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Using Pitch and STATCOM Controllers in Variable Speed Wind Turbines for Improving Power Quality and Low Voltage Ride-Through

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Abstract

With regard to their simplicity and high certainty for electricity production, wind power plants in power system play an important role in supplying energy, hence controlling wind turbines has attracted many attentions during recent years. For accessing to an acceptable level of certainty we should apply special controlling strategies in a way that not only respond to consumers' demands in normal condition but also do the same in oscillation times such as changes in atmosphere and load. In this research we have used Pitch and STATCOM controllers in wind turbine variable speed Doubly Fed Induction Generators (DFIG), which improve system stability. The results indicate that using STATCOM controller would improve the LVRT capability and would preserve correct performance of connected to grid DFIG wind turbines. In this research we have two wind turbines 2MW connected to grid in IEEE standard 9 bus simulated through MATLAB/SIMULINK package.

Keywords: DFIG, Pitch Angle, STATCOM, LVRT.

1. Introduction

With regard to ever increasing demand for energy and termination of fossil fuels, every day we witness a new technology in using renewable sources of energy. Renewable energies play an important role in supplying energy demands during recent decades. This is specially highlighted when there is a shortage in supplying power in power plants with fossil fuels. Nowadays with the developments in technology and controllers we can overcome to the oscillations resulting from weather condition and short connections. Much has been done in this regard during recent years.

In refer [1] using capacitor and STATCOM in a fixed speed wind power plant was suggested to improve the quality of grid power. From among the major reasons of wind grid power cut off we can name voltage changes (high or low voltages) in connected to grid bud. With regard to the fact that low voltage in the bus depends on the share of connected reactive power grid, through STATCOM and capacitor bank they tested the effect of injection or absorption of reactive power to the grid. In refer [2] the fixed model of wind turbine pitch angle was studied. The aim of was to develop a fixed pitch angle for wind turbines, which identifies mechanical power, turbine torque and transferring power of induction generators. Mali studied grid voltage drop in wind turbines with power instruments. With the existence of grid voltage drop there was a lack of harmony between produced powers and delivered one. Through studying some standards for connecting wind turbines to local grids in fault times they examined system power using different methods like electronic convertors. Studies had showed that during grid voltage drop if power instrument have the capacity to inject reactive power to the grid to preserve its voltage the system will be stable[3] . Since fixed speed turbines cannot control their reactive power and since doubly fed induction generators disable to completely control transient oscillations [4], hence maintaining a real and reactive power balance in a grid is very important. One of the main strategies for maintaining real and reactive power balance is to use complimentary compensators in the grid. Compensators are generally designed according to power electronic technologies, which compensate real and reactive power through recognizing shortage or excess of them and normalize the grid condition as far as possible [5].

During fault time, the balance between inflow and outflow of power will be disturbed. After reaching to a balance Low Voltage Ride-Through (LVRT) if we want to maintain correct performance of wind turbines during fault time, to have more suitable voltage profile and to improve grid transient respond we can use a Static Compensator (STATCOM) in the grid [6]. In this paper first we have studied wind turbines then we have studied pitch angle controllers; in the third section we have studied the structure and performance of STATCOM and finally in the fourth section we have discussed simulation and presented the results.

2. Wind turbines

Controlling strategy is discussed in two kinds of turbines: fixed speed and variable speed wind turbines [7]:

2.1. Fixed-Speed Wind Turbines

Fixed-speed wind turbines were mainly used up to 1990; they are also of widespread use in today’s common systems. In these turbines there is only a fixed speed that is optimal for the turbines but generally we cannot use maximum of wind capacity. The change in wind velocity will effect oscillations in mechanical torque and then electrical power of the grid [8]. From the advantages of this turbine we can name its simplicity, reliability and low cost of its electrical pieces and from among its disadvantages we can name uncontrollability of reactive power consumption and the decrease in power quality. Figure (1) shows an example of this kind of turbines. In such turbines for grid connection soft installation is used.

