A Control Topology for Regulating Power, Voltage and Frequency of PMSG based Wind Energy Conversion System

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***Abstract*:- The global need for cheap environment friendly energy generation has grown over recent decade due to the depletion of fossil sources. Considering the needs of future generation, renewable sources are the main focus of research work in recent decades. Compared to other sources wind energy is found to be one of the preferred alternative for many power corporation. But because of the random and erratic nature of wind some mean of control strategy must be developed in order to extract as much power as possible. Therefore in this paper a Hill-climb search (HCS) algorithm is implemented which can efficiently track the optimum power point at fast varying wind condition and also demonstrates battery connected operation for an independent wind energy conversion system (WECS). The hill-climb search algorithm is independent of the wind turbine power-speed characteristics and the wind speed hence it is a sensor less approach. Here the wind speed is changed in step wise manner and the maximum power is tracked using the HCS algorithm in SIMULINK based environment. Thus a variable speed operation is obtained from the permanent magnet synchronous generator (PMSG). Due to variable speed operation and variation of load (due to fault and overload condition) leads to huge oscillation and variation in the grid frequency and voltage waveform. Hence a voltage-frequency (VF) controller is designed to bring down the change in voltage and frequency into permissible limit. The VF controller is operated by a voltage source converter (VSC) and hybrid battery storage system. The VF controller regulates the active and reactive power supplied by battery and the generator and controls voltage and frequency fluctuation. In order to verify the proper working of the VF controller different load disturbances are introduced to the WECS and the voltage and frequency of the three-phase three-wire connection system are monitored regularly in a MATLAB based SIMULINK environment.**

Keywords: MATLAB,WECS,HCS,VSC,VF controller

I. INTRODUCTION

Due to the increasing environmental concern the old ways of power generation by burning fossil fuel has been substituted by much suitable and environment friendly renewable sources. Scientists have predicted that there is only a limited amount of fossil fuels in the earth's crust and it is going to deplete within 30-50 years. So, we need to come up with some other viable and more effective alternative which lead to increased focus on renewable sources. Wind energy is safe, inexhaustible, environment friendly and is capable of supplying growing energy demand. But, due to the erratic nature of wind a smart control strategy have to be designed to capture power equivalent to the theoretical limit. Explorations in the field of maximum power from wind conversion system has been a crucial part in transforming wind energy a preferred alternative in energy industry.

Energy Conversion Principle for Wind Turbine

The energy contained in wind is extracted using the wind turbine blades, as the wind flows the blades starts rotating. The power trapped in wind is given by

$$Pm,wind = 0.5\,(\rho A V w^{3}) \quad (1)$$

and the power captured by WG blades

Pm is a function of blade profile,
radius (R),
wind speed (Vw)
power coefficient (Cp).

$$Pm = 0.5\,\rho A V w\, 3Cp = 0.5\,\rho Cp(\lambda, \beta)\pi R\, 2Vw^{3} \quad (2)$$

Where ρ is air density (typically 1.225 kg per m3) and Cp is a function of tip-speed ratio (λ) and pitch angle (β).

$$\lambda = w.\,R\,V \quad (3)$$

Where w is the WG rotor speed of rotation (rad/s).

Maximum Power Point Extraction Concept

In order to obtain maximum efficiency and for maximum utilization of wind turbine system it is necessary to extract as much power as can be extractable at any wind speed. This is so because of the erratic nature of wind speed and its seasonal availability. This process of power conversion is in-effective as it leads to wastage of wind energy. There comes the concept of maximum power point tracking (MPPT), which is designed to track the optimum point in power versus speed curve at different wind speed. From the wind turbine power equation (2) it is clear that maximum power corresponds to maximum Cp. For a particular pitch angle maximum Cp occurs at a particular tip-speed ratio (TSR). Hence to achieve maximum power at a particular wind speed, rotational speed of turbine must be set at optimum TSR value. For turbines with fixed speed operation there can only be one optimum point corresponding to a particular

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speed. Hence it is not possible to carry out the MPPT operation in fixed speed operation. Where as in variable speed operation extraction of maximum power is possible at all wind speed as it will allow the turbine speed variation. Variable speed operations are therefore preferred in most WECS.

