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Impact of Different Types of Wind Turbines Generators on Voltage Sag

Eng.Sameh Karem Saeed[1], Dr.Salah-Aldin Kamal[2], Dr.Mohammad Kamal Alshaer[3]

PG Student, Dept. of Electrical Power Engineering, Helwan University, Cairo, Egypt[1]

Lecturer, Dept. of Electrical Power Engineering, Azhar University, Cairo, Egypt[2]

Assistant Professor, Dept. of Electrical Power Engineering, Azhar University, Cairo, Egypt[3]

ABSTRACT: This paper Discusses an investigation for impact of different type of wind turbines on voltage sag and the explanation for each type impact, a comparison between wind turbines have been discussed, also an assessment for the Doubly-Fed Induction Generator (DFIG) efficiency has been presented.

This investigation Based on practical tests and Readings from wind turbines in Zaafrana wind power plant at Suez Gulf Area in Egypt also based on simulation performed on MATLAB program. The readings is used to compare between DFIG and other types of generator such as Fixed Speed or Variable Speed Induction Generator (FSIG , VSIG) at the same site from efficiency point of view. At first the Wind Turbine combination shall be explained as it is useful to explain the advantages and disadvantages of using every type in wind turbine system. Also a simulation for the wind turbine response during normal and abnormal conditions is done using MATLAB program.

KEYWORDS: Voltage sag, Wind turbine efficiency, Fixed speed Induction generator , Doubly-Fed Induction Generator and Variable speed Induction generator,

I.INTRODUCTION

In general the operation of wind turbines can be at fixed speed or variable speed. For a fixed speed wind turbine the generator is directly connected to grid. Based on [12] While a variable speed wind turbine has a generator controlled by power electronic converter. There are several reasons for using variable-speed operation of wind turbines; among those are the possibility to reduce the mechanical structure stresses, acoustic noise reduction and the possibility to control active and reactive power. The major wind turbine manufactures are developing new larger wind turbines in the 1 to 5-MW range. These large wind turbines are all based on variable-speed operation with pitch control using a direct-driven synchronous generator (with or without gearbox) or a doubly-fed induction generator (DFIG). Fixed-speed induction generators wind turbines with stall control are considered unfeasible for those large wind turbines. Today, doubly-fed induction generators wind turbines are commonly used by the wind turbine manufacturer in larger scale wind turbines. In order to illustrate our investigation at first wind turbines types must be discussed.

--Speed wind turbine with an Induction Generator (FSIG)

This type of turbines are used in old wind turbine since 1997 in Nordex Wind turbines in Egypt Specifically Hurgada wind farm & Zafarana wind farm at Egypt and redeveloped to another types as will be discussed later.

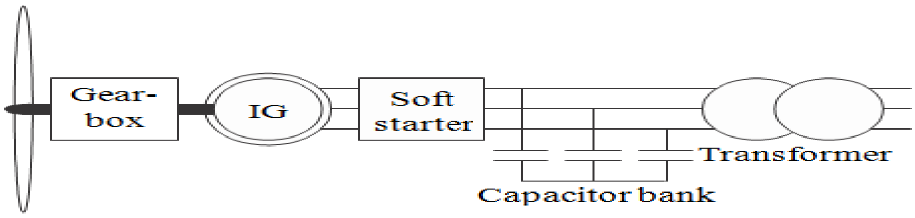

Figure (1) Fixed-speed wind turbine

Fixed speed wind turbine with an induction generator have simple Electrical system consisting of a rotor turning a low speed shaft, a gearbox, a high speed shaft and an induction generator. From electrical system point of view this wind turbines are considered as large fan drives with torque applied to the low-speed shaft from the wind power. The induction generator of the fixed-speed wind turbine is directly connected to grid [1, 2, 3].

--Variable-speed wind turbine with an induction generator (VSIG) using fully Rated Converter (FRC)

The Variable-speed wind turbine consists of an induction generator connected with a converter. The stator of the generator connected to grid via fully rated converter. The gearbox ratio is designed to keep maximum rotor speed corresponds to rated speed of the generator. The Generator may be made with multiple poles which reveal that there is no need for gearbox, because of this “full-power” converter system generator is commonly used for other applications; the advantage of this system is its well-developed and durable control [2, 3].