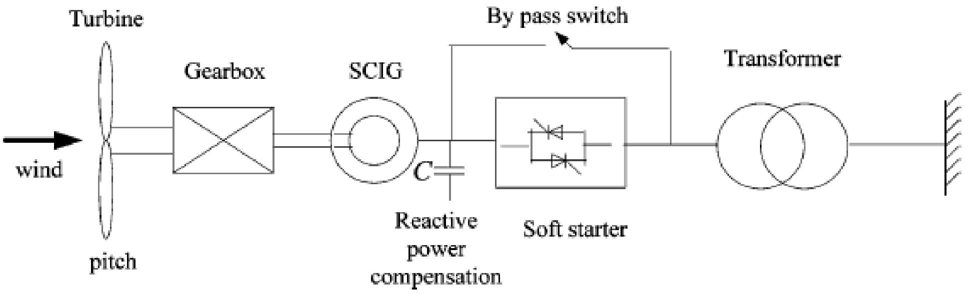

Figure. 1. Fixed-speed wind turbine

2.2. Variable Speed Wind Turbines

The gradual innovations in the technology of turbines had led to Variable Speed Wind Turbines, which is basically for regulating power in wind turbines [9]. The aim of designing this turbine is to obtain maximum aerodynamic productivity, maximum power and to decrease mechanical loads of wind turbines [10]. In this kind of turbines the induction generator does not connected directly to the grid, but it is generally connected through a power converter; an example of such turbines is shown figure (2). Power mode system of variable speed wind turbines DFIG is a back to back converter (AC/DC/AC) based on pulse width, which is connected between grid and generator in series. For grid side and generator side IGBT/DIODE converter is used in which generator side converter acts as rectifier and grid side converter acts as inverter. A capacitor is used between these two converters, which acts as a DC voltage source [11]. These converters should be designed and manufactured in proportion to generator power to transfer maximum stator power [12].

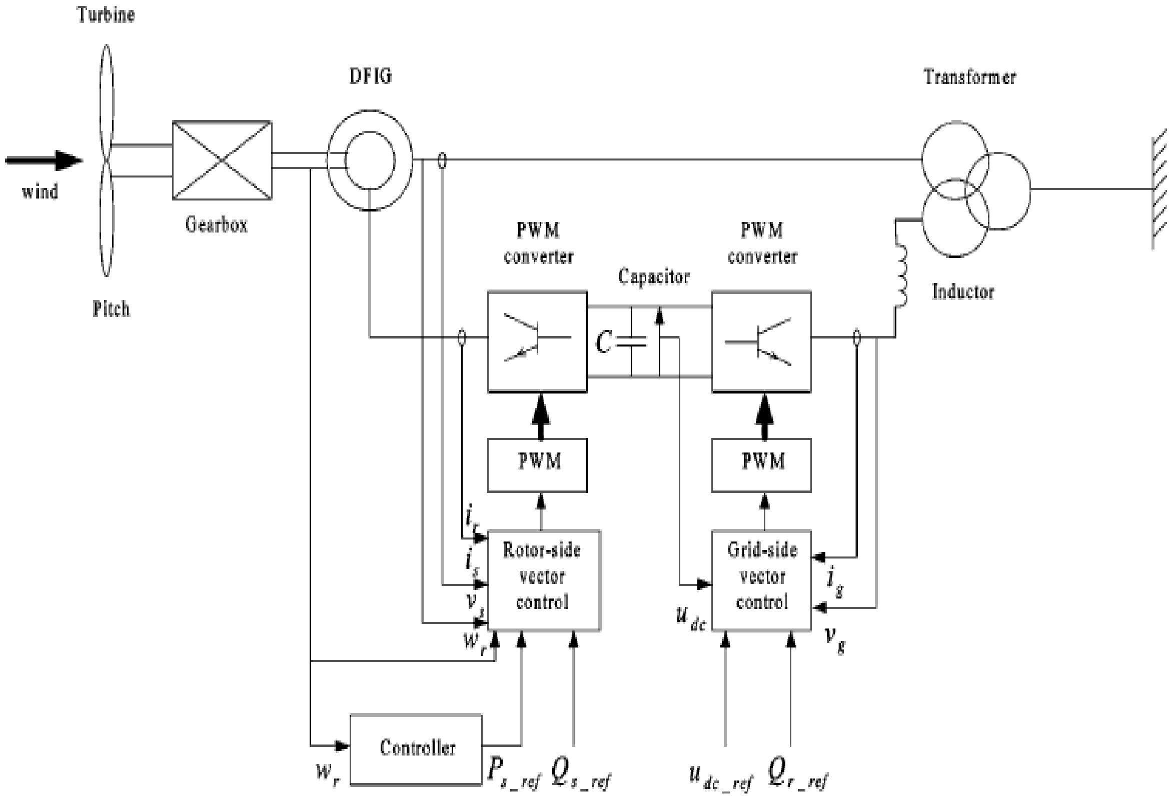

Figure.2. Variable speed wind turbines (DFIG)

3. Blade pitch angle

Controlling systems play an important role in nowadays' modern wind turbines. Today, designing controller for wind turbines is an important issue for the engineers. For optimal use of wind energy the blades must be installed perpendicular to wind direction. For attaining to this goal we need a controlling system to continuously regulate roller blades in wind direction. The function of pith angle controller is to regulate wind contact angle with the blade in different wind velocities. This system is often of hydraulic kind, which is done in turbine gearbox and the change in blade angle is due to oil pressure.

