International Journal for Modern Trends in Science and Technology
Volume: 03, Issue No: 04, April 2017
ISSN: 2455-3778
http://www.ijmtst.com

A Frame Work for Control of Gird Connected Wind Power Using Two Layer Control

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To Cite this Article
V.Sarath Kumar, D.Rupesh, K.Prudhvi Raj, Ch.Prasanth Kumar, K.Manasa, A.Jawahar, Ch.Rajyalakshmi and Ch.Vishnu Chakravarthi, "A Frame Work for Control of Gird Connected Wind Power Using Two Layer Control", *International Journal for Modern Trends in Science and Technology*, Vol. 03, Issue 04, 2017, pp. 45-52.

ABSTRACT

Recently, several large-scale wind generation projects have been implemented all over the world. It is economically beneficial to integrate very large amounts of wind capacity in power systems. Unlike other traditional generation facilities, using wind turbines present technical challenges in producing continuous and controllable electric power. With increase in contribution of wind power into electric power grid, energy storage devices will be required to dynamically match the intermitting of wind energy. When wind turbines are connected to a grid, they should always maintain constant power. In order to maintain constant active power, the use of Doubly-Fed Induction Generators (DFIG) with Energy Storage System (ESS) like super capacitor (or) batteries can be used, with a two layer control scheme. In the two layers control there is a high-layer controller known as Wind Farm Supervisory Control (WFSC), which generates the active power (P), Stator Power (Ps), Energy storage power (Pe), DC voltage (Vdc) etc., references for the low-layer WTG controllers. The low-layer controller has two different controls i.e., Grid side controller (GSC) and Rotor side controller (RSC) which are used to control the AC/DC/AC converters of DFIG wind turbines and to generate the desired active power demand specified by the grid operator. Simulation is carried out in Matlab to evaluate the performance of wind farm equipped with 15 DFIG wind turbines with and without ESS to provide a constant active power of 36MW.

KEYWORDS: *Wind Energy, DFIG, Active Power, reactive power, Two layer control*

I. INTRODUCTION

In recent years with growing concerns over carbon emission and uncertainties in fossil fuel supplies, there is an increasing interest in clean and renewable electrical energy generation. Among various renewable energy sources, wind power is currently the fastest growing form of electric generation. Although wind power currently only provides about 3% of European electricity and 2% of the U.S.'s electrical energy demands, it is reasonable to expect a high penetration of wind power into the existing power system in the near future, e.g., by 2030.With the rapid increase in penetration of wind power in the power system, it becomes necessary to require wind farms to be have as much as possible as conventional power plants to support the network active power, voltage and frequency.

Modern variable-speed wind power systems, predominantly based on the Doubly-Fed Induction Generator (DFIG) technology[1], are equipped with back-to-back, AC/DC/AC power electronic converters whose intermediate DC voltage and excellent controllability renders them technically attractive to incorporate energy storage devices such as a flywheels, super capacitors, batteries, etc., it is shown that a DFIG-based wind-power/storage system can deliver pre-specified amount of power to the grid, despite windpower fluctuations. In this work a wind farm equipped with doubly-fed induction generator (DFIG) wind turbines, where each WTG's is equipped with a super capacitor energy storage system (ESS) to maintain constant active power control to the grid. Two different control schemes are developed one for Rotor side control (RSC) using stator flux reference frame and the other for Grid side control (GSC) using current reference frame are developed to provide the firing pulses to the converters. A wind farm supervisory control (WFSC) is developed to generate the active power reference to the RSC and GSC. WTG controllers then regulate each DFIG wind turbine to generate the desired amount of active power, where the deviations between the available wind energy input and desired active power output are compensated by the ESS.

Simulation is done in Matlab for the grid connected wind farm, the wind farm consists of 15 DFIG wind turbines each with 4MW capacity at different and constant wind speeds. A constant active power P_{ref} is taken at 38MW which can be specified by the grid operator and the wind farm has to supply this constant active power. Simulation results are studied for the active power supplied by wind farm with and without Energy Storage System (ESS). Here we can observe that with ESS the active power supplied by wind farm is almost constant.

II. Doubly-Fed Induction Generator Systems

For variable-speed systems with limited variable-speed range, e.g. ±30% of synchronous speed, the DFIG can be an interesting solution. As mentioned earlier the reason for this is that power electronic converter only has to handle a fraction (20–30%) of the total power. This means that the losses in the power electronic converter can be reduced compared to a system where the converter has to handle the total power. In addition, the cost of the converter becomes lower. The stator circuit of the DFIG is connected to the grid while the rotor circuit is connected to a converter via slip rings. DFIG system with a back-to-back converter can be seen in Fig. 1.

