

Load Voltage and Frequency Regulation in PMSG based Standalone Wind Energy Conversion System

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ABSTRACT

Stand alone variable speed wind energy conversion system with PMSG is proposed in this paper. Two back to back VSCs are connected to interface PMSG with load. Constant voltage in DC link between two VSCs can be maintained constant by using a battery energy storage system (BESS). BESS is efficient to maintain load voltage and frequency to be regulated during variable wind speed conditions. MPPT based vector controlling is used to control generator side converter to maintain unity power factor at PMSG which improves generated power and efficiency. Load side converter is controlled to maintain regulated voltage and frequency at load side. Simulations are performed using MATLAB/SIMULINK to check effectiveness of control strategies. Performance is checked with increase in wind speed; decrease in wind speed and with unbalanced/non linear loads.

Keywords

PMSG, wind energy, MPPT, Battery Energy storage, voltage source converters.

1. INTRODUCTION

Wind energy conversion system is economically feasible and environment friendly in power generation. Because of its environmental benefits, technological advance and government incentives wind energy conversion is growing fast from last decade. Annual growth rate of wind energy conversion is 40% during last 15 years. Wind turbines are designed either for constant wind speed or for variable wind speed. Comparing with constant speed wind turbines, 10% to 20% more output can be gained from variable speed wind turbines. Power electronic converters are required in between wind generation and utility side to maintain regulated voltage and frequency at load side [1].

Depends on the type of wind turbines three types of generators are utilised in wind energy conversion. Squirrel cage induction generator (SCIG) is coupled to a fixed speed wind turbine through a gear box and is directly connected to grid. Doubly fed induction generator (DFIG) is coupled to variable speed wind turbine through a gear box and its stator is directly connected to grid. Rotor windings of DFIG are fed by power electronic converters to control rotor frequency and hence rotor speed. Third type of generator is a low speed high torque synchronous generator (PMSG) [2]. PMSGs are gaining popularity in wind energy conversion system due to their self excitation property, high efficiency, reduced weight and compact construction. Because of no requirement of mechanical components such as slip rings reliability of conversion increases.

Controlling of variable wind speed turbine with doubly fed induction generator is presented in [3]. Rating of power converters in such type of conversion depends on speed range.

PMSG based variable speed wind energy conversion system is presented in [4]. In this configuration load is connected to PMSG through a diode rectifier and a DC chopper. Controlling of power factor at generator side is not possible which reduces efficiency of generator. Harmonic distortion at generator side is also high because of diode rectifier. In [5], a z source inverter is connected to grid for PMSG based wind energy conversion system. Matrix converters are best alternative to back to back converters [6]. These converters can convert variable AC to constant AC to match the grid requirement. But main disadvantage of matrix converter is number of switches are high and hence switching losses are more and controlling is more complicated [7].

Adaptive MPPT algorithms are essential to know the optimal operating point of wind turbines [8]. Different types of MPPT algorithms including TSR control, optimal torque control, Power signal feedback control and perturbation and observation control are studied in [9-10]. Performance of tip speed ratio control is very efficient during variable wind speed condition.

In this paper PMSG based standalone wind energy conversion system is connected to load through two back to back VSCs. Control strategies for two converters are proposed to maintain regulated voltage and frequency at load side. A battery energy storage system is connected at DC link of two converters to regulate DC side voltage.

2. SYSTEM CONFIGURATION

Fig 1. Shows PMSG based wind energy conversion system with two VSCs and a BESS in DC link. Generator side converter is connected to three phase terminals of PMSG; load side converter is connected to unbalanced/non linear loads through a star delta transformer for neutral terminal. Transients at load side due to switching of LSC are reduced by a high pass RC filter.

