

Programming Simulation of Transient Stability Analysis for Alternative Wind Turbine Generators

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Abstract

Due to the urgent need for renewable electrical energy sources in order to reduce the impact of global warming and its bad impact on the climate, the wind power is one of these sources that can be used for producing electrical power. This power can be produced by using wind turbines which have undergone extensive technological development specially in the recent decades and in different kinds of generators are designed and manufactured in wind turbine power plant. These types operate essentially in two forms according to the speed of the turbine shaft, constant speed or variable speed. Each type of speed has many advantages and disadvantages which can be clearly shown during the period of change in speed and also the sudden disturbance in wind speed. In this work, four types of fixed and variable speed generators were considered during a period of high disturbance in wind speed by studying the system transient stability using fast decoupled technique for solving the mathematical formulation and getting each generator's performances especially terminal voltages, active power and power factor, as they constitute one of the important characteristics of the generator. The results specify that the full-converter variable speed generator has good characteristics compared to the three types and the load is continuously feeding through wind disturbance period time.

Keywords: Transient Stability, Constant Speed, Variable Speed, Induction Generator, Full Converter, Full-Converter, Permanent Magnet, Synchronous Generator, Dynamic Simulation.

1. Introduction

Renewable energy represents one of the most types of energy which take more attention today due to the global warming phenomena which is going to have more effects owing to the firing of fossil fuels and carbon dioxide emissions with the increasing of electrical power demand. The most common type of renewable energy in this time is wind energy which has been getting great development in the recent years and wind turbine generators' capacity increased to high generating capacity and found wide applications rapidly in most countries of the world. In wind turbine the kinetic energy in the wind is converted into mechanical energy which causes the turbine rotation proportional to the speed cubic of the wind [1]. This mechanical energy is converted to electrical power through the alternator and then transmitted to the power to the network grid. Wind plant systems built in open areas, so they must be reliable under any extreme conditions and climate changes such as high temperatures, cold and frosts, storms, hurricanes, various climatic variations and at the same time with long maintenance intervals.

Several researches about how to improve and increase wind turbine rigidity and capacity in order to get more reliable power plant with best performances. Major companies which are specialized in the production of electric generating equipment are considerably interested to increasing wind turbine capacity [2]. Power system components circuit breakers, switchgear and the same time protection system should be carefully selected in order to be compatible with operation with the connected network. One of the most important parts of wind turbine is turbine blades which

depend mainly on high accuracy with high reliability and numerical estimation of its performance in all of operation conditions [3]. The flow of wind around turbine blade is simulated and different turbulence models and aerodynamic performance are investigated. A mathematical model for different generator types are represented respectively by fixed and variable speed including doubly fed induction generator and synchronous generator with permanent rotor magnet is considered [4]. The model behavior is studied when fault events occur and the stability is investigated under transient conditions where the action of static converter controller is detected at different forms of faults. Single turbine representation of wind power plant is considered by taking dynamic model with steady wind speed event and a symmetrical fault occurred, the reactive power controller matches the actual setting for voltage control or reactive power control [5]. Several data sets are required to measure at the point of interconnection of the wind power turbine.

In this paper, the dynamic performances of four types of wind turbine generators are studied by using the equivalent short circuit level with 8.0 MW power exchange with the wind power plant which consists of eight wind turbines each generator rated capacity is 1500 KW. The objective of this work is to evaluate the dynamic response of the wind turbines due to the change in the wind profile that the wind turbines are subjected to. The transient analysis is performed using transient stability analysis using fast decoupled method.

2. Wind Generator Models

As the wind turbine operates in a form of primary prime mover, so that any type of generator can be equipped with the turbine gear

box shaft depending on the characteristic of the turbine. Fixed speed wind turbine can be equipped with induction generator which can be in two form; squirrel cage and wound rotor induction generator. The types of generators that have analyzed are:

Directly coupled constant speed induction generator type: The easiest principle for this type is to coupled directly to the gear box shaft and at the same time connected electrically to the grid. This type of coupled is called Danish concept where a good benefit of simple structure of wind turbine with low investment is needed in addition to less maintenance costs [7].

