AN EFFICIENT VARIABLE SPEED STAND ALONE WIND ENERGY CONVERSION SYSTEM & EFFICIENT CONTROL TECHNIQUES FOR VARIABLE WIND APPLICATIONS

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ABSTRACT

This paper provides an efficient control technique for the operation of a direct-drive synchronous generator-based stand-alone variable-speed wind energy conversion system. The control strategy for the generator-side converter with maximum power extraction is presented. This control provides a constant output voltage and frequency which capable of delivering to variable loads. The main attention is DC link voltage control deals with the chopper control for various load conditions, also a battery storage system with converter and inverter has to be used to deliver continuous power at the time of fluctuated wind. The PI Controller in switch mode rectifier can be replaced with vector control technique to improve the output voltage level. The simulation results show this control strategy gives better regulating voltage and frequency under sudden varying loads. Dynamic representation of DC bus and small signal analysis of the system are presented. The dynamic controller shows very good performance.

KEYWORDS: *PMSM, boost converter, inverter, driver circuit, dynamic controller and PIC/DSP.*

I. INTRODUCTION

In this paper a design of efficient control techniques in variable speed to give continuous Supply to load is implemented. Variable-speed wind turbines have many advantages over fixed-speed generation such as increased energy capture, operation at maximum power point, improved efficiency, and power quality [1]. There liability of the variable-speed wind turbine can be improved significantly by using a direct- generator. PMSG has received much attention in wind-energy application because of their property of self-excitation, which allows an operation at a high power factor and high efficiency [2].Optimum power/torque tracking is a popular control strategy, as it helps to achieve optimum wind energy utilization [3]–[4].The switch-mode rectifier has also been investigated for small-scale variable-speed wind turbine [5], [6].It is very difficult to obtain the maximum voltage level by using PI controller. In order to obtain the maximum output, PWM control can be used.

For a stand-alone system, the output voltage of the load side converter has to be controlled in terms of amplitude and frequency. Previous publications related to PMSG-based variable-speed wind turbine are mostly concentrated on grid connected system [6]-[8]. Much attention has not been paid for a stand-alone system. Many countries are affluent in renewable energy resources; however, they are located in remote areas where power grid is not available. Local small-scale standalone distributed generation system can utilize these renewable energy resources when grid connection is not feasible. In this paper, a control strategy is developed to control the load voltage in a stand-alone mode. As there is no grid in a stand-alone system, the output voltage has to be controlled in terms of amplitude and frequency. The load-side pulse width modulation (PWM) inverter is using a relatively complex vector-control scheme to control the amplitude and frequency of the inverter output voltage. The stand-alone control is featured with output voltage and frequency controller capable of handling variable load.

II. BLOCK DIAGRAM

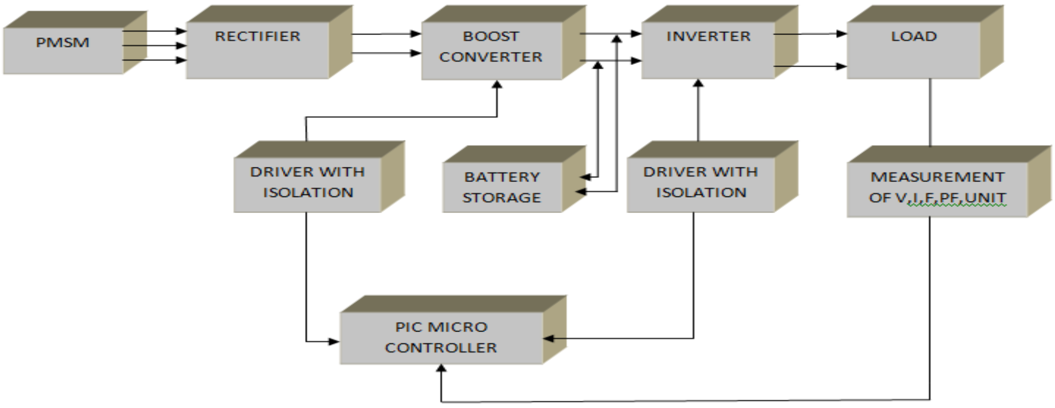


Fig 1. Block diagram of the project

Generator converts the variable speed mechanical power produced by the wind turbine into electrical power. The power produced in the generator having variable frequency and voltage AC power. This Ac power converted into DC power with the help of uncontrolled rectifier. The dc power will be have variable voltage. This variable voltage is boostered to rated level with the help of boosted converter. Boosted dc power is converted into fixed frequency AC power and it is delivered to load. Between load and inverter as storage system with converter and inverter is used to store the energy. This storage system will store the energy at the time of load lesser than maximum level. Also this storage system is used to deliver power to load when the boost converter unable to boost up the voltage. Microcontroller is used to control boost converter and inverter to get fixed frequency and voltage.