Voltage and Frequency Control Action

In fixed speed operation there is no need for voltage or frequency control as the generator and grid shares the same frequency. But, in case of variable speed operation the need for control is inevitable. Due to variable speed operation the wind generator and grid frequencies are different and any change in load or wind speed can affect the grid voltage and frequency. This leads to a weaker grid, prone to faults and power outage. In order to avoid this we must design a controller which will damp out the variation in the voltage and frequency. This will confirm a reliable and steady power generation.

II WIND ENERGY CONVERSION TECHNIQUE

A general Wind power conversion system involves a wind turbine, a wind generator and a gear box arrangement. Therefore different types of available turbines and generators are discussed below.

II.a.Wind Turbine

Wind turbine is the first and the most important part of wind energy conversion system. Depending upon the axis of orientation of turbine blades wind turbines (WT) are classified into two groups;

- Horizontal axis WT
- Vertical axis WT

Horizontal Axis Wind Turbine

As the name suggests the horizontal axis wind turbine (HAWT) blades are placed along the horizontal axis. The general construction of a HAWT involves a tower with a flat horizontal base at the top called nacelle. The nacelle mounts the generator and gearbox arrangement. Therefore HAWT are mechanically more complex, the gyroscopic action of turbine blade produces stress when yaw mechanism turns to catch the wind.

Vertical Axis Wind Turbine

The VAWT needs lower cost of installation and vary less maintenance requirement compared to HAWT. Another advantage of VAWT is that, its operation is independent of the direction of wind speed and it works fine at low wind speed.

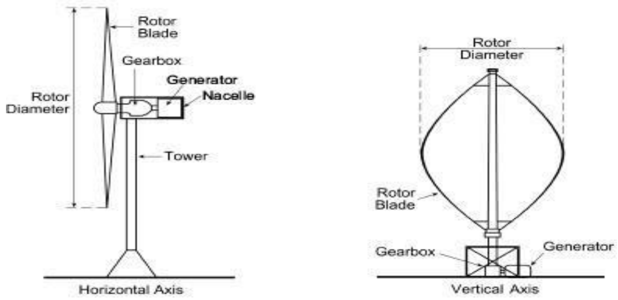

Figure.1.Horizontal axis and Vertical axis WT

II.b.Synchronous Generator

The generator has poles as rotor housed on the prime mover carrying a three phase winding and armature as stator housed inside the body. Depending on type of excitation synchronous generators are of two type permanent magnet synchronous generator (PMSG) and Wound field synchronous generator (WFSG). Higher power application require WFSG whereas PMSG is preferred for low power application.

The advantages of synchronous generator are;

- No gear box requirement. Gear box involves faults and break downs which needs frequent attention.
- Self-excited. There is no need for external exciter or prime mover. Hence higher power factor and efficiency can be achieved.
- High power to mass ratio. So compared to other equivalent rating generators synchronous has the least size.

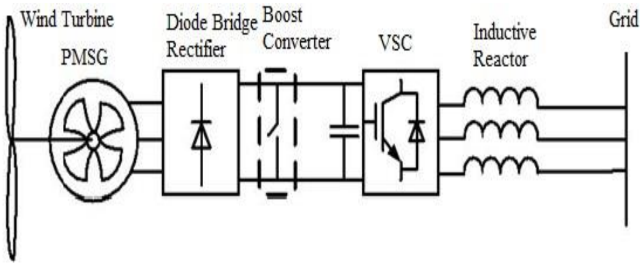

Figure 2. Permanent magnet synchronous generator based WECS

III.VOLTAGE FREQUENCY CONTROL TECHNIQUES

There are two general types of VF control schemes incorporated in wind energy conversion system;

a. Synchronous reference frame theory (SRF)
b. Instantaneous current component theory (ICC)
c. SVPWM theory

III.a.SVPWM Theory

This technique of VFC evaluates the stator linkage flux and the generator torque by estimating reference d-q axis current

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values. The dynamic performance of such a system is improved. From the phase current values d-q axis current values are estimated using Clark and Park transformation theories. The technique used in this control strategy controls the generator torque, speed and flux linkage in a three-way single approach. The error in speed is fed to PI controller which gives the generator torque and the error in torque is fed to another PPI controller whose output gives the phase angle difference between PMSG flux and actual stator flux. From these values of PWM control signal is achieved using inverse Park's transformation.