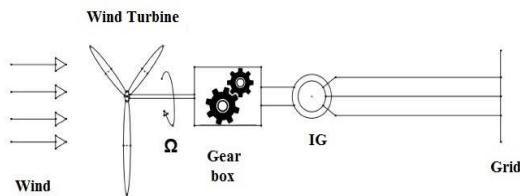


Fig.1: Directly coupled induction generator

In this model no power converter or complex controller is required. As show in figure 1 the generator is coupled to blade shaft through a gear box which is essential to convert low rotational blades turbine to a compatible value in order to produce electrical power at fixed frequency such as 50 or 60 Hz depending on the grid characteristic. The generator speed change by a few percent because of generator slip is due to the change in wind speed. The generator equipped with soft starter mechanism and an installation for reactive power compensation is associated [8]. Generator speed cannot be controlled quickly because speed control be possible only by the influence of pitch angle of blades and this chance is not a fast response, also, this model not appropriate for wide wind speed range in addition to power fluctuations. As the fluctuation of wind speed is transferred directly to the grid and cause high inrush current during grid connection to the wind turbine generator, so that the connection must done gradually in order to limit inrush current. The terminal voltage of the generator lead to be instable in the case of a fault without any reactive power compensation system and when the fault is cleared the generator draw a large amount of reactive power from the grid which cause additional decrease in terminal voltage [8].

Full convertor variable speed induction generator type: For variable speed wind turbines, there are three main component are exist, wind turbine, generator, and electronic power converter. When the grid is connected to the plant the reactive power is drawn from the grid and the induction generators be able to use full converter [9]. This point let us make numerous configurations and couple this converter to the generator terminals and this decoupling of the generator to the grid allows to work with different frequencies on each side as shown in fig. 2. This leads to the advantage to change the usual operation typology of generator because it been able to work with different n frequencies, also, in this

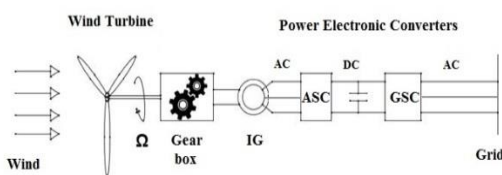


Fig. 2: Full convertor variable speed induction generator

Type it is not necessary to be worried about the rotor speed. To take advantage of variable speed operation, a power electronic interface must be provided between the generator terminals and the grid. The full converter is a suitable option for cage induction machine in wind Power application. The convertor is formed by a rectifier, an inverter and a capacitor between both. The rectifier and the inverter, are composed by Insulated Gate Bipolar Transistor and these are controlled by Space Vector Pulse Width Modulation. The reactive power can be adjusted by set the control standards properly [5]. In this type of generator reactive power compensation can be chosen for operation at one of the following conditions; constant power factor, constant reactive power, or constant voltage terminals.

Doubly fed variable speed induction generator: Double fed induction generator take a considerable attention in wind power plant. Its adjustable speed construction is similar to wound rotor induction motor and using slip ring to allow current into or out of the rotating three phase winding. In order to enable dynamic modeling of generator a bi-directional power converter assembled from two AC/DC linked by a DC bus. The double converters as show in fig. 3. Is decouple the rotating speed of the generator from grid frequency to allow variable speed operation of the wind turbine.

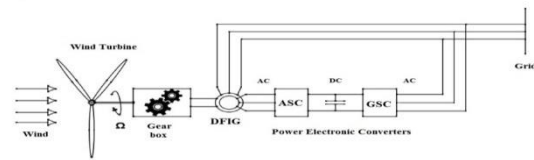


Fig. 3: Doubly fed variable speed induction generator

The convertor is connected to the grid by using an inductance because it is possible to dimension the rotor winding and the power electronics that the rotor voltage is high enough to fed into the grid.

Full convertor variable speed permanent magnet synchronous generator: The reliability of the variable speed wind power system can be improved considerably by using a permanent magnet synchronous generator.

