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Energy Management and Controlling of Wind Turbine Using DFIG with Hybrid Energy Storage in Battery-Supercapacitor

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Abstract: ***This paper has presented the control as well as the strategy for energy management for Wind Turbine which is connected to a DFIG system. Controllers for Grid Side as well as to the Rotor Side, hybrid supercapacitor and battery storage for energy is being connected to the grid side of the system which has been used as a backup system for the network, having the aim for supplying to the load. A design for the controlling of deliberated power system has been established in paper. MATLAB/Simulation results and graphs have been demonstrated the presentation of the storage network which explains the usage of hybrid energy in battery–supercapacitor arrangement. Moreover, showing the efficacy of the complete management strategy for the achieve energy and viability of the proposed wind turbine energy network.***

Keywords: Doubly Fed Induction Generator, DFIG

1. Introduction

The energy produced using the wind being a quick developing renewable energy of this era has a drawback that the generation of the wind power has been erratic because it depends on the weather conditions. It is essential to have energy storage from a wind system to get a smooth output. The developing nations of the world are seen to be focusing on the renewable resources of energy production and particularly the wind energy. DFIG is now a well-known turbine system that is used for the offshore wind farms because of its features. [1]-[2].

The DFIG is a generator used for the induction of the wound rotor with consecutive converters in between AC grid as well as the rotor windings. The power is fed by the stator to the grid directly. Following report puts forward the management of energy and control of a DFIG along with the Battery SC storage for the hybrid energy, along with a load of AC residential, which is connected with utility grid used in the form of a backup source.

The measured model is inclusive with all of system components. For the coordination of the flows of power among various sources of energy and load demand, there has been designing for the system of a strategy for the management of power. The usage of MATLAB/Simulink is done for the verification of system performance under different scenarios to carry out the studies of simulation.

The converter of ac/dc/ac which are bidirectional, having a link bus of dc which is common is to be connected to a Rotor circuit. The three main components: the RSC, DC-link as well as GSC together give the formation to consecutive converters. Then, DC-link offers decoupling among 2 sides of AC with varying frequencies. The DC-link voltage has been controlled using GSC.

A scheme for the GSC vector control provides with autonomous control of reactive power that has been replaced among grid and GSC as well as the slip active, for upholding the voltage of the DC-link continuous, also, for certifying sinusoidal supply currents.

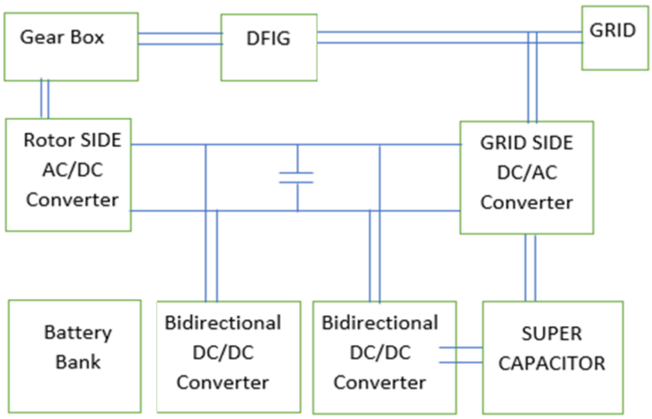

Figure 1: Block Diagram of the Complete System

2. Modeling of the System

2.1 Doubly Fed Induction Generator Model

The DFIG model presented in this paper is the dq0 stationary rotating frame as the simulation of the model of DFIM is appropriate with this frame. The DFIM model's transient solution is probable due to the conversion from the abs to dq0 using which the differential equations having variations in the time that has been transformed into the differential equations having inductances that are constant, [3]-[4].

