Control of DFIG Based Wind Turbine with Hybrid Controllers

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Abstract- There have been a few areas still suffering with the problem of huge power interruptions and power quality problems due to the enormous problems on the grid side and also there exists some areas suffering with lack of grid connection. A solution is required to avoid these power problems and providing grid independency for continuous power supply. The solution and an alternative to the main grid is the microgrid with the utilization of the renewable sources. This paper presents the design of wind turbine system with the usage of Doubly Fed Induction Generator (DFIG) as the power generating system which can be operated in grid-connected mode or in grid disconnected mode based upon the requirement. The DFIG enhances the transfer of power through the stator and also through the rotor, where the parameters like torque, DC link voltage and power of the system have been controlled with the two different hybrid controllers like neural network with PID controller and neural network with the predictive controller. A comparison has been provided between the performance of hybrid controllers in terms of DC link voltage and frequency of the supply. The system was realized and the results have been verified by using MATLAB Simulink.

Keywords: Doubly Fed Induction Generator (DFIG), Neural Network with PID controller, Neural Network with Predictive Controller.

1. Introduction

The utilization of renewable energy sources provides huge advantages like an unrestricted, readily existing and environmentally non pollutant. Especially the integration of renewable sources to the main grid can be called as a micro grid provides reliable, efficient and uninterrupted power supply to the consumers. The micro grid can be operated in islanded mode of operation reducing burden on the conventional grid or can also be operated in connection with the conventional grid providing supply to the grid incase of disturbances in the grid. This enhances the use of microgrid for local areas and obtaining the continuous power supply with the use of different types of energy sources [1].

Among the numerous available sustainable energy sources, the wind energy especially has the advantage of non investment of collecting the source and availability of source everywhere in the universe [2]. But the usage of wind has been existing from the few years with the help of horizontal and vertical axis wind turbine using fixed speed conversion systems [3] which involves the disadvantages of power supply only from the rotor, high mechanical stress, requires larger gearboxes, no controlling of voltage transmitted to grid. This can be reduced with the choosing of variable speed conversion systems which provides the transfer of power with the variation of speed. Among the numerous variable speed systems, DFIG has been chosen which is capable of transferring power through the stator [4-6] and also through the rotor and the power can be utilized efficiently from both sides. But there has to be a converter at the rotor to enable the power flow through the converter and power will be transferred to the stator directly. And to transfer the power at the rotor, two back to back converters named as rotor side converter and grid side converter has been chosen[33]. To enhance the power transfer between the converters, a battery with a DC link capacitor [7-9] has been used utilizing the advantages of the storage system. The transfer of the power has to be controlled to provide reliable power supply providing gate pulses to the converter. So two controllers namely DC link voltage controller and rotor power controller at the rotor side maintains control over the voltage, power transferred. The conventional controller like PID controller can be used for controlling power transfer but it involves certain disadvantages like unstable response, lack of proper tuning and oscillations around a certain operating point [28].

The intelligent controller like fuzzy controller can be used, but again involves disadvantage like restricted inputs, lower speed and longer time for the execution[30]. The neural network can be opted for the system control, but again involves disadvantages like longer time to process and requirement of huge amount of data. With the individual controller [10-15] the system suffers with slower dynamic response, lower efficiency. A hybrid controller with the combination of two controllers like neural network with the proportional-integral-derivative controller providing the performance combination of PID and neural network and neural network with the predictive controller [16-18] providing the performance combination of predictive controller and neural network which improves the performance of the system. The predictive controller provides the prediction of future output data based on present and past input data and output data [30-33]. The predicition will be provided over specified control horizon there by controlling parameters more adequately. Also the predictive controller involves advantages like easier tuning of the variables, requiring smaller computations, controlling over the specified prediction. The hybrid controllers provides the advantages of using two controllers at a time there by providing greater reliability and the proposed two hybrid controllers with the use of neural networks have been used for the DC link voltage controlling [19-21] the voltage across the capacitor and controlling the power through the rotor and also controlling the frequency of the power. Based up on the availability of supply from the stator of wind energy system, it can be operated in combination with the grid connection or it can be operated in standalone mode utilizing the energy storage systems which continuously charges and discharges there by providing uninterrupted power supply[22-29].

The paper is organized as follows: Section 1 presents an introduction to the proposed wind turbine system, Section 2 deals with the block diagram model of the proposed system with different controllers and their mathematical modeling. Section 3 deals with the hybrid controllers and Section 4 deals with the discussion of simulation work and results. Section 5 deals with the conclusions drawn from the proposed work.

2. Block Diagram Explanation of The Proposed Controlled Wind System

The block diagram of the proposed controlled DFIG based wind turbine system has been shown in below Fig.1. It consists of a horizontal axis wind turbine with DFIG consisting of stator and rotor [22-25]. When the turbine generates mechanical energy with the rotation of the blades, the energy will be fed to the DFIG. Then, with the supply of the mechanical energy the electrical energy will be supplied at the stator and rotor terminals.

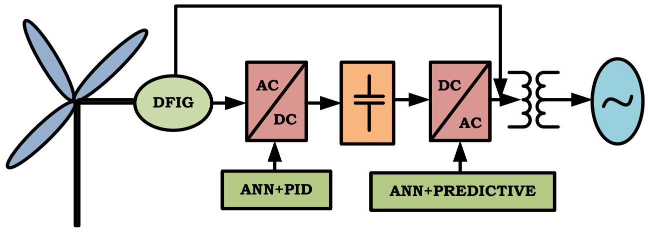

Fig. 1. Block diagram of the controlled DFIG based wind turbine.

The output at the stator terminals will be fed at the point of common coupling through the coupling transformer and the output at the rotor will be fed to the AC-DC converter which converts the AC power into DC power and then stores in the battery and the DC link capacitor. The gate signals for the three phase rectifier will be obtained from the DC link voltage controller maintaining the constant voltage of the capacitor. When there is a requirement for the power transfer at the point of common coupling through the rotor, then the gate pulses of the DC-AC converter is turned ON converting the DC power into three phase AC power at the point of common coupling [7-10].

The gate pulses of the inverter have been controlled with the torque controller, thereby controlling the rotor side power, torque, active power and reactive power. For the DC link voltage control and torque control, two hybrid controllers named as neural network combined with the PID controller and neural network combined with the predictive controller [9-13] have been used for processing the actual value and the error. When there is no power supply from the wind turbine system, then the power can be collected from the main grid and can be supplied to the wind turbine system through the converters in the reverse direction from the grid to the system. The power supply can be in both the directions either from the wind turbine system to the main grid or from the main grid to the wind turbine system.

3. Proposed Hybrid ANN- PID Controller and ANN-Predictive Controller

The proposed system employs two converters whose gate pulses have been controlled with the two control techniques named as DC link voltage controller and torque controller. The control technique has been employed with the two controllers named as neural network with PID controller and neural network with predictive controller.