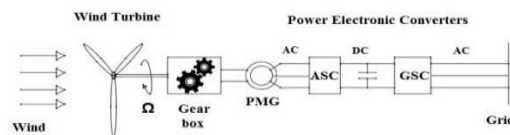


Fig. 4: Full convertor variable speed permanent magnet generator

As show in fig. 4 This type of wind generator consist from three phase stator winding and the field rotating winding is replaced by a permanent magnet [10]. This replacement has many advantages of which elimination of copper field winding, higher power density, lower rotor inertia, and more robustness. At the same time, this design has drawbacks of loss magnetic field flexibility to control and the possibility of demagnetization effects and in addition to the its cost. The generated power for this type of generator is at variable voltage in both amplitude and frequency, so that, power electronic interface is required to convert the variable frequency and voltage into a constant grid or load frequency and voltage. Full convertor similar to that used for induction generator is used also for this kind of generator and the reference speed is computed according to the wind turbine output power and controlled to the wanted output power. The output voltage is controlled through control structure to maintained its value at specified value during any transient condition in the system or wind speed variation.

3. Speed-Power Turbine Relation

The transformation of Wind kinetic energy is a composite system that converts wind energy to mechanical energy in a form of rotating power or moment of wind turbine with basic factors such as wind speed, turbine shape, and dimension [1]. The wind speed and direction is change vary widely with season and time of day which cause significant effect on the energy yield from the turbine [11]. A turbine may deliver completely different amount of energy when it is mounted in two sites with the same average wind velocity but different velocity distribution. The power curve of 1.5 MW is shown in Fig. 5. The turbine has cut in speed where the turbine does not yield any active power. The second part of the curve is between cut in and rated speed where the active power increases with wind speed and this increase should be cubic in nature as shown in equation and at the *same* time depend on turbine design [12]:

Kinetic energy definition:

$$KE = \frac{1}{2}mv^2 \quad (1)$$

Power is kinetic energy per unit time is:

$$P = \frac{1}{2} \frac{dm}{dt} v^2 \quad (2)$$

Fluid mechanics gives mass flow rate

$$\frac{dm}{dt} = \rho Av \quad (3)$$

Substituting equation 3 in equation 2 results:

$$P = \frac{1}{2} \rho Av^3 \quad (4)$$

For

$$P_{wind} = \frac{1}{2} \rho Av_w^3 \quad (5)$$

Where

ρ air density, A effective area, v air velocity m mass of air. The third part of the curve represent constant rated regardless of the change in wind speed and design of the turbine is arranged to limit the power to this maximum level and there is no further increase in the output power. How this is done varies from design to design but typically with great turbines, it is done by adjusting the blade angles so as to keep the power at the constant level. The last part is cut out speed, as the speed increases above the rate output wind speed, the forces on the turbine blades continue to increase and, at some point, there is a danger of damage to the rotor. As a result, a braking system is working to bring the rotor to a stop. This is called the cut-out speed and is usually around 25 m/sec and the turbine is shut down due to safety reasons.

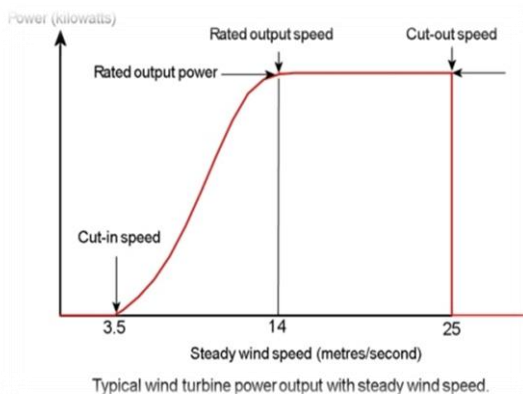


Fig5: Speed power curve

4. Transient Turbine Analysis

The transient disturbance condition study in this work is the state of instantaneous wind speed variation which can be considered as transient case taken few time. Simulating of wind turbine in the transient state involves two operations: integrating the differential equations that govern the dynamic behavior of the system apparatus and solving the algebraic equations which describe the power flows in the system. The algebraic equations relate to the load flow problem, which can be formulated in matrix notation as:

$$[Y] * [V] = [I] \quad (6)$$

Where $[Y]$ admittance matrix, $[V]$ vector of voltage, $[I]$ vector of current

This equation is solved iteratively, until convergence is achieved, with respect to the results from the integration of the differential equations representing the rest of the system components. By decompose the injections at the bus-bar into injections attributable to the grid $[I_c]$ and to the generators $[I_g]$ respectively :

$$[Y] * [V] = [I_c] + [I_g] \quad (7)$$

by transferring $[I_g]$ to the left-hand side of the equation and introducing finite difference equations obtain:

$$[Y + Y_g] * [V] = [I_c] \quad (8)$$

$$[Y'] * [V] = [I_c] \quad (9)$$

Where $[Y_g]$ is a diagonal matrix the elements of which are nil for load buses. Equation (9) is solved by the "admittance matrix method", creating imaginary swing buses behind the generator buses across admittance equal to the corresponding term in $[Y_g]$. This means running an iterative procedure with the equation:

$$[V_k + 1] = [V_k] + [Y']^{-1} * [dR_k] \quad (10)$$

Until the residual error dR_k is within the desired tolerance, k being the iteration index.

Transient stability simulation requires a power flow solution to establish the initial condition of the system and any control system such as excitors, convertor,.....tec. The simulation involves application of wind speed variation investigating the response of the system by monitoring different variables that characterize the system. The power flow is automatically performed prior to the start of the Transient Stability simulation and the initial conditions established by the Power Flow solution are automatically made available to the model. The power flow algorithm use Fast Decoupled.

5. Wind Turbine Dynamic Simulation

The program that used in this research is CYME 7.1 software where operation data of wind turbine details like rated power, maximum power, speed curve, blade data, and drive train. For each of four generators types data are entered to the program including rated capacity, rated power, rated voltage, power factor, and rated speed.

Also, for each generator equivalent circuit for stator parameters and for three types of induction generator rotor like single circuit, double circuit, and deep bar rotor. At the same time the blade pitch control is an essential point and in addition to power coefficient curve which depend on power coefficient equation of the turbine. DC link data and convertor control information is introduced in the program. The wind variation is taken as a time

dependent analysis and initial load flow using Fast Decoupled method is used in the solution procedures.

6. Simulation Results

The transient condition is consider the variation of wind speed during 30 second as shown in figure 6 where excessive change of speed in occurred and the performances of each generators is analyzed using Load-Flow under transient condition by Fast Decouple method with a tolerance 0.01 MVA and the maximum number of iteration is 60 .

For induction generator at constant speed the terminal stator voltage is varied from 598 to 614 volt depending on wind speed value.

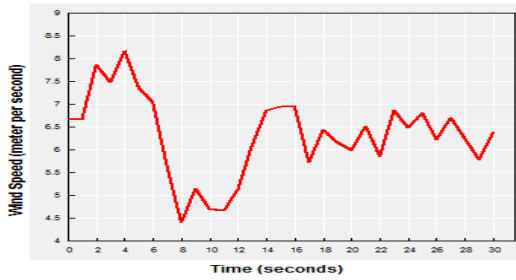


Fig. 6: Wind speed against time variation

For induction generator at constant speed the terminal stator voltage is varied from 598 to 614 volt depending on wind speed value as show in figure 7 .

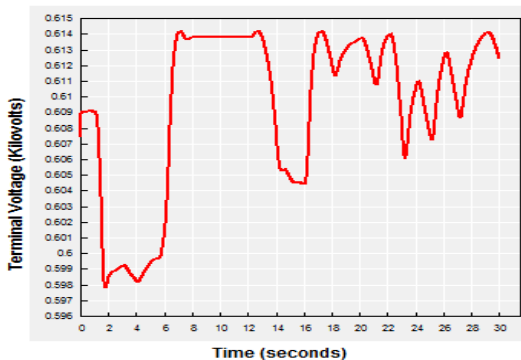


Fig. 7: Induction gen. constant speed voltage against time

For Full convertor induction generator variable speed type the terminal voltage is varied in very small value from 608 to 609 volt.

