# A New Control Strategy for PMSG Based Wind Energy Conversion System feeding Microgrid

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***Abstract:*** *Renewable energy sources grabbing tremendous attraction because of its continual availability and less environmental effects. This paper makes use of wind energy as the source and the wind energy conversion system is modeled with PMSG and high gain Resonant Switched Capacitor (RSC) Converter. Control algorithm is developed with Particle Swarm Optimization (PSO) and Maximum Power Point Tracking (MPPT) technique was applied to Wind Energy Conversion System (WECS) that maintains the output voltage level as constant and DC current is used as a perturbation variable to achieve the peak power point by varying the duty cycle. This response is compared with conventional techniques such as P&O method and without MPPT controller. The developed power is utilized for Microgrid applications. Hardware implementation of this project has been done and the results are compared with simulation results. The simulation is carried out in MATLAB Simulink to obtain the system performance.*

***Key words:*** *WECS, PSO, MPPT, RSC, Microgrid.*

## 1. Introduction

Wind energy is considered as a better alternative energy source among existing renewable energy sources. Here the generator used is PMSG which offers several advantages like high power density, no gear box required and self excited nature as described in [1].

As the topology discussed [2] consists of simple DC to DC boost converter, diode rectifier and an inverter. Then multilevel DC to DC converter [3] is emerged which can give higher efficiency of about 93% than the conventional DC to DC converter. Though it offers better efficiency it may lead to large components size for withstanding high voltages and current and high switching stress. So that the High gain Resonant Switched Capacitor (RSC) was proposed with three stages will result in better efficiency with small inductor and capacitor values.

Particle Swarm Optimization (PSO) based MPPT technique is said be more efficient [4] than other techniques. Because it offers the advantage of reduced convergence time and results in adaptive step size, so that the oscillation around peak power point can be avoided. The generated power will have high efficiency than other methods which can be delivered to localized loads by the help of Microgrid station near the wind generation system.

Microgrid is a small scale local network of energy distribution; it will have several loads connected to it. The Microgrid has the major advantage of improved efficiency because transmission losses get reduced.

## 2. Objective

The main objective is to grab the maximum power from the wind by the help of particle swarm optimization technique based MPPT controller for WECS with high gain resonant converter for Microgrid applications and to compare the performance obtained by PSO based controller with conventional controller.

## 3. System Overview

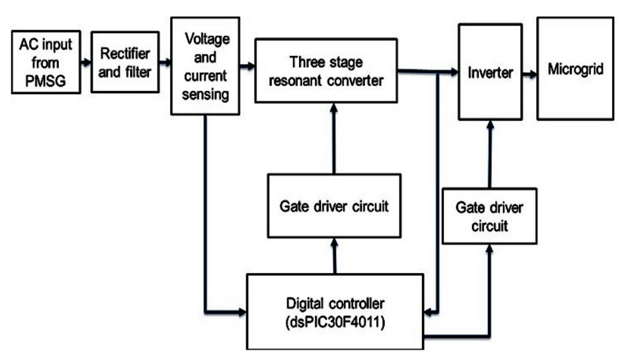


Fig. 1. Block Diagram of PMSG based Wind Energy Conversion System

Fig.1 depicts the block diagram of the WECS. This system consists of wind turbine, PMSG, rectifier, high gain resonant converter; Particle Swarm Optimization (PSO) based MPPT controller and an inverter which supplies power to Microgrid. The developed power can be used for Microgrid applications.

### A. Wind turbine modelling

The kinetic energy of blowing wind into mechanical energy by the help of wind turbine. Power coefficient ($C_p$) and tip speed ratio ($\lambda$) are the two important parameters used to model the wind turbine. The mechanical power ($P_m$) extracted from the wind can be calculated from equation (1).

$$P_m = 0.5\rho AC_p (\lambda, \beta)\, V_w^3 \tag{1}$$

where $C_p$ ($\lambda$, $\beta$) is power coefficient, $\rho$ is air density, A is area of turbine shaft, $\lambda$ is the tip speed ratio, $V_w$ is wind velocity and $\beta$ is pitch angle fixed to $0^o$ to extract maximum wind power.

