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Islanding Operation Of Dfig Based Battery Energy Storage System For Three Phase Load

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Abstract: This paper deals with a new Isolated wind generation system by employing a Doubly fed induction generator (DFIG) driven by a variable speed wind turbine. In this paper, two back to back connected Hysteresis controlled Insulated Gate Bipolar Transistors (IGBT) based Voltage Source converters(VSC) with a Battery energy storage system at their dc link. The main objective of this paper is to make the isolated system with a variable speed wind turbine using DFIG to supply the local loads, hilly and remote areas. The proposed electromechanical system using DFIG are modeled and simulated in MATLAB using simpower system toolbox for balanced/unbalanced, resistive and reactive load.

Keywords: Doubly fed induction generator (DFIG); Autonomous wind energy conversion system (AWECS); VF controller; transient stability.

1. Introduction:

In recent years, renewable energy sources have attracted the great interest because conventional sources of energy are limited and a number of problem associated with their use like:- environmental pollution, large grid requirement etc. Government of the whole world are forced for the alternative energy sources such as wind power, solar energy and small hydro-electric power[1]. All renewable energy resources can be considered as distributed generation resources. The wind is one of the most important renewable energy sources. This paper emphasis on wind turbinewhich is classified in two ways- Fixed speed wind turbine with squirrel cage induction generator work regardless of wind speed and another one is variable speed wind turbine with doubly fed induction generator which work and rotate according to wind speed. In the recent year DFIG is commonly used instead of SCIG because they track power according to wind speed. The variable speed machine have several advantages instead of fixed speed wind turbine machine like:- Reduce mechanical stress, dynamically compensate torque, power pulsation, improve power quality and system efficiency, reduce converter rating and reduce cost and losses in result of that an improved efficiency[2].

This paper emphasis on variable speed based DFIG. The generator speed (above and below synchronous speed) is varied within a certain range and converter interfaces are required to manage slip power, which is only the fraction of total system power. The model has two back two connected hysteresis controlled Insulated gate bipolar Transistors based voltage source converterwith a common capacitive dc link have thecapability to flow power bidirectional in the system. The both side converter is referred one for stator side and another one is rotor side.

The proposed model used for standalone system where the power is fed directly to the local loads for the application where the grid connectivity is not possible. The system can also be made to work combination with grid and local loads.In Islanding mode the generator supply the local loads during the light load and heavy load condition, the excess power is absorbed/ supplied by battery energy storage system which is connected parallel to dc link capacitor. A three phase load autonomous wind energy conversion system is employed using DFIG operated at variable speed for supply the power to local loads and also perform the function of load leveling and harmonic elimination.

In section 2, the system description of proposed AWECS system is described.In section 3,modeling of the mechanical system is presented for the AWECS. In section 4, the control algorithm is presented for the AWECS. In section 5, the MATLAB Based modeling and rating of various components of the proposed system is shown. In section 6, the simulation results for the proposed system under resistive, reactive load condition are given. Finally in section 7, the conclusion of the AWECS is proposed.