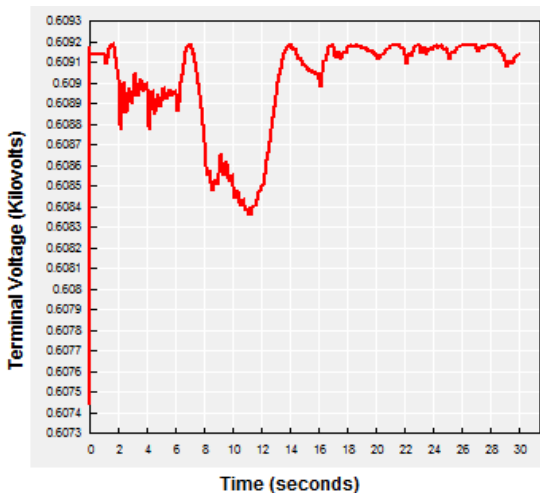


Fig. 8: Full convertor-variable speed voltage

For the third type of generator is Full convertor permanent magnet synchronous generator variable speed. The variation of voltage value from 601 to 609 volt as its shown in figure 9 . this variation is within the acceptable limits values.

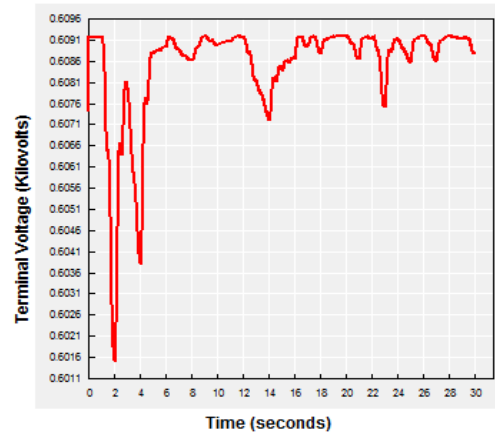


Fig. 9: Full convertor permanent magnet synchronous generator

For Doubly-fed induction generator-variable speed, the voltage value change from 607 to 609 volt as shown in figure 10. The second important generator performance is the active power generated depending on wind speed value. The active power for constant speed type is shown in figure 12 where the change is clearly shown

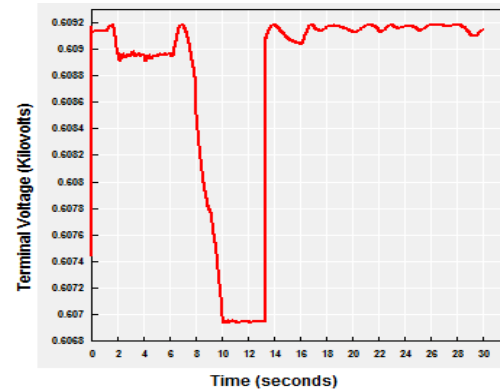


Fig. 10: Double-fed variable speed voltage

The active power that delivered to the grid and it is reduced to zero value when the wind speed is reach to the cut-in value for few seconds and then return to the appropriate value. Figure 11 explain this variation clearly and this is one of the disadvantages of wind turbine stations where they are greatly affected by the wind speed as its shown in equation 4.

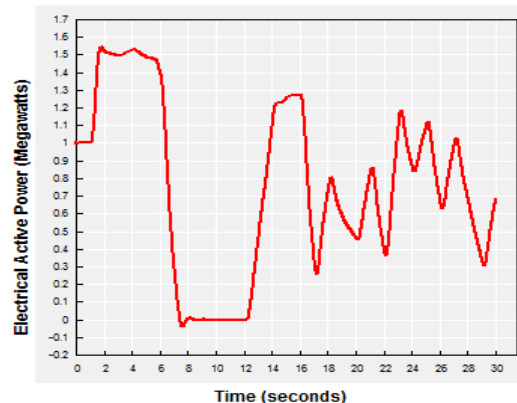


Fig. 11: Constant speed type active power variation

The active power for full-converter variable speed shown in figure 12 where the power does not reach zero value during the few second when the wind is in transient condition and this is due to continuity of