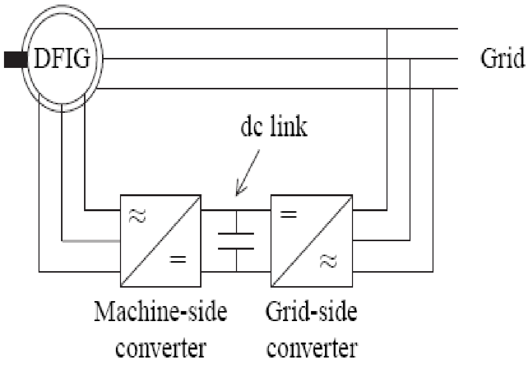


Fig 1 DFIG system with a Back to Back Converter

The back-to-back converter consists of two converters, i.e., machine-side converter and grid-side converter that are connected "back-to-back." Between the two converters a dc-link capacitor is placed, as energy storage, in order to keep the voltage variations (or ripple) in the dc-link voltage small. With the machine-side converter it is possible to control the torque or the speed of the DFIG and also the power factor at the stator terminals, while the main objective for the grid-side converter is to keep the dc-link voltage constant. The speed–torque characteristics of the DFIG system can be seen in Fig.3.4, as also seen in the figure, the DFIG can operate both in motor and generator operation with a rotor-speed range of $\pm\Delta\omega_{max}r$ around the synchronous speed, ω_1.

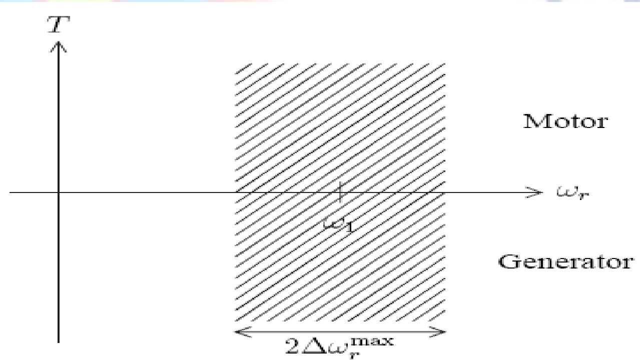


Fig 2 Speed-Torque Characteristics of DFIG

A typical application, as mentioned earlier, for DFIG is wind turbines, since they operate in a limited speed range of approximately ±30%. Other applications, besides wind turbines, for the DFIG systems are, for example, flywheel energy storage system, stand-alone diesel systems, pumped storage power plants, or rotating converters feeding a railway grid from a constant frequency public grid.

2.1 Modeling of the Wind-Turbine Doubly-Fed Induction Generator

The wind turbine and the doubly-fed induction generator are shown in Fig3. The AC/DC/AC converter is divided into two components, the rotor-side converter (C_{rotor}) and the grid-side converter (C_{grid}). C_{rotor} and C_{grid} are Voltage-Source Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source. A coupling inductor L is used to connect C_{grid} to the grid. The three-phase rotor winding is connected to C_{rotor} by slip rings and brushes and the three-phase stator winding is directly connected to the grid.

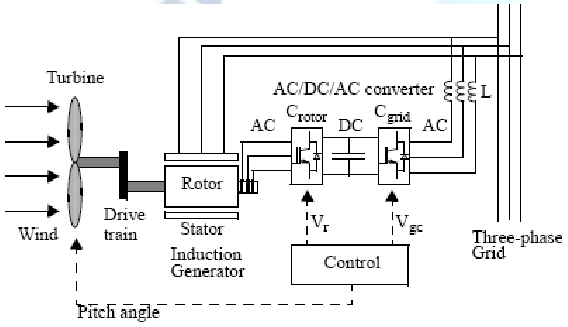


Fig 3 DFIG connected to Wind Turbine

The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The control system generates the pitch angle command and the voltage command signals V_r and V_{gc} for C_{rotor} and C_{grid} respectively in order to control the power of the wind turbine, the DC bus voltage and the voltage at the grid terminals. An average model of the AC/DC/AC converter is used for real-time simulation The DC bus is simulated by a controlled current source feeding the DC capacitor. The current source is computed on the basis of instantaneous power conservation principle: the power that flows inside the two AC-sides of the converter is equal to the power absorbed by the DC capacitor.

III. DFIG WITH ENERGY STORAGE SYSTEM (ESS)

The ESS consists of a super capacitor bank and a two-quadrant DC/DC converter connected to the dc link of the DFIG as shown in figure 4. The ESS serves as either a source or a sink of active power, and therefore, contributes to control the generated active power of the WTG.