Equivalent model of DFIG that uses the simultaneous rotating reference frame (qd-frame) is presented in the equation (1) to (4).

$$V_{ds} = R_s . i_{ds} + \frac{d}{dt}\Phi_{ds} - \omega_e \Phi_{qs} \tag{1}$$

$$V_{qs} = R_s . i_{qs} + \frac{d}{dt}\Phi_{qs} - \omega_e \Phi_{ds} \tag{2}$$

$$V_{dr} = R_r . i_{dr} + \frac{d}{dt}\phi_{dr} - (\omega_e - \omega)\phi_{qr} \quad (3)$$

$$V_{qr} = R_r . i_{qr} + \frac{d}{dt}\phi_{qr} - (\omega_e - \omega)\phi_{dr} \quad (4)$$

The stator as well as the rotor fluxes are written below as:

$$\phi_{ds} = L_s i_{ds} + M i_{dr} \quad (5)$$

$$\phi_{qs} = L_s i_{qs} + M i_{qr} \quad (6)$$

$$\phi_{dr} = L_r i_{dr} + M i_{ds} \quad (7)$$

$$\phi_{qr} = L_r i_{qr} + M i_{qs} \quad (8)$$

In these equations, $R_s, \ R_r, L_s and\ L_r$ are respectively the resistances as well as the inductances of the rotor winding & the stator windings and M is the mutual inductance.

$V_{ds}, V_{qs}, V_{dr}, V_{qr}, i_{ds}, i_{qs}, i_{dr}, i_{qr}, \phi_{ds}, \phi_{qs}, \phi_{dr}\ and \phi_{qr}$ are the components of d and q of stator as well as the rotor voltages, current and the flux, where as ω in electrical terms is rotor speed and ω_e is the angular velocity of the simultaneously rotating frame (reference). The torque that is electromagnetic has been expressed in the form [3]:

$$C_e = P * \frac{M}{L_r}(\phi_{dr} * I_{qs} - \phi_{qr} * I_{ds}) \quad (9)$$

Where P → No. of pole pairs.

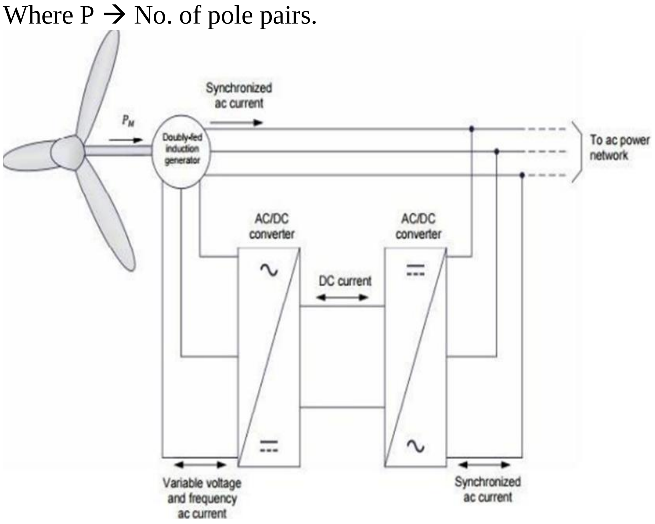

Figure 2: Block Diagram of the DFIG System

The active and the reactive powers at stator also rotor side are defined as:

$$P_s = V_{ds}\, i_{ds} + V_{qs}\, i_{qs} \quad (10)$$

$$Q_s = V_{qs}\, i_{ds} - V_{ds}\, i_{qs} \quad (11)$$

$$P_r = V_{dr}\, i_{dr} + V_{qr}\, i_{qr} \quad (12)$$

$$Q_s = V_{qr}\, i_{dr} - V_{dr}\, i_{qr} \quad (13)$$

2.2 Wind Turbine Modeling

The turbine of the wind is used to extract the energy. Then it is transformed into mechanical power. Between the mechanical power as well as speed of wind the algebraic relation is presented by:

$$P_m = \frac{1}{2} * C_p * \rho * \pi * R^2 * V^3{}_{wind} \quad (14)$$

The mathematical estimations of Cp is [1]:

$$C_p(\lambda, \beta) = c_1\left(\frac{c_2}{\lambda_1} - c_1\beta - c_4\right)e^{\frac{c_5}{\lambda_i}} + c_6\, \lambda \quad (15)$$

where,

ρ is the density of air ($\rho = 1.225\ kg/m^3$), R is radius of the rotor, Vwind is the wind speed and Cp is the Wind turbine performance characteristics.