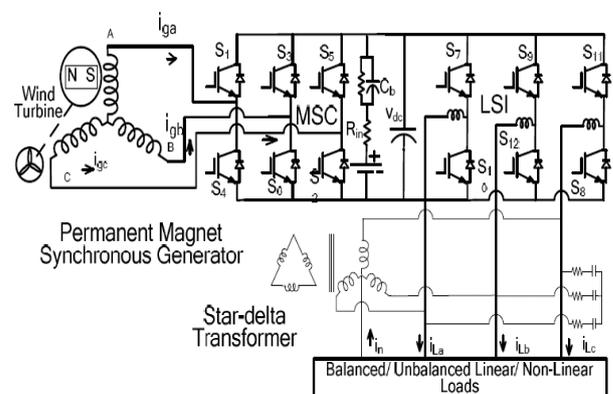


Fig 1: System Configuration

2.1 Wind Turbine Modelling

Mechanical torque developed by wind turbine is given by

$$T_m = \frac{1}{2} \rho \pi R_t^2 C_p(\lambda, \beta) \frac{V^3}{\Omega_r} \quad (1)$$

Where $\lambda = \frac{R_t \Omega_r}{V}$

ρ is the air density, R_t is the radius of the turbine, Ω_r is the rotational speed of turbine rotor in rad/sec., λ is top speed ratio, β is pitch angle and C_p rotor power coefficient.

An empirical expression for $C_p(\lambda, \beta)$ is

$$C_p = [0.5 - 0.00167(\beta - 2)]$$

$$\sin\left(\frac{\pi(\lambda+0.1)}{12-0.3(\beta-2)}\right) - 0.00184(\beta - 2)(\lambda - 3) \quad (2)$$

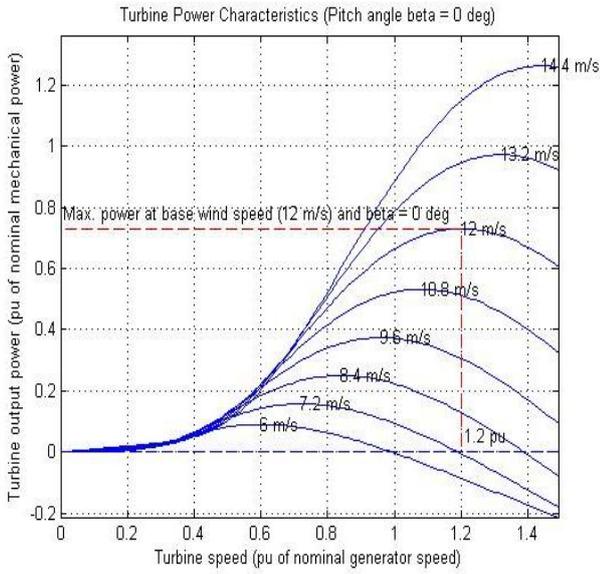


Fig 2: Wind Turbine Characteristics

Relation between turbine output power and turbine speed is shown in fig 2. from these characteristics optimum power for maximum energy for a particular wind speed can be determined. For a wind speed always there is a turbine speed to achieve maximum turbine power.

2.2 Drive train model

A drive train consists of blade pitching mechanism, rotor shaft, spinner, a hub with blades. By considering drive train as spring connected discrete masses with damping and stiffness coefficients, the equation of i th mass motion described as

$$\frac{d^2 \theta_i}{dt^2} = \frac{v_i c_i}{J_i} \frac{d\theta_{i-1}}{dt} - \frac{v_{i+1}^2 c_{i+1} + c_i}{J_i} \frac{d\theta_i}{dt} + \frac{v_i k_i}{J_i} \theta_{i-1} - \frac{v_{i+1}^2 k_{i+1} + k_i}{J_i} \theta_i + \frac{v_{i+1} k_{i+1}}{J_i} \theta_{i+1} + \frac{\tau_i}{J_i} - D_i \frac{d\theta_i}{dt} \quad (3)$$

V_i is transmission rate between i and $i-1$ masses

C_i is shaft viscosity [kg/ms]

K_i is shaft elastic constant [N/m]

J is moment of inertia of i th mass [kg.m²]

T_i is external torque [N.m] applied to the i th mass

D_i is damping coefficient [N.m/s]