PWM Inverter

The Inverter is such a device which is employed to convert DC to AC and it can also convert AC to DC. It consists of six electronic switches connected to boost converter output at one end and three phase three wire load in the other (see Figure 8). It helps in controlling active and reactive power independently. As the reactive power regulates the dynamic voltage, hence the system stability can be improved using PWM inverter. Hence in order to summarise the benefits of PWM inverters are;

- It leads to precise control of grid power
- Stabilizes the loading of transmission line to its rated thermal limit
- Limits the effect of faults between two system by reducing chance of cascading outage of connected grids
- Suitably transmitting from offshore wind farms to AC grids on mainland.

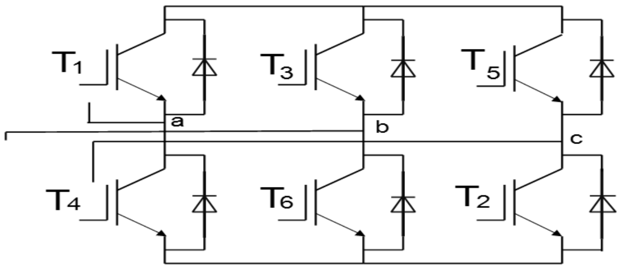

Figure.3. PWM Inverter model

Pulse Width Modulation (PWM) Generator

The PWM generator used to generate rectangular pulses for controlling the on/off of the switch. The major advantage of using PWM controller are;

- The switching power loss is very low as at switched off condition it takes no current and during on period power transfer is possible, so there is no voltage drop across the electronic switch.
- Variable duty cycle can be easily changed, hence it finds its application in most of the digital control circuits.

III.b. POWER OPTIMIZATION TECHNIQUE

For power optimization it is needed to design a control algorithm which is optimized, less-complex and effective. There are three major speed control algorithm for variable speed operation they are;

(i)Tip speed ratio (TSR)

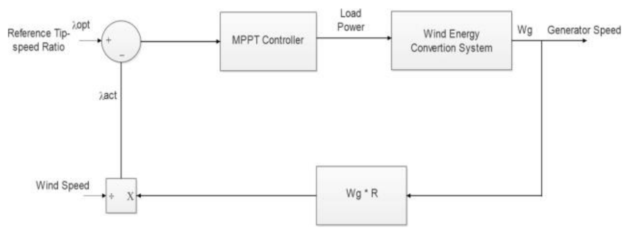

Figure 4. Tip speed ratio MPPT control strategy

The actual wind speed is calculated using anemometer and the tip speed ratio corresponding to the value is measured. This TSR value is compared with reference TSR value, the difference of which is fed to the MPPT controller.

(ii) **Power signal feedback (PSF)**

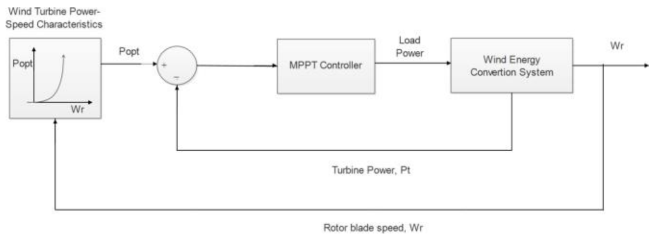

Figure 5. Power signal feedback based MPPT control strategy

The optimal power value is calculated from wind generator power versus speed characteristics, which is compared with observed generator power. The error is fed to the MPPT controller.

(iii) Hill climb search (HCS)

Hill climb search algorithm is a mathematical optimization technique in where the control algorithm continuously tracks the optimum power point of the wind energy power-speed characteristics. This method is preferred over other two method as it does not require the wind energy power-speed characteristics which is not accurate and keeps changing as the rotor ages (see Figure 6).

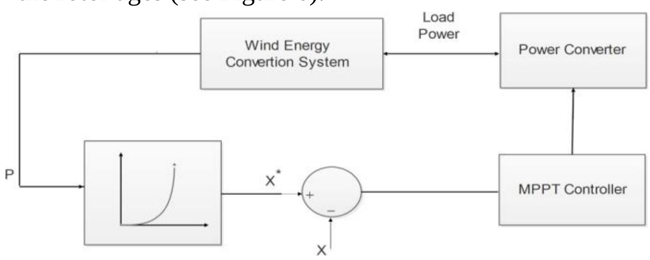

Figure 6. Hill climb search MPPT control strategy

The parameter X (duty cycle, voltage, current etc.) is measured and compared with optimum value of that

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parameter X^*. The error is fed to MPPT controller which regulates the power converter to optimise the output of WECS.