III. MATHEMATICAL MODELLING OF WECS

A. Model of Wind Turbine with PMSG

Wind turbines cannot fully capture wind energy. The components of wind turbine have been modelled by the following equations [8-10].Output aerodynamic power of the wind-turbine is expressed as:

$$P_{Turbine} = \frac{1}{2}\rho A C_P(\lambda, \beta) v^3 \qquad (1)$$

Where, ρ is the air density (typically 1.225 kg/m3), A is the area swept by the rotor blades (in m2), Cp is the coefficient of power conversion and v is the wind speed (in m/s). The tip-speed ratio is defined as:

$$\lambda = \frac{\omega_m R}{v} \qquad (2)$$

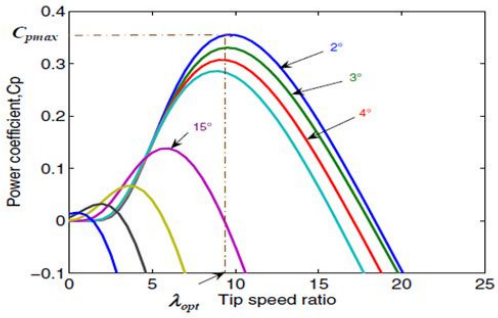


Fig 2.characteristics of Cp Vs λ; for various values of the pitch angle β

Where ω_m and R are the rotor angular velocity (in rad/sec) and rotor radium (in m), respectively. The wind turbine mechanical torque output m T given as:

$$T_m = \frac{1}{2}\rho A C_P(\lambda,\beta)v^3 \frac{1}{\omega_m} \quad (3)$$

The power coefficient is a nonlinear function of the tip speed ratio λ and the blade pitch angle β (in degrees). If the swept area of the blade and the air density are constant, the value of Cp is a function of λ and it is maximum at the particular opt λ. Hence, to fully utilize the wind energy, λ should be maintained at opt λ, which is determined from the blade design. Then:

$$P_{Turbine} = \frac{1}{2}\rho A C_{P\max} v^3 \quad (4)$$

A generic equation is used to model the power coefficient Cp (λ, β) based on the modeling turbine characteristics described in [2], [7-9] and [11] as:

$$C_P = \frac{1}{2}(\frac{116}{\lambda_i} - 0.4\beta - 5)e^{-(\frac{21}{\lambda_i})} \quad (5)$$

The characteristic function *Cp* (λ ,β) vs λ, for various values of the pitch angle β, is illustrated in Fig.2. The maximum value of *Cp* (λ ,β) , that is *Cp,*max =0.36, is achieved for β =2º and for λ =9.6. This particular value λ*opt* results in the point of optimal efficiency where the maximum power is captured from wind by the wind turbine. For each wind speed, there exists a specific point in the wind generator power characteristic, MPPT, where the output power is maximized. Thus, the control of the WECS load results in a variable-speed operation of the turbine rotor,

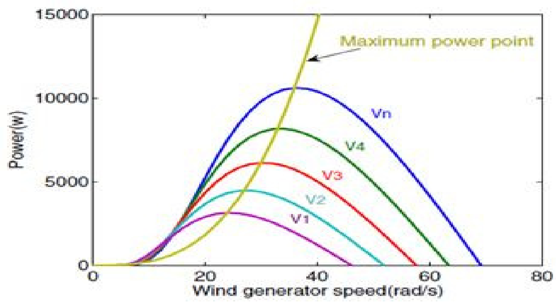


Fig 3.wind generator power curves at various wind speed

So the maximum power is extracted continuously from the wind (MPPT control) .That illustrated in Fig.3.