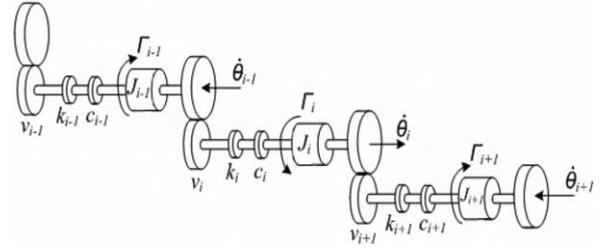


Fig 3: Transmission model of N masses

Study of torsional fatigue has to consider dynamics of all parts. But to simplify the modelling drive train is treated as one lumped mass model during interaction between wind farms and AC grids. Hence drive train model can be simplified by following equation

$$\frac{d\omega_g}{dt} = \frac{\tau_e - \tau_{w.g}}{J_{eq}} - \frac{B_m}{J_{eq}} \cdot \omega_g$$

Where g is the parameter of the generator side, ω_g is the mechanical angular speed, B_m is damping coefficient, τ_e is the electromechanical torque, $\tau_{w.g}$ is the aerodynamic torque, J_{eq} is the equivalent rotational inertia.

2.3 MPPT Algorithm

Even with variable wind speed tip speed ratio is constant for a wind turbine. By choosing optimal value for TSR maximum energy can be extracted from wind turbine. Characteristics between coefficient of power and TSR are shown in fig 4. During variable wind speed error between optimal TSR and actual TSR force the conversion system to change speed of the generator to maintain reduced error.

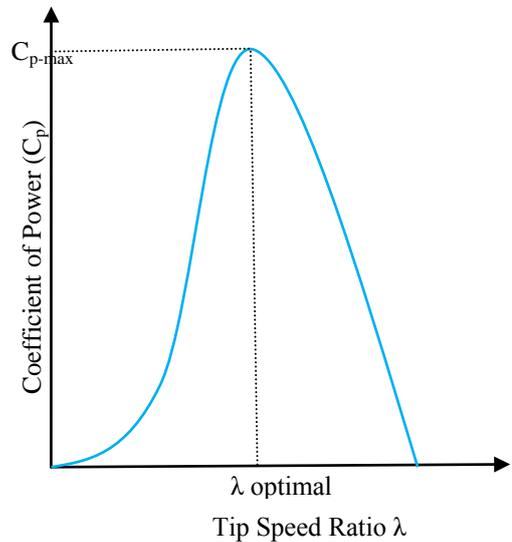


Fig 4: Characteristics between coefficient of power and TSR

2.4 PMSG model

Using Synchronous reference frame two axis based dynamic model of PMSG can be derived. Following assumptions are taken while deriving the mathematical model of PMSG. Damping windings are not considered. Considering stator winding is symmetrical. Neglect dependency of rotor inductance on rotor position due to stator slots. Neglect damping windings. Consider resistances of all windings are constant and neglecting capacitance. Position of stator winding is sinusoidal along the air gap while considering

4.1 Decrease in wind speed

In this case performance of PMSG is evaluated during decrease in wind speed. Balanced linear load is connected to load side converter. Upto 1.5 sec of simulation wind speed is 12 m/s then speed is reduced to 8 m/s. 7.1 rad/s is speed of PMSG upto 1.5 sec for wind speed of 12 m/s, then speed will be reduced to 4 rad/sec due to fall in wind speed as shown in fig 8. This is because of MPPT algorithm, which provides new reference rotor speed and actual rotor speed tracks this change in reference rotor speed. Stator current of PMSG is shown in fig 7. Linear load of 16 KW with 0.9 lagging pf is connected at load side. Decrease in wind speed reduces the amount of power generated by PMSG as shown in fig 13. Because of energy storage system connected in DC side will maintain the load voltage to be constant. Hence load cannot be disturbed because of variation in wind speed. Constant load voltage and current are shown in fig 9. Magnitude and frequency of load voltage is shown in fig 12.

