active and reactive power must be respected in order to achieve a successful initialization. Inconsistencies between the power flow and the dynamic model will result in an unacceptable initialization. The proposed wind frame connection on Canal Zone as shown in figure (2).

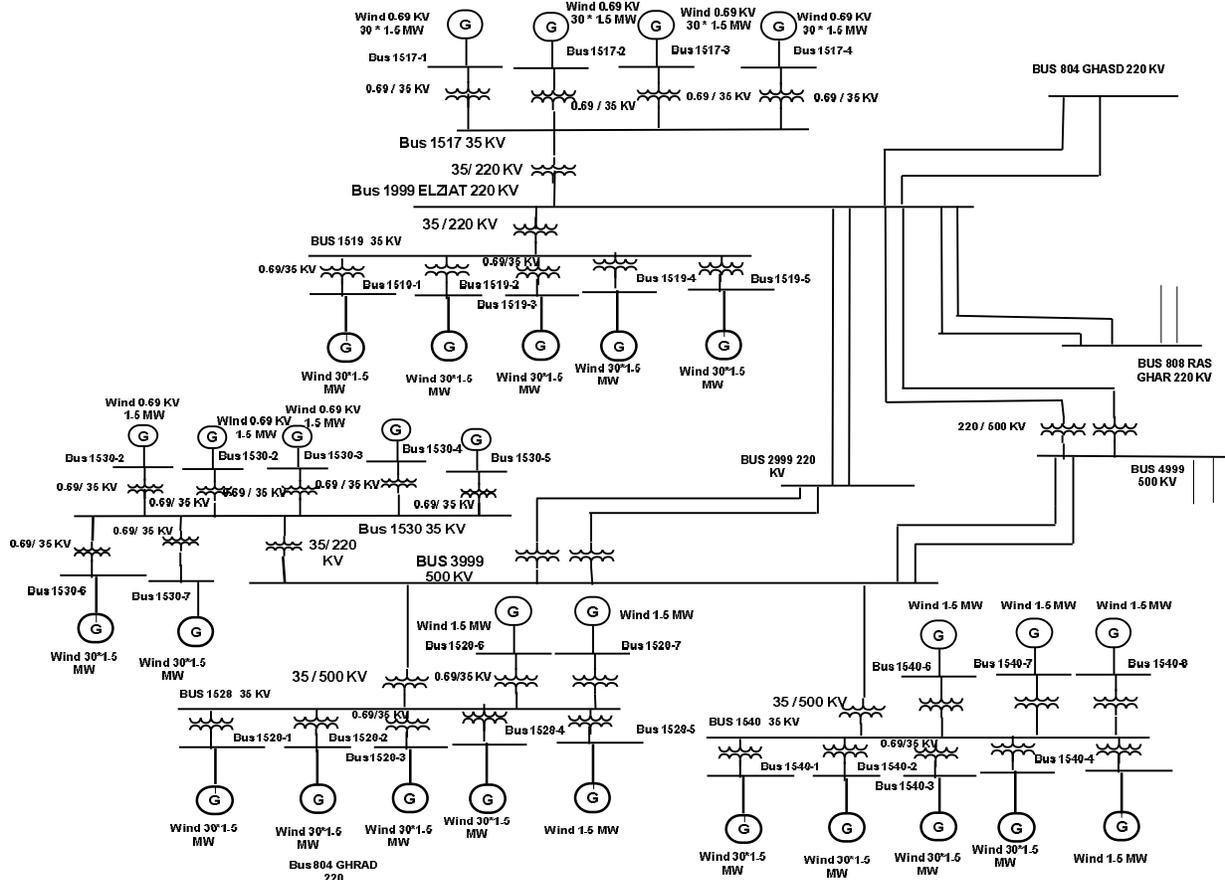


Fig. (2) Proposed wind frame connection in Canal Zone

4. Dynamic model of DFIG

The variable speed wind turbine using DFIG are more popular technology which is used world-wide due to advantages such as high energy efficiency and controllability. DFIG is basically a standard, wound

rotor induction generator with a voltage source converter connected to the slip-rings of the rotor. The stator winding are coupled directly to the grid and the rotor winding is connected to power converter as Shown in figure (3) [8, 9, 10].