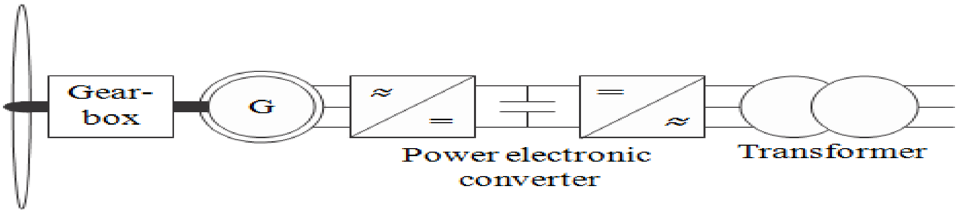

Figure (2) Variable speed induction generator

While the main disadvantage of this type is the converter has to handle 100% of the output power, which means increasing power losses at converter power electronics therefore lowering the efficiency. Also increasing the rated power of turbine means increasing the size of converter so become unfeasible [4].

--Variable-speed wind turbine with a doubly-fed induction generator (DFIG)

This type of wind turbines is the ultimate developed turbines which used in Zaafrana wind farm in Gamesa wind turbine. The turbine consists of a wind turbine with doubly-fed induction generator. In This system the stator of the generator is connected directly to grid while the rotor of the generator is connected to a back to back converter via the slip rings. This system has lately become commonly used as generators for wind turbines of variable-speed operation. The main advantage of this system is that the power electronic converter has to handle only from 20 to 30% of total power [1, 6].

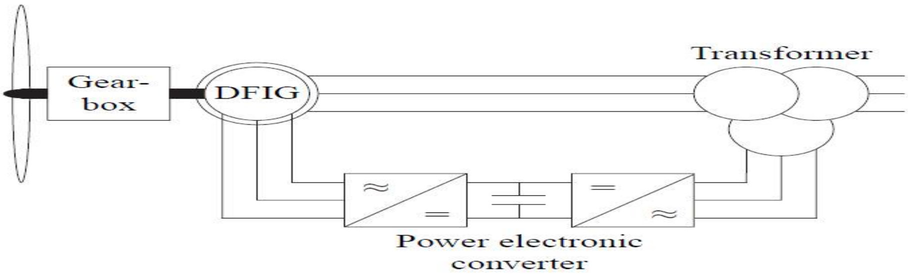

Figure (3) Variable-speed wind turbine with a doubly-fed induction generator

So the losses in the power electronic converter have been reduced compared with the type where the converter has to handle total power. Also, the cost of the converter will be lower. There are variant methods of DFIG that uses controllable external rotor resistances. Some of the disadvantages of this method are that power is unnecessary dissipated in the external rotor resistances and at this method the controlling of the reactive power it is not possible [7, 8].

II. PRACTICAL READING FROM ZAFARANA WIND FARM

In Zafarana wind farm the wind turbines connected to Feeder in the substation by Rows, Every row consists of numbers of turbines. The assessment based on the official reading from Zafarana substation feeder's meters.

-- Readings for DFIG (Feeder J52): The following Readings for Feeder J52 connected with a row consists of 6x1.5MW in the Spanish Project uses GAMESA Wind Turbines DFIG type. The Efficiency in percent of turbine rated Power 1.5MW.

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Month	Average Wind Speed (m/s)	Total Power Generated (MWH)	Generated Power for Each Turbine (MWH)	Effeciency (%)
Nov-14	6.948	1332	222.00	20.56
Dec-14	6.142	1379	229.83	20.59
Jan-15	7.445	1610	268.33	24.04
Feb-15	7.246	1592	265.33	26.32
Mar-15	8.838	1764	294.00	26.34
Apr-15	9.196	1887	314.50	29.12
May-15	7.714	1649	274.83	24.63
Jun-15	9.624	1908	318.00	29.44
Jul-15	9.823	1962	327.00	29.30

-- Readings for FSIG (Feeder J36): Feeder J36 connected with two rows every row consists of 8x0.4MW in the Danish Project uses Nordex Wind Turbines FSIG type. The Efficiency in percent of turbine rated Power (0.4MW).