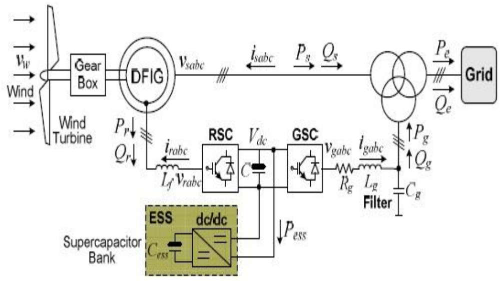


Fig 4 DFIG of Wind Turbine connected with Energy Storage System (ESS)

The dc/dc converter contains two IGBT switches S1 and S2. Their duty ratios are controlled to regulate the active power Pg that the GSC exchanges with the grid. In this configuration, the dc/dc converter can operate in two different modes, i.e., buck or boost mode, depending on the status of the two IGBT switches. If S1 is closed and S2 is open, the dc/dc converter operates in the buck mode; if S1 is open and S2 is closed, the dc/dc converter operates in the boost mode.

The duty ratio D1 of S1 can be approximately expressed as and the duty ratio D2 of S2 is D2 = 1 – D1.

$$D_1 = \frac{V_{SC}}{V_{dc}}$$

Also the nominal dc-voltage ratio Scan/Vdc,n is 0.5, where VSC,n and Vdc,n are the nominal voltages of the super capacitor bank and the DFIG dc link, respectively. Therefore, the nominal duty ratio D1,nof S1 is 0.5.The duty ratio D1 of the dc/dc converter is controlled depending on the relationship between the active powers (Pr)of the RSC and (Pg)of the GSC. If Pr is greater than Pg, D1 is controlled greater than 0.5. Consequently, the super capacitor bank serves as a sink to absorb active power, which results in the increase of its voltage VSC. On the contrary, if Pg is greater than Pr then D1 is controlled less than 0.5. Consequently, the super capacitor bank serves as a source to supply active power, which results in the decrease of its voltage VSC. Therefore, by controlling the duty ratio of the dc/dc converter, the ESS serves as either a source or a sink of active power to control the generated active power of the WTG.

In Fig. 3.9, the reference signal Pg* is generated by the high-layer WFSC.

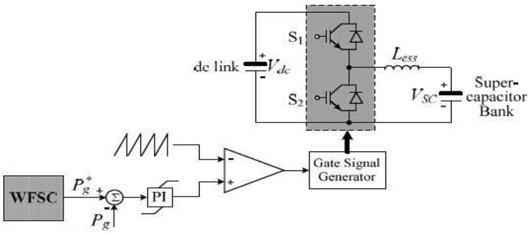


Fig 5 Configuration and control of ESS for DFIG Wind Turbine

3.1 Rotor side controller (GSC)

In the RSC, the independent control of the stator active power Ps and reactive power Qs is achieved by means of rotor current regulation in a stator-flux oriented synchronously rotating reference frame. The overall RSC control scheme is shown in fig 6 consists of two cascaded control loops. The outer control loop regulates the stator active and reactive powers independently, which generates the reference signals Idr* and Iqr* of the d-axis and q-axis current components, respectively, for the inner-loop current regulation. The outputs of the two current controllers are compensated by the corresponding cross-coupling terms Vdr_0 and Vqr_0, respectively, to form the total voltage signals, Vdr and Vqr. They are then used by the PWM module to generate the gate control signals to drive the RSC

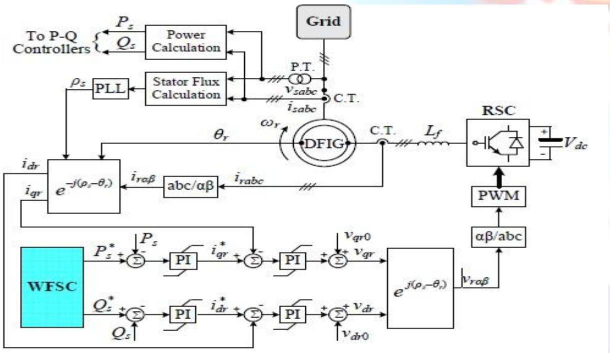


Fig 6 Overall vector scheme of the RSC

3.2 Grid side controller (GSC)

The overall vector control scheme of the GSC, in which the control of the dc-link voltage Vdc and the reactive power Qg exchanged between the GSC and the grid, is achieved by means of current regulation in a synchronously rotating reference frame. The equivalent circuit of grid connected inverter is shown in fig 7.