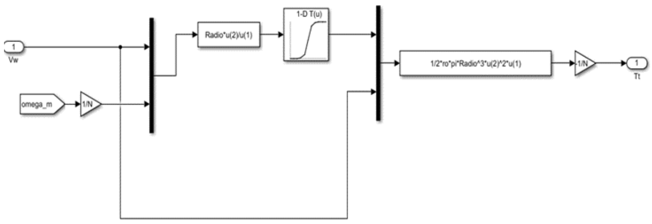

Figure 3: Simulink Model of the Wind Turbine System

Values related to constants $c_1 to\ c_6$ mainly depend on the manufacturer and also the type of wind turbine.

$$\lambda = \frac{\Omega_{turb} R}{V_{wind}}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08} - \frac{0.0035}{\beta^3 + 1} \quad (16)$$

2.3 Grid Side Converter Control

Before The objective of the GSC is to help the system in maintaining the regular voltage in the DC-link between the consecutive converters. For the accomplishment, the scheme of the vector control has been used that to provide autonomous controlling of the active as well as the reactive power which that flows between grid and GSC. On basis of the current flowing in it, the regulation for PWM converter is decided. For the regulation of the DC-link voltage, direct axis current has been used and quadrature axis current has been used for the regulation of the reactive power. The d-q theoretical or frame (reference) theory, that was used for overcoming issue parameters having variations in the time with the AC machines is the basic of the vector control,[6]. Basically, to transform variables of the stator into a simultaneously rotating frame (reference) which has been fixed at the rotor. Using transformations, one can eliminate the inductances having the issue of time variations occurring because of a working electric circuit which is relative and electric circuit having the issue of variations in the magnetic reluctances. The change of three to 2-phase axis in the stationary position is presented as:

$$\begin{bmatrix} V_{qs}^s \\ V_{ds}^s \\ V_{0s}^s \end{bmatrix} = \begin{bmatrix} cos\theta & \cos(\theta - 120) & \cos(\theta + 120) \\ sin\Delta\theta & \sin(\theta - 120) & sin(\theta + 120) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (17)$$

Conversion of the 2-phase axis in the stationary position to the 2-phase simultaneous axis in rotation is given by:

$$V_{qs} = V_{qs}^s cos\theta_e - V_{ds}^s sin\theta_e \quad (17)$$

$$V_{ds} = V_{qs}^s sin\theta_e + V_{ds}^s cos\theta_e \quad (18)$$

The GSC voltage in the d-q substance is attained by typical configuration of the strategy of the control is presented by

$$V_q = Ri_q + L\frac{di_q}{dt} + \omega_e L i_d + v_{qi} \quad (19)$$

$$V_d = Ri_d + L\frac{di_q}{dt} - \omega_e L i_d + v_{di} \qquad (20)$$

Apply Laplace transforms to above two equations

$$V_q = (R + sL)i_q + \omega_e L i_d + v_{qi} \qquad (21)$$

$$V_d = (R + sL)i_d - \omega_e L i_q + v_{di} \qquad (22)$$

Considering,

$$V_q' = (R + sL)i_q \qquad (23)$$

$$V_d' = (R + sL)i_d \qquad (24)$$

Calculations for the angular position of voltage supply is done as:

$$\theta_e = \int \omega_e dt = \tan^{-1}\frac{v_\beta}{v_\alpha}$$

Where v_α and v_β are the stator-voltage components

The control scheme uses the loops for the controlling the current i_d as well as the i_q with the mandate obtained from the voltage of the DC link error with a regular controller for PI. The factor of the displacement on the supply side of inductor is determined by the demand. The current controlling loops plant is given by:

$$F(S) = \frac{i_q}{v_q'} = \frac{i_d}{v_d'} = \frac{1}{R + sL}$$

Substituting (24), (25) in (22) and (23) respectively, and being $V_q(s) = 0$ the reference for the voltages values $V_{q\ ref}$ and $V_{d\ ref}$ can be obtained by:

$$V_{q\ ref} = -v_q' - \omega_e L i_d + v_q \qquad (25)$$

$$V_{d\ ref} = -v_d + \omega_e L i_q + v_d \qquad (26)$$

The value of $V_{q\ ref}$ and $V_{d\ ref}$ are the reference values of the input to converter of PWM using which the DC voltage level and the needed factor of power is attained.