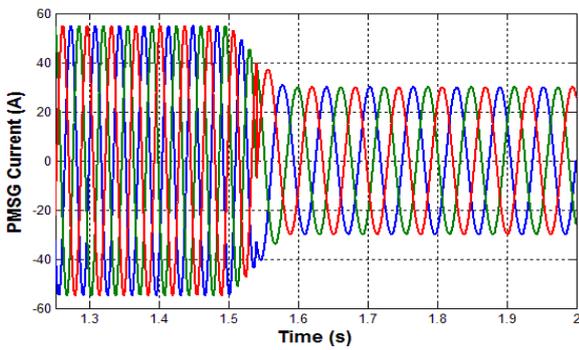


Fig 7: PMSG Current during change in wind speed

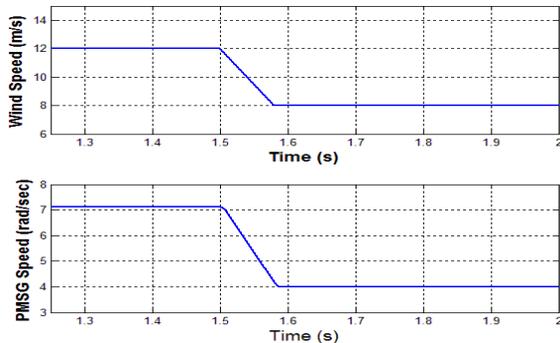


Fig 8. change in wind speed and PMSG speed

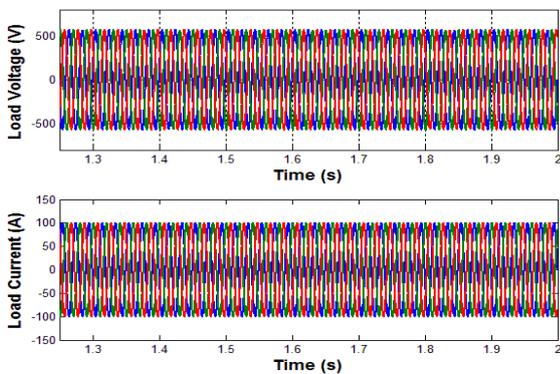


Fig 9: load voltage and current for change in wind speed

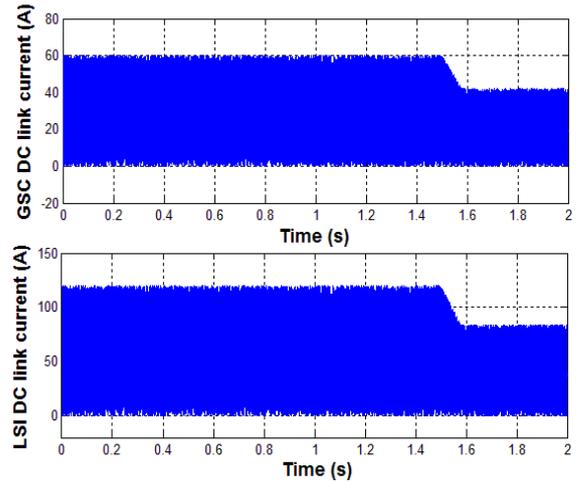


Fig 10: DC link Currents of PMSG side and load side

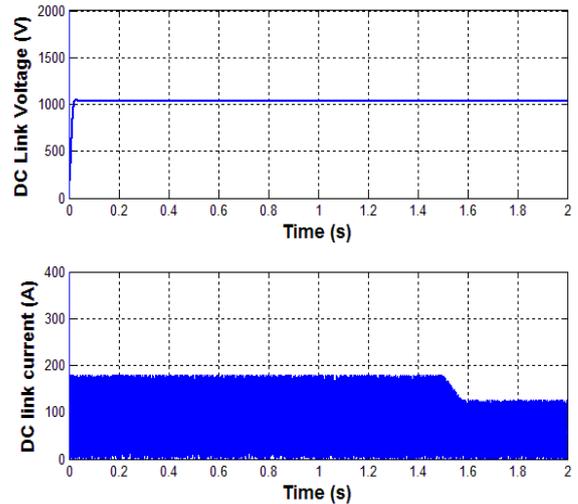


Fig 11: DC link voltage and current

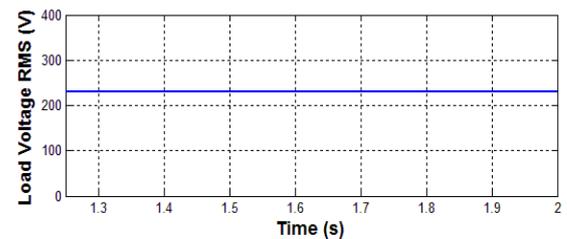


Fig 12. Load voltage and frequency of load voltage

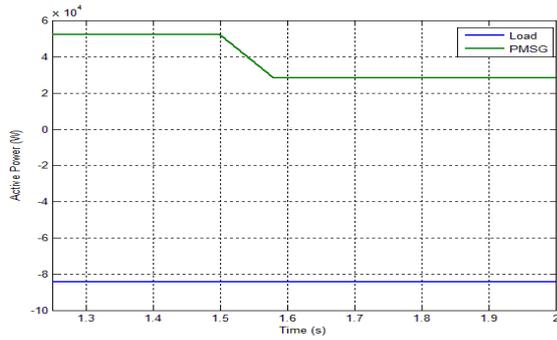


Fig 13. Load and PMSG Active power

4.2 Increase in wind speed

In this case wind speed is increased from 8 m/s to 12 m/s at 3 seconds. Increase in wind speed increases reference rotor speed by MPPT, then actual speed tracks this increase in reference speed. Fig 14 and 15 shows wind speed and rotor speed. Increase in wind speed increases the power generated by PMSG, hence PMSG stator current also changes. But due to constant load this increase in generation can be stored in energy storage system. Load voltage and load current are shown in fig 17. Constant voltage and increased current of BESS due to wind speed are shown in fig 19.