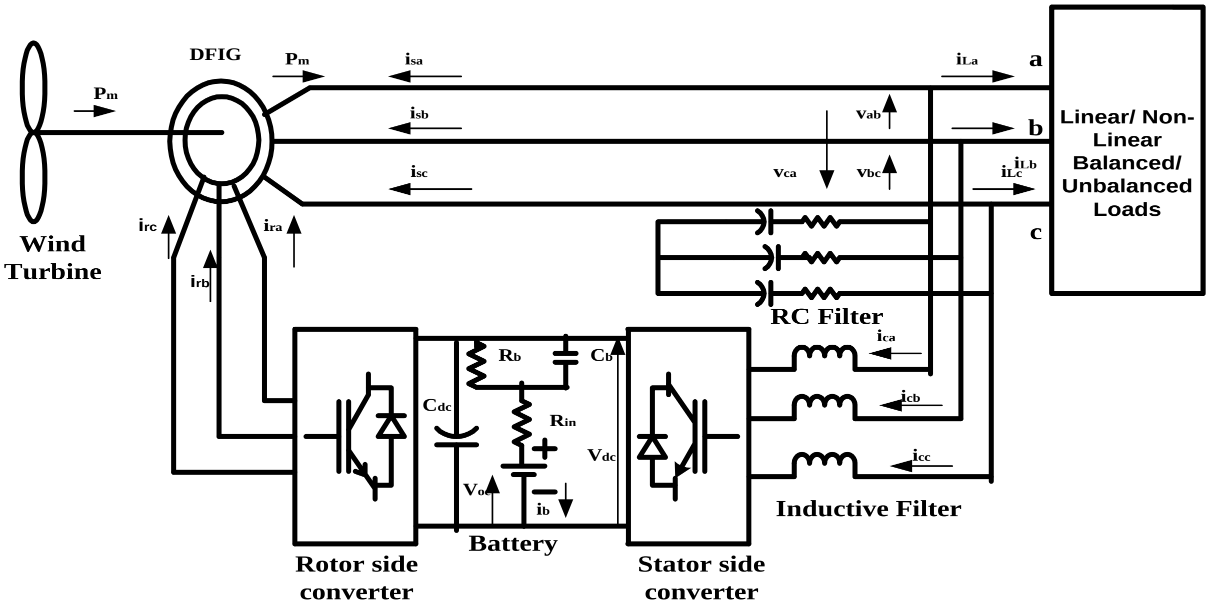

Figure. 1- Schematic diagram of the AWECS using DFIG

2. System description :

Three wire Autonomous wind energy conversion system (AWECS) using Doubly fed induction generator DFIG with battery energy storage system shown in Fig. 1 with two back two back connected hysteresis controlled Insulated gate bipolar transistor based voltage source converters are connected between the stator and rotor of the DFIG with bidirectional power flow between the converters.

The system employed battery energy storage systemwhich is connected with dc link,the advantage of using BESS at the dc bus is that no additional converter is required for transfer of power to or from the battery. Further, the battery keeps the dc- bus voltage constant during load disturbances or load fluctuation. The inductors are connected in series with the BESS to remove ripples from the battery current[3].

In this paper, a three phase three wire autonomous (or isolated) wind turbine system is proposed for isolated location, which is not connected to the grid. A control strategy using indirect current control is proposed for the stator side converter of the AWECS, the control signals for switching of the stator side converter are generated from the error of the reference stator current and the sensed stator currents, rather than the error of the stator side convertor currents. In the proposed system the dc bus voltage is kept constant by the battery, the control strategy of stator side converter is different from rotor side converter, i.e., to maintain an active power balance in the system by transferring the excess power to the battery or for providing deficit power from the battery. Further the rotor side converter provides the requisite reactive power for the load. The stator side converter is controlling loadvoltage and stator voltage.The objective of the rotor side converter is to provide the requisite magnetizing current to the DFIG and to achieve Maximum power tracking.

The terminal voltage of the equivalent battery is given by Eq. 1,

$V_{battery} = (2\sqrt{2}/\sqrt{3})V$(1)

where V is the line rms voltage (V = 415v)

At no load, voltage across the terminals of SEIG is rated voltage of 415 V. The battery voltage must be more than the peak of line voltage for satisfactory operation of Hysteresis controller. A slightly higher round-off value of 750 V is considered.

Since the battery is an energy storage unit, its energy is represented in kWh when a battery is used to model the battery unit, the equivalent capacitance can be given by Eq. 2,

$C_{bat} = (kwh * 3600 * 10^3) / 0.5 (V^2_{ocmax} - V^2_{ocmin})$(2)

$C_{bat} = (6*4*3600*10^3) / 0.5 [(760^2) - (740^2)]$

$C_{bat} = 5760$ F

3. Modeling of the mechanical system:

The aerodynamic power generated by wind turbine can be expressed as by the Eq. 3,

$P=0.5\rho AC_pV^3\omega$ (3)

Where the aerodynamic power is expressed as a function of the specific density (ρ) of the air, the swept area of the blade (*A)*, and the wind speed ($V^3\omega$) .