B. PMSG Model

Dynamic modeling of PMSG can be described in d-q reference system as follows [1], [10]:

$$v_{gq} = -\left(R_g + p.L_q\right).i_q - \omega_e L_d i_d + \omega_e \psi_f \quad (6)$$

$$v_{gd} = -\left(R_g + pL_d\right)i_d + \omega_e L_q i_q \quad (7)$$

Where Rg is the stator resistance, Lq and Ld are the inductances of the generator on the d and q axis, ψ f is the Permanent magnetic flux and electrical rotating speed of the generator, defined by

$$\omega_e = p_n \omega_m \quad (8)$$

Where Pn is the number of pole pairs of the generator and ωm is the mechanical angular speed. In order to complete the mathematical model of the PMSG, the expression for the electromagnetic torque can be described as [11]:

$$T_e = \frac{3}{2} p_n \left[\left(L_d - L_q\right) i_d i_q - \psi_f i_q\right] \quad (9)$$

If id = 0, the electromagnetic torque is expressed as:

$$T_e = -\frac{3}{2} p_n \psi_f i_q \quad (10)$$

C. Wind-Turbine Characteristics

The amount of power captured by the wind turbine (power delivered by the rotor) is given by,

$$T_{m\_opt} = K_{opt} \left(\omega_{m\_opt}\right)^2. \quad (11)$$

Where ρ is the air density (kilograms per cubic meter), v is the wind speed in meters per second, A is the blades' swept area, and C*p* is the turbine-rotor-power coefficient, which is a function of the tips peed ratio (λ) and pitch angle (β).ω*m* = rotational speed of turbine rotor in mechanical radians per second, and R = radius of the turbine. If the wind speed varies, the rotor speed should be adjusted to follow the change.
The target optimum torque can be given by

$$P_t = 0.5\rho A C_p(\lambda, \beta) \times (v_\omega)^3 = 0.5\rho A C_p \times \left(\frac{\omega_m R}{\lambda}\right)^3 \quad (12)$$

The mechanical rotor power generated by the turbine as a function of the rotor speed for different wind speed is shown in Fig. 4.

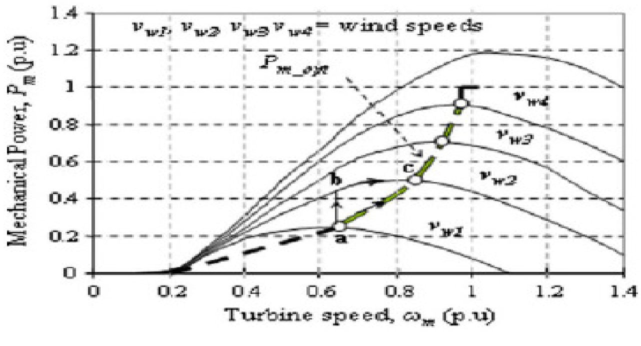


Fig 4. Mechanical power generated by the turbine as a function of the rotor
Speed for different wind speeds.

The optimum power is also shown in this figure. The optimum power curve (Popt) shows how Maximum energy can be captured from the fluctuating wind. The function of the controller is to keep the turbine operating on this curve, as the wind velocity varies. It is observed from this figure that there is always a matching rotor speed which produces optimum power for any wind speed. If the controller can properly follow the optimum curve, the wind turbine will produce maximum power at any speed within the allowable range.

IV. IC PIC16F877A MICRO CONTROLLER

PIC is a family of Harvard architecture microcontrollers made by Microchip Technology. It is the controller IC for controlling purpose and it convert the given signal into the digital signal and it will send the appropriate signal to receiver side. This PIC microcontroller is used to control all parts of the circuit. This is used to fire all IGBT's and relay. The main advantage of CMOS and RISC combination is low power consumption resulting in a very small chip size with a small pin count. The main advantage of CMOS is that it has immunity to noise than other fabrication techniques.

A. Features

1. Pin out compatible to the PIC16C73B/74B/76/77
2. Interrupt capability (up to 14 sources)
3. Eight level deep hardware stack
4. Direct, indirect and relative addressing modes
5. Power-on Reset (POR)
6. Power-up Timer (PWRT) and
7. Oscillator Start-up Timer (OST)
8. Watchdog Timer with its own on-chip RC oscillator.