3.1. Controlling blade pitch angle based on PID controller

One of the ways of controlling wind turbine power is to change turbine blade angle proportionate to the change in wind velocity. For this reason different methods like PI and PID controllers [12] have been used for controlling wind turbine power. Integral proportion controller is a derivative for improving dynamic response and or for deleting permanent fault. Figure (3) shows the control system of blade pitch angle based on PID controller used in wind turbines.

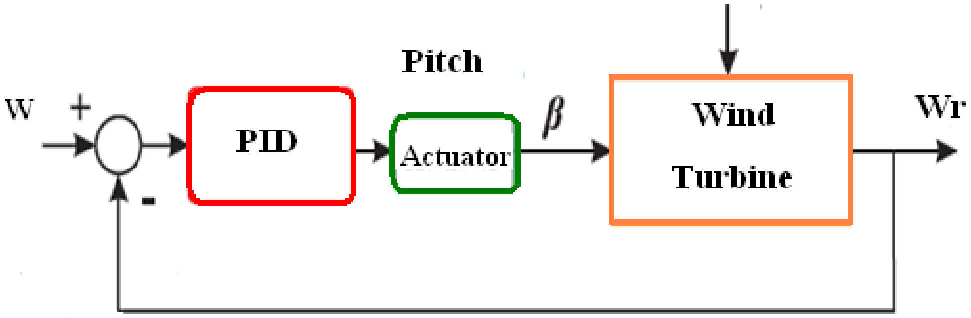

Figure.3. controlling pitch angle through PID

For controlling the position of wind turbine blade, PID controller changes way that rotor velocity is fixed on W_{ref} mode. A feedback is received from turbine velocity, which is subtracted from reference velocity, then the difference is sent to PID controllers to obtain turbine blade angle, which is finally resulted in rotor velocity. Rotor velocity error is considered as controller entrance and the change in blade position angle is defined as controller exit.

3.2. The area of pitch angle performance

Figure (4) shows the curve of wind turbine velocity power and performance in different areas [7]:

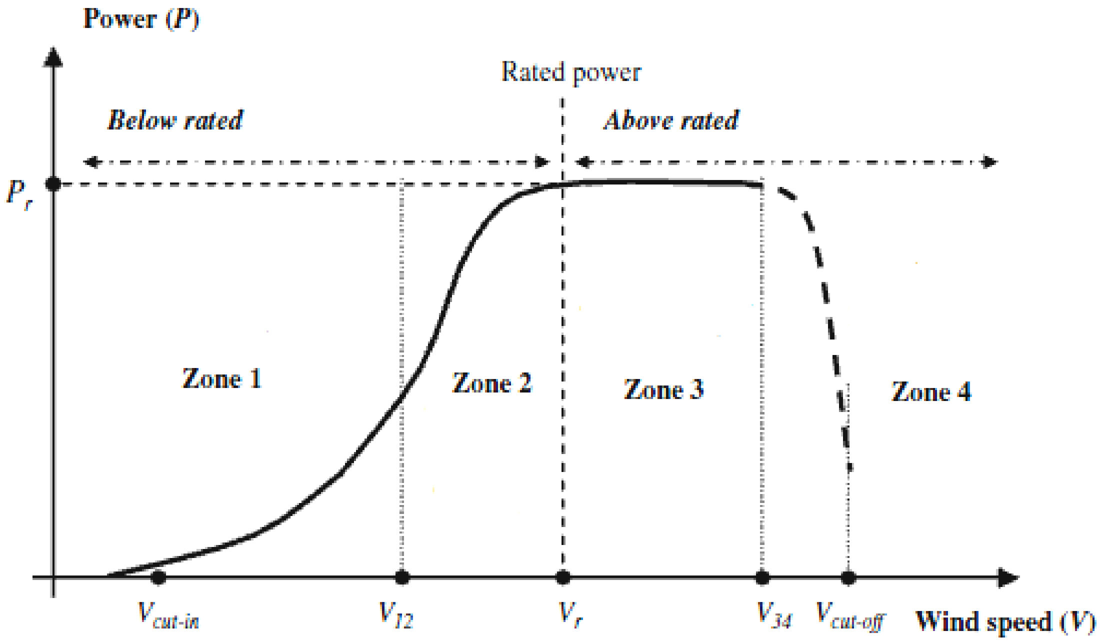

Figure.4.The curve of wind turbine velocity power and performance in different areas [7]