3.1. ANN- PID Controller Based DC- Link Voltage Controller

The block diagram for the DC link voltage controller has been shown in below Fig.2. The actual DC link voltage will be compared with the reference DC link voltage and the error will be fed to the neural network consisting of layers where the weighted input will be calculated and passing through the activation function generates the output of the layer. The output of the layer has been fed to the PID controller for maintaining the steady state response and the processed error from the PID controller has been fed to the gate pulses of the converter. The expression for power of the DC link capacitor [1] can be given as equation (1) and (2).

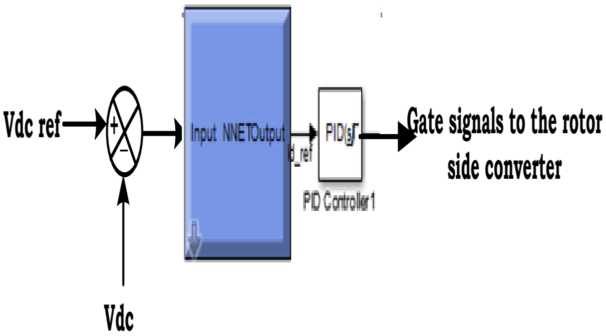

Fig. 2. Block diagram of DC- link voltage technique with ANN-PID.

$$P_{cap} = \frac{1}{2} C \frac{dV_{cap}^2}{dt} \tag{1}$$

$$P_r - P_g = \frac{1}{2} C \frac{dV_{cap}^2}{dt} \tag{2}$$

3.2. ANN- Predictive Controller Based DC- Link Voltage Controller

The block diagram for the DC link voltage controller has been shown in below Fig.3.

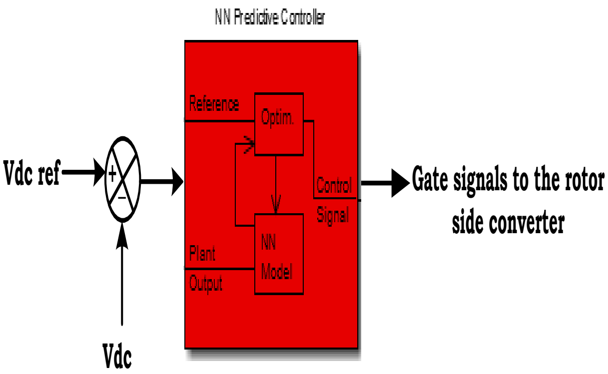

Fig. 3. Block diagram of the DC link voltage technique with ANN- Predictive.

The actual DC link voltage will be compared with the reference DC link voltage and the error will be fed into the neural network to the predictive controller consisting of layers where the weighted input will be calculated and passing through the activation function generates [5-9] the output of the layer. The output of the layer has been fed to the predictive controller, which considers the future processed error of the neural network and predicts the future change in the DC link voltage. The predicted change in the variable generates the control signal for the rotor side converter.

3.3. ANN- PID and ANN- Predictive Controller Based Torque Controller

If an abnormal condition occurs in the proposed system, power flow into the grid may not be in reasonable condition owing to the excessive currents in the stator, rotor circuits, thereby ensuing in uncontrolled [10-15] torque, power and speed. To avoid such conditions, torque controller for the rotor side converter has been proposed which controls the torque thereby controlling the currents, real and reactive power of the system. The electromagnetic torque generated from the DFIG [1] can be given as equation (3).

$$T_e = \frac{L_m V_{ds} i_{dr}}{w_s (L_s + L_m)} \tag{3}$$

4. Simulation Realization of The Proposed Controlled Wind Turbine System

The proposed wind turbine system has been simulated using MATLAB simulink and the simulink model is shown in below Fig.4 and the results have been discussed with the seven test cases considering faults, with battery, without battery.

4.1. ANN- PID Controller

Section 1: When Operating System in Grid Connected Mode with Battery

This mode starts at the start up of the system from t=0 Sec to t=7sec. Initially the wind speed of 10m/Sec is fed to the turbine from t=0 Sec to t=7sec. From t=0 Sec to t=3sec, the DC link voltage is maintained at an initial capacitor voltage value. The breaker at GSC is enabled at t=3sec, then there is sudden transient in the output, then the DC link voltage controller turns on and maintains the voltage, frequency at the reference value.

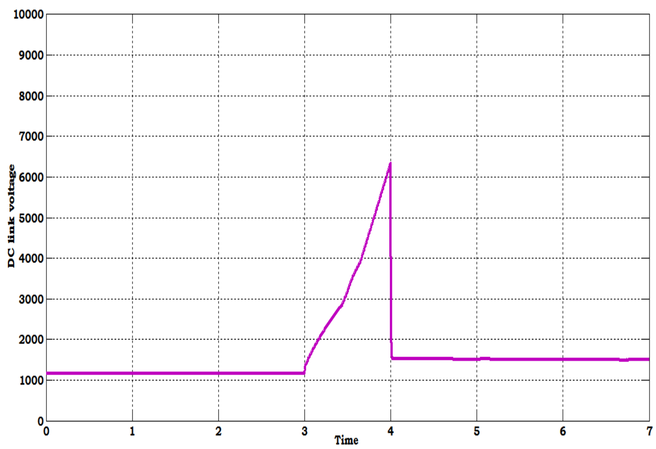

Fig. 5. The waveform of DC link voltage across the DC link capacitor when operating system in grid connected mode with battery.