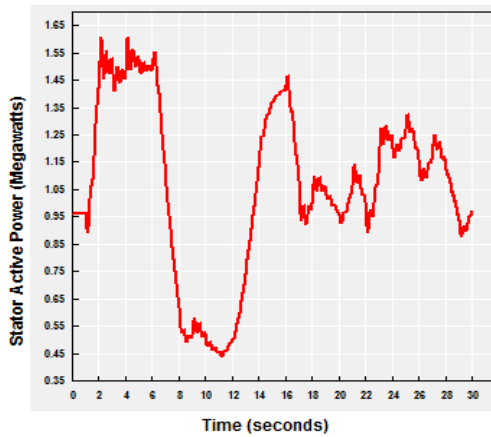


Fig. 12: Full-converter type active power

Turbine speed during cut-in speed time. Figure 13 exhibit this variation at the transient condition. The behavior of synchronous generator with permanent magnets is different than the other types where the stator winding absorb the active power from the grid so that the active power is negative sine and this been clear in figure 14 where the wind speed is in transient condition.

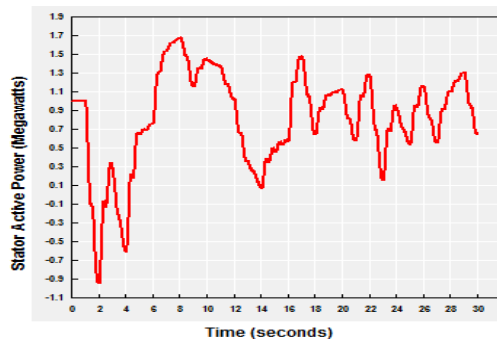


Fig. 13: Full-converter synchronous generator active power

For double-fed type, the performance is similar to that for constant speed type, see figure 14 .

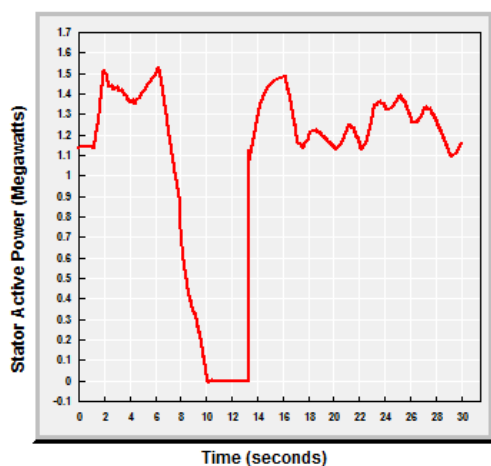


Fig. 14: Double-fed variable speed active power

The power factor is one of the most important performances of the generator and the control of reactive power is take more intention because that the induction generator need source of

reactive power in order to generate the electrical power and to control the terminal voltage of the generator. For constant speed type the power factor variation is shown in is shown in figure 15 .

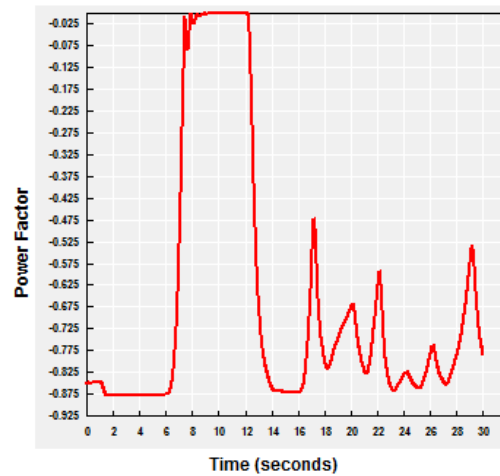


Fig. 15: Constant speed type power factor

Power factor increased with the increasing of active power and reduced to a very poor value with