Tip speed ratio can be formulated as given in equation (2).

$$\lambda = R\omega_r / Vw \tag{2}$$

where R is radius of wind turbine and $\omega_r$ is rotor angular frequency.

### B. PMSG Modelling

PMSG [5] is modelled in such a way that the source EMF ($e_w$) is proportional to the generator speed ($\omega_m$) and the equivalent resistance is twice the value of per phase resistance of the generator. Relationship between $e_w$ and $\omega_m$ is given in equation (3).

$$e_w = K_w\, \omega_m \tag{3}$$

Neglecting the damping and friction, the mechanical dynamics can be reduced and the electric torque developed from PMSG [9] is given in equations (4) and (5).

$$Jd\omega_m/dt = T_m - T_e \tag{4}$$

$$T_e = P_e / \omega_m = e_w\, i_{dc} / \omega_m = K_w\, i_{dc} \tag{5}$$

where $K_w$ is the generator EMF constant J is moment of inertia and $i_{dc}$ represents the DC current measured after rectifier. $T_m$ is the turbine mechanical torque and $T_e$ is electrical torque.

### C. Diode Rectifier

Diode rectifier is modelled as per the standards provided in [6] whose function is to convert AC signal to DC signal.

### D. Resonant Converter

This paper proposes a three stage resonant converter topology shown in figure 2 which offers higher voltage gain [7] and [8]. Here the proposed converter is modelled which is based on ZCS (Zero Current Switching) quasi resonant converter.

Resonant converter consists of six resonant capacitors ($C_{rt1}$, $C_{rt2}$, $C_{rt3}$, $C_{rb1}$, $C_{rb2}$ and $C_{rb3}$), two output filter capacitors ($C_{to}$ and $C_{bo}$), six resonant inductors ($L_{rt1}$, $L_{rt2}$, $L_{rt3}$, $L_{rb1}$, $L_{rb2}$ and $L_{rb3}$), two output resonant inductors ($L_{to}$ and $L_{bo}$), eight diodes ($D_{t1}$, $D_{t2}$, $D_{t3}$, $D_{to}$, $D_{b1}$, $D_{b2}$, $D_{b3}$ and $D_{bo}$) and six switches ($S_{t1}$, $S_{t2}$, $S_{t3}$, $s_{b1}$, $S_{b2}$ and $S_{b3}$). The switches ($S_{t1}$, $S_{t2}$, $S_{t3}$) and ($S_{b1}$, $S_{b2}$, $S_{b3}$) are controlled with complementary duty cycle. The subscripts't' and 'b' represents the components at the top portion and bottom portion of the converter.

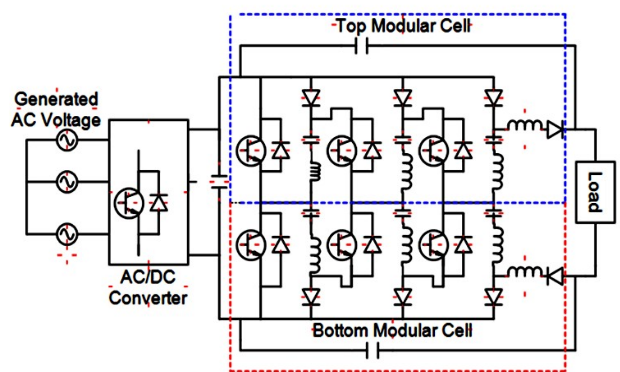


FIG. 2. THREE STAGE RESONANT CONVERTER

The gain is higher as the number of stages increased, the output voltage for k stage converter is given in equation (6)

$$V_o = (2^{k+1} - 1)\, V_s \tag{6}$$

where $V_s$ and $V_o$ represent input voltage and output voltage of resonant converter and k represents number of stages.
For three stage converter the output voltage is given in equation (7).

$$V_o = 15\ V_s \quad (7)$$

The simulation circuit of three stage resonant converter is shown in figure 3 which is designed with the parameters listed in Table I