To generate the constant frequency, the additional generated power with increased wind speed is stored into the battery and the speed of the generator is maintained almost constant. The TSR is defined as the ratio of the linear speed at the tip of the blade ($\omega_T R$) and the wind speed ($V\omega$) ,ω_T being the rotational speed of the wind turbine. The polynomial relation between Cp and λ at a particular pitch angle for the considered wind turbine is represented as by the Eq. 4[5],

$Cp = C_1 \{(C_2 / \lambda i) - C_3 \beta - C_4)\} e^{-(c/\lambda i)} + C_6 \lambda$ (4)

Where $1/\lambda i = \{1/ (\lambda i + C_7 \beta)\} - \{C_8 / (\beta^3 + 1)\}$ and $\beta = 0^0$

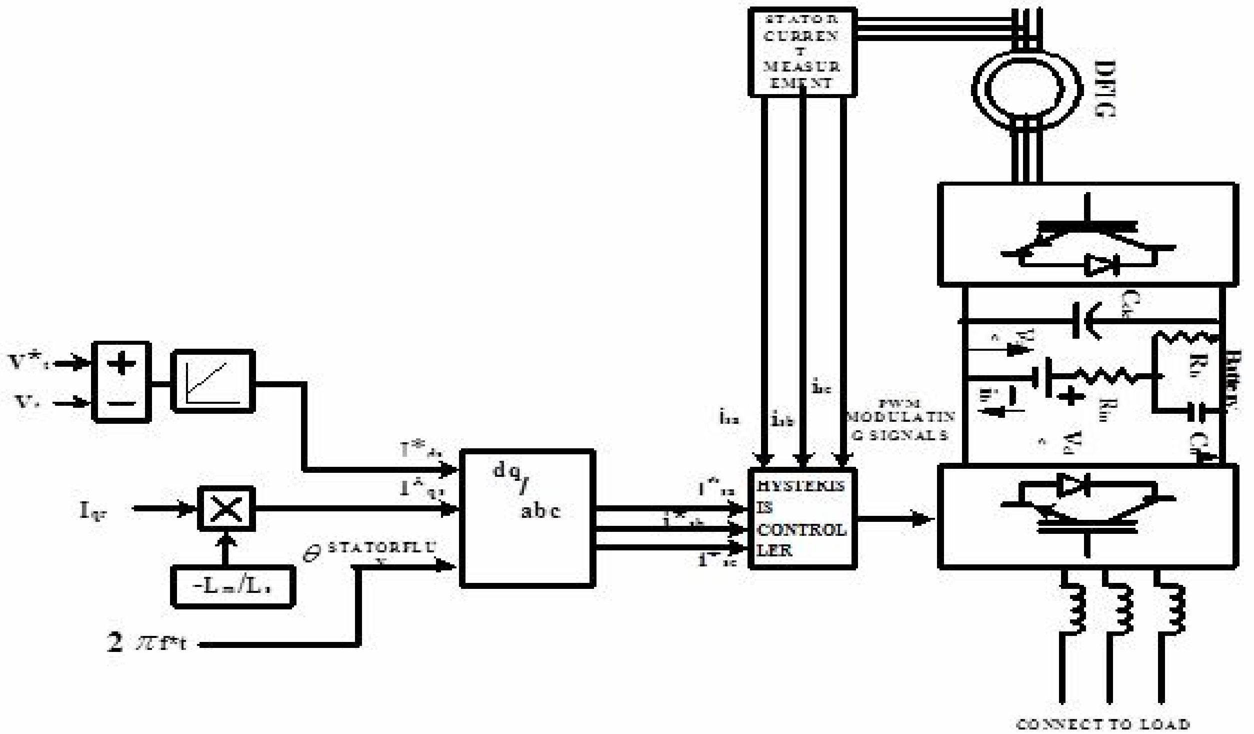

Figure. 2 Control scheme for stator side converter

4. Control Algorithm:

The objective of the rotor side converter of DFIG is to achieve Maximum power tracking and to provide the required magnetizing current to the DFIG, and the objective of stator side converter is to control the magnitude and frequency of the load voltage. The detailed control algorithm for the two converters is described in the following sections[4].