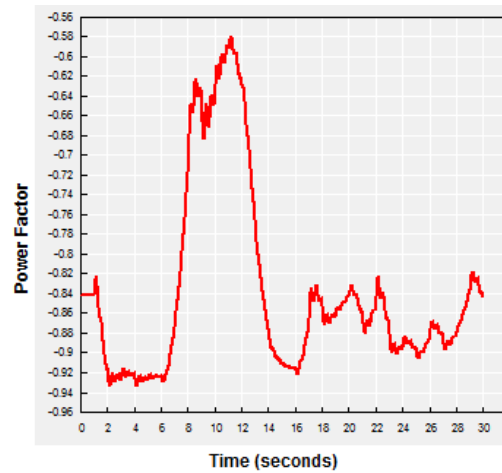


Fig. 16: Full converter generator power factor

the reduction of speed near to cut-in speed value. For full converter generator, the power factor curve is similar to that for constant speed type as shown in figure 16.

For synchronous generator, the power factor is remain at preferred value as the wind is in transient condition as shown in figure 17 .

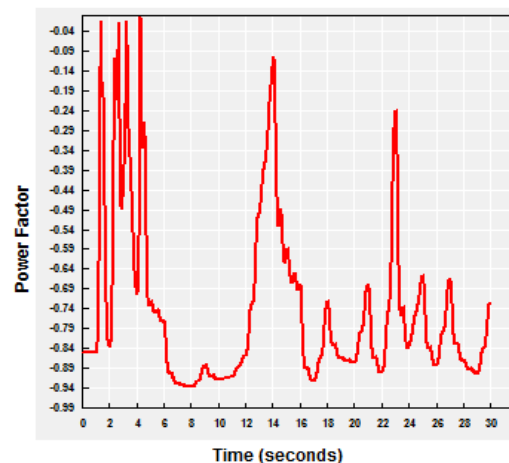


Fig. 17: Synchronous generator type power factor

Power factor values with speed change for double-fed generator is similar to that for constant speed type as shown in figure 18 .

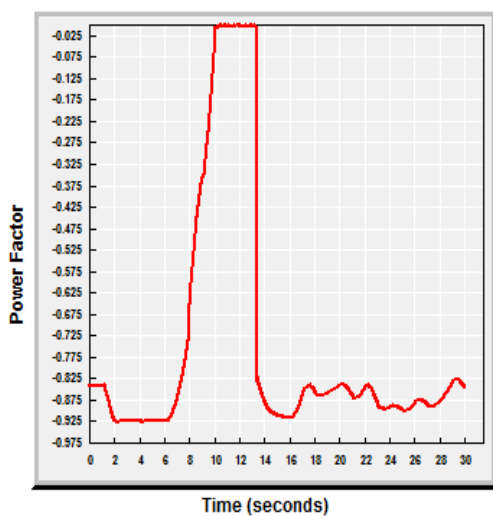


Fig. 18: Double-fed generator power factor

7. Conclusions

By observing the results obtained during the period of disturbance in wind speed, which represents the state of transient stability, that characterize the most state of work in wind turbines plant where its performances depend directly on the value of wind speed. The terminal voltage for Full convertor variable speed generator is more stable from the other types during transient condition. Also the active stator power for this type is remain within the acceptable limit value and does not reach zero value and this criteria exhibit more respectable performance. For the remaining three types, the active power (which represent the most effective thing) reach zero and sometime negative values. The results for power factor variation during transient condition show that the values for Full convertor induction generator is also in good values in cooperation with the other generators types. Thus the best types of wind turbine generators in the residences and areas where the wind is in disturbance condition at the most times is, Full convertor variable speed generator type due to the stabilize voltage terminal and the active power flow to the loads and the power factor values that remain at acceptable values, which gives the guarantee for the continuously of feeding loads at various wind speeds which are within the limits of cut in and cut out speed value.

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Appendix

Table: Wind Turbine Generator Data

Generator Data	Value
Apparent Power	1750 KVA
Rated Voltage	570 Volt
Frequency	60 Hz
Active Power	1500 KW
Rated Current	2450 Ampere
Speed	1800 r.p.m
No. of Poles	4
Power Factor	0.90
Efficiency	97%
Moment of Inertia	25.0 kg.m2