Wind turbines start from cut in speed and produce electricity up to nominal speed of cut out. In the first area (wind speed is lower than cut in speed), which is related to torque controlling the goal is to maximize wind turbine aerodynamic efficiency in such condition the turbine is not operated because its production power would be lower than its losses. Second area or partial load area (wind speed between cut in and nominal speed) is related to the transfer of wind turbine power with average speed. The main controlling goal in this area is to obtain maximum power through rotor speed regulation, while blade pitch angle is fixed in its optimal value (nearly close to zero). Third area (wind speed is between nominal and cut out speeds) in which wind speed is beyond nominal value, hence due to electrical limitations and for avoiding turbine damage in this area the exit power should be fixed in its nominal value. In this area the controlling goal is to regulate rotor speed in nominal speed limit and fixing power in its nominal value through controlling blade pitch angle. Many controlling methods of wind turbines are done in this area. Fourth area (wind speed is higher than cut out speed) is a developed area; in this area for preserving turbine, power is not generated and turbine is not operated. Sometimes for dealing with such problem rotor speed and load limitations are considered [13].

4. STATCOM

In the area of power electronic instruments we have witnessed important developments during recent decades, which have led to manufacturing flexible AC transfer system; this system increases power and voltage controllability for increasing productivity and stability. STATCOM is one of the parallel controllers used for voltage regulation and improving system stability through the injection or absorption of reactive power [14].

The produced or absorbed power by the STATCOM depends on the capacity of voltage source capacitor. Voltage stability is referred to a potential of power system, which keeps the voltages of power system buses in a defined limit both in stable mode and after voltage oscillations. A power system will suffer from instability or voltage sag when there is a change in the condition of a system in a way that leads to voltage uncontrollability. The main factor of voltage instability is inability to keep balance between active and reactive production and consumption power of the system. By keeping balance we mean entrance mechanical power to the turbine is equal to the exit electrical power of the generator [15].

Convertors used in this compensator supply the required reactive power and its exit can be regulated constantly. Accordingly when there are a lot of changes in power grid voltage we use STATCOM to overcome such oscillations. The main goal of this compensator is to control reactive power and supplying back up voltage during fault times. One of the main advantages of STATCOM for penetration to average voltage grids is the increase in the use of diverse production resources such as wind and solar energy, which controls voltage of reactive power by relatively small capacitors through creating a DC link voltage and after modulation by an inverter [16]:

4.1. The Basis of STATCOM Performance

The circuit structure of STATCOM, which is shown in figure (5), includes a transformer, voltage source convertor, and DC link which is connected parallel to grid and can exchange reactive power with power system [14].

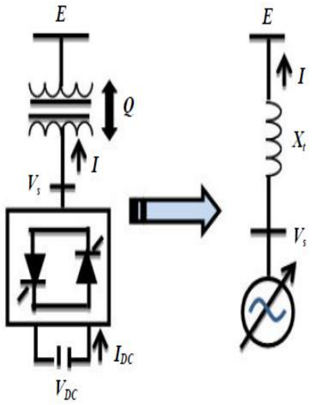

Figure. 5. STATCOM circuit structure

If a voltage resource converter is just used as a compensating reactive power, DC resource can be replaced by a small DC capacitor. In this case the exchanging power between AC and DC system is just reactive power. In this mood the converter charges the capacitor and keeps the voltage at the required level. The converter absorbs some active power from AC system and uses it to compensate the internal losses and to keep the capacitor voltage at the required level. V-I characteristic is shown in figure (6); if the voltage produced by STATCOM is lower than system voltage, STATCOM would act as a self-load and absorb reactive power from the system, but if it acts as a parallel capacitor and inject reactive power to the system, its voltage must be higher than system voltage; when system voltage is equal to STATCOM voltage, reactive power will not be exchanged.