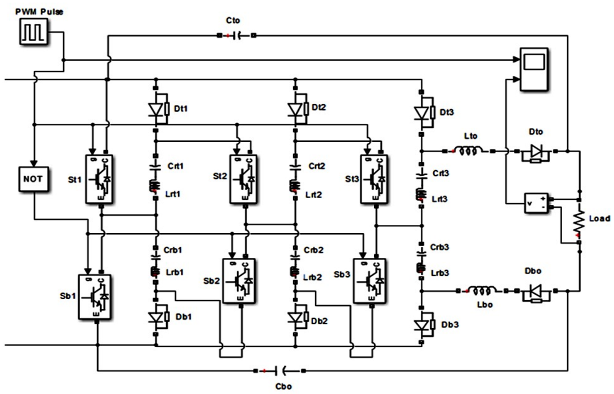


Fig. 3. Simulation Diagram of Resonant Converter

**E. PSO based MPPT controller**

Particle swarm optimization technique is a computational technique that provides a candidate solution with regard to a given measure of quality by optimizing a problem using iterations as illustrated in [1]. The PSO algorithm is implemented with duty cycle as particle position and its step size as velocity to obtain the maximum wind power point. Equation (8) expresses the position and velocity of the particle in terms of duty cycle (d) [9].

$$v_i^{k+1} = w \text{ x } v_i^k + c_1 \text{ x } r_1 \text{ x } \{d_{Pbesti}^k - d_i^k\} + c_2 \text{ x } r_2 \text{ x } \{ d_{Gbesti}^k - d_i^k \}$$
$$d_i^{k+1} = d_i^k + v_i^{k+1} \quad (8)$$

where
- v- particle velocity
- w - momentum factor
- $r_1$, $r_2$ - random values between (0.1)
- $c_1$, $c_2$ - positive constants known as acceleration constants
- $d_{Pbest}$ – Particle best duty cycle
- $d_{Gbest}$ – Group best duty cycle

**F. Inverter**

Voltage source inverter is used for converting DC voltage from resonant converter to single phase AC voltage. The design of inverter is mandatory for grid interfacing. The single phase inverter is modelled with frequency of 50 Hz.

**G. Microgrid**

Conventional grid [10] is lagging in efficiency than Microgrid because of transmission losses. Microgrid simulation diagram is depicted in figure 4 which is modelled for both on grid and off grid topologies [11] and [12].Three loads to be connected with Microgrid are battery, motor and resistive load such as LED.