IV. CONTROL METHODOLOGY AND ALGORITHM

(i) The Implemented MPPT technique

The power from wind generator is fed to a diode bridge rectifier, so we have here;

$$P_g = 3V_{ph}I_{ph} = V_{dc}I_{dc} \quad (4)$$ (4)

Where P_g represents generator output power, V_{ph}, I_{ph}, V_{dc}, I_{dc} are the output voltage and current of the PMSG and rectifier respectively. From the Figure wind generator power versus speed characteristics, it is evident that it has a single maximum power point and at maximum power production

$$\frac{dP}{dw} = 0 \quad (5)$$

(ii) MPPT Control Algorithm

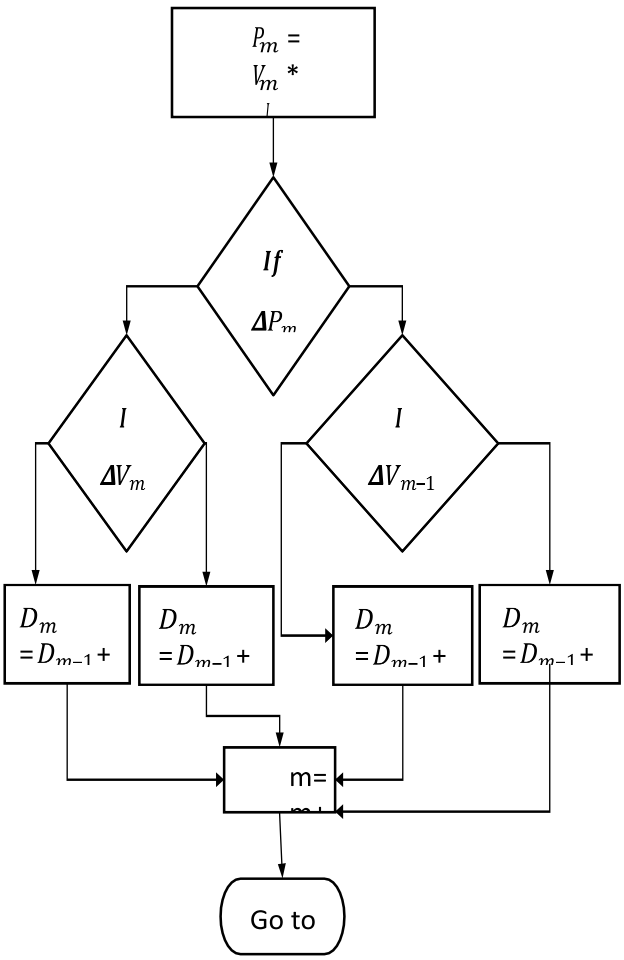
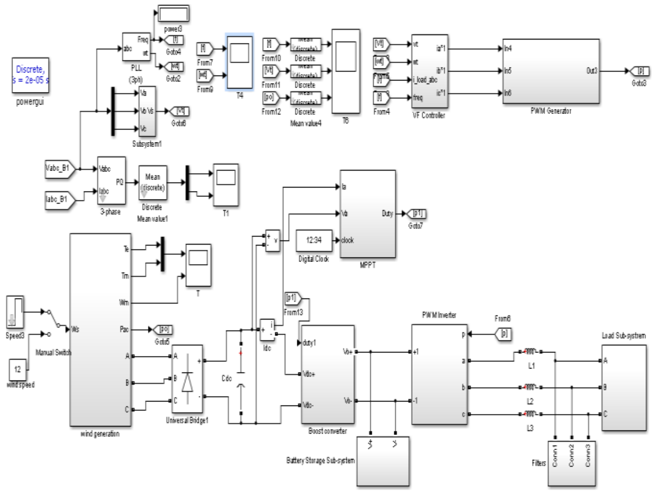


Figure 7. MPPT Algorithm used in this paper

The output of the VFC gives the three phase reference load current. The difference between load reference and actual load current of the three phase system is fed to a proportional controller to amplify the error. This amplified error signal is then compared with the triangular high frequency carrier signal (above 5 kHz), and the gate pulse signal is generated for controlling PWM inverter.