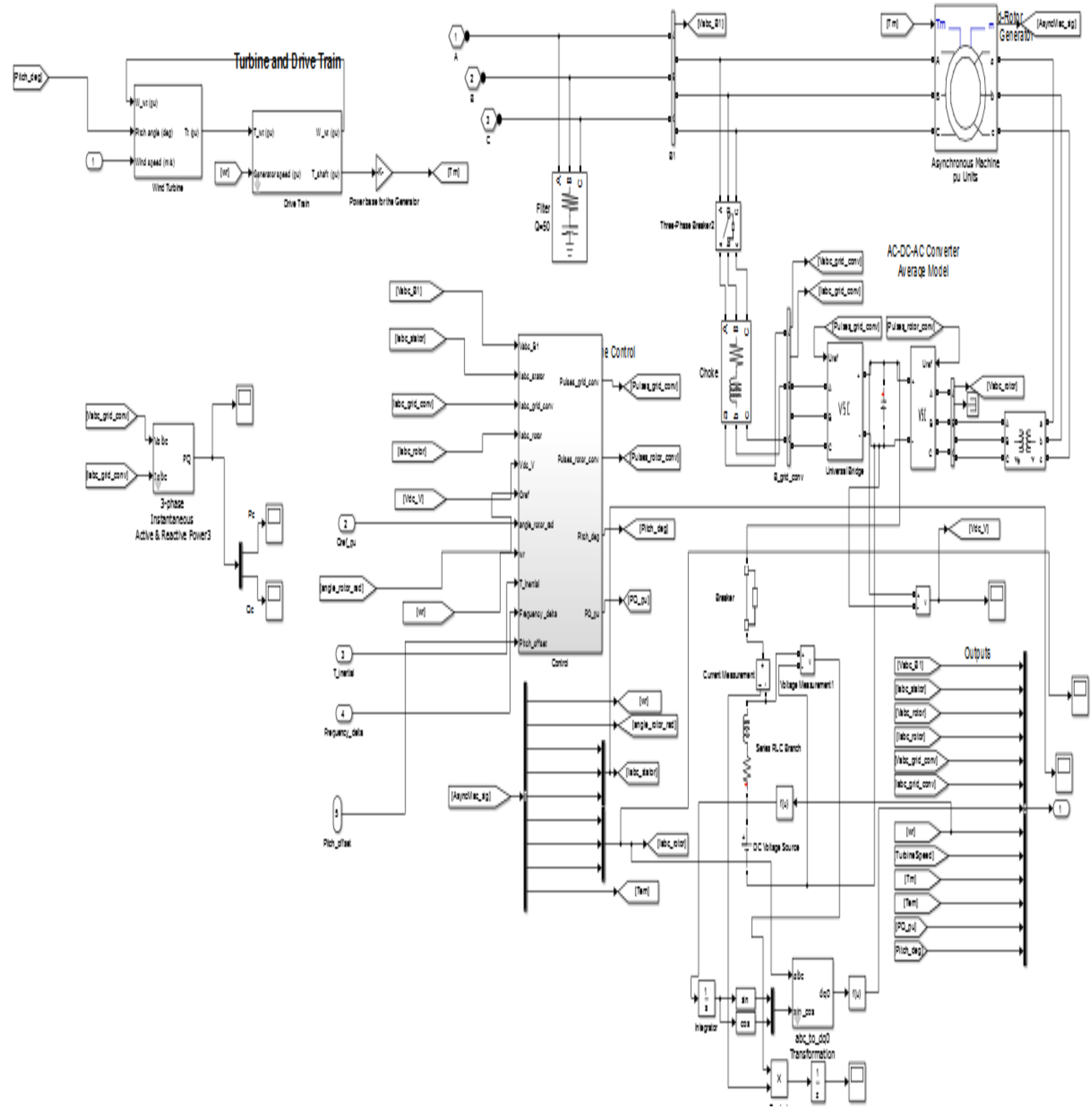

Fig. 4. Simulink diagram of proposed wind turbine system

The breaker at RSC is enabled at t=3.5sec and the battery is closed from t=4 sec to t=7sec which shows there is continuous tracking action of the controllers there by maintaining frequency , speed, DC link voltage constant(VDC). And also the proposed system has been controlled with neural network fed with PID controller for maintaining the DC link voltage, frequency, speed, torque of the system. The Fig. 5 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4 s again it maintains constant value stating that the system is operating in steady state condition.

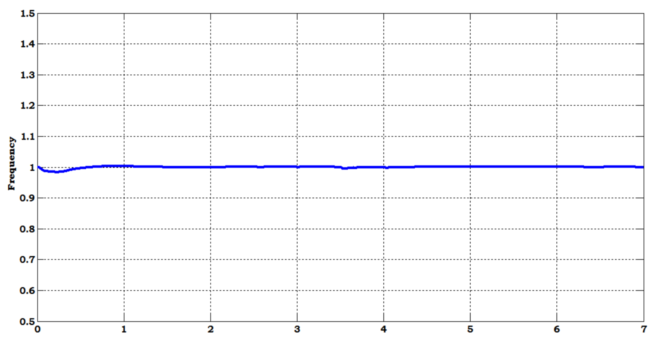

Fig. 6. The waveform of frequency of supply when operating system in grid connected mode with battery.

The above figure shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=7s, even there is disturbance of connection at the system.

Section 2: *When Operating System in Grid Connected Mode with Sudden Disconnection of Battery*

This mode will be same as section 1 from t=0 Sec to t=7sec. It starts with the turning on of the converters and connecting the battery to the system. But at t=7sec, the battery was suddenly disconnected from the system and the below graphs shows the DC link voltage and frequency of the supply which shows that there is continuous tracking action of the controllers there by maintaining frequency, DC link voltage constant even after disconnecting the storage system and operating in grid connecting mode without storage system

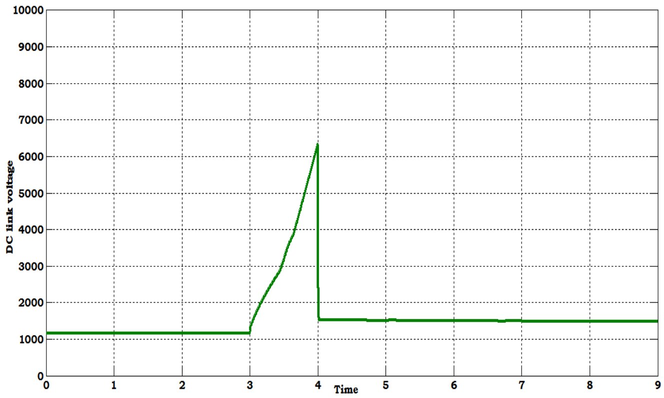

Fig. 7. The waveform of DC link voltage across the DC link capacitor when operating system in grid connected mode with sudden disconnection of battery.

The above figure.7 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4 s again it maniantins constant value stating that the system is operating in steady state condition up to t=9s.

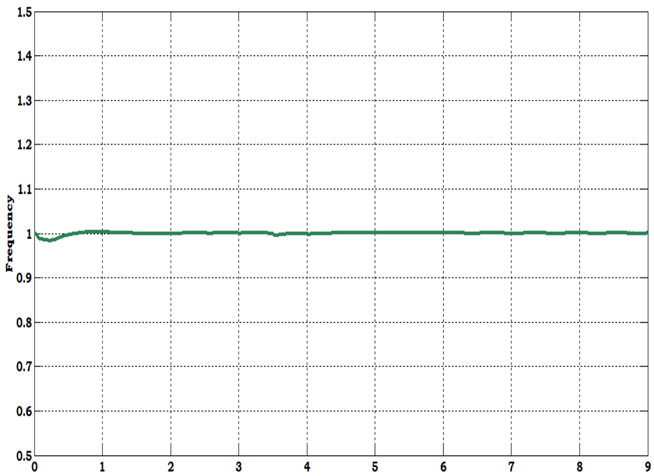

Fig. 8. The waveform of frequency of supply when operating system in grid connected mode with sudden disconnection of battery.

The above figure shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=9s, even there is disturbance of disconnection at the system.

Section 3: When Operating System in Grid Connected Mode with Sudden Connection of Other Units

This mode will be same as section 1 from t=0 Sec to t=7sec and same as case 2 from t= 7 Sec to t=9sec. It starts with the turning on of the converters and connecting the battery to the system and at t=7sec, the battery was suddenly disconnected from the system. At t=9 sec, the system was made to operate with sudden connection of each parallel unit like solar system, other wind system and other loads which are before in disconnection at the same point of common coupling. And this operation continues from t=9sec to t=15 sec.