Month	Average Wind Speed (m/s)	Total Power Generated (MWH)	Generated Power for Each Turbine (MWH)	Effeciency (%)
Nov-14	6.948	716	44.75	15.54
Dec-14	6.142	694	43.38	14.57
Jan-15	7.445	745	46.56	15.65
Feb-15	7.246	722	45.13	16.79
Mar-15	8.838	793	49.56	16.65
Apr-15	9.196	807	50.44	17.51
May-15	7.714	672	42.00	14.11
Jun-15	9.624	796	49.75	17.27
Jul-15	9.823	812	50.75	17.05

-- Readings for VSIG (Feeder J37) : Feeder J37 connected with row every row consists of 9x0.885MW in the Danish Project uses Nordex Wind Turbines FSIG type. The Efficiency in percent of turbine rated Power (0.885MW).

Month	Average Wind Speed (m/s)	Total Power Generated (MWH)	Generated Power for Each Turbine (MWH)	Effeciency (%)
Nov-14	6.948	1114	123.78	19.43
Dec-14	6.142	919	102.11	15.51
Jan-15	7.445	1165	129.44	19.66
Feb-15	7.246	1060	117.78	19.80
Mar-15	8.838	1122	124.67	18.93
Apr-15	9.196	1203	133.67	20.98
May-15	7.714	1076	119.56	18.16
Jun-15	9.624	1242	138.00	21.66
Jul-15	9.823	1264	140.44	21.33

III.SIMULATION OF ZAFARANA WIND FARM

This example shows simulation of Row of wind turbines at zafarana wind farm contains of 6 wind turbines using Doubly-Fed Induction Generator (Gamesa Manufacturer) this row is connected to zafarana area substation via feeder (J52) have been performed in MATLAB.

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Every turbine 1.5MVA connected to a 22 kV distribution system (zafarana substation) exporting power to a 220 kV grid through a 25 km 20 kV feeder. A 200 kW zafarana plant building is also connected on the 690V bus of the wind farm. The wind turbines have a protection system monitoring voltage, current, machine speed and The DC link voltage. The turbine mechanical power as function of turbine speed is displayed in for wind speeds ranging from 6 m/s to 14m/s. Figure 4 shows Zafarana simulation diagram.
The Wind farm is simulated by a single block which consists of 6 wind turbines entire as follows:
- The nominal wind turbine mechanical output power: 6*1.5 MW.
- The generator rated power: 6*1.5/0.9 MVA (6*1.5 MW at 0.9 Power Factor).

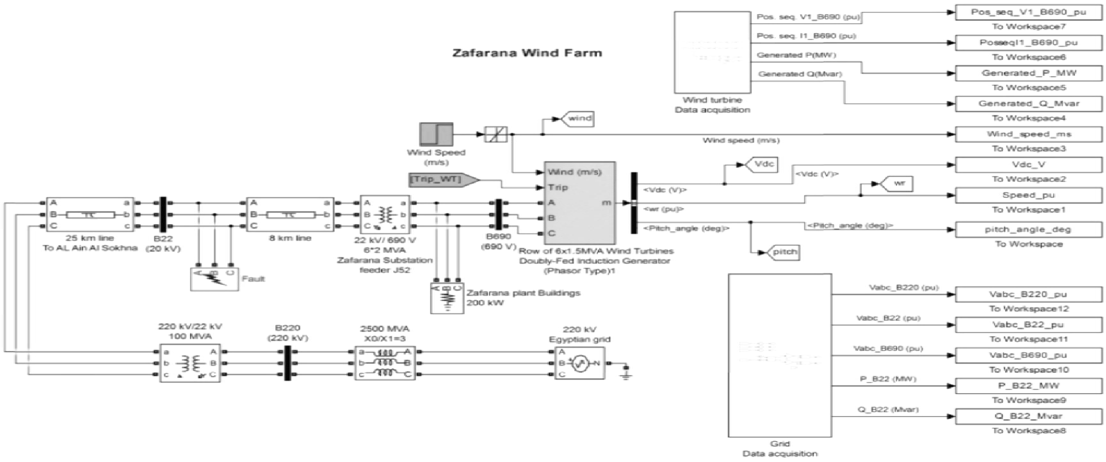

Figure (4) Simulation Diagram of Zafarana Wind Farm (Feeder J52) Connected to grid.