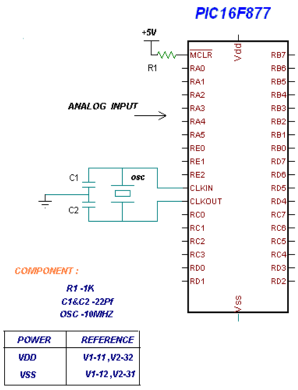


Fig 5. Architecture of IC PIC16F877A

V. BOOST CONVERTER

A. Boost Converter Control Strategy

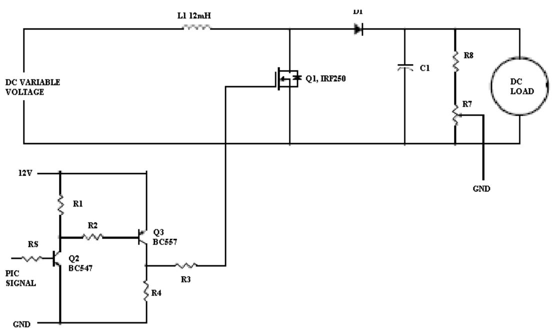


Fig 6. The power circuit is a dc-dc boost converter. The command circuit is the one, in which the analogue controller was replaced with a Fuzzy one. The output of the Fuzzy controller is v_c.

In average current control method, an input voltage sensing is required to obtain a sinusoidal reference, an analogue multiplier to combine this reference with the output information, and an error amplifier in current loop to extract the difference between the input current and the reference to generate the control signal for modulating the input current. There are a lot of very sophisticated researches of boost converter dynamics. The most of PFC is based on boost converter, because of its input inductor which reduces the total harmonics distortion and avoids the transient impulse from power net, the voltage of semiconductor device below output voltage, the zero potential of Q's source side which makes it easy to drive Q and its simple structure. Therefore, satisfied teaching of advanced power electronics should be introduced by unity power factor and high efficiency by DC-DC boost converter. In this section one inductor and an IGBT are used to boost up the voltage. When the Dc voltage is lesser than the rated level, it will boost up the voltage. IGBT is used to charging and discharging the inductor. This IGBT is control by micro controller.

VI. CONTROL OF LOAD-SIDE INVERTER

The control strategy of Vector-Control Scheme is used to perform the control of the grid side converter. They control of the DC-link voltage, active and reactive power delivered to the grid, grid synchronization and to ensure high quality of the injected power [2].The objective of the supply-side converter is to regulate the voltage and frequency. The control schemes are in the inner loops where they use different reference frames to perform the current control. In the first case, the currents are controlled in the synchronous rotating reference frame using PI controllers. The dc voltage PI controller maintains the dc voltage to the reference value. The PI controllers are used to regulate the output voltage and currents in the inner control loops and the dc voltage controller in the outer loop. This is the classical control structure, it is also known as dq-control. It transforms the grid voltages and currents from the abc to the dq reference frame. In this way the variables are transformed to DC values which can be controlled more easily. This structure uses PI controllers since they have good performance for controlling DC variable.