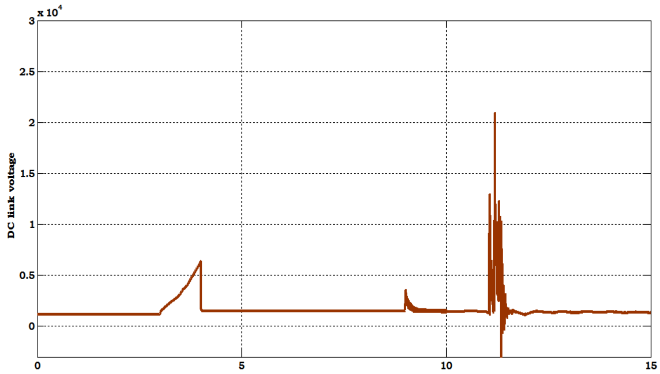

Fig. 9. The waveform of DC link voltage across the DC link capacitor when operating system in grid connected mode with sudden connection of other units.

The above figure.9 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=15s even after certain disturbances like sudden connection of other parallel units.

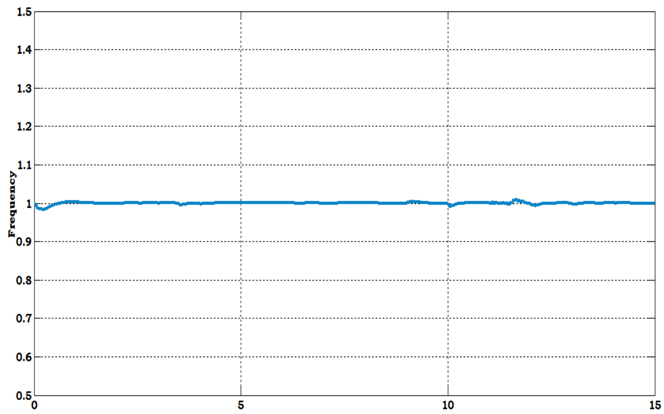

Fig. 10. The waveform of frequency of supply when operating system in grid connected mode with sudden connection of other units.

The above graph of Fig.10 shows frequency of the supply where there is continuous tracking action of the controllers there by maintaining frequency as a constant even after disconnecting different parallel units connected at the same point of common coupling.

Section 4: When Operating System in Grid Connected Mode with Sudden Fault

This mode will be same as section 1 from t=0 Sec to t=7sec. At t=7 sec, the system was made to operate with the occurrence of fault and the analysis of system during faulted condition from t=7 s to t=8s. At t=8s, the fault was cleared and again the system was operated in normal condition.

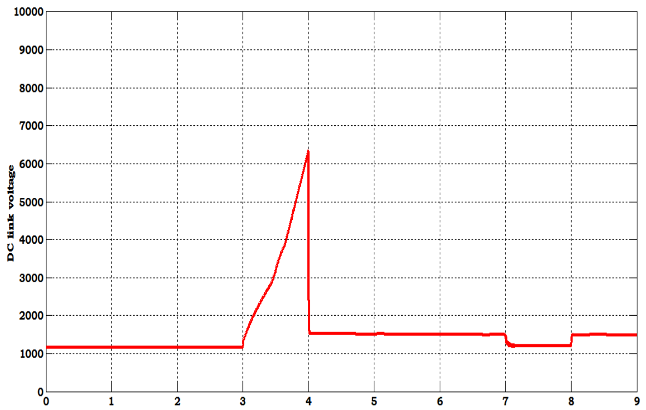

Fig. 11. The waveform of DC link voltage across the DC link capacitor when operating system in grid connected mode with sudden fault.

The above figure. 11 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=7s and then there is slight decrease in the voltage due to occurrence of the fault.

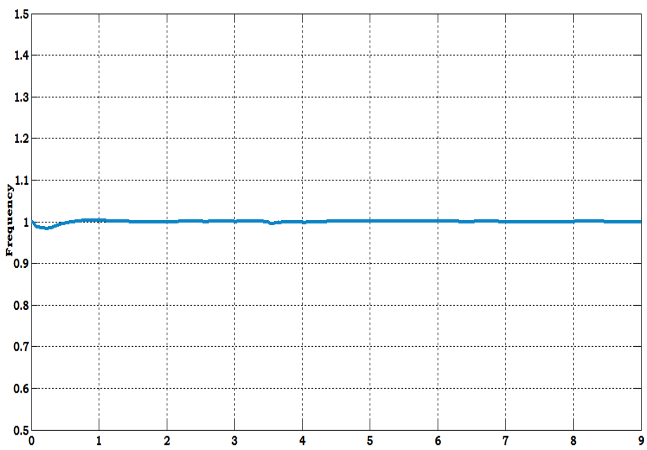

Fig. 12. The waveform of frequency of supply when operating system in grid connected mode with sudden fault.

The above figure shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=9s, even there is disturbance of fault occurrence at the system.

Section 5: When Operating System in Islanded Mode

This mode will be same as section 1 from t=0 Sec to t=7sec. At t=7 sec, the system was made to operate with disconnection of the proposed wind turbine system from the point of common coupling. The system was analysed in islanded mode from t=7s to t=9s with the isolation of grid to the proposed system

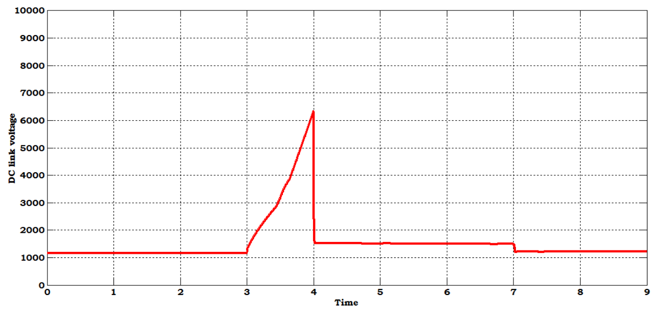

Fig. 13. The waveform of DC link voltage across the DC link capacitor when operating system in islanded mode.

The above figure shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=7s and then there exists a small decrease in the voltage due to sudedn disconnection from the grid.

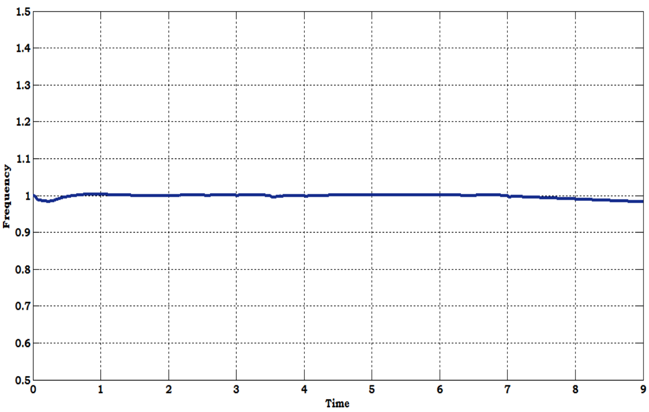

Fig. 14. The waveform of frequency of supply when operating system in islanded mode.