3.1 Turbine Response to a Change in Wind Speed

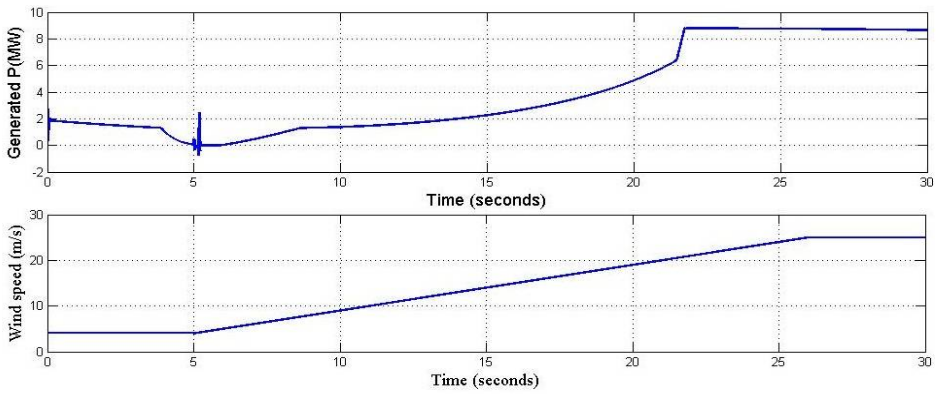

Figure (5) Generated Power with changing wind speed.

Figure (5) shows the change of turbine Output Power to the change in wind speed Initially, wind speed is set at 4 m/s, and then at t=5s, wind speed starts to increase to 25 m/s. the generated active power starts increasing smoothly with the turbine speed to reach its rated value of 9MW in approximately 17s. At t=22s the increasing in wind speed don't cause increase in power due to the tracking characteristics at figure 6 that the turbine reached point D at which The power is one per unit (1 pu) [9].

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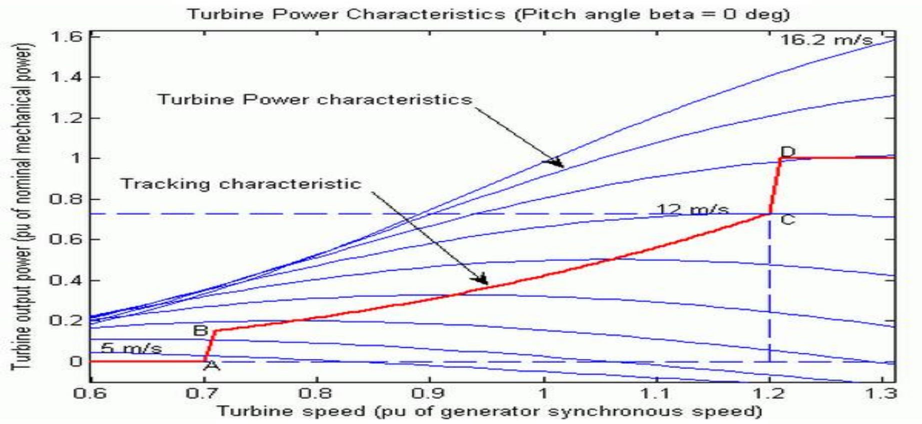

Figure (6) Tracking Characteristic of the system and the Turbine.

After point D the pitch angle must be used to reduce the turbine speed as shown in (Figure 8) the pitch angle control system shown in figure (7).

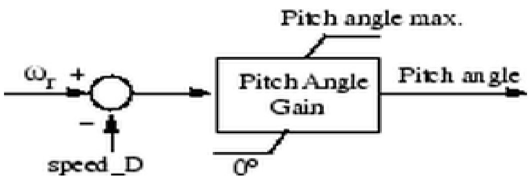

Figure (7) Pitch Control System

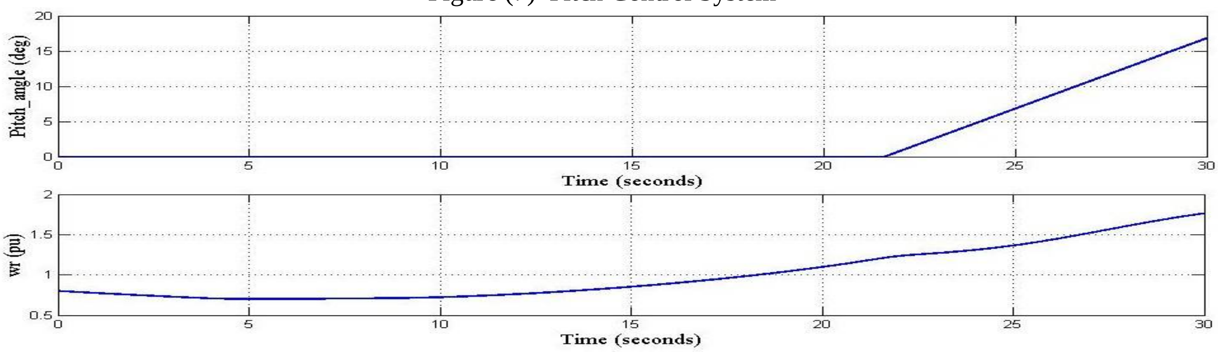

Figure (8) the pitch response to a change in wind speed.