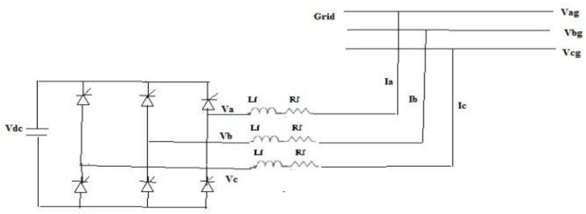


Fig 7 Equivalent circuit of Grid side controller

Again, the overall GSC control scheme shown in fig 8 consists of two cascaded control loops. The outer control loop regulates the dc-link voltage Vdc and the reactive power Qg, respectively, which generates the reference signals idg* and iqg* of the d-axis and q-axis current components, respectively, for the inner-loop current regulation. The outputs of the two current controllers are compensated by the corresponding cross-coupling terms vdg_0 and vqg_0, respectively, to form the total voltage signals, Vdg and Vqg. They are then used by the PWM module to generate the gate control signals to drive the GSC.

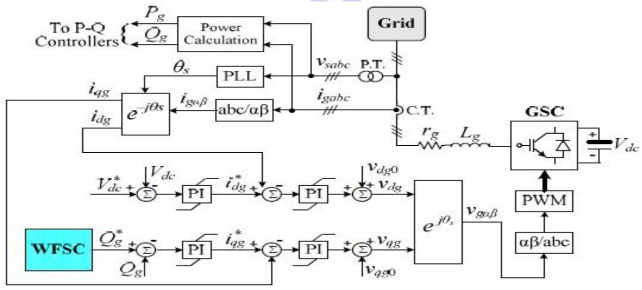


Fig 8 Grid side controller (GSC) scheme

3.3 Wind Farm supervisory control

The objective of the WFSC is to generate the reference signals for the outer-loop power controllers of the RSC and GSC as well as the controller of the dc/dc converter of each WTG, according to the power demands from the grid operator. The reactive power references of the RSC and GSC controllers can be determined by controlling the power factor at the PCC at the desired value, which is not in the scope of this paper. In this work, the reactive power references of all RSC and GSC controllers are simply set as zero.

IV. Simulation Study

Simulation studies are carried out to verify the effectiveness of the proposed control schemes under various operating conditions. Some typical results are shown and discussed in this section. At one end grid is taken as 120kv and it is stepped down to 25kv and it is further stepped down to 575v and is given to different loads. At the other a wind farm is connected which has 15 wind turbines connected to it which each has a rating of 4 MW and 575v. The wind turbines WTG1, WTG6, WTG9 are provided with different wind speeds within the range of 10-14 m/s. And all the remaining wind turbines are provided with constant wind speed of 15 m/s.

Here the simulation is done in order to maintain the real power supplied by the wind farm is to be maintained constant. The constant real power is given as P_{ref} to the wind turbines under different conditions like wind turbines operating without any energy storage system, operating with energy storage system with two layer conventional controllers. The amount of real power that has to be maintained constant i.e., P_{ref} is specified by the grid operator and in this case the power is to be maintained at 36MW.Also we will observe the variations of wind speed and variations in voltages in the energy storage system for WTG1, WTG6, WTG11 and the response of the system for step changes in input power demand given by the grid operator.