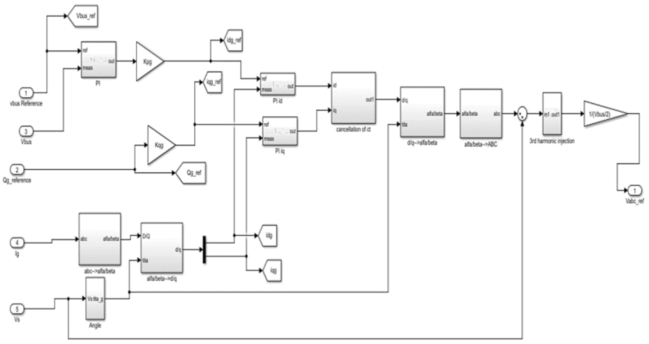

Figure 4: Simulink Model of the Grid Side Controller

2.4 Rotor Side Converter Control

A control for the vector has been adopted to the side converter of the rotor for controlling the power (reactive) as well as stator active. The axis loop which is direct is used for controlling the reactive power while quadrature axis has been used for controlling the active power [8]. A vector control that is stator flux-oriented has been applied to the side converter of the rotor [9]. RSC controller block diagram is presented in Fig.5. The reactive power has been controlled using the direct axis loop while the active power control is done by the axis of the quadrature. The related equations,

$$V_{dr} = R_r i_{dr} + \sigma L_r \frac{di_{dr}}{dt} - \omega_{sl}\sigma L_r i_{qr} \qquad (27)$$

$$V_{rr} = R_r i_{qr} + \sigma L_r \frac{di_{qr}}{dt} - \omega_{sl}(\sigma L_r i_{dr} + L_o i_{ms}) \qquad (28)$$

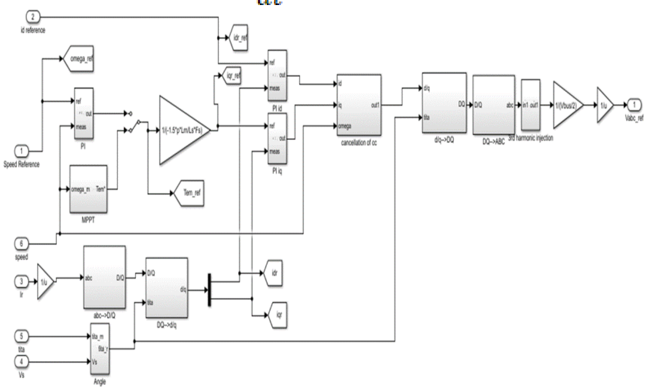

Figure 5: Simulink Model of the Rotor Side Controller

2.5 PI Controller based DFIG

Use The controller-based Proportional Integral technique is used to control the voltage of the DC –link. The usage of the control techniques helps to achieve a better control over the DFIG. It has the advantages of [6]

1) Continual DC-link voltage in case of wind turbine/park.
2) When speed of the wind is limited, the generation of the active power is permitted.
3) The charge of maintenance is diminished and the exploration for case of the wind turbine/park.

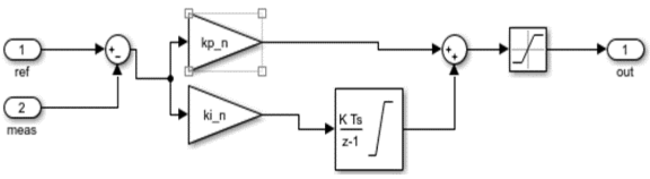

Figure 6: Simulink Model of PI Controller for DFIG

3. Storage Integration

The model of the battery is on the basis of a battery model of the lead acid. This simulation has to be carried on short time periods, which is more suitable to be used as a model that is simplified.

The model of the battery has two operation modes that are, the charge and the discharge. The battery is charged while the battery input current is positive while discharge is in case of current has been negative. V_1 *and* R_1 are decided by the equations depending on procedure of its battery.