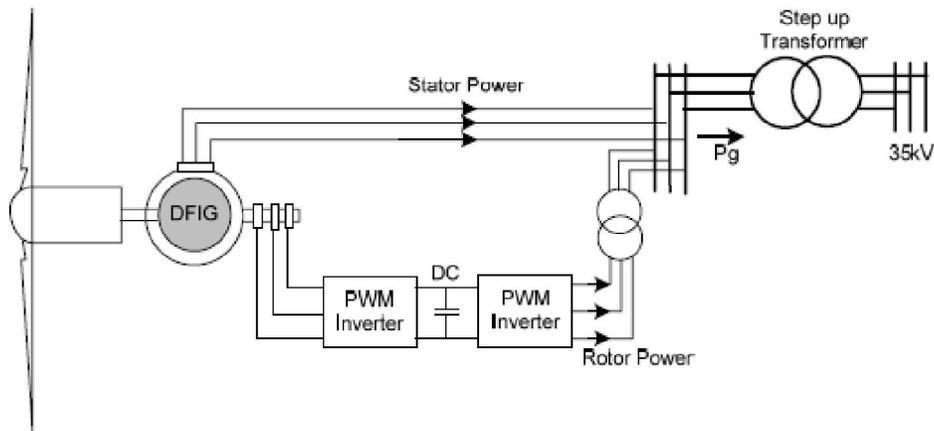


Fig. (3) Double- Fed induction generator

5. Simulation Result

**Effect Electrical disturbance on wind power plant
1- Fault on Bus 1517 (WPP)**

A three-phase short circuit is applied to the generator terminal on bus 1517 (wind power plant) when $t = 2$ sec and cleared when $t = 2.2$ sec, with the line being tripped at the same time. The simulation result is shown in Figure (4).

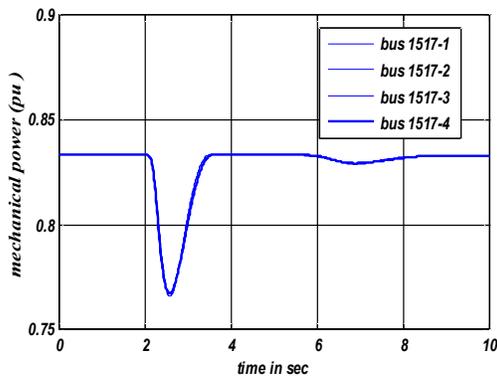
As shown from Figure (4.a-e), when the fault can be cleared correctly, the system can run stable and the wind power plant can operate without dropping the unit. The change in mechanical power, change in active power, change in reactive power, change in the generator speed and change in the bus voltage.

The mechanical power of power generators is shown in Figure (4.a). Clearly, short circuit occurrence at its bus changes the mechanical power of generators. They oscillate severely during the fault duration (from $t = 2$ to 2.2 sec). Then, the oscillations start to damp from $t = 2.2$ sec till sec and goes to steady state situation which is the same as the new

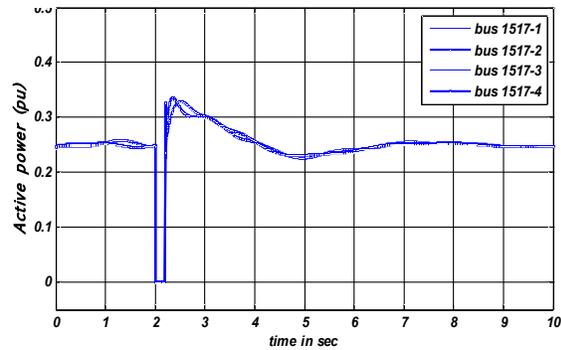
initial conditions. Figure (4.b) shows the change in generators active power surrounding generators active power violations, the active power to zero P.U suddenly during the fault time 0.2. After fault clearance, the active power starts to recover the same initial condition at $t=8$ sec.

Figure (4.c) shows the surrounding generator reactive power oscillations start to damp from $t = 2.2$ sec till 8 sec and goes to steady state situation which is the same as the initial conditions. The speed generators are shown in Fig (4.d). Clearly, short circuit occurrence at its bus changes the speed generators. They oscillate severely during the fault duration (from $t = 2$ to 2.2 sec). Then, the oscillations start to damp from $t = 6$ sec. till sec. and goes to steady state situation which is the another initial conditions.