The above figure shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=9s, even there is disturbance of connection at the system.

Section 6: When Operating System in Islanded Mode with Sudden Connection of Other Units

This mode will be same as section 1 from t=0 Sec to t=7sec. At t=7 sec, the system was made to operate with disconnection of the proposed wind turbine system from the point of common coupling. The system was analysed in islanded mode from t=7s to t=9s with the isolation of grid to the proposed system. At t=9 sec, the system was made to operate with the sudden connection of each parallel unit like solar system, other wind system and other loads which are before disconnected at the same point of common coupling. And this operation continues from t=9sec to t=15sec.

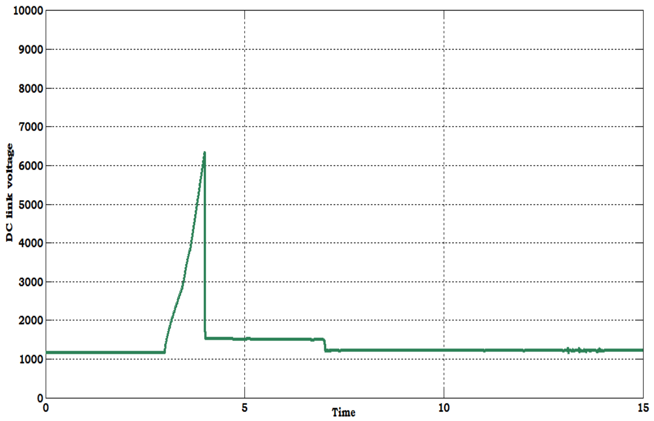

Fig. 15. The waveform of DC link voltage across the DC link capacitor when operating system in islanded mode with sudden connection of other units.

The above figure .15 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=7s and then there exists a small change in the voltage due to sudden connection of other parallel units.

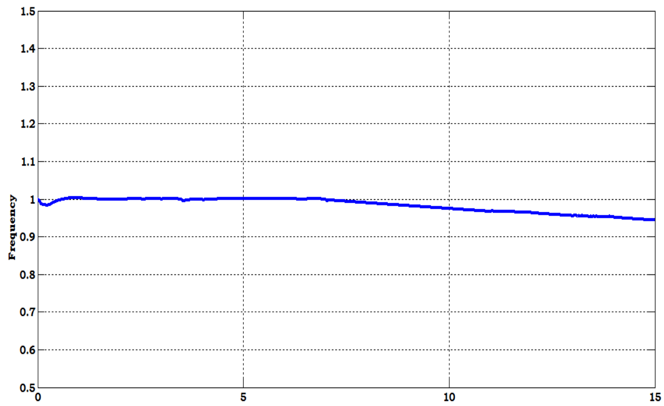

Fig. 16. The waveform of frequency of supply when operating system in islanded mode with sudden connection of other units.

The above figure. 16 shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=15s, even there is disturbance of connection at the system.

Section 7: When Operating System in Islanded Mode with Sudden Fault

This mode will be same as section 1 from t=0 Sec to t=7sec. At t=7 sec, the system was made to operate with the occurrence of fault and the analysis of system during faulted condition in islanded mode of operation with the disconnection of grid.

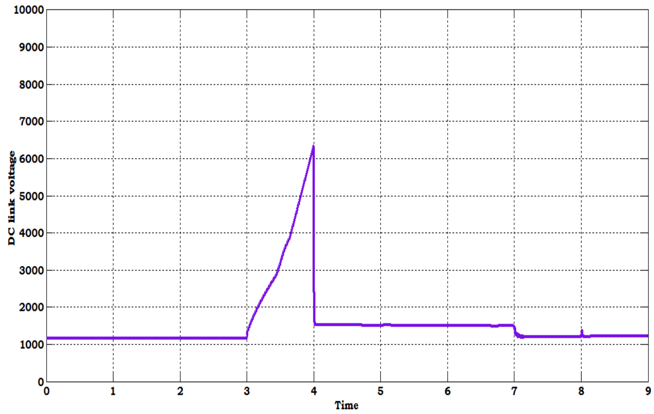

Fig. 17. The waveform of DC link voltage across the DC link capacitor when operating system in islanded mode with sudden fault.

The above figure. 17 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=7s even and there exists a small change in voltage due to occurrence of fault in islanded mode.

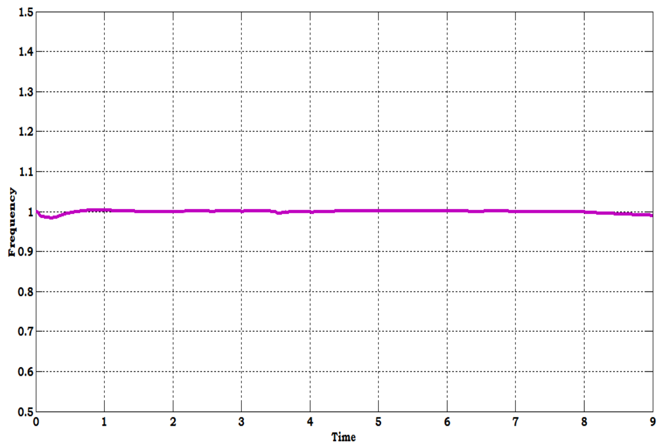

Fig. 18. The waveform of frequency of supply when operating system in islanded mode with sudden fault.

The above figure. 15 shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=9s, even there is disturbance of fault occurence at the system.

4.2. ANN- Predictive Controller

The proposed wind turbine system has been simulated using MATLAB simulink and the simulink model is shown in below figure. 19 using NN fed predictive controller.

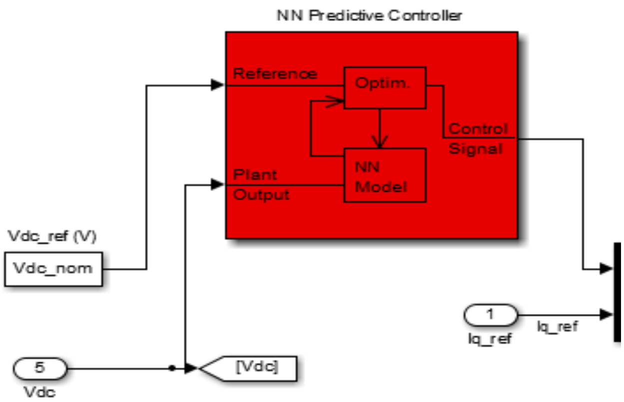

Fig. 19. Simulink diagram of NN fed with predictive controller.