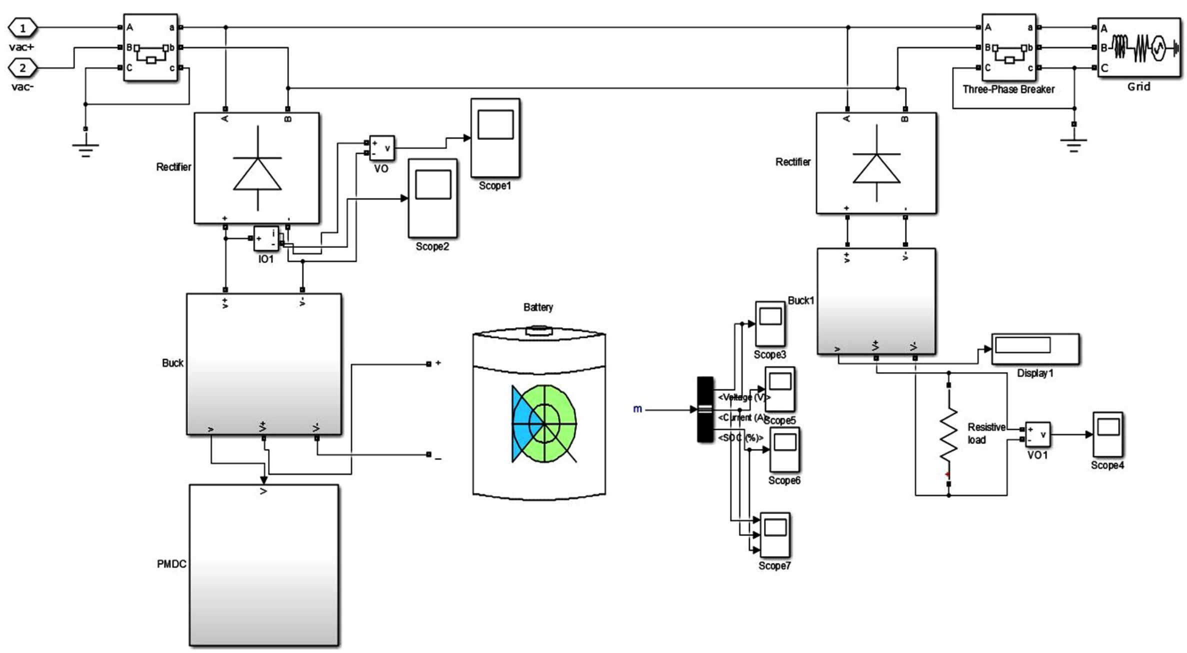


Fig. 4. Simulation Circuit of Microgrid

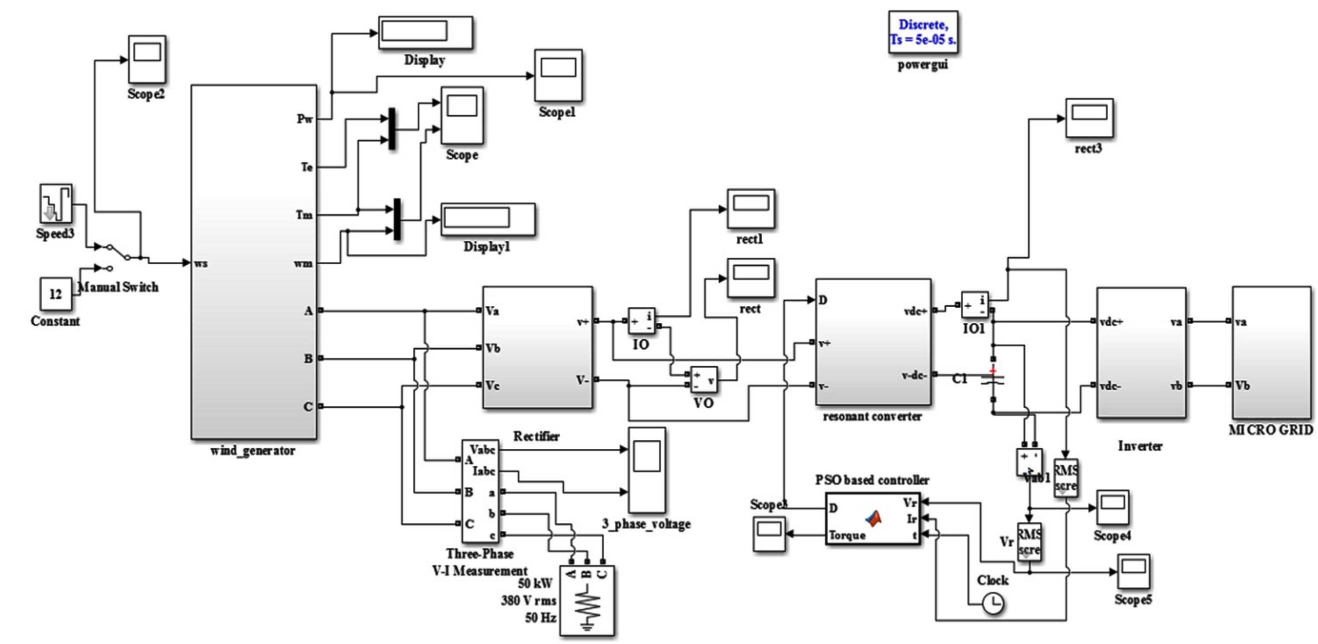


Fig. 5. Simulation Circuit of Proposed System

## 4. Simulation Results And Discussion

The simulation is carried out using MATLAB/Simulink and results are obtained. The simulation circuit of overall system is shown in figure 5.