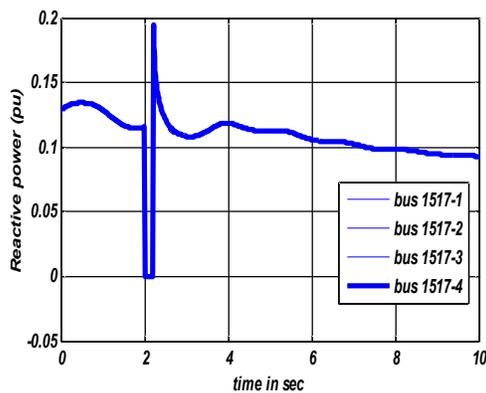
Figure (4.e) shows the surrounding buses voltage violations, the voltage dips to zero P.U suddenly during the fault time 0.2. After fault clearance, the voltage starts to recover itself.



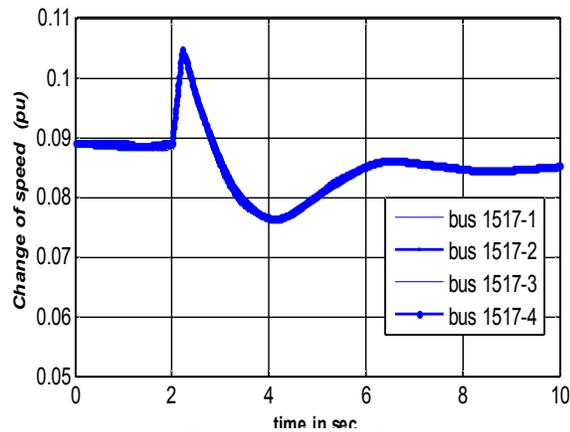
(a) Mechanical power



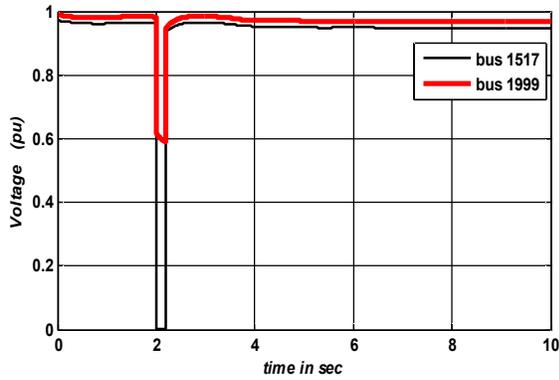
(b) Change in Active generation power



(c) Reactive generation power



(d) Change generator Speed



(e) Bus Voltage

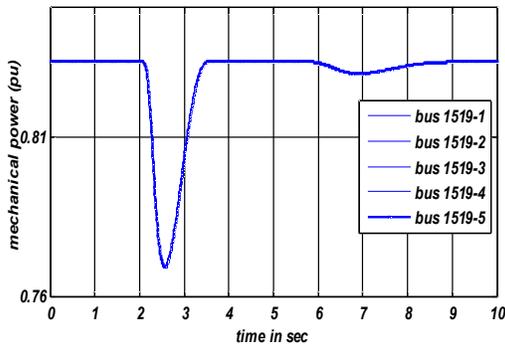
Fig (4) Effect the fault from 2 to 2.2 sec on bus 1517 on WPP and Grid

2- Fault on Bus 1519 (WPP)

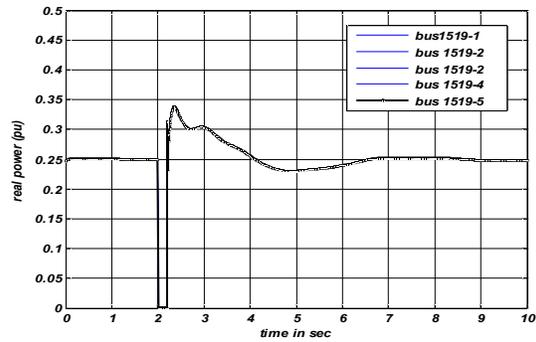
A three-phase short circuit is applied to the generator terminal on bus 1519 (wind power plant) when $t = 2$ sec and cleared when $t = 2.2$ sec, with the line being tripped at the same time. The simulation result is shown in Figure (5). As shown from Figure (5.a-e), when the fault can be cleared correctly, the system can run stable and the wind power plant can operate without dropping the unit. The change in mechanical power, change in active power, change in reactive power, change in the generator speed and change in the bus voltage.

reactive power, change in the generator speed and change in the bus voltage.