Section 1: When Operating System in Grid Connected Mode with Battery

This mode starts at the start up of the system from t=0 Sec to t=7sec. Initially the wind speed of 10m/Sec is fed to the turbine from t=0 Sec to t=7sec. From t=0 Sec to t=3sec, the DC link voltage is maintained at an initial capacitor voltage value. The breaker at GSC is enabled at t=3sec, then there is sudden transient in the output, then the DC link voltage controller turns on and maintains the voltage, frequency at the reference value. The breaker at RSC is enabled at t=3.5sec and the battery is closed from t=4 sec to t=7sec which shows there is continuous tracking action of the controllers there by maintaining frequency , speed, DC link voltage constant. And also the proposed system has been controlled with neural network fed with predictive controller for maintaining the DC link voltage, frequency, speed, torque of the system.

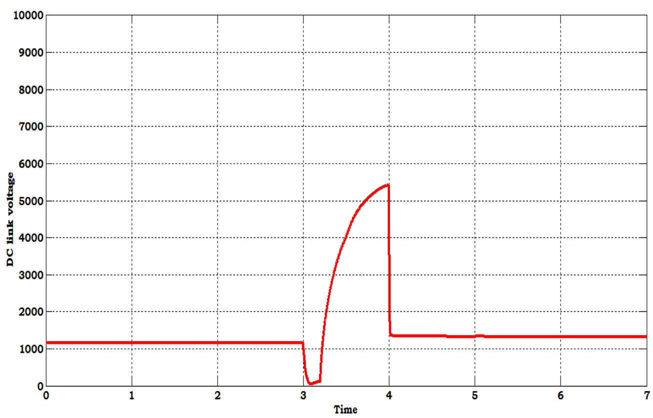

Fig. 20. The waveform of DC link voltage across the DC link capacitor when operating system in grid connected mode with battery.

The above Fig. 20 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4 s again it maintains constant value stating that the system is operating in steady state condition.

The below Fig. 21 shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=7s, even there is disturbance of connection at the system.

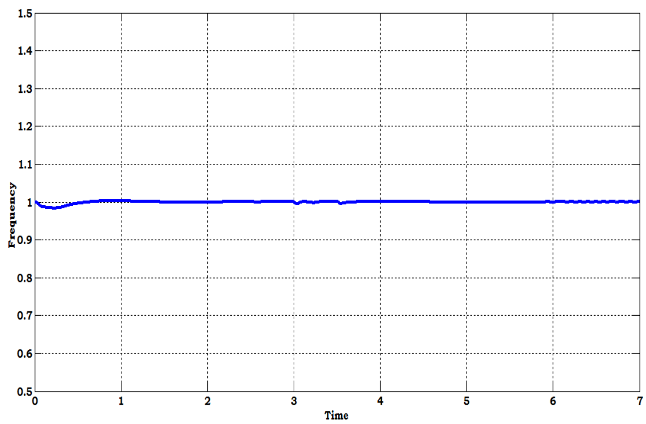

Fig. 21. The waveform of frequency of supply when operating system in grid connected mode with battery.

Section 2: When Operating System in Grid Connected Mode with Sudden Disconnection of Battery

This mode will be same as section 1 from t=0 Sec to t=7sec. It starts with the turning on of the converters and connecting the battery to the system. But at t=7sec, the battery was suddenly disconnected from the system and the below graphs shows the DC link voltage and frequency of the supply which shows that there is continuous tracking action of the controllers there by maintaining frequency, DC link voltage constant even after disconnecting the storage system and operating in grid connecting mode without storage system.

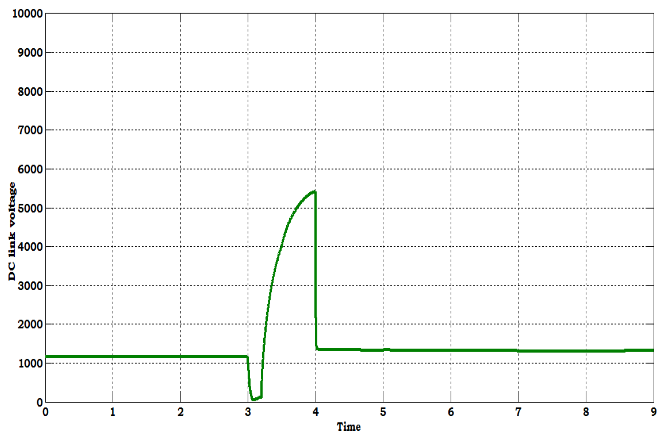

Fig. 22. The waveform of DC link voltage across the DC link capacitor when operating system in grid connected mode with sudden disconnection of battery.

The above Fig. 22 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4 s again it maniantins constant value stating that the system is operating in steady state condition up to t=9s.

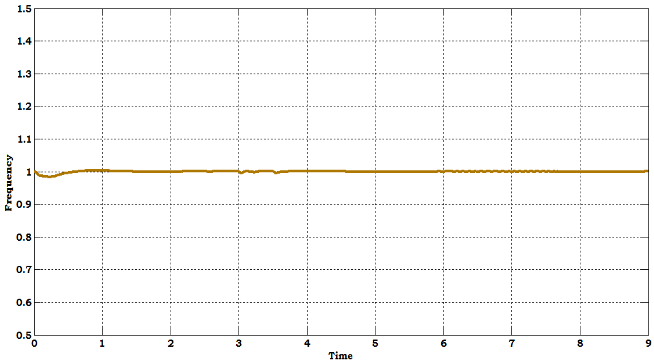

Fig. 23. The waveform of frequency of supply when operating system in grid connected mode with sudden disconnection of battery.

The above Fig. 23 shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=9s, even there is disturbance of connection at the system.

Section 3: When Operating System in Grid Connected Mod with Sudden Connection of Other Units

This mode will be same as section 1 from t=0 Sec to t=7sec and same as case 2 from t= 7 Sec to t=9sec. It starts with the turning on of the converters and connecting the battery to the system and at t=7sec, the battery was suddenly disconnected from the system. At t=9 sec, the system was made to operate with sudden connection of each parallel unit like solar system, other wind system and other loads which are before in disconnection at the same point of common coupling. And this operation continues from t=9sec to t=15 sec.

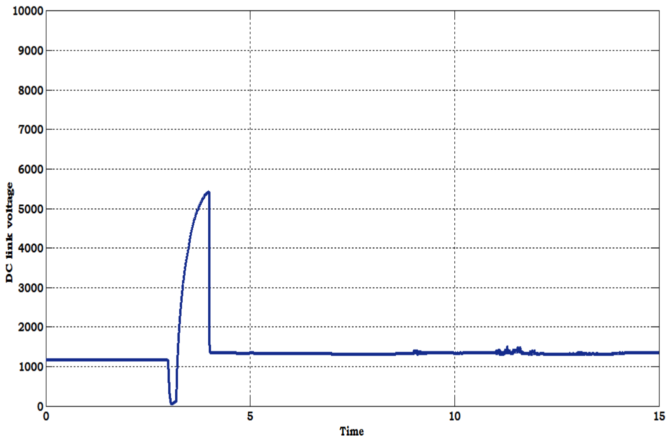

Fig. 24. The waveform of DC link voltage across the DC link capacitor when perating system in grid connected mode with sudden connection of other units.