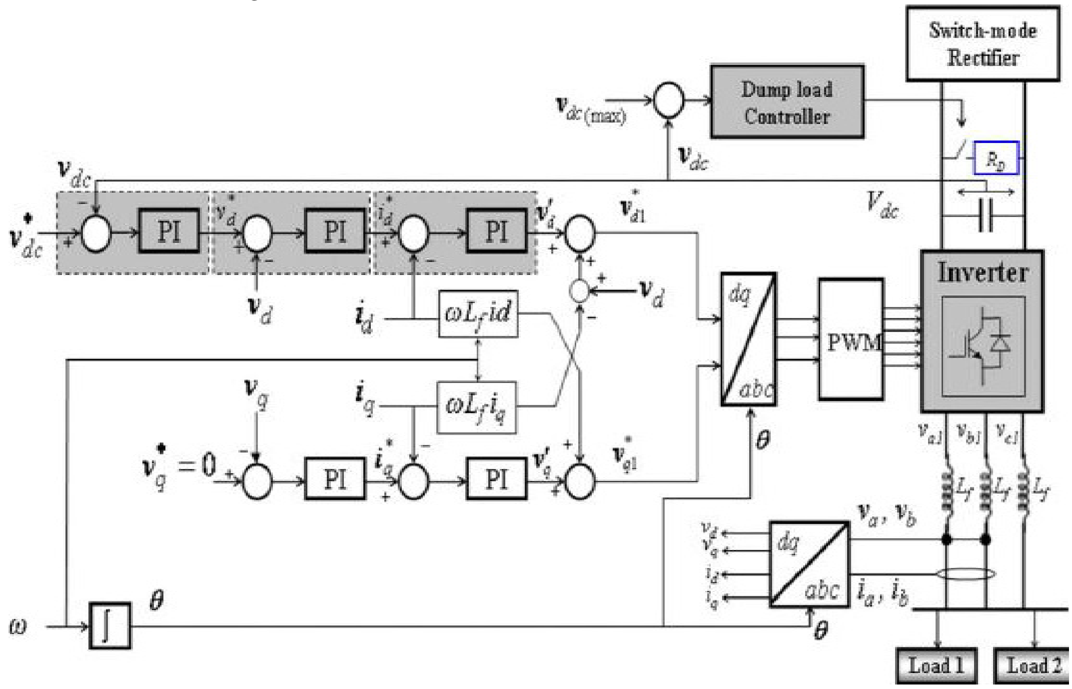


Fig 7.vectrol control technique

VII. CONTROL OF SWITCH-MODE RECTIFIER WITH MAXIMUM POWER EXTRACTION

The structure of the proposed control strategy of the switch mode rectifier is shown in Fig. 8. The Control objective is to control the duty cycle of the switch ***S*** to extract maximum power from the variable-speed wind turbine and transfer the power to the load. The control algorithm includes the Following steps.

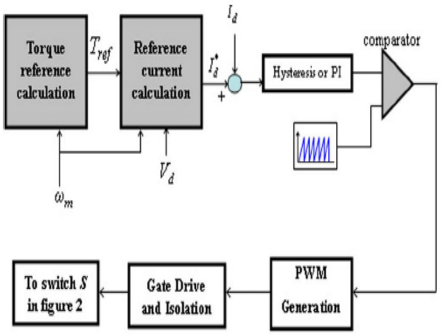


Fig 8. Control strategy of the switch-mode rectifier.

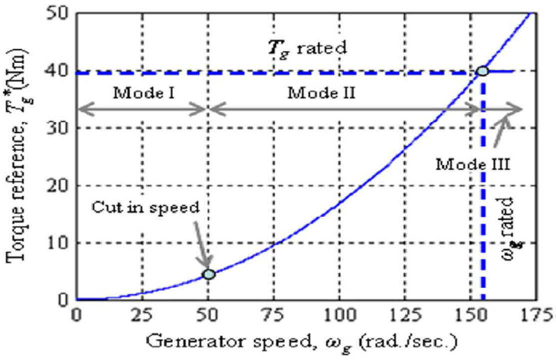


Fig 9.wind & generator speed analysis

1) Measure generator speed _g.
2) Determine the reference torque (Fig. 8) using the following equation:

$$T_g^* = K_{\text{opt}}(\omega_g)^2. \qquad (13)$$

3) This torque reference is then used to calculate the dc current reference by measuring the rectifier Output voltage Vd as given by

$$I_d^* = (T_g^* \times \omega_g)\,/V_d. \qquad (14)$$

4) The error between the reference dc current and measured dc current is used to vary the duty cycle of the switch to regulate the output of the switch-mode rectifier and the generator torque through a Proportional–integral (PI) controller. The generator torque is controlled in the optimum torque curve as shown in Fig.9.Finally, the generator will reach the point "c" were the accelerating torque is zero. A similar situation occurs when the wind velocity decreases. In the proposed method, the wind speed is not required to be monitored, and, therefore, it is a simple output-maximization control method without wind-speed sensor (anemometer).

VIII. RESULT AND DISCUSSION

The model of the PMSG-based variable-speed wind-turbine system of Fig. 1 is built using Matlab/Simpower dynamic system simulation software. The simulation model is developed based on a Kollmorgen 1-kW domestic permanent-magnet synchronous machine. It is seen that the controller can regulate the load voltage and frequency quite well at constant load and under varying load conditions.