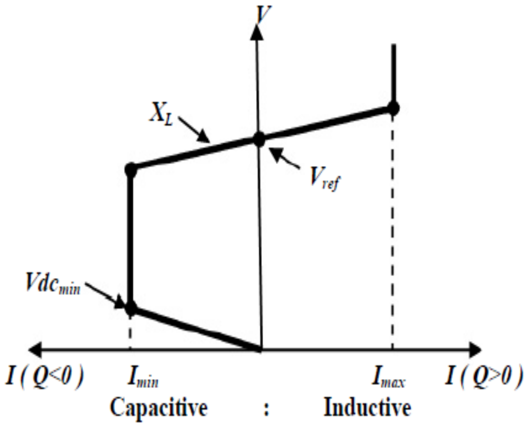

Figure. 6. V-I characteristic [14]

The position of STATCOM between two buses is shown in figure (7). The additional damping provided by a STATCOM is first evaluated for a single machine infinite bus (SMIB) system the equivalent circuit of the system is shown in Fig7, where $X1$ represents the equivalent reactance between the machine internal bus and the STATCOM bus k, and $X2$ represents the equivalent reactance between bus k and the infinite bus. In Fig7, the STATCOM is represented by a reactive shunt current source for given machine internal voltage ($E \angle \delta$) and infinite bus voltage ($V \angle 0$), the information parameters **(**Nomenclature) in the table (1). The value of produced voltage by STATCOM is obtained through the following equation:

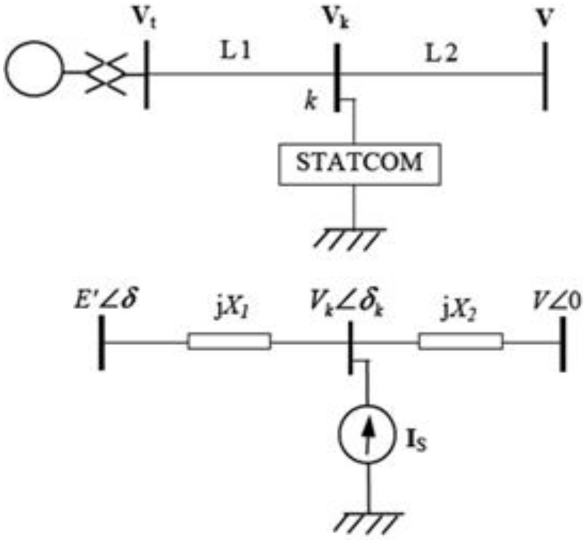

Fig.7. position of STATCOM between two bus

$$V_K = \frac{E' X_2 Cos(\delta - \delta_K) + V X_1 Cos\delta_K}{X_1 + X_2} + \frac{X_1 X_2}{X_1 + X_2} I_S \quad (1)$$

$$\delta_K = \tan^{-1}\left(\frac{E' X_2 Sin\delta}{V X_1 + E' X_2 Cos\delta}\right) \quad (2)$$

The active and reactive exchanged power between AC system and voltage resource convertor is as following:

$$Q = \frac{V_{out}^2 - V_{out} V_{ac} Cos a}{X} \quad (3)$$

$$P = \frac{V_{ac} V_{out} Sin a}{X} \quad (4)$$

Tale.1. The information of parameter's

V_{ac}	V_{out} AC Output Voltage System Bus Voltage P Active Power Q Reactive Power δ Load Angle δ_k	AC

Critical Clearing Angle
α
Firing Angle
and V
δ Angle between E
E
Voltage range
X
Reactance of the branch
V Machine
Voltage infinite-bus

5. Simulation and result of the system under study

The simulation model of wind turbine system is shown in figure (8). The required information for different equipment used in MATLAB/SIMULNK is summarized in table (2).