The above Fig. 24 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=15s even after certain disturbances like sudden connection of other parallel units.

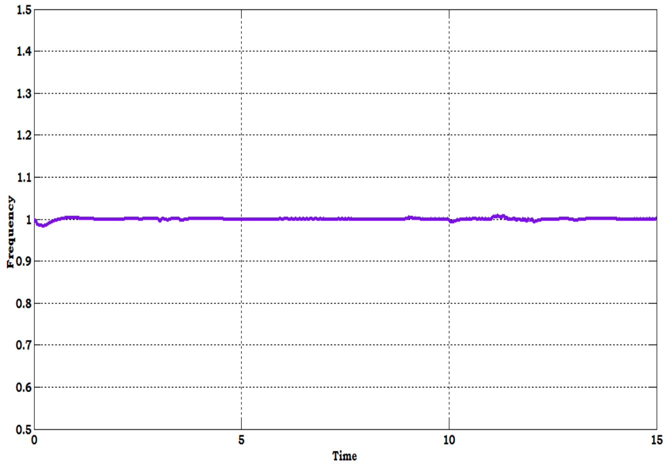

Fig. 25. The waveform of frequency of supply when operating system in grid connected mode with sudden connection of other units.

The above Fig. 25 shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=15s, even there is disturbance of connection at the system.

Section 4: When Operating System in Grid Connected Mode with Sudden Fault

This mode will be same as section 1 from t=0 Sec to t=7sec. At t=7 sec, the system was made to operate with the occurrence of fault and the analysis of system during faulted condition from t=7 s to t=8s. At t=8s, the fault was cleared and again the system was operated in normal condition.

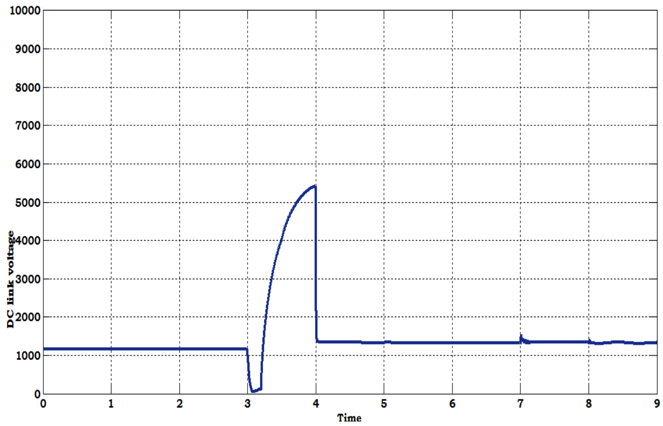

Fig. 26. The waveform of DC link voltage across the DC link capacitor when operating system in grid connected mode with sudden fault.

The above Fig. 26 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=7s and then there is slight decrease in the voltage due to occurrence of the fault.

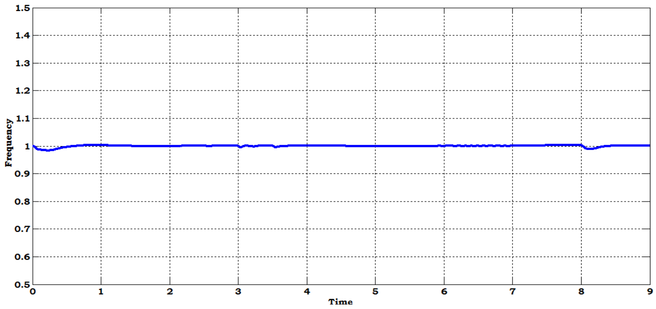

Fig. 27. The waveform of frequency of supply when operating system in grid connected mode with sudden fault.

The above Fig. 27 shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=9s, even there is disturbance of fault occurence at the system.

Section 5: When Operating System in Islanded Mode

This mode will be same as section 1 from t=0 Sec to t=7sec. At t=7 sec, the system was made to operate with disconnection of the proposed wind turbine system from the point of common coupling. The system was analysed in islanded mode from t=7s to t=9s with the isolation of grid to the proposed system.

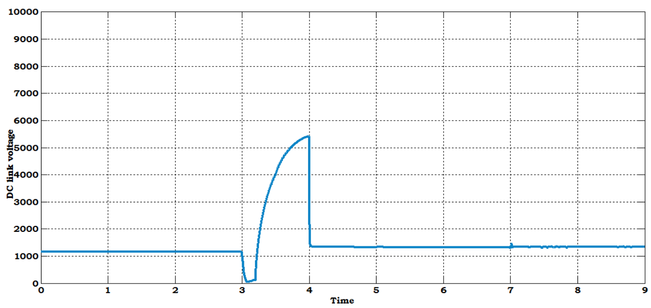

Fig. 28. The waveform of DC link voltage across the DC link capacitor when operating system in islanded mode.

The above Fig. 28 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=7s and then there exists a small decrease in the voltage due to sudedn disconnection from the grid.

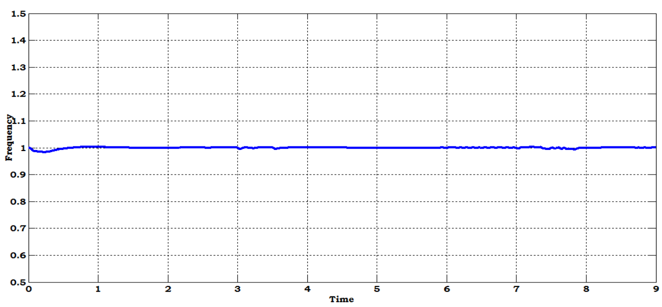

Fig. 29. The waveform of frequency of supply when operating system in islanded mode.

The above Fig. 29 shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=9s, even there is disturbance of islanded connection at the system.

Section 6: When Operating System in Islanded Mode with Sudden Connection of Other Units

This mode will be same as section 1 from t=0 Sec to t=7sec. At t=7 sec, the system was made to operate with disconnection of the proposed wind turbine system from the point of common coupling. The system was analysed in islanded mode from t=7s to t=9s with the isolation of grid to the proposed system. At t=9 sec, the system was made to operate with the sudden connection of each parallel unit like solar system, other wind system and other loads which are before disconnected at the same point of common coupling. And this operation continues from t=9sec to t=15sec.