The BSS is used to store energy during high wind speed period when energy generation is more or during low energy demand cycle. Similarly it supplies the excess energy need during higher load demand.



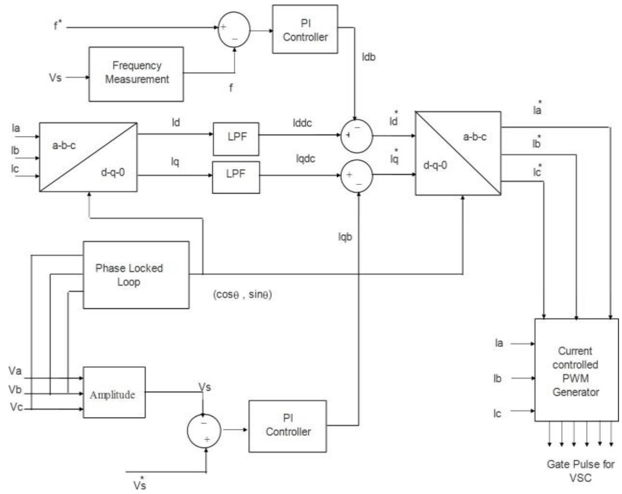


Figure 8. Voltage frequency controller model

V. SIMULATION MODEL AND RESULTS

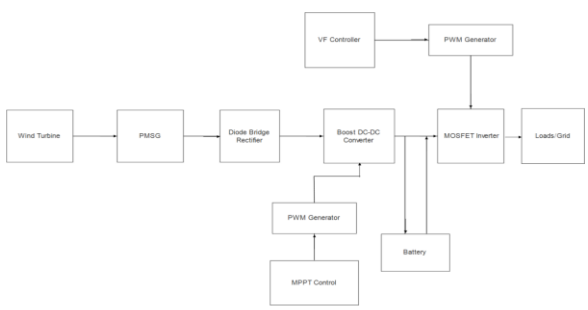


Figure 9. Block diagram of implemented model

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In this WECS design a wind turbine is connected to PMSG whose power is rectified using diode bridge rectifier. The rectified power is then boosted up to the DC-link voltage level. The switching of Boost converter is controlled with MPPT controller. A battery is connected in the DC-link to supply or store the deficit or extra power needed. The DC power is converted to AC using IGBT inverter. The three phase load is connected to the inverter.

OVERALL WECS MODEL

Figure 10. SIMULINK model of proposed WECS

From the SIMULINK model it is observed that the WECS consists of a wind turbine, a PMSG, a diode bridge rectifier, a boost converter, a PWM inverter, a battery storage system, VF controller, filters and load sub-system.

VF CONTROLLER MODEL

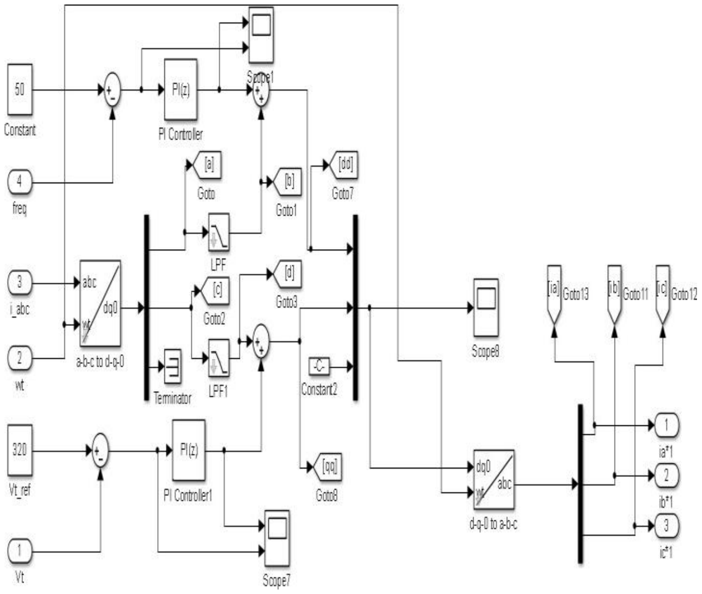

Figure 11. SIMULINK model for voltage frequency controller

The VF controller takes nominal voltage, nominal frequency, three phase load current, terminal voltage, and grid frequency as input. With the help of PI controller and LPF it gives load reference currents. The reference frequency is 50 Hz and the reference voltage is 320V.