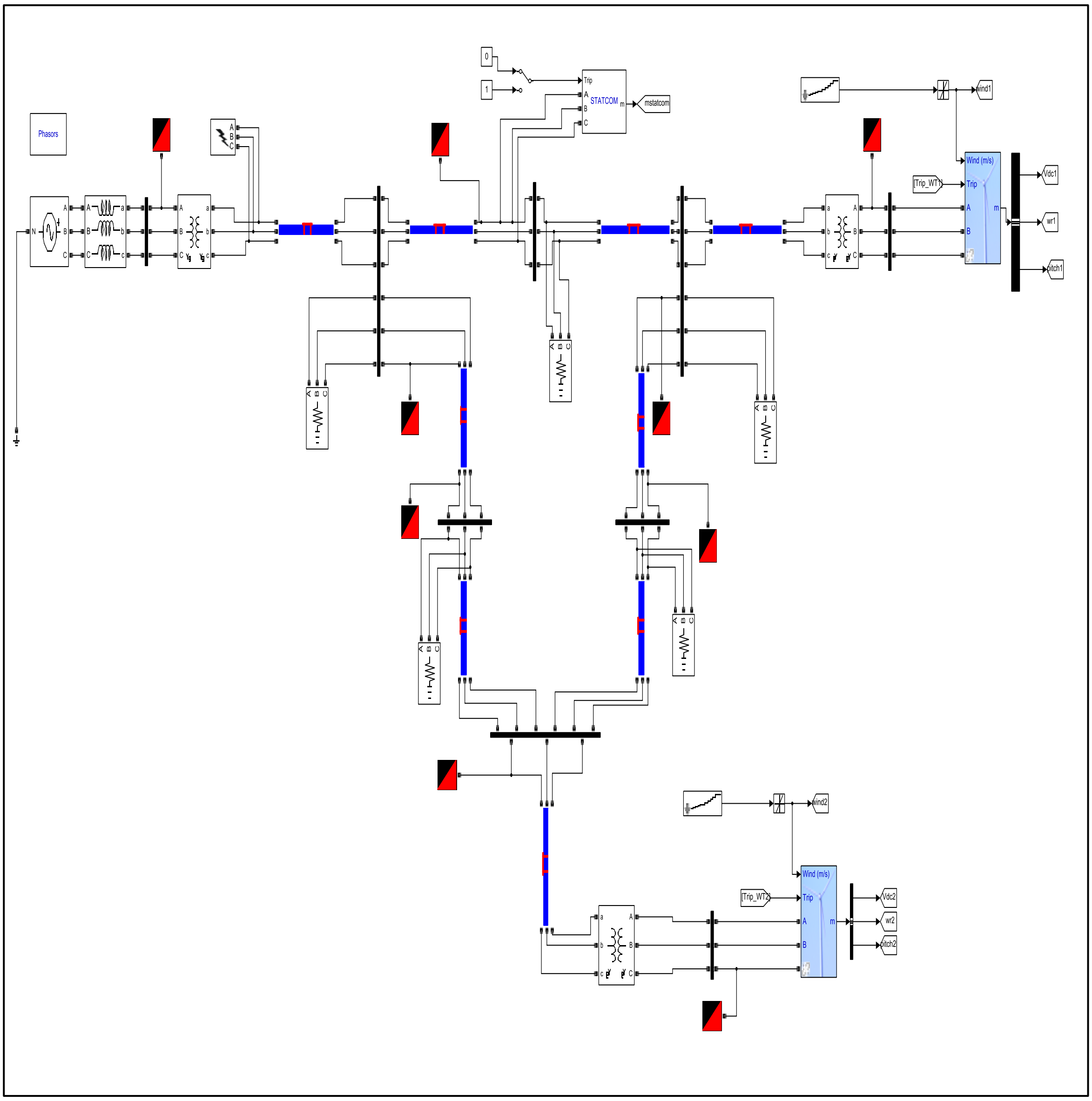

Figure. 8. The system under study with controllers

Tale.2. The required information for the system study

Wind turbine	Prate=2/.97MW , Vrate=575v, Wind rate=12m/s f=60Hz, Rstator =0.00706 pu , Rrotor=0.005pu Lstator=0.171 pu, pu Lrotor=0.156, Lm=2.9 pu, DC bus= 1200v, capacitor=6*10000e-6, 132kv,2500MVA,T1=132/20KV, T2=575/20KV LOADS,L1=L2=L3=L4=L5=500KV
Pitch angle(PID)	Maximum Pitch angle=45 deg Kp=200 Ki=100 Kd=50
STATCOM	V_{ref}=1pu , Rstat =0,0073pu, Xstat =0,22pu, Cstat =1,125mF, Vdc =4000, Vac gain,kp=5,ki=100, Vdc gain,kp=.0001,ki=.02, Current gain,kp=.3,ki=10,kf=.22

In this case, only the pitch control is used to try to achieve the LVRT of wind farm based DFIG. After the fault, wind farm absorbs more reactive power from the weak system, which condition may lead to the terminal voltage continue to decline and the voltage cannot recover to its normal level. Figure (9) shows the suggested wind speed; the basic considered wind velocity for wind turbine is 12 m/s. With the increase in wind velocity the obtained power from turbine will exceed nominal value and this could endanger different mechanical parts. Hence for controlling power and velocity of wind turbine rotor in high speeds pitch controller will be used. Pitch controller efficiency, active power and rotational speed of turbine rotor are shown in figures (10), (11) and (12) respectively. In controlling system of pitch angle whenever wind velocity is lower than 12 m/s, rotor speed will be lower than reference velocity and the position of pitch angle will be fixed in zero to optimize system for energy production; and when it is higher 12 m/s, rotor speed will exceed reference velocity. Hence, for keeping rotor velocity and turbine production power by controller, pitch angle will be fixed in nominal value.