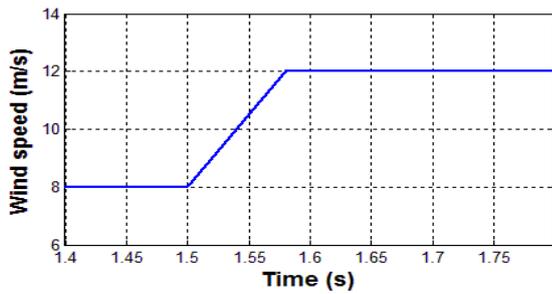


Fig 14: Increase in wind speed

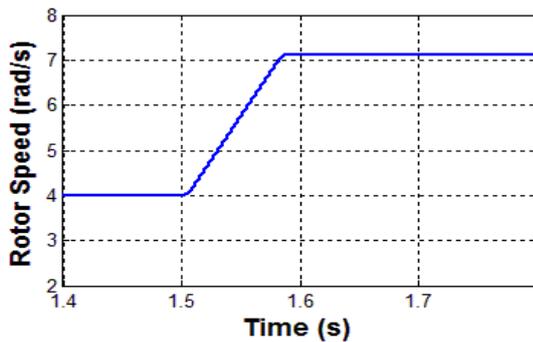


Fig 15: Change in rotor speed

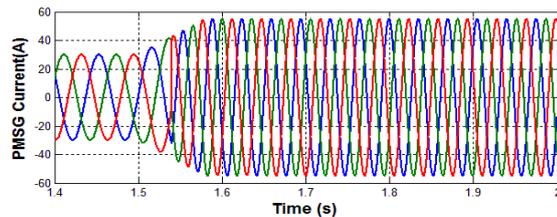


Fig 16: PMSG Current during increase in wind speed

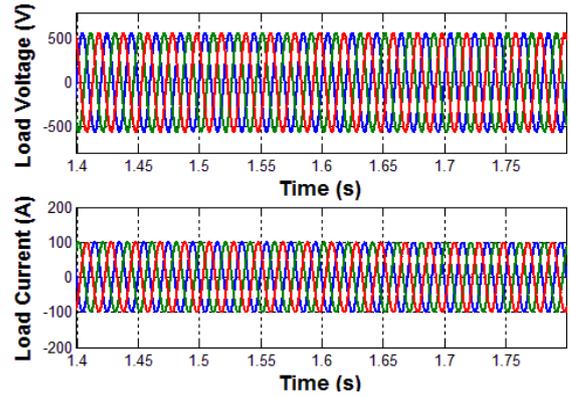


Fig 17: Load voltage and current

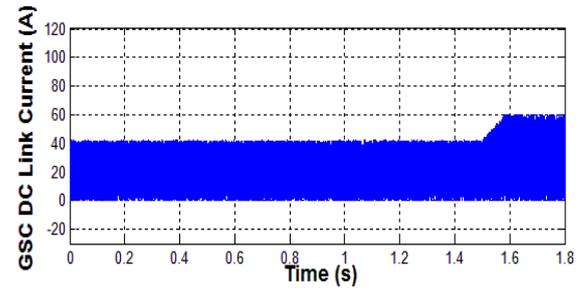


Fig 18. Generator side and load side DC currents

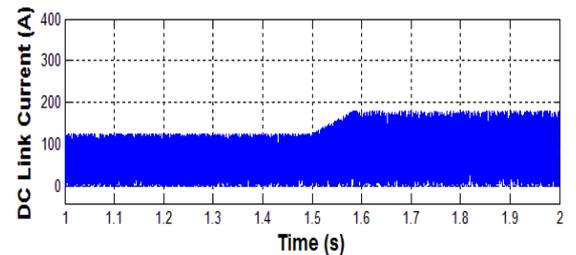
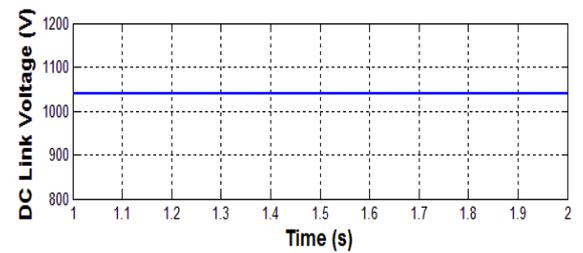


Fig 19. Voltage and current of BESS

4.3 Constant wind speed with unbalanced nonlinear loads.

In this case wind speed is maintained at constant value of 12 m/s and load is changed to unbalanced non linear load. Three single phase diode rectifier loads are connected to each phase. Load in phase a is removed from 0.2 sec to 0.4 sec. And load in phase b is removed from 0.25 sec to 0.4 sec. Even with unbalanced load, load voltage shown in fig 21 is maintained constant because of control strategy of load side converter. Effect of unbalanced and harmonic currents of load on PMSG stator currents is almost negligible due to DC link between load and PMSG. Stator currents are shown in fig 20. Amplitude and frequency of load voltage are maintained constant as shown in fig 23. Total harmonic distortion of load current is 36% and load voltage is maintained at 1.5%.