MPPT CONTROL RESULT

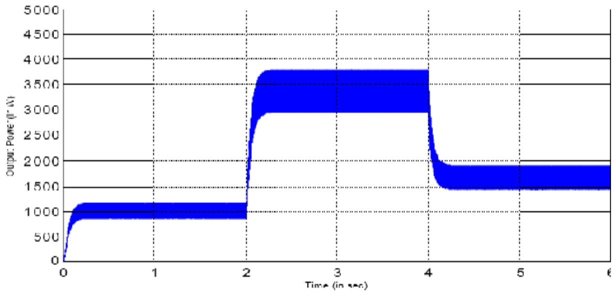

Figure 12. Output power vs. Time with MPPT

VOLTAGE FREQUENCY CONTROL RESULT

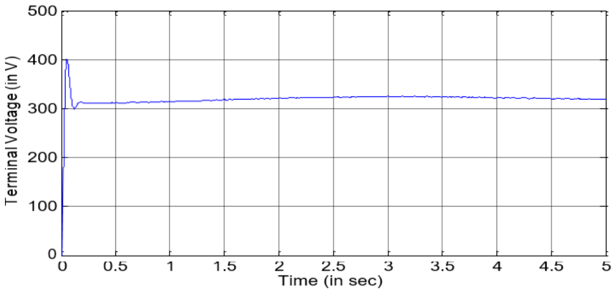

Figure 13. Terminal voltage versus time plot for wind change at t=2.5s

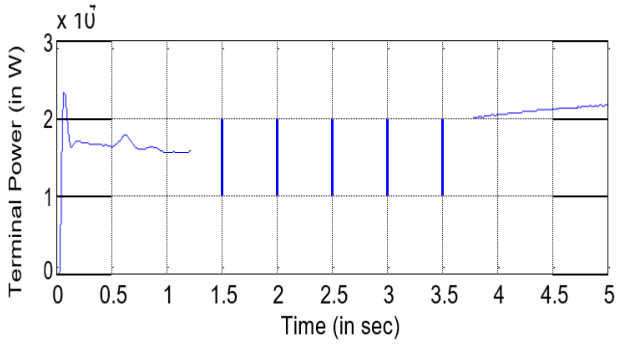

Figure 14. Terminal power versus time plot for wind change at t=2.5s

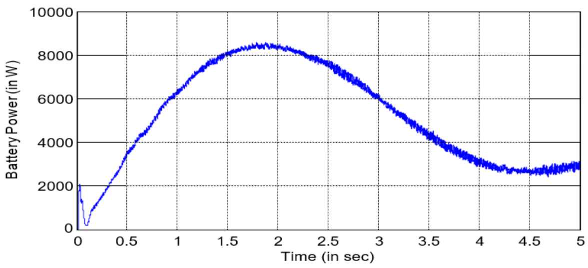

Figure 15. Battery power versus time plot for wind change at t=2.5s

VI. CONCLUSION

From the Figures MPPT Power versus time plot it is clearly visible that with MPPT action the generated output power of the PMSG is increased by 20%. This hence shows the fact that without the MPPT action auto tracking of maximum power is not possible.

The action of VF controller to wind change at 2.5s shows minor disturbances in frequency and terminal power seems to increase after wind change. The battery supplies more power at lower wind speed for speed below rated speed. The output of VF controller to over load shows very low variation in frequency from the reference value i.e. 50 Hz.

From Figure it is observed that the terminal voltage of DC link is fixed at its reference value which is 320 V and the terminal power is observed to increase after overload and at the same time battery which is initially charging up to 3 sec starts supplying power.

A stand-alone WECS is designed using power electronic converters and PMSG to extract maximum power at varying wind speed and to balance the effect of voltage and frequency variation due to change in load conditions. We can see from the results of MPPT algorithm on wind generator power

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output that without MPPT the PMSG power was low and after implementation of MPPT it has been enhanced. Similarly from the results of voltage and frequency control the following results are observed, even with non-linear load;

- Successful removal of voltage and current harmonics.
- Load balancing even at faults.
- Indirect current control action.
- DC and AC bus-bar stabilization.

Also, the battery based system (BBS) output at these variable loading is also observed and it is found that during sudden increase in load the battery starts discharging and during high wind condition it gets charged.

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