4.1 Control for stator side converter:- As shown in Fig. 2,the function of stator side converter is formation of local grid by controlling the frequency and regulating the stator voltage. Instator side converter the control algorithm for derivation of stator flux angle ($\Theta_{statorflux}$), references d-axis stator current (I^*_{ds}), reference q-axis stator current (I^*_{qs})andderivation of control signal for the stator side converter isdescribed as:

4.1.1 Frequency control :- The stator frequency control is achieved by generating the stator flux angle by integrating the reference stator frequency (50 Hz).At the n^{th} sampling instant,$\theta_{stator\ flux}$ is given by Eq. 5,

$$\theta_{stator\ flux} = 2\pi fnT_{samp} \qquad (5)$$

Where T_{samp} is the sampling time, f stator frequency which is considered 50 Hz. $\theta_{stator\ flux}$ is used for transformation of stator voltage and current from d-q references to three phase reference frame.

4.1.2Reference d-axis stator current:- The reference value for I^*_{ds} is generated from difference of the desired voltage (V^*_t) and the sensed voltage (Vt). The sensed voltage is calculated by the Eq. 6,

$$Vt = \{(v^2_{ab} + v^2_{bc} + v^2_{ca})/3\}^{1/2} \qquad (6)$$

In this (v_{ab}, v_{bc} and v_{ca}) are the instantaneous line voltages. V_t taken as 415 V, The voltage error is obtained by the difference of given below by the Eq. 7,

$$V_{terr\ (n)} = V^*_t - V_t (7)$$

This fed to the PI controller with gains Kpvand K_{iv}.The output of PI controller is given by the Eq. 8,

$$I^*_{ds\ (n)} = I^*_{ds(n-1)} + K_{pv}(V_{terr(n)} - V_{terr(n-1)}) + k_{iv}V_{terr(n)} \qquad (8)$$

4.1.3 Reference q-axis stator current: The I^*_{qs} is generated which is given by the Eq. 9,

$$I^*_{qs\ (n)} = -L_m L_{qr(n)} / L_s \qquad (9)$$

4.1.4 Hysteresis controlled signal for stator side converter: -The sum of three phase instantaneous in-phase and quadrature components current becomes the reference BESS controller current (i^*_{sa}, i^*_{sb}, i^*_{sc}).

The hysteresis current controller controls the BESS current in a band around the desired reference current. This method controls the switches in an inverter asynchronously, to ramp the current through an inductor up and down to follow the reference. The sensed current signal (i_a, $i_b i_c$) at the input of BESS controller is compared with the desired reference current signal ($i^*_{sa} i^*_{sb} i^*_{sc}$) and the resulting error signal ($i_{saerror} = i^*_{sa} - i_a$) becomes the input of the hysteresis comparator.

4.2 Control for rotor side converter:-The objective of the rotor side converter is to achieve optimum torque for maximum power tracking for DFIG and to provide the required magnetizing current to the DFIG. The rotor side converter control scheme is shown in Fig. 3.