Table 1. Design parameters for simulation circuit

| Component | Symbol | Value |
|---|---|---|
| Radius of turbine | R | 0.81 m |
| Air density | ρ | 1.08 $kg/m^3$ |
| Inertia | J | 0.01 $kg.m^2$ |
| Winding resistance | $R_w$ | 4.4 Ω |
| EMF constant | $K_w$ | 10.48 V.s/rad |
| Resonant capacitors | $C_{rt1}$-$C_{rt3}$ and $C_{rb1}$-$C_{rb3}$ | 1000 µF |
| Output Capacitors | $C_{t0}$ and $C_{b0}$ | 1000 µF |
| Resonant inductors | $L_{rt1}$-$L_{rt3}$ and $L_{rb1}$-$L_{rb3}$ | 1 µH |
| Output inductors | $L_{t0}$ and $L_{b0}$ | 1 µH |
| Momentum factor | W | 0.18 |
| Positive constants | $c_1$ and $c_2$ | 2.4 and 1.6 |

The PMSG is modelled for 2.5 kW power rating with three stage resonant converter. The switching frequency of resonant converter was 5 kHz based on the resonant frequency. Table 1 lists the specifications of the capacitors and inductors.

The proposed model of wind turbine will result in voltage range of 30 V to 60 V which is boosted up with the help of resonant converter upto 15 times the input voltage (i.e) 450 V to 900 V [2].

The P and O based MPPT control algorithm results in fixed step size variation in duty cycle for top and bottom switches as shown in figure 6 and 7. Whereas PSO based MPPT controller [13] and [14] will result in adaptive step size variation in duty cycle which is shown in figure 8. By this control technique we can obtain constant voltage for time varying input wind speed.

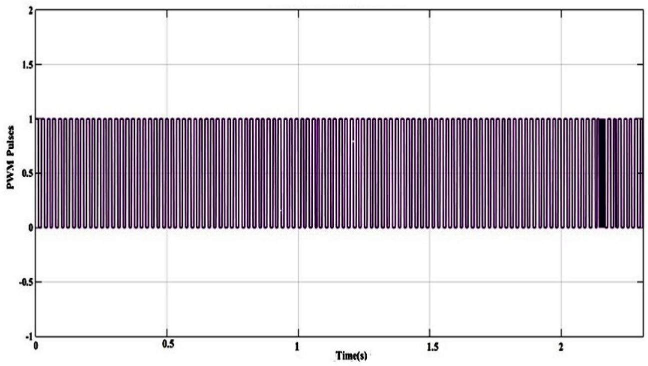


Fig. 6. PWM Pulses for Top Switches of Resonant Converter by P and O MPPT control

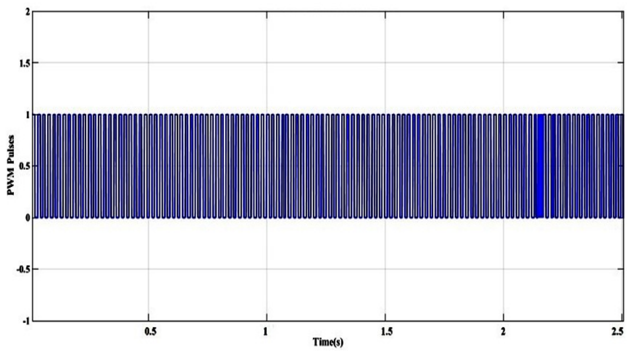


Fig. 7. PWM Pulses for Bottom Switches of Resonant Converter by P and O MPPT control.

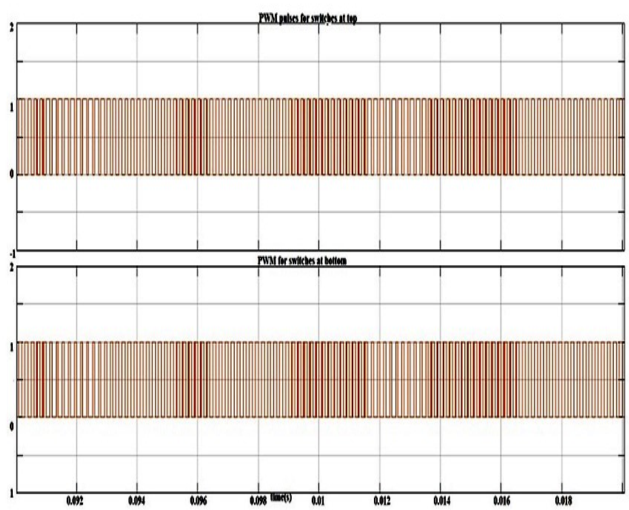


Fig. 8. Proposed PSO based Controller PWM Pulses for Top and Bottom Switches of Resonant Converter

The output voltage waveform is obtained across resonant converter without MPPT controller (i.e. fixed duty cycle) is shown in figure 9.