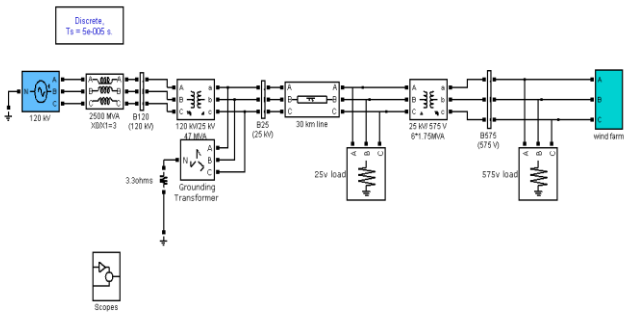


Fig 9 Diagram of Wind Farm connected to Grid

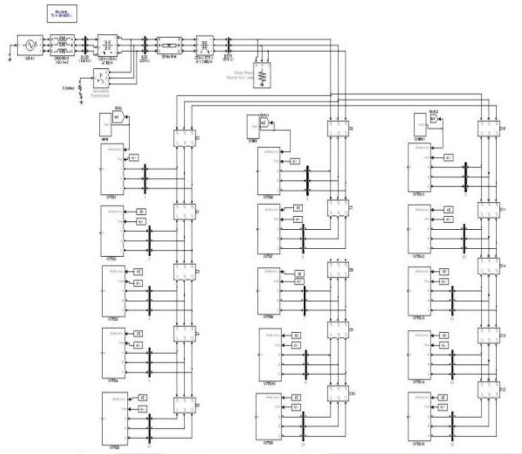


Fig 10 Diagram of grid connected to 15 WTG's

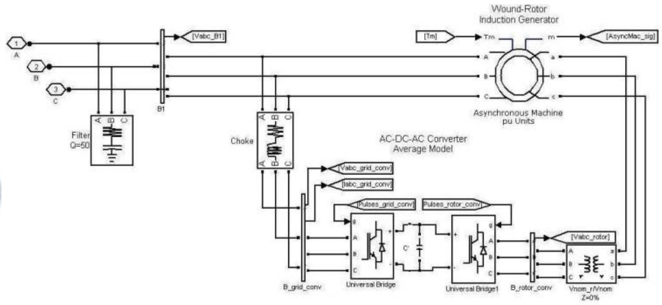


Fig 11 Doubly-Fed Induction Generator (DFIG) of wind turbine

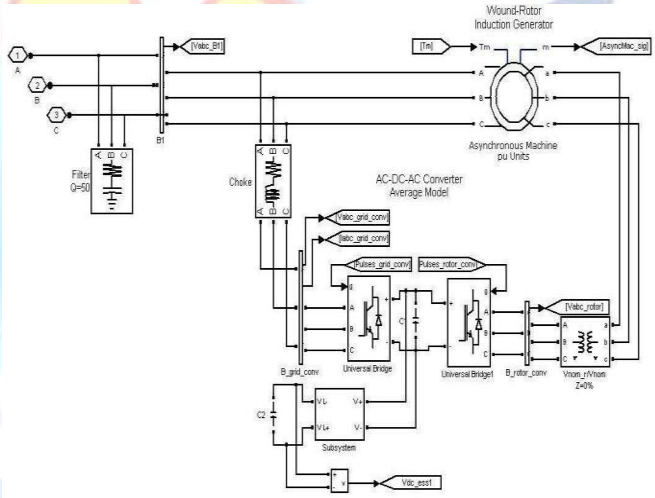


Fig 12 Doubly-Fed Induction Geneerator (DFIG) wind turbine with Energy storage

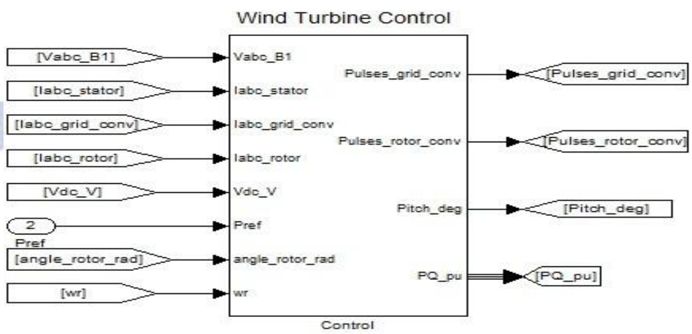


Fig 13 Control structure for Wind Turbine

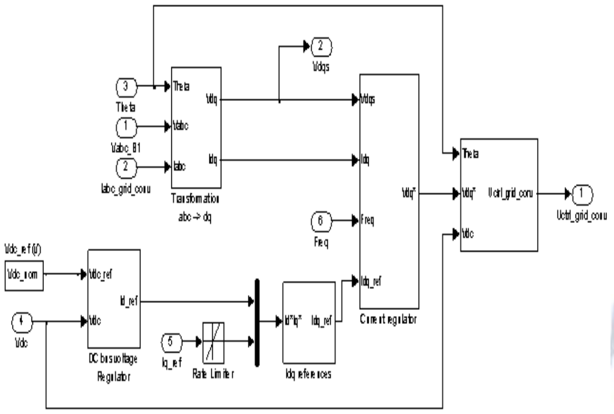
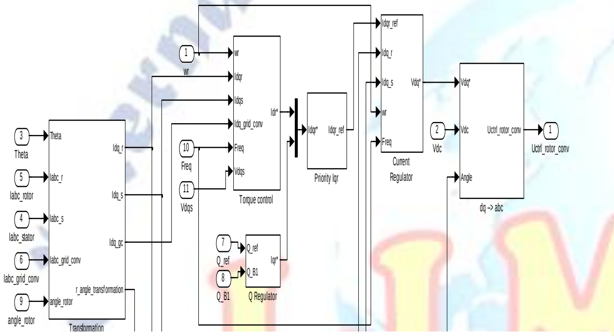