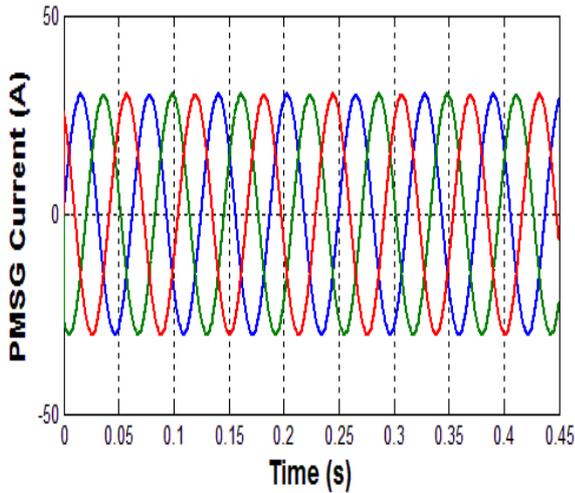


Fig 20. PMSG Current

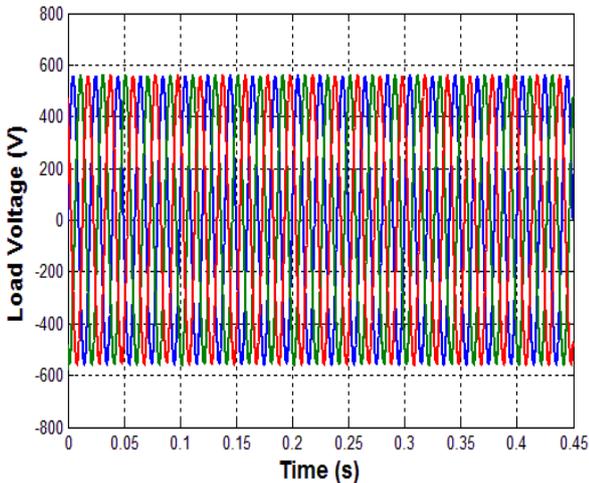


Fig 21. Load Voltage

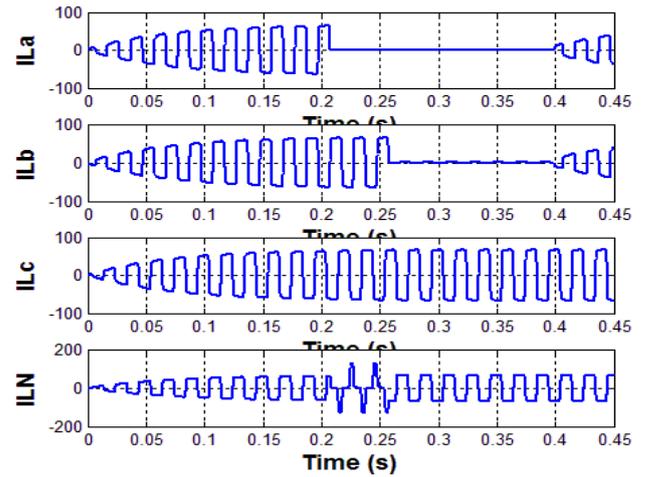


Fig 22. Load Currents

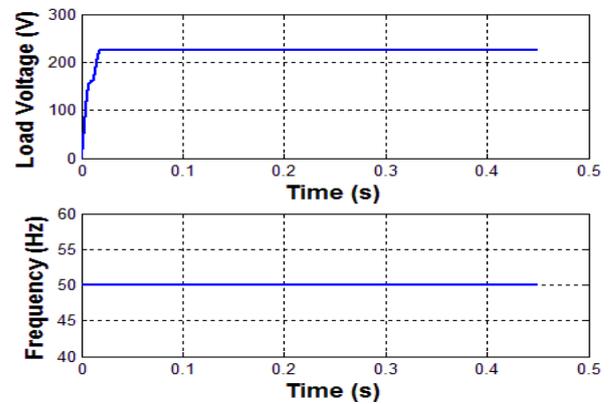


Fig 23. Load voltage magnitude and frequency

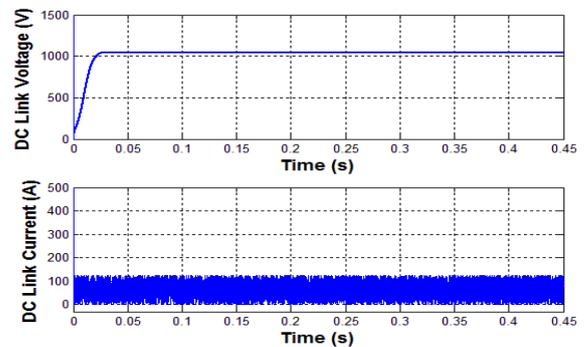


Fig 24. Voltage and current of BESS

5. CONCLUSION

A new configuration with two back to back VSCs is proposed to regulate load voltage and frequency in a PMSG based stand alone wind energy conversion system. DC link between two back to back VSCs are connected to a Battery Energy Storage System. Unity power factor operation at PMSG is achieved by MPPT based control strategy applied to generator side converter. Even during hange in wind speeds load voltage and frequency are regulated by control strategy applied to load side converter.

6. REFERENCES

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