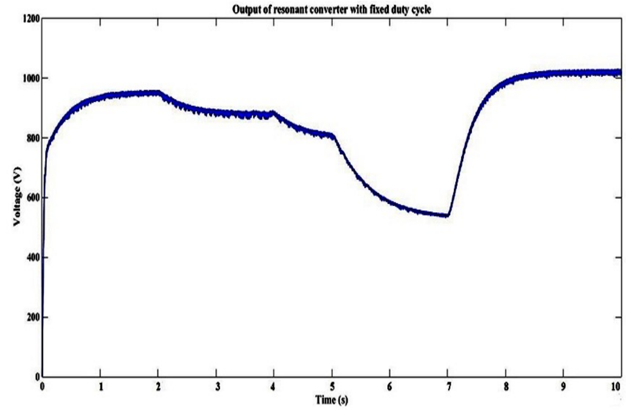


Fig. 9. DC output waveform without MPPT

Whereas the PSO based MPPT controller will result in constant DC output voltage across resonant converter and corresponding AC output voltage obtained by inverter is shown in figure 10 and 11.

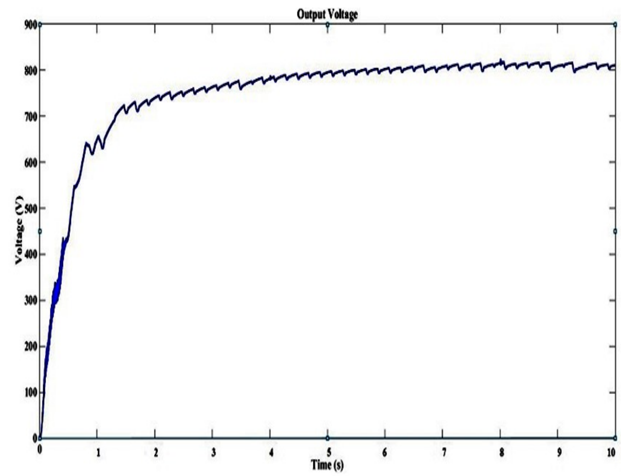


Fig.10. DC Output Voltage from Resonant Converter

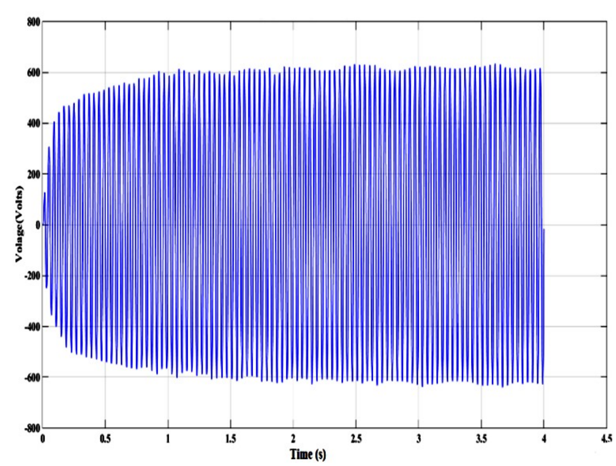


Fig.11. AC Output Voltage from Inverter

The power variation curves shown in figure 12 which compares the output power of WECS without MPPT, P and O based MPPT and PSO based MPPT controller.

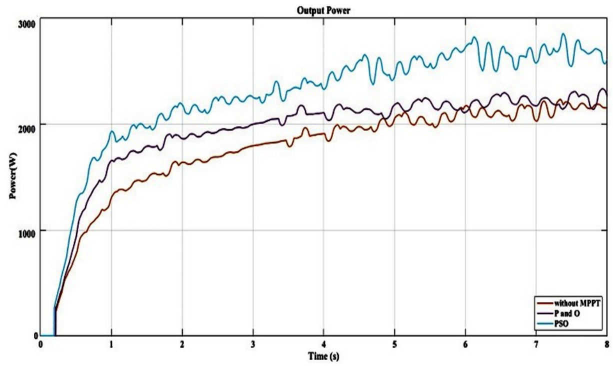


Fig. 12. Comparison of Output Power

The efficiency of WECS with (P and O control, PSO based MPPT control) and without MPPT controller is compared and enumerated in Table 2.