Fig 14 Grid side Control



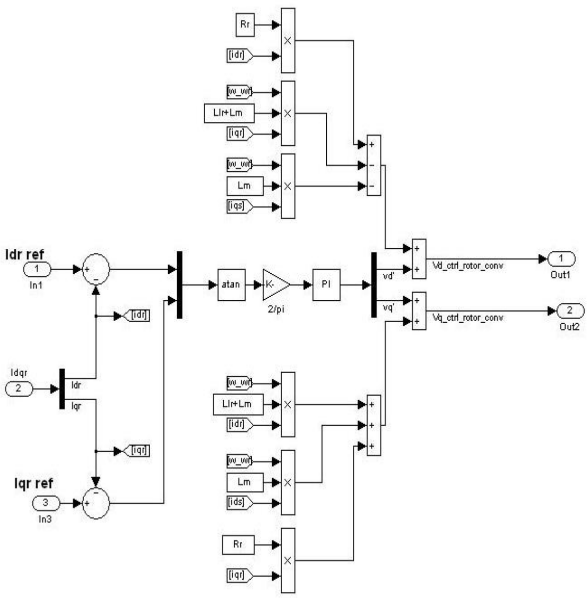


Fig 15 Grid side control Current regulator

Fig 16 Rotor side control

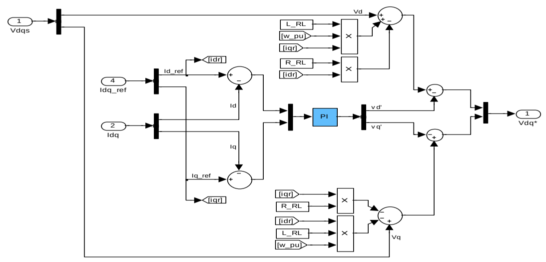


Fig 17 Rotor side current regulator

Figure 6.1 shows the grid is connected to a wind farm, fig 17 shows that 15 WTG's are connected in the wind farm. Figure 6.3 and fig 6.4 shows a Doubly Fed Induction Generator (DFIG) of a wind turbine connected without and with Energy storage System (ESS). Figure 6.5 shows the control architecture of wind turbine to which the voltage, current of the stator, current of rotor, speed and P_{ref} are given from the wind farm supervisory control.

Figure 14 and fig 16 shows the grid side control (GSC) and the rotor side control (RSC) which are designed in chapter 4 to produce the firing pulses to grid and rotor side converters. Figure 15 and fig 17 shows the current regulators used in grid side control and rotor side control.

V. Simulation Results

Simulation results are studied for some operating conditions and are discussed below. A constant active power of 36MW is considered and this power can be specified by the grid operator.

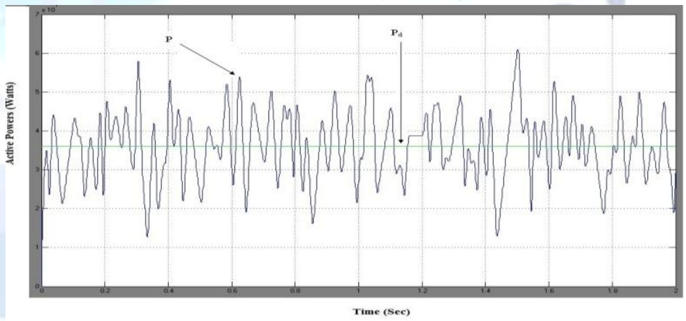


Fig 18 Total power of wind farm without ESS and constant grid power.