Over that time frame the turbine speed increases from 0.83 pu to 1.25 pu. At first, the pitch angle of the turbine is 0 and the wind turbine operating point follows the curve of the turbine power characteristics up to point D figure 6 then the pitch angle is increased to limit the mechanical power.

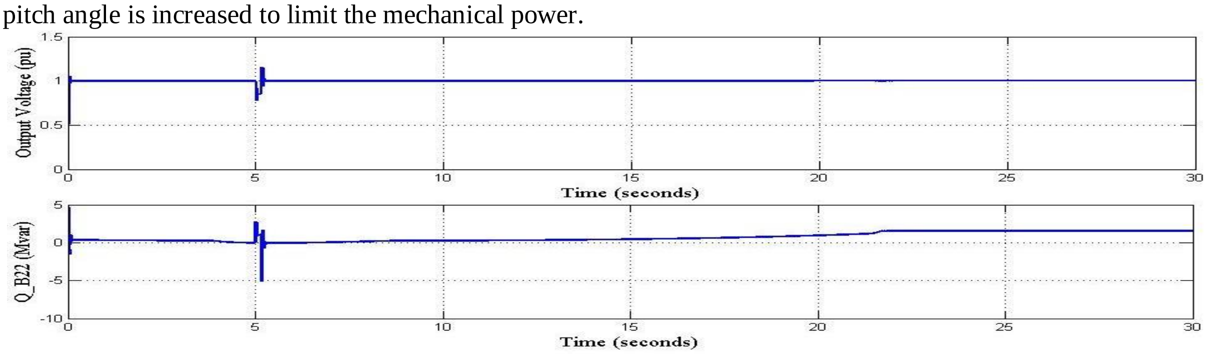

Figure (9) the turbine Output Voltage.

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Figure (9) Illustrates that the Output Voltage of The Turbine is fixed with the change of wind speed. As discussed before at Rotor-Side Converter Control System the reactive power is controlled to maintain the voltage 1 pu. So at nominal power, the wind turbine absorbs 0.7 Mvar (generated Q=-0.7 Mvar) to control voltage at 1pu. The grid terminals voltage is controlled by the reactive current flowing in the converter Rotor-Side Converter [9].

3.2 Simulation of a Fault on the Transmission System 22KV: We simulated the impact of a single phase-to-ground fault occurring on the 22 kV line. At t=5 s a phase-to-ground fault is applied on phase A at B22 bus (see figure (10)).

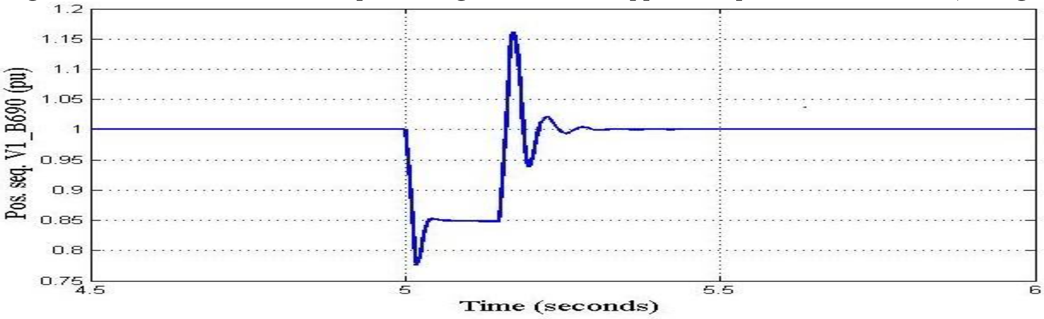

Figure (10) Positive Sequence Voltage during Fault

As shown in figure (10) the positive sequence voltage at wind turbine terminals (V1_B690) drops to 0.78 pu during the fault. Which is above the undervoltage protection threshold 0.75 pu for 0.1 second. The wind farm in this case stays in service. When the fault is cleared after 150 ms, the system return stable and the voltage return to the prefault condition with a fast and smooth response [9].