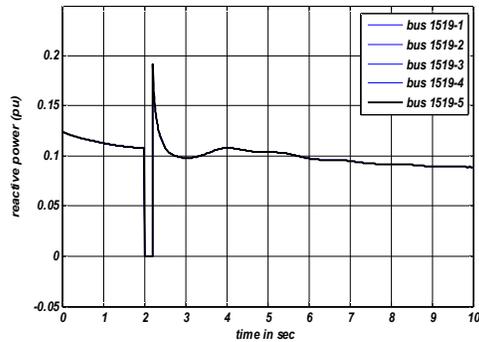
The mechanical power of power generators is shown in Fig (5.a). They oscillate during the fault duration (from $t = 2$ to 2.2 sec). Then, the oscillations start to damp from $t = 2.2$ sec till sec and goes to steady state situation which is the same as the new initial conditions. Figure (5.b) shows the change in generators active power surrounding generators active power violations, the active power to zero P.U suddenly during the fault time 0.2. After fault clearance, the active power starts to recover the same initial condition at $t = 7$ sec. Figure (5.c) shows the surrounding generator reactive power oscillations start to damp from $t = 2.2$ sec till 8 sec and goes to steady state situation which is the same as the initial conditions. The speed generators are shown in Figure (5.d). Clearly, short circuit occurrence at its bus changes the speed generators. They oscillate during the fault duration (from $t = 2$ to 2.2 sec). then, the oscillations start to damp from $t = 9$ sec till sec and goes to steady state situation which is the anther initial conditions. Figure (5.e) shows the surrounding buses voltage violations, the voltage dips to zero P.U suddenly during the fault time 0.2. After fault clearance, the voltage starts to recover itself.



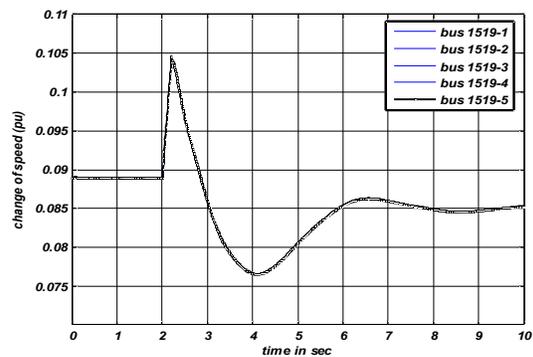
(a) Mechanical power



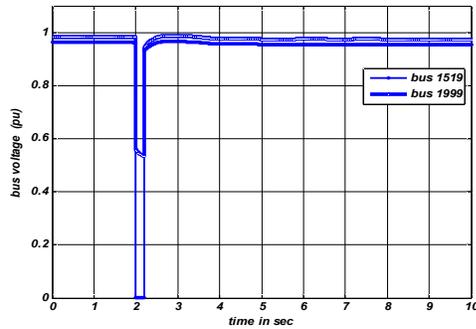
(b) Active generation power



(c) Reactive generation power



(d) Change generator Speed



(e) bus voltage

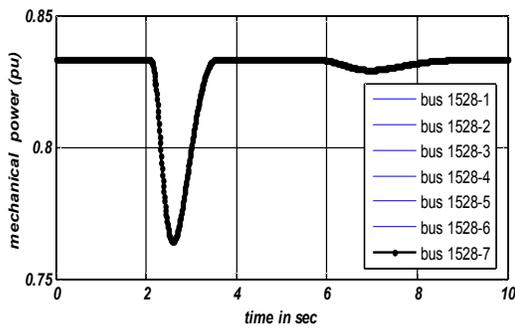
Fig. (5) Effect the fault from 2 to 2.2 sec on bus 1519 on WPP and Grid Functions

3- Fault on Bus 1528 (WPP)

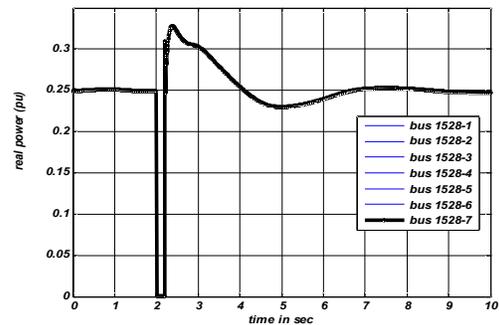
A three-phase short circuit is applied to the generator terminal on bus 1530 (wind power plant) when $t = 2$ sec and cleared when $t = 2.2$ sec, with the line being tripped at the same time. The simulation result is shown in Figure (6). As shown from Fig. (6, a, b, c, d, e), when the fault can be cleared correctly, the system can run stable and the wind power plant can operate without dropping the unit. The change in mechanical power, change in active power, change in

reactive power, change in the generator speed and change in the bus voltage.