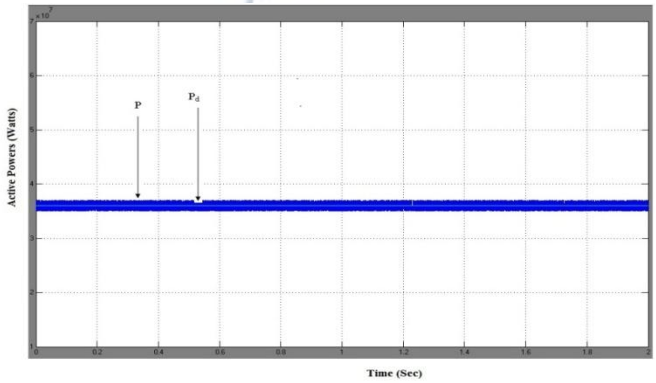


Fig 19 Total power of wind farm with ESS and constant grid power

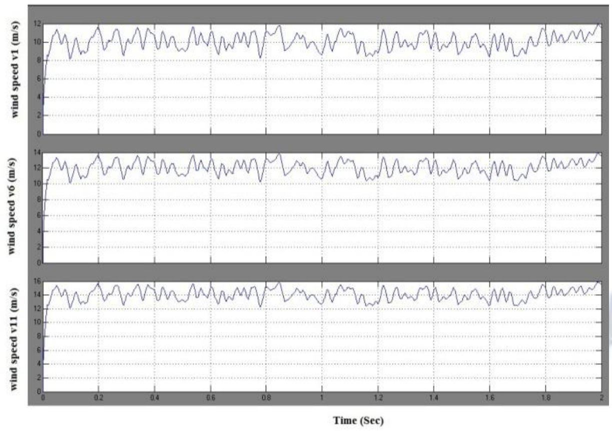


Fig 20 Wind speed variations for WTG1, WTG6 and WTG11

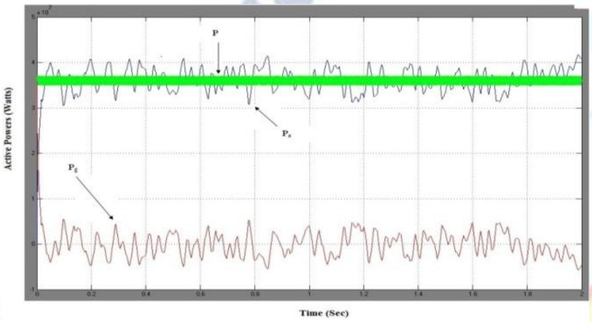


Fig 21 Total active power of stator (Ps), GSC (Pg) and point of common coupling (P)