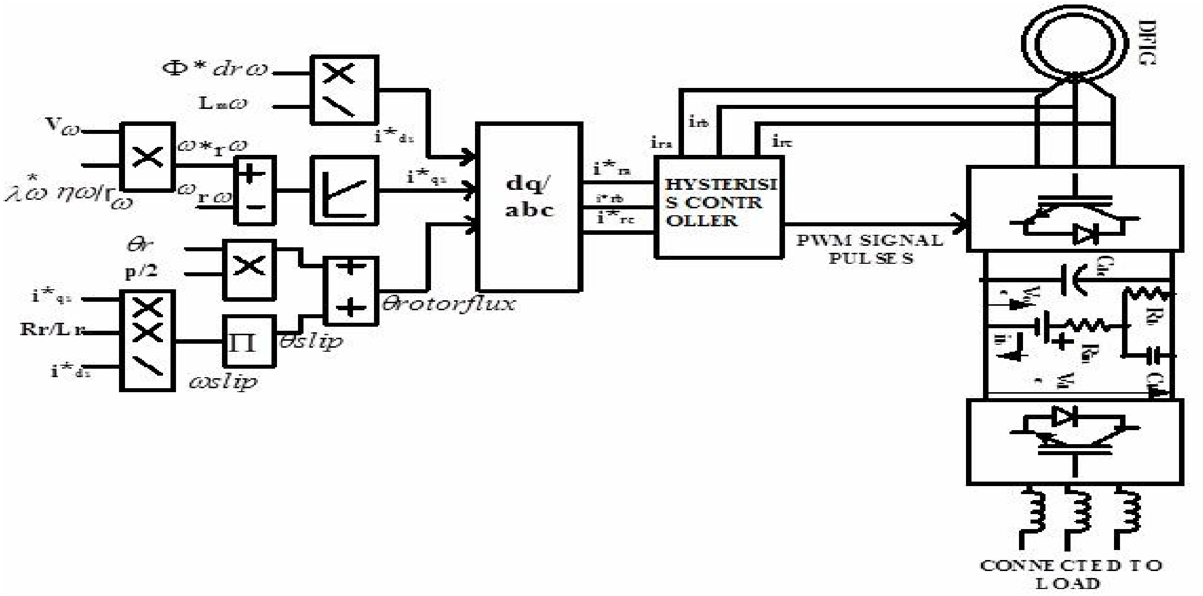

Figure. 3 Control scheme for rotor side converter

4.2.1 Speed control loop for Maximum power tracking and reference q-axis DFIG rotor current generation: In the proposed scheme the rotor position (Θ_{rw}) of DFIG and the wind speed are sensed. The rotor speed (ω_{rw}) of DFIG is determined from its rotor position (Θ_{rw}).Thetip speed ratio (λ_w) for a wind turbine of radius r_ω and gear ratio η_ω at a wind speed of V_ω is defined as by the Eq. 10,

$$\lambda_w = \omega_{r\omega} r_\omega / \eta_\omega v_\omega \qquad (10)$$

For maximum power tracking wind turbine of the DFIG should operate at the optimum tip speed ratio (λ_w), And the reference rotor speed (ω^*_{rw}) for maximum power tracking is generating by the Eq. 11, given below,

$$\omega^*_{rw} = \lambda^* V_w \eta_\omega / r_\omega \qquad (11)$$

The reference rotor speed is of DFIG is compared with $\omega_{r\omega}$for calculating the rotor speed error and which is given by the Eq. 12,

$$\omega_{rwer(n0} = \omega^*_{rw(n)} - \omega_{r\omega(n)} \qquad (12)$$

This error is fed to the PI controller, At the n^{th} sampling instant, the output of the speed PI controller with proportional gain $K_{p\omega}$ and integral gain $K_{i\omega}$gives the reference q-axis DFIG rotor current ($I^*_{qr\omega}$) given belowby the Eq. 13,

$$I^*_{qr\omega(n)} = I_{qr\omega(n-1)} + K_{p\omega}(\omega_{rwer(n)} - \omega_{rwer(n-1)}) + K_{i\omega}\omega_{rwer(n)} \qquad (13)$$

4.2.2 Reference d-axis DFIG rotor current generation: The reference d-axis DFIG rotor current (I^*_{drw}) is determined from the rotor flux set point (φ^*_{drw}) at the n_{th} sampling instant as given by the Eq. 14,

$$I^*_{drw\ (n)} = \varphi^*_{drw\ /}\, L_{mw} \qquad (14)$$

Where, L_{mw} is the magnetizing inductance of DFIG[3].

4.2.3 Generation of Hysteresis signal for rotor side converter: The generation of rotor side control signal is same as stator side generation of control signal is described in above section in (4.1.4).

5. MATLAB based Modeling:

A simulation model is developed in MATLAB using Simulink and Sim power system set toolbox. The modeling of DFIG using wind turbine is carried out using 7.5 Kw, 415 V, 50 Hz, 4 pole machine, Δ- connected induction generator.In this system two loads are considered for modeling one is resistive and another one is reactive load. The unbalanced load is modeled using breakers at individual phases.The simulated transient waveforms consist of, generator voltage (vgabc1), generator currents (igabc1), load currents ($I_L$abc1), terminal voltage (Vt1), frequency (f1), battery current (I_{bat1}) and wind speed (wind). The x-axis represents time in seconds. This simulation is done on MATLAB version 7.8 with ode 3 solver. The detailed modeling description of each part is given in the following section.

6. Result and discussion:

The performance of the DFIG system with the proposed control algorithm is demonstrated for balanced/ unbalanced resistive and reactive load. Thesystem is also studied under varying DFIG rotor speed due to wind speed variations.