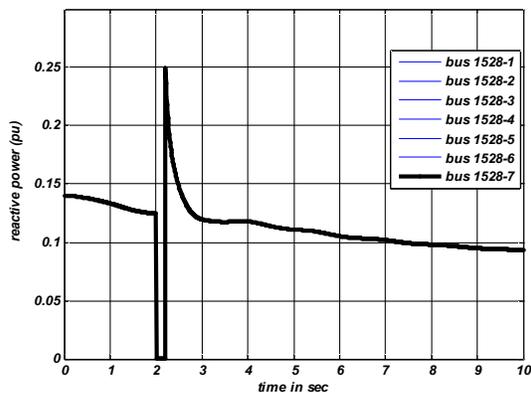
The mechanical power of power generators is shown in Figure (6.a). They oscillate during the fault duration (from $t = 2$ to 2.2 sec). Then, the oscillations start to damp from $t = 2.2$ sec. till sec. and goes to steady state situation which is the same as the same initial conditions. Figure (6.b) shows the change in generators active power surrounding generators active power violations, the active power to zero P.U suddenly during the fault time 0.2. After fault clearance, the active power starts to recover the same initial condition at $t=8$ sec. Figure (6.c) shows the surrounding generator reactive power oscillations start to damp from $t = 2.2$ sec till 8 sec and goes to steady state situation which is the same as the initial conditions. The speed generators are shown in Fig (6.d). Clearly, short circuit occurrence at its bus changes the speed generators. They oscillate during the fault duration (from $t = 2$ to 2.2 sec). Then, the oscillations start to damp from $t = 9$ sec. till sec. and goes to steady state situation which is the anther initial conditions. Figure (6.e) shows the surrounding buses voltage violations, the voltage dips to zero P.U suddenly during the fault time 0.2. After fault clearance, the voltage starts to recover itself.



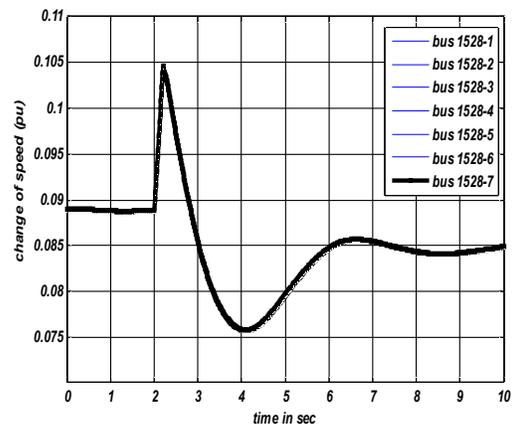
(a) Mechanical power



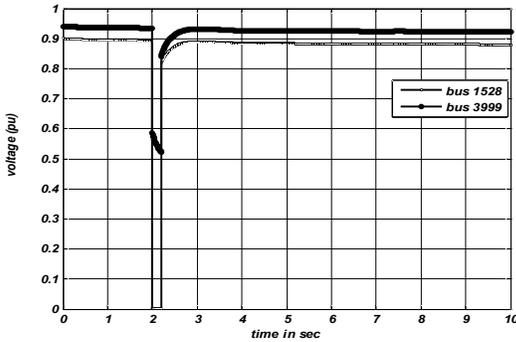
(b) Active generation power



(c) Reactive generation power



(d) Change generators Speed



(e) Change in bus voltage

Fig. (6) Effect the fault from 2 to 2.2 sec on bus 1528 on WPP and Grid Functions

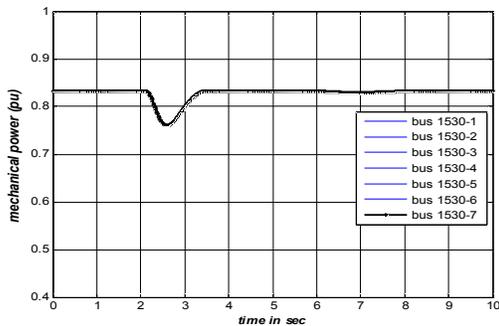
4- Fault on Bus 1530 (WPP)

A three-phase short circuit is applied to the generator terminal on bus 1530 (wind power plant) when $t = 2$ sec and cleared when $t = 2.2$ sec, with the line being tripped at the same time. The simulation result is shown in Figure (7). As shown from Figure (7, a, b, c, d, e), when the fault can be cleared correctly, the system can run stable and the wind power plant can operate without dropping the unit. The change in mechanical power, change in active

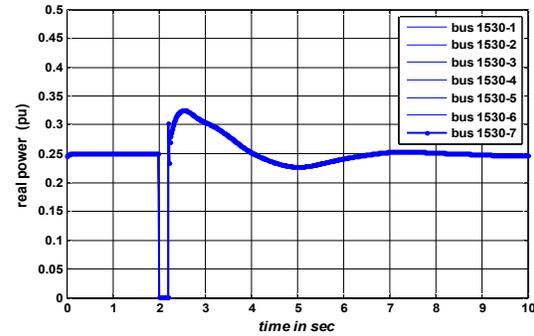
power, change in reactive power, change in the generator speed and change in the bus voltage.