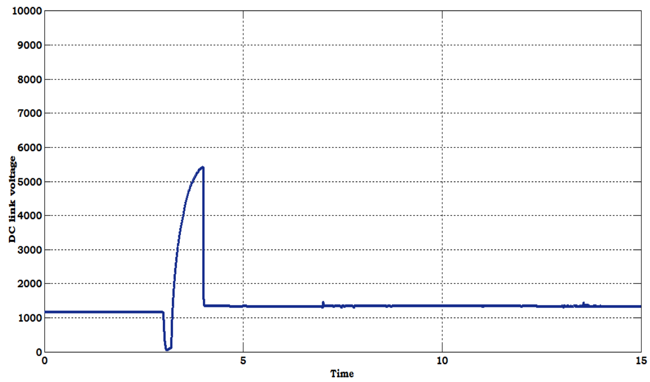

Fig. 30. The waveform of DC link voltage across the DC link capacitor when operating system in islanded mode with sudden connection of other units.

The above Fig. 30 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=7s and then there exists a small change in the voltage due to sudden connection of other parallel units.

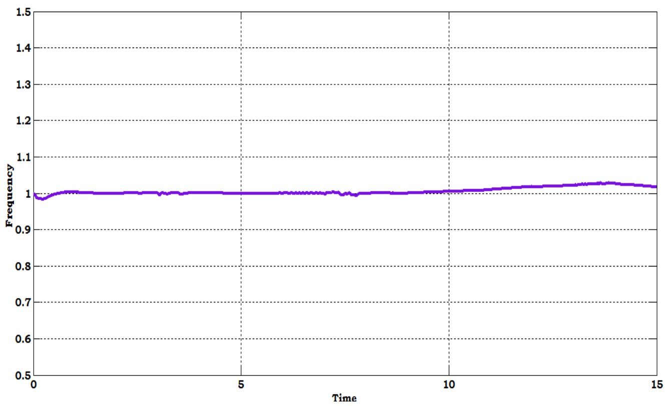

Fig. 31. The waveform of frequency of supply when operating system in islanded mode with sudden connection of other units.

The above Fig. 31 shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=15s, even there is disturbance of connection at the system.

Section 7: When Operating System in Islanded Mode with Sudden Fault

This mode will be same as section 1 from t=0 Sec to t=7sec. At t=7 sec, the system was made to operate with the occurrence of fault and the analysis of system during faulted condition in islanded mode of operation with the disconnection of grid.

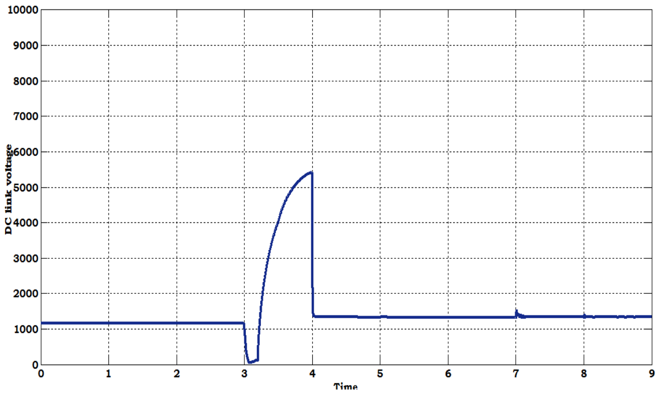

Fig. 32. The waveform of DC link voltage across the DC link capacitor when operating system in islanded mode with sudden fault.

The above Fig. 32 shows the waveform of DC link voltage across the DC link capacitor which mainatins a constant value from t=0s to t=3s, and then there is an increase in the voltage stating the connection of converters and at t=4s again it maintains constant value stating that the system is operating in steady state condition up to t=7s even and there exists a small change in voltage due to occurrence of fault in islanded mode.

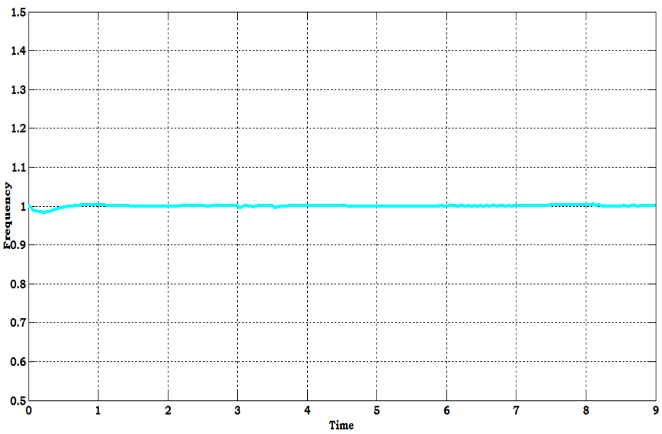

Fig. 33. The waveform of frequency of supply when operating system in islanded mode with sudden fault.

The above Fig. 33 shows the waveform of frequency of the supply from the proposed wind turbine system which maintains a constant value from t=0s to t=9s, even there is disturbance of fault occurence at the system.

Table 1. Comparison of ANN with PID, ANN with MPC controllers

Section No	ANN with PID	ANN with MPC
Section 1	VDC-const-1150V Freq- const-1pu	VDC-const-1150V Freq- const-1pu
Section 2	VDC-const-1150V Freq- const-1pu	VDC-const-1150V Freq- const-1pu
Section 3	VDC-oscillations-5% Freq- oscillations-3%	VDC-less oscillations-2% Freq- less oscillations-1.5%
Section 4	VDC- constant-1150V Freq- constant-1pu	VDC- small variation-1143V Freq- small variation-0.99pu
Section 5	VDC- slight change-1145V Freq- slight change-0.98pu	VDC- constant-1150V Freq- constant-1pu
Section 6	VDC-fluctuations-5% Freq- fluctuations-3%	VDC- constant-1150V Freq- constant-1pu
Section 7	VDC- constant-1150V Freq- constant-1pu	VDC- constant-1150V Freq- constant-1pu

The above Table.I shows the comparison of the proposed system with two different types of controllers named as neural network with PID and neural network with MPC in terms of DC link voltage(VDC) and frequency(Freq) and from the above comparison table it can be concluded that the neural network with MPC shows the better performance in terms of frequency among the other controller for all the cases maintaining constant values irrespective of disturbances like sudden connection of other parallel units, fault occurrence and sudden disconnection of energy storage system.

Table 2. Specifications of the DFIG system

S. No	Parameter	Value
1	DC link voltage (VDC)	1150V
2	DC link capacitor	10000uF
3	Wind speed	10m/s
4	Grid nominal voltage	120KV
5	DFIG rated voltage	575V
6	Rated frequency	50Hz

The above Table .II shows the specifications of proposed system, like rated voltage of the system, frequency, rated wind speed and grid voltage.

5. Conclusions

The design of wind turbine system with the usage of doubly fed induction generator as the power generating system has been presented in this paper. The two different hybrid controllers like neural network with PID controller and neural network with predictive controller have been used for the doubly fed induction generator. The controllers have provided the control of the DC link voltage and rotor power, torque and frequency. A comparison has been provided between the performance of controllers in terms of DC link voltage and frequency of the supply with different test cases(section) like consider faults, island mode and grid connected mode considering battery and without considering battery. The system was realized and the results have been verified by using MATLAB Simulink.

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