3.3 Impact of DFIG on voltage sag

In order to illustrate the impact of the voltage sag, we will connect 2 MVA Cement Factory with Its Protection System to B22 (20Kv) before zafarana substation. The plant details shown in figure (11)

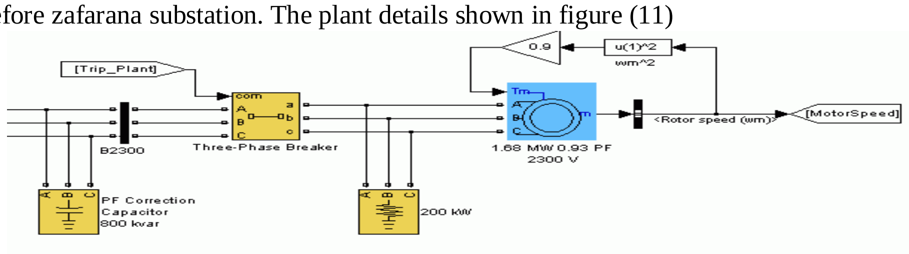

Figure (11) 2MVA Cement Plant

The impact of a voltage sag resulting from a remote fault on the 220 kV system (B220). In this simulation the wind speed have been maintained constant at 8 m/s. A voltage drop with 0.15 pu lasting 0.5 seconds is done to occur at t = 5 second . The simulation results are shown in figure (12) (1. At t = 5 second, the voltage falls below 0.9 pu and at t=5.22 second , the protection system trips the Cement plant because an undervoltage occurring and lasting more than 0.21 seconds has been detected (over the protection settings for the system). The Cement plant current falls to 0 A and motor speed gradually decreases, while the wind farm generating a power at level of 1.88 MW. After the Cement plant has tripped, 1.25 MW of power is exported to the grid [9].

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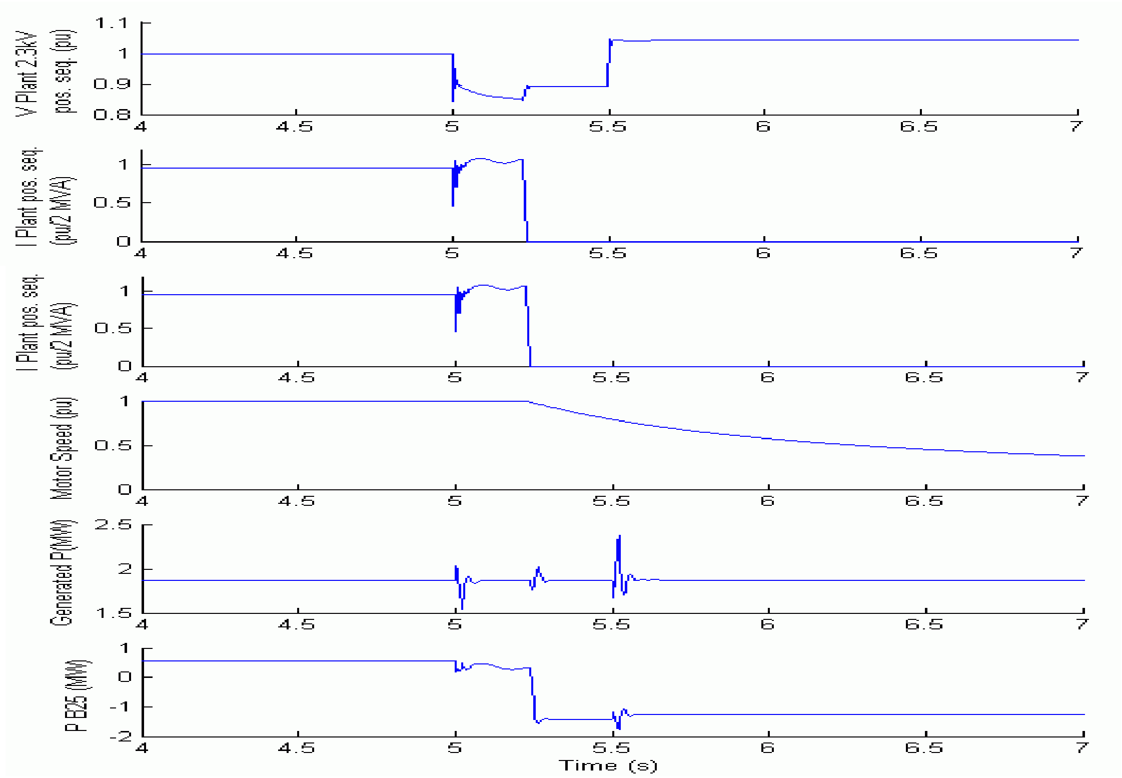