In this case, only the STATCOM is considered to achieve the LVRT of wind farm based DFIG The STATCOM can provide necessary reactive power to maintain the constant voltage at wind generator terminal as shown in Fig.13.And reactive power that wind farm absorbs from the weak system is less than the one only using the pitch control. It can prove that the method using STATCOM in wind farm not only can supply reactive power to maintain the terminal voltage but also can improve the wind farm transient stability during fault occurred. When there is no fault in the system the value of produced active power will be equal to the value of injected active power to the grid. 3-phased fault between bus number 1 and 7 is occurred in the times of 2 and 2.3. Before the fault, voltage of bus 7 is in the nominal value of 1.02pu after the fault, voltage of bus 7 decreases up, which is shown in figure (13). For preventing low voltage a 3 MVAR STATCOM has been used. Hence this bus is located in the middle bus grid it is a desired position for using STATCOM. As you can see in figure (13) with STATCOM the value of voltage is improve which shows a increase of 9 percent in voltage.

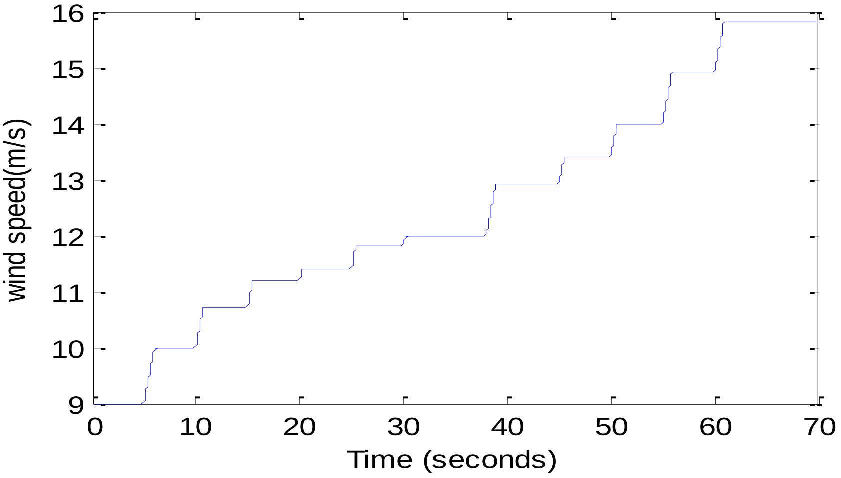

Fig.9. Suggested speed model for wind turbines

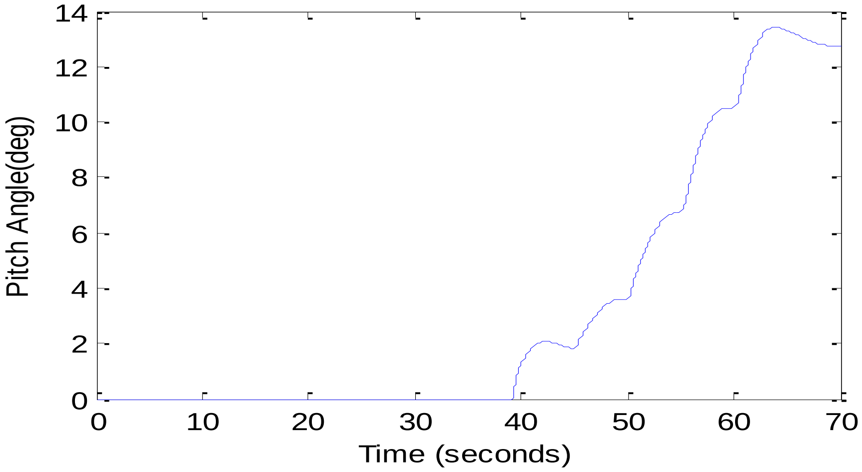

Fig. 10. The changes in pitch angle

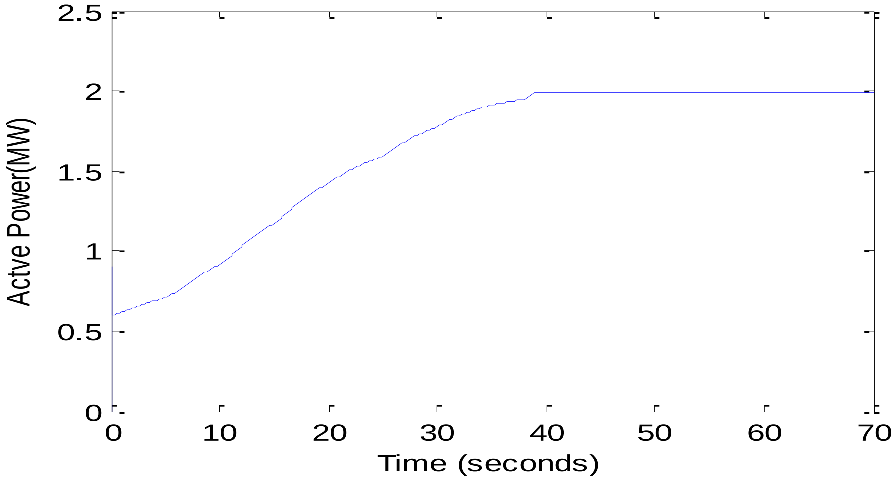

Fig.11. controlling wind turbine production power through pitch angle

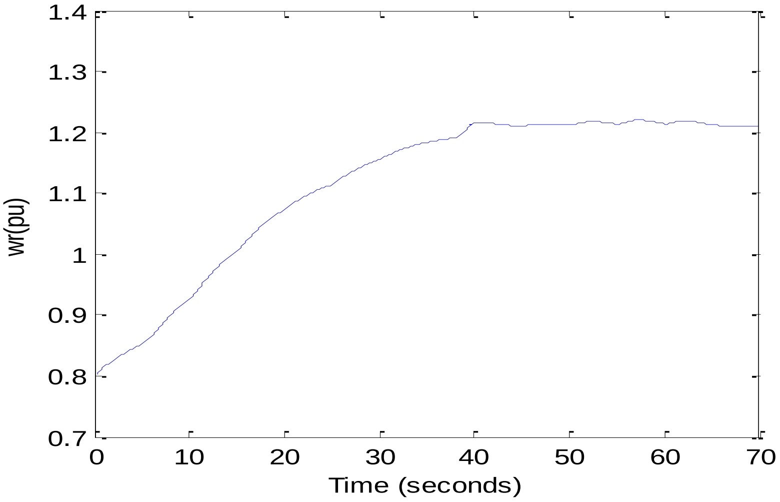

Fig.12. rotational speed of turbine rotor