A. Overall Circuit Diagram & Results Analysis Using Psim Software

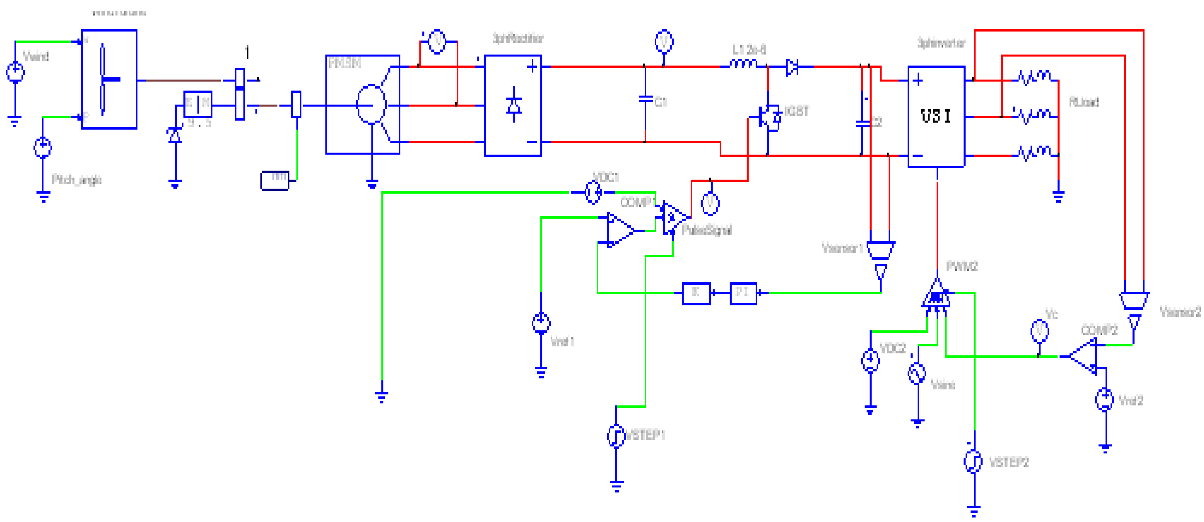


Fig 10. Simulation circuit for PMSG based stand alone variable speed wind turbine using PSIM