Figure (12) Voltage sag simulation results (DFIG)

-- Impact of FSIG on voltage sag : Now, the DFIG wind turbines used in last simulation model will replaced with FSIG wind turbines (with the same power rated) in order to study the impact of voltage sag when using FSIG type without any power electronics converters on the system[9]. The simulation is repeated. With the same conditions. The simulation Results are shown in Figure (13) we will notice that the Cement plant does not trip anymore. This is because the voltage support provided by the reactive power generated by the wind turbines using FSIG during the voltage sag keeps the plant voltage above the protection threshold (0.9 pu) [10,11]. The plant voltage during the voltage sag is now 0.93 pu [9].

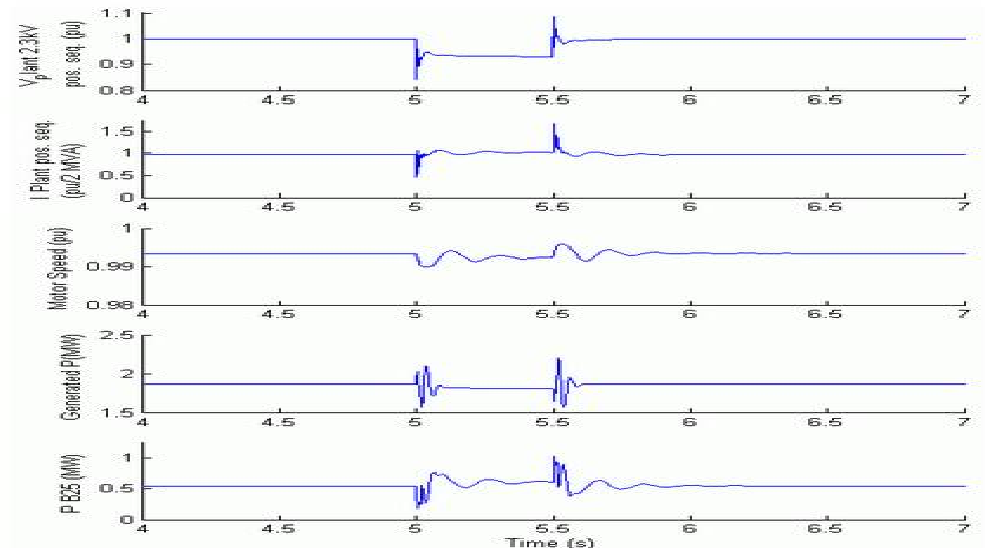

Figure (13) Voltage sag simulation results (FSIG)

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IV.CONCLUSION

It can be seen from readings (section 2) that the turbine use DFIG system has about 20-29% efficiency and produce more energy compared to the turbine use fixed-speed system and variable speed system.

DFIG has the flexibility with the change in wind speed. This flexibility is due to the robust control system used in the turbine and used in the convertor So that the power captured from the wind increases.

Of great importance to point out is that the DFIG system allows the manufacturer to manufacture turbines with large rated power. Because the converter only has to handle from 20 to 30% of total power of the system. This means that the power electronic losses can be reduced in comparison to VSIG or FRC type that has to handle the total system power, apart from the cost saving of using a smaller converter. all of this result in more power produced and less cost. This point was obvious in the rated power of DFIG turbine with 1.5MW and the rated Power of FSIG turbine is 0.4MW. So the efficiency is not the only advantage of DFIG.

For all that advantages of DFIG compared with FSIG type but there is disadvantage can be concluded from simulation that the voltage sag during the fault is higher when using DFIG wind turbines than it when using FSIG, This is because the voltage support provided by the reactive power generated by the wind turbines using FSIG with the absence of the power electronic system which used in the DFIG type and also used in the (VSIG or FRC) type.

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