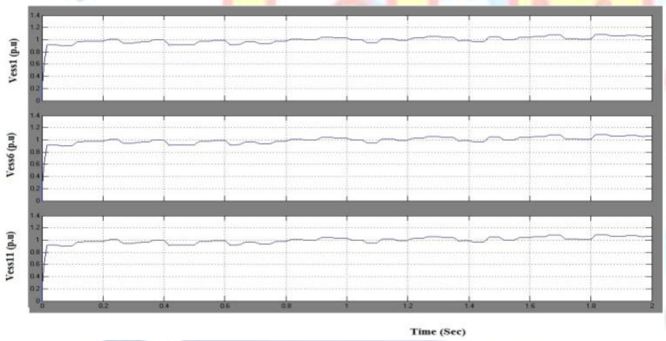


Fig 22 Voltages of super capacitors of WTG1, WTG6 and WTG11

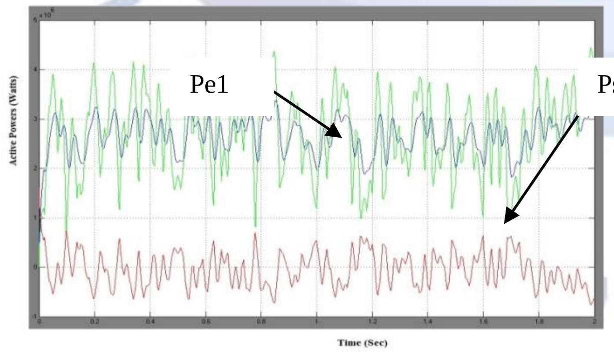


Fig 23 Active powers of WTG1

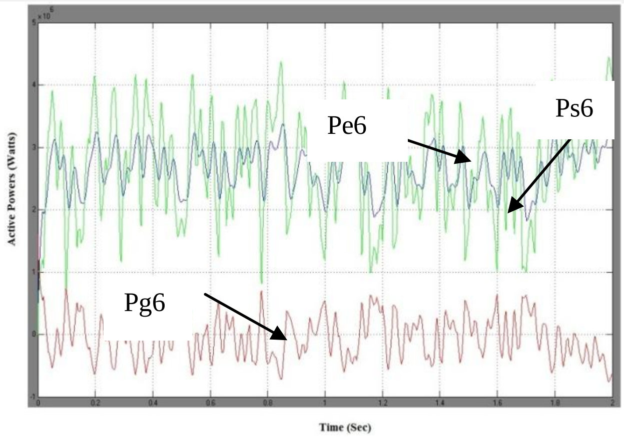


Fig 24 Active powers of WTG6

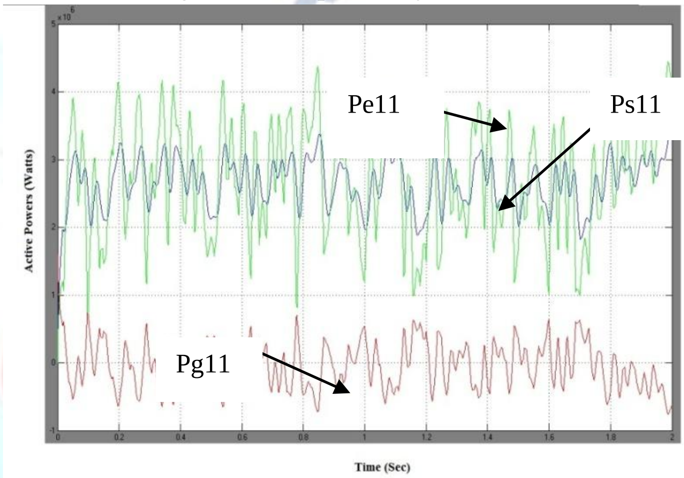


Fig 25 Active powers of WTG11

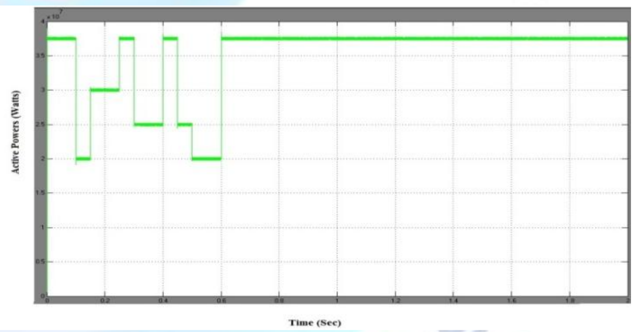


Fig 26 Power tracking of wind farm with step change in grid power

Figure 18 shows the total active power supplied by the wind farm without Energy Storage System (ESS) and the constant grid active power. Here we can observe that the fluctuations are very large the max total active power of wind farm is about 60 MW to min of 1.3MW. Figure 19 shows that the active power supplied by the total wind farm with ESS has fewer oscillations and is near to grid constant power, here the max power is 37MW and min power is 35MW which is very near to the grid power of 36MW.

Figure 20 shows the variations of wind speeds provided to the Doubly-Fed Induction Generator WTG1, WTG6 and WTG11. The variation of WTG1 is in between 8-12 m/s, WTG6 is between 10-14 m/s and that of WTG11 is in between 12-16 m/s. All the remaining turbines receive a constant wind speed of 15 m/s.

Figure 21 shows the total stator active power (Ps) and GSC active power (Pg) and the total power at the point of common coupling of all WTG's (P). Here we can observe that the variations of the stator active power are exactly compensated by the variations of the GSC active power consequently, the total output active power of the wind farm is constant. Figure 6.14 shows the voltages of the super capacitor banks of WTG1, WTG6, and WTG11. These voltages are always maintained within the operating limits of [0.7, 1.1] p.u.

Figure 23 to fig 25 shows the stator power (Psi), and the GSC active power Pgi of WTG 1, WTG6 and WTG11 which are usually not constant. The deviations between the RSC active power and the GSC active power of each WTG are stored in or supplied by the ESS (Pei).

Figure 6.18 shows the power tracking capability of the wind farm, here step changes [38 20 30 25] MW in active power at grid are given as Pref to the wind farms and under these conditions also the wind farm with ESS is able to supply the constant power.

VI. Conclusion

With the penetration of wind energy in power systems it is always necessary to maintain the constant active power of the grid. With wind energy connected to the grid it is difficult to maintain constant power as the wind energy varies continuously with wind speed and makes it difficult to connect to the grid as it affects the total grid power. The development of power electronic devices like AC/DC/AC converters it is possible to use a Doubly-Fed Induction Generator (DFIG) with Energy storage system (ESS) to maintain constant power to the total wind farm and makes it feasible to interconnect the wind farm to the grid.

In the present work, the design of a wind farm is done using 15 DFIG's each producing 3.6MW power. The proposed control strategies for controlling the rotor and grid side converters are also described. The simulation is done with a 120kv grid which supplies a constant power of 36MW which is connected to the wind farm. Simulation results are observed for the power supplied by the wind farm with and without ESS, here observation has been made that without ESS the total power generated by wind farm has high variations compared to the wind farm with ESS where we can observe a constant active power is obtained. With step changes in power at the grid, the power tracking performance of the wind farm generates active power by the wind farm dynamically by tracking the power demand with good precision. This power tracking capability cannot be achieved without using the ESSs or the proposed control scheme. The proposed system and control schemes provides a promising solution to help achieve high levels of penetration of wind power into electric power grids.

Acknowledgment

The authors would like to express their gratitude to Dr.S.V.H Rajendra, Secretary, AlwarDas Group of Educational Institutions, Dr.C.Ghanshyam, Principal for their encouragement and support throughout the course of work. The authors are grateful to Dr.N.C.Anil, Vice-Principal, Sanketika Institute of Technology and Management and staff members for providing the facilities for publication of the paper.

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