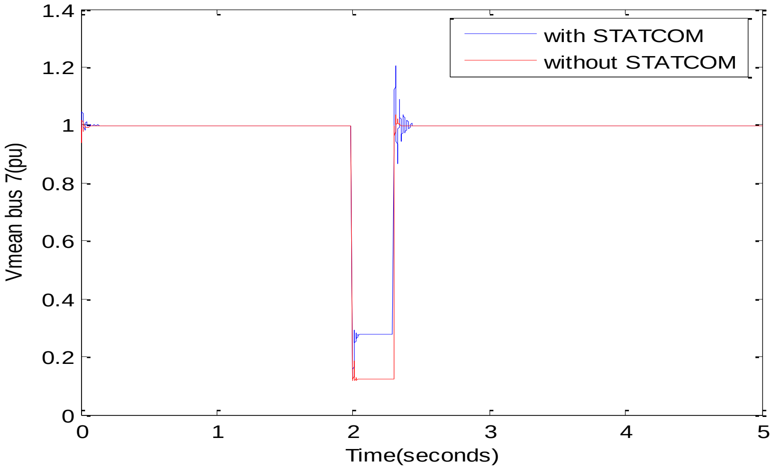

Fig.13. voltage (bus 7) without STATCOM and with STATCOM

6. Conclusion

In this paper for improving power and preventing LVRT we have used pitch and STATCOM controllers in wind turbines. As it is seen pitch controller plays an important role in fixing rotor speed and production power of wind turbines. For preventing voltage sag and for correct performance of grid turbines and for improving transient stability in power system STATCOM controller is used in middle bus. For control the power and speed of the high wind speeds, a PID-based controller proposed. In this controller, the turbine rotor speed is given feedback and is reduced from the reference speed, and the difference between them is given to the PID controller, to the optimum Pitch angle of the turbine and speed the rotor. The rotor speed error is the controller input and the pitch angle changes as output controller. In order to protect the wind turbines connected to the network at the time of the fault and the continuous operation of the network, the STATCOM controller was used to compensate for the voltage through the reactive power injection in the network connected to the network and the LVRT voltage reduction was used. As it is seen with the presence of STATCOM, voltage sag shows a increase of 9 percent. The obtained results indicate an improvement in the transient stability of the power system and an increase in safety and reliability of the system.

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