6.1 Performance of DFIG with BESS Feeding Balance/Unbalanced Resistive Load:The performance of wind turbine using DFIG and its controller is shown in Fig.4 with balanced/unbalanced linear resistive load at varying wind speed. Before the application of consumer load, the battery consumes all the generated active power. At 2.2sec balanced load is applied to the system, later on at 2.3sec one of the phase is removed and again at 2.4 sec another phase is also removed hence load becomes unbalanced. Results in charging and discharging of battery and maintain load balancing is shown in transient wave form. Later on one by one phasearereconnected to the system. Hence in the balanced, unbalanced and no load condition voltage and frequency of the system remain constant.

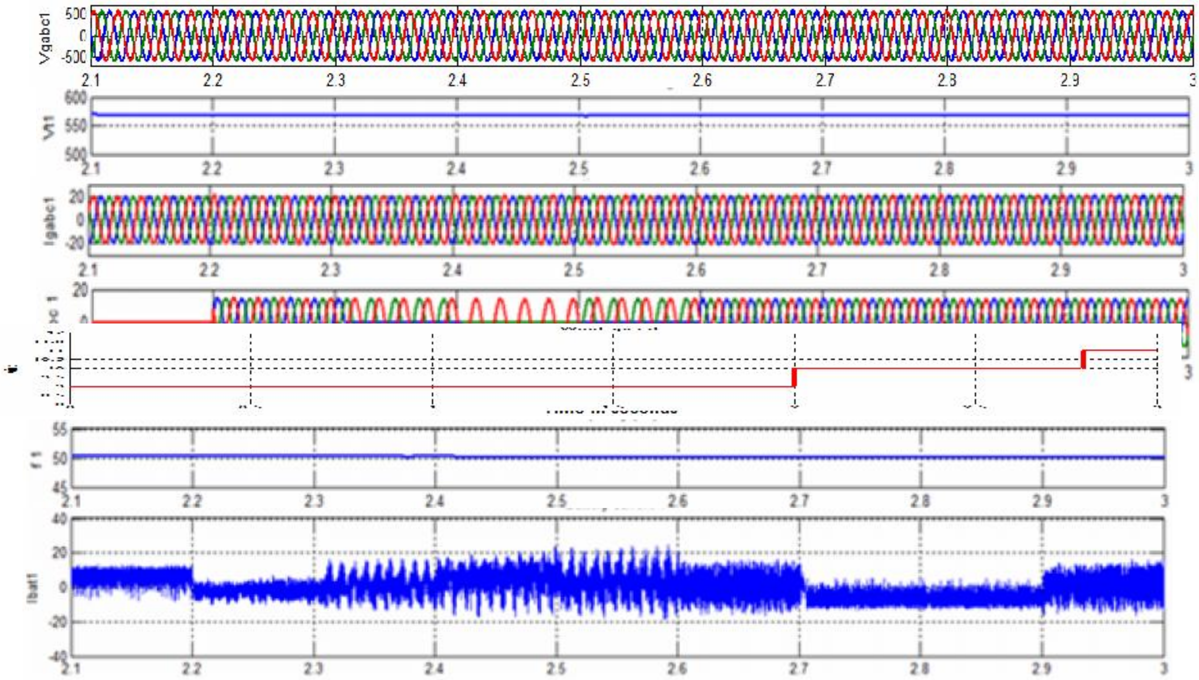

Figure . 4 Performance of wind turbine system using DFIG with balanced/ unbalanced linear resistive load at varying wind speed

6.2 Performance of DFIG with BESS Feeding Balance/Unbalanced Reactive Load:Similarly The performance of BESS based VF controller for wind turbine using DFIG is shown in Fig.5 with balanced/unbalanced linear reactive load at varying wind speed. Before the application of consumer load, the battery consumes all the generated active power. At 2.2sec balanced load is applied to the system, later on at 2.3sec one of the phase is removed and again at 2.4 sec another phase is also removed hence load becomes unbalanced. Results in charging and discharging of battery and maintain load balancing is shown in transient wave form. Later on one by one phase arereconnected to the system. Hence in the balanced, unbalanced and no load condition voltage and frequency of the system remain constant.