The mechanical power of power generators is shown in Fig (7.a). They oscillate during the fault duration (from $t = 2$ to 2.2 sec). Then, the oscillations start to damp from $t = 2.2$ sec. till sec. and goes to steady state situation which is the same as the new initial conditions. Figure (7.b) shows the change in generators active power surrounding generators active power violations, the active power to zero P.U suddenly during the fault time 0.2. After fault clearance, the active power starts to recover the same initial condition at $t=9$ sec. Figure (7.c) shows the surrounding generator reactive power oscillations start to damp from $t = 2.2$ sec till 8 sec and goes to steady state situation which is the same as the initial conditions.

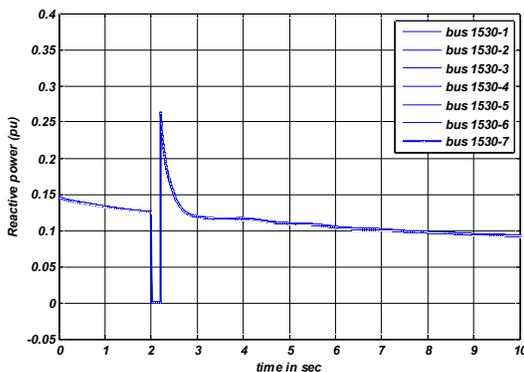
The speed generators are shown in Figure (7.d). Clearly, short circuit occurrence at its bus changes the speed generators. They oscillate during the fault duration (from $t = 2$ to 2.2 sec). Then, the oscillations start to damp from $t = 7$ sec till sec and goes to steady state situation which is the anther initial conditions. Figure (7.e) shows the surrounding buses voltage violations, the voltage dips to zero P.U suddenly during the fault time 0.2. After fault clearance, the voltage starts to recover itself.



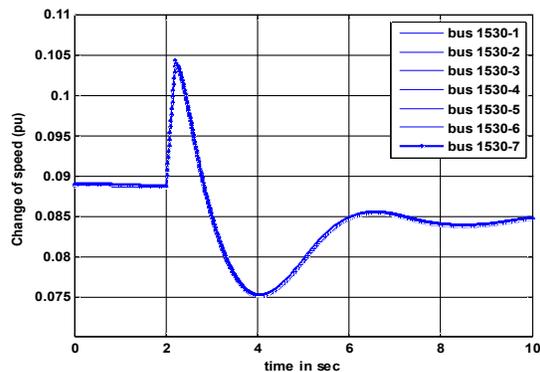
(a) Mechanical power



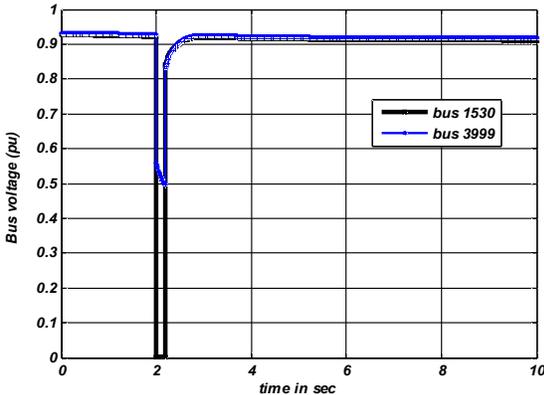
(b) Active generation power



(c) Reactive generation power



(d) Change generator Speed.



(e) Change in bus voltage
Fig. (7)

Conclusion

Power flow, short circuit and dynamic analyses were carried out in order to check the influence of the proposal wind farm on the Egyptian electrical grid in respect of the Grid Code requirements. The large scale PSS/E model was used for the computer simulations. The PSS/E wind turbine stability model WT3 was used for the dynamic simulation with the objective of simulating the dynamic performance of DFIG technology WTGs. The overall conclusion of these analyses is that the proposal wind farm project does have an influence on the transmission system, but all of the requirements of the Grid Code relating to the wind farm connection were satisfied.

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