3.1 Bidirectional DC to DC Converter for Battery & Supercapacitor

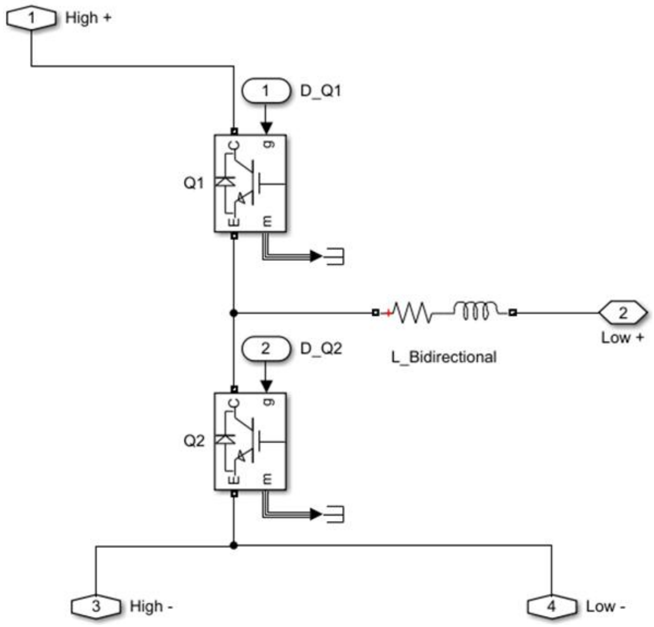

Figure 7: Bidirectional DC to DC Converter for Battery and Supercapacitor

3.2 Supercapacitor Modeling

The DFIG system contains two converters which are integrated. This is the reason that it is preferred to be used for adding a new converter. The storage of energy of the UC has been considered as the application of storage of wind energy in the sector because of the various merits over the system of storage for energy of battery.

Though there are several advantages, it has disadvantages which are related to the SCs. One will be able take its care during control designing.

The energy stored with respect to its weight in the UC of first generation is lower when compared to the electrochemical batteries. The amount of energy stored brings variations in the voltage. To make sure that the energy is stored and recovered efficiently, switching equipment and the electronic control is essential.

There are various models developed for description of the Double-Layer SC. The most widespread model known as the two branches model is used in our study, that is well-known. (As represented in figure 8).

4. Simulation and Results

Simulink Diagram of Complete System

Simulink diagram of the complete system which consists of the following systems:

a) Wind Turbine
b) DFIG
c) Grid Side controller
d) Rotor Side Controller
e) Battery and Supercapacitor
f) Bidirectional DC to DC Converter
g) Monitor (To get the outputs graphs).