B. Output Waveforms

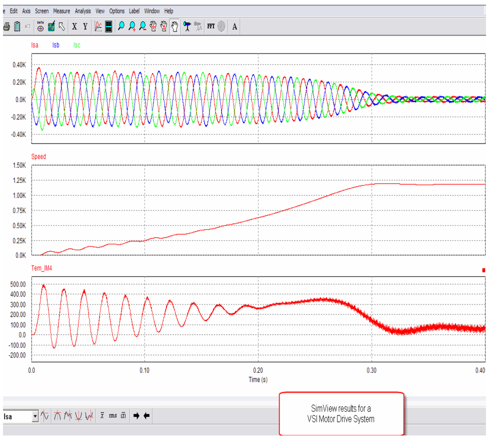


Fig 11. Result of VSI motor drive system

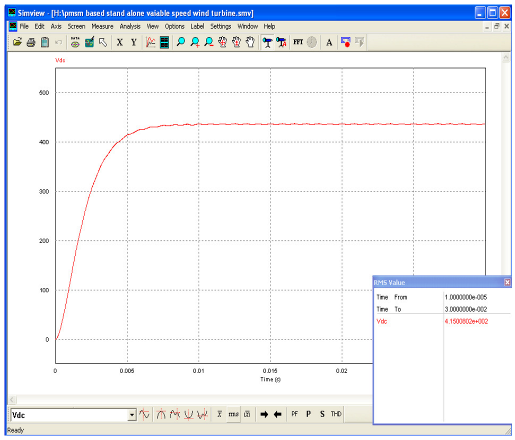


Fig 12. Result of generator o/p voltage

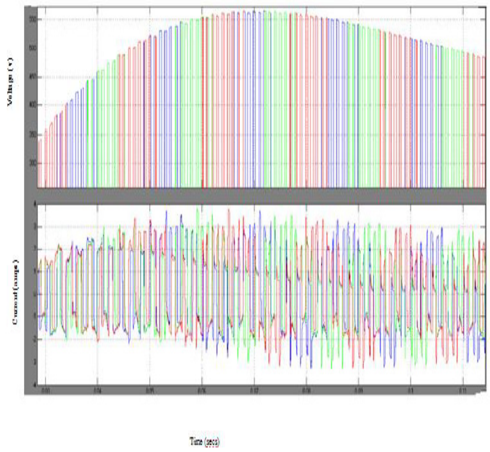


Fig 13.inverter side o/p voltage

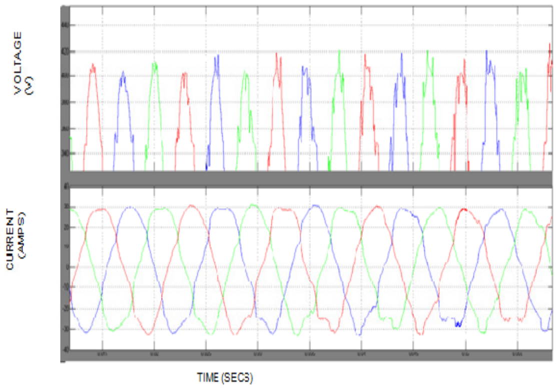
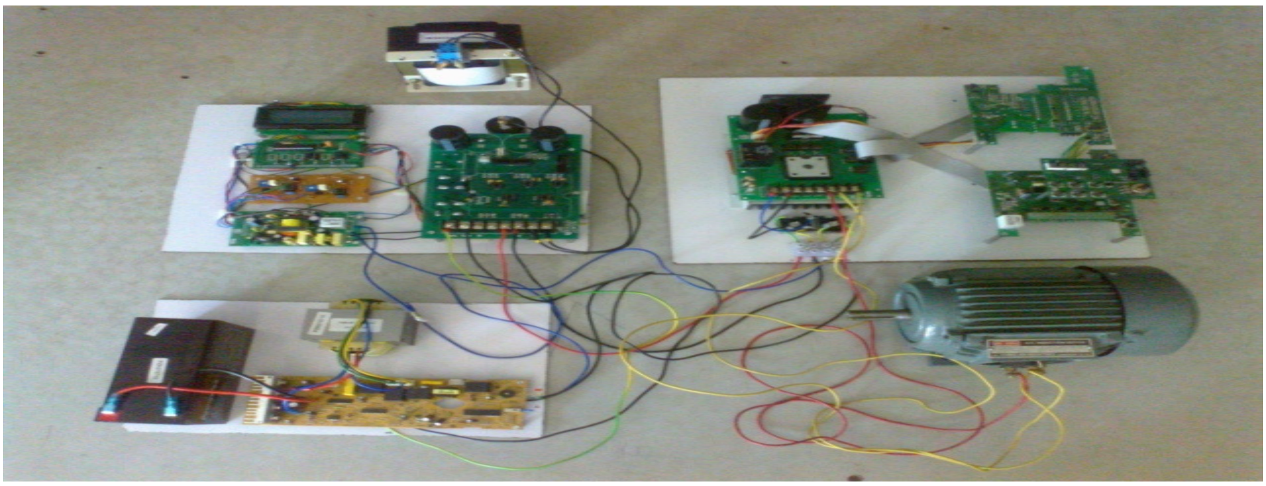


Fig 14. Measurement of voltage & current

C.Screenshot



D. Future Scope

The PI controller in switch mode power supply can be replaced with perturbation and observation method to improve the output voltage level. It present the inverter is controlled by voltage & frequency method. It can be enhanced in future by inverter control strategies .these strategies are base current and dc link voltage. The harmonic introduced in grid connecting eliminating by filters.

IX. CONCLUSION

A control strategy for a direct-drive stand-alone variable speed wind turbine with a PMSG has been presented in this paper. A simple control strategy for the generator-side converter to extract maximum power is discussed and implemented using Simpower dynamic-system simulation software. The controller is capable of maximizing output of the variable-speed wind turbine under fluctuating wind. The load-side PWM inverter is controlled using vector-control scheme to maintain the amplitude and frequency of the inverter output voltage. It is seen that the controller can maintain the load voltage and frequency quite well at constant load and under varying load condition. The generating system with the proposed control strategy is suitable for a small-scale stand-alone variable-speed wind-turbine installation

for remote-area power supply. The simulation results have proves that Regulating the o/p voltage & frequency under sudden load variations and typical wind movement and the controller works very well and shows very good dynamic and steady-state performance.

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