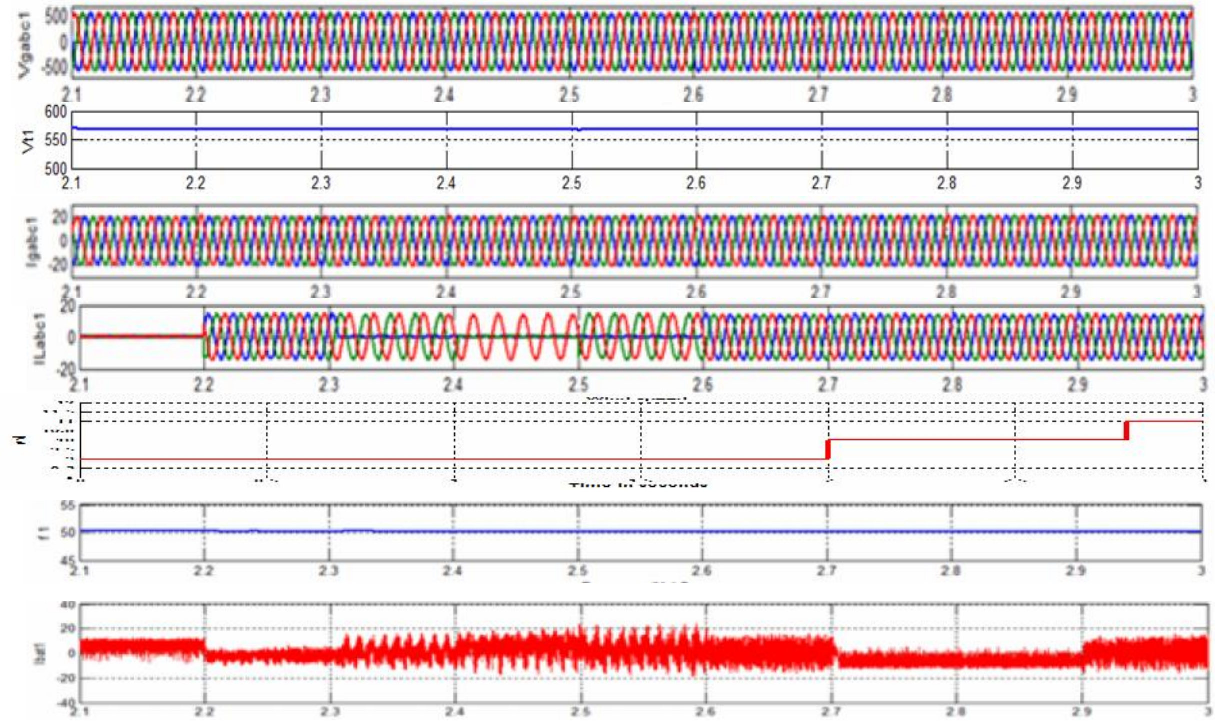

Figure . 5 Performance of wind turbine system using DFIG with balanced/ unbalanced linear reactive load at varying wind speed

7. Conclusion:

Among the renewable energy sources, wind energy have the ability to complement others. Further, there are many isolated locations which cannot be connected to the grid and where the wind potential exists, for such locations, a new three-phase three- wire autonomous wind energy conversion system, using DFIG driven by wind turbine along with BESS, has been modeled and simulated in using sim Power System tool boxes. The design procedure for MATLAB selection of various components has been demonstrated for the proposed isolated system. The performance of the proposed isolated system has been demonstrated under different electrical (consumer load variation) and mechanical (with wind-speed variation) dynamic conditions. It has been demonstrated that the proposed isolated system performs satisfactorily under different dynamic conditions while maintaining constant voltage and frequency. Moreover, it has shown capability of MPT, harmonics elimination, and load balancing.

Appendix:

1. Machine parameters:

7.5kW, 415V, 50Hz, Y-connected, 4-pole, Rs = 1Ω,
Rr =0.77Ω, Xlr= Xls= 1.5Ω, J= 0.1384kg-m2

2. Controller parameters:

K_{pf}= 1, K_{if} = 10
K_{pd} = 0.02, K_{id} = 0.0025.

3. Battery parameters:

L_f = 3mH, R_f = 0.1Ω and C_{dc} = 4000µf, R_1=10K
R_o=0.01 Ω, C_{bat}=5760 F

4. Consumer Loads:

Resistive load= 2.5 kW single phase loads.
Reactive load = 2.5kW, 1.875 KVAR 0.8PF lagging single phase loads.

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