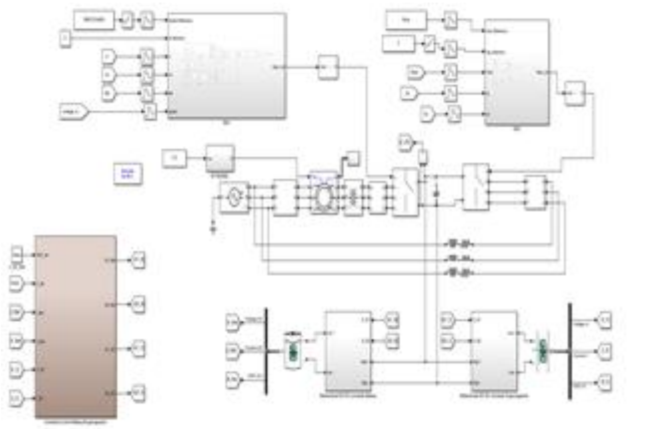

Figure 8: Simulink Model of the Final System

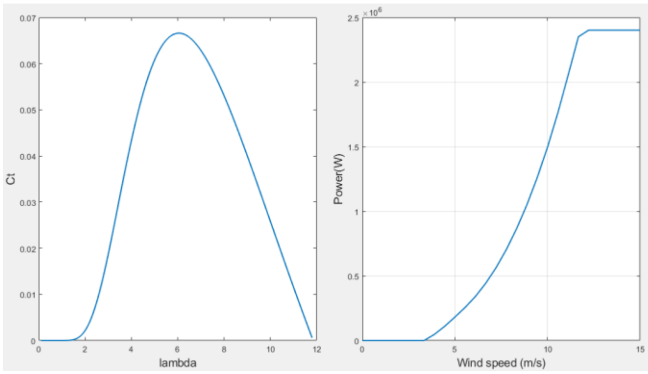

Figure 9: Characteristics of $C_p(\lambda)$ and Wind Speed

5. Simulation Results

Output graphs of the rotor side control parameters

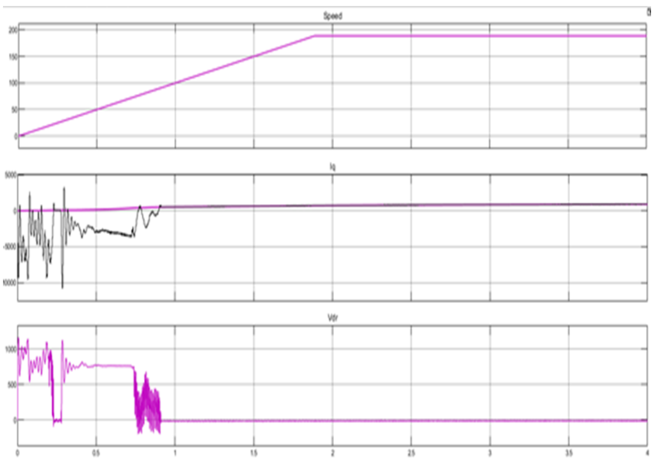

Figure 10: Shows output of (a) Speed of wind, (b) Iqr, (c) Vdr

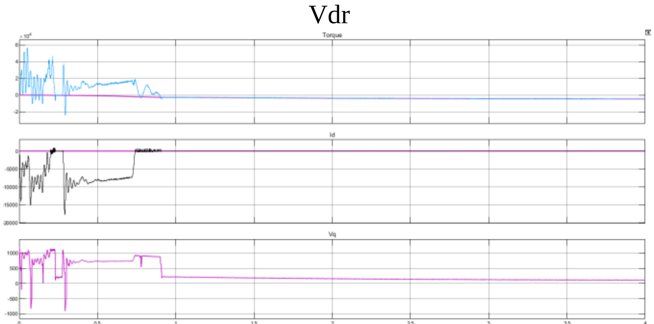

Figure 11: Shows output of (a) Torque (b) I_d and (c) V_q

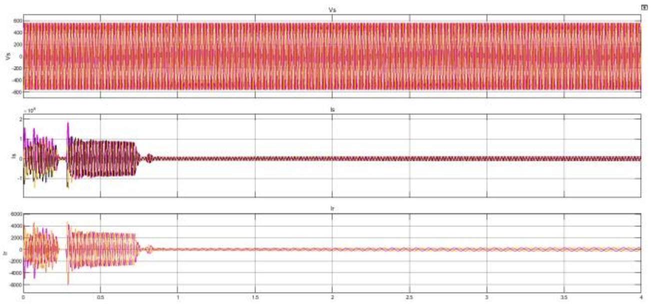

Figure 12: Shows output of (a) V_S, (b) I_S and (c) I_r

Output Graphs of the Grid Side Control Parameters

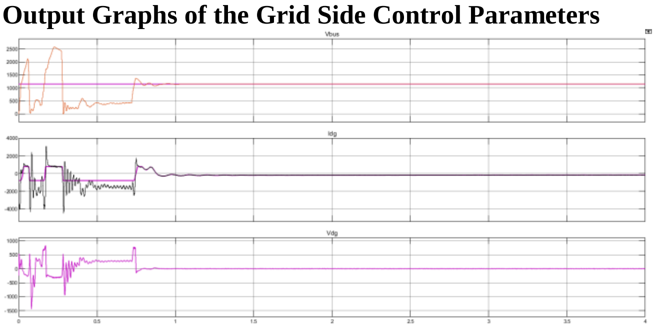

Figure 13: Shows output of (a) V_{Bus}, (b) I_{dg} and (c) V_{dg}

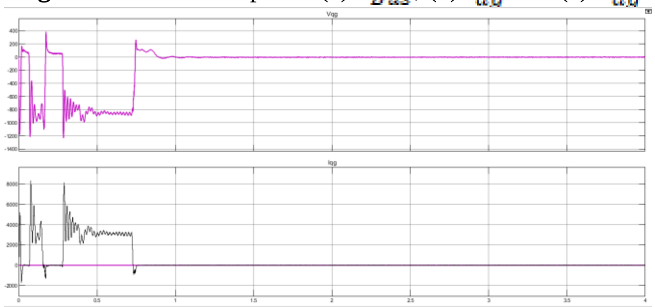

Figure 14: Shows output of (a) V_{qg}, (b) I_{qg}

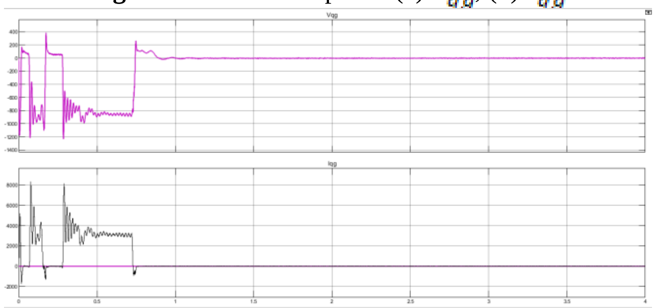

Figure 15: Shows output of (a)V_s, (b) I_g

Output of the Supercapacitor Voltage and Current

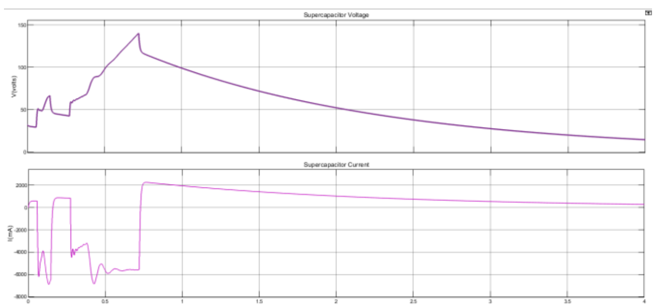

Figure 16: Shows output of (a) Supercapacitor Voltage, (b) Super Capacitor Current

Output of the Battery Voltage and Current

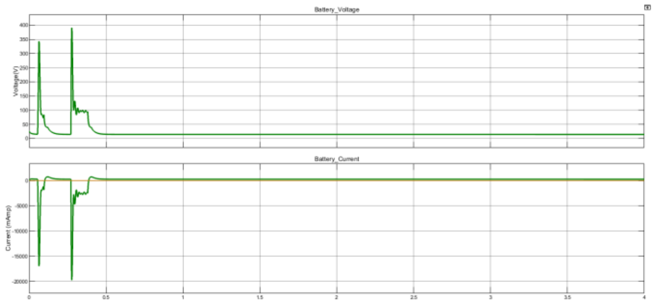

Figure 17: Shows Output of (a) Battery Voltage, (b)Battery Current

6. Conclusion

This paper has showed the control as well as the energy management strategy for Wind Turbine which is connected to a DFIG system. Controllers for Grid Side as well as to the Rotor Side, hybrid supercapacitor and battery storage for energy is being connected to the grid side of the system which has been used as a backup system for the network, having the aim for supplying to the load. A design for the controlling of the deliberated power system has been established in this paper. Simulation results and graphs using MATLAB and Simulink demonstrate the performance of the storage network which explains the usage of hybrid battery–supercapacitor arrangement. Moreover, showing the efficacy of the complete management strategy for the achieve energy and viability of the proposed wind turbine energy network. Figure 10, 11 and 12 shows the output graphs of the rotor side control parameters. Similarly figure 13, 14 and 15 shows the output graphs of the grid side control parameters, and figure 16 shows the output of the supercapacitor voltage and current and figure 17 shows the output of the battery voltage and current.

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