Table 2. Comparison of efficiency for various control techniques

| Method | Efficiency (%) | Percent improvement |
|---|---|---|
| Without MPPT | 82.6 | - |
| With HCS Based MPPT | 90.64 | 8.01 |
| PSO based MPPT controller | 95.6 | 13 |

## 5. Hardware Configuration

The hardware implementation of the system is configured with 60 W power capacity and their results are verified in the laboratory. The MOSFET gate pulses are obtained by using dsPIC30F4011 and driver circuit. Design of the experimental setup is made with the parameters as listed in Table 3.

Table 3. Hardware Component Details

| Component | Specification |
|---|---|
| Transformer | 230 V / 12 V, 230 V / 24 V |
| Diode | IN4001, IN4004 |
| MOSFET switch | IRFP250N |
| Capacitor | 1000 μF |
| Inductor | 1 μH |
| Controller | dsPIC30F4011 |
| Filter capacitor | 2.2 μF |
| Opto-coupler | TLP250 |
| Transistor | 2N222A,Ck100 |
| Variable resistor | 100 KΩ |


Fig. 13. a) PMSG based Wind Turbine Model

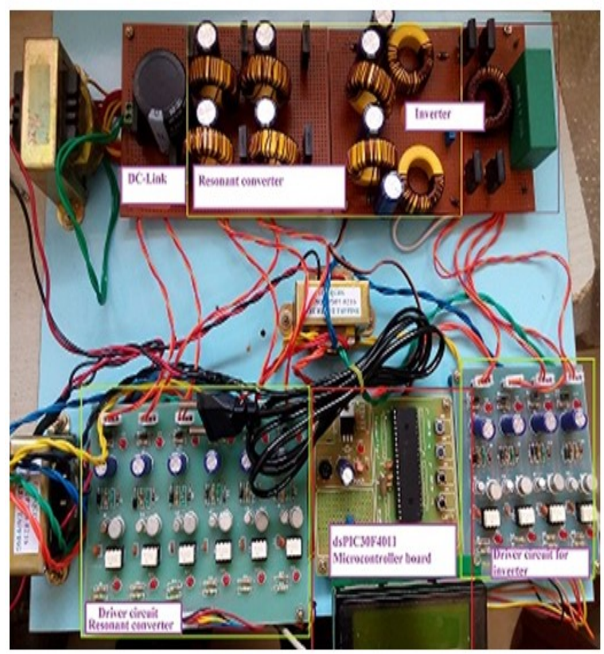


Fig. 13.b) Converter and Inverter configuration of Proposed Model

The hardware configuration for the proposed model is shown in figure 13 (a & b). The input DC voltage is fixed to 20 V by running the turbine at a constant speed which is measured by digital storage oscilloscope and it is shown in figure 14.

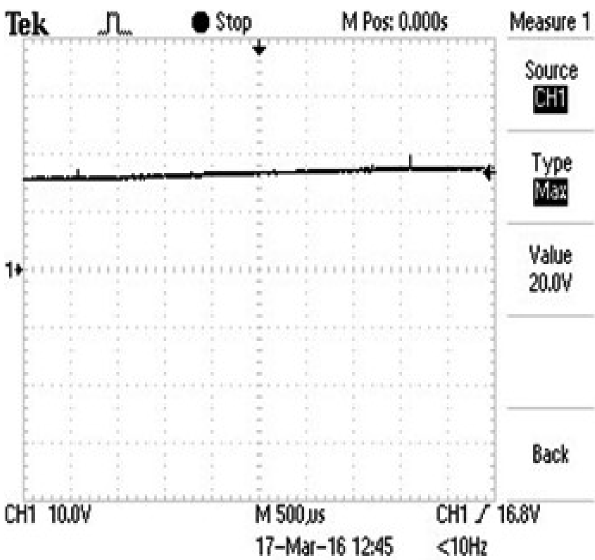


Fig. 14. Input Voltage for Converter Circuit

The gate pulses for power MOSFET is generated by using control circuit which includes dsPIC30F4011 microcontroller and driver circuit. The generated PWM pulse is shown in figure 15 which is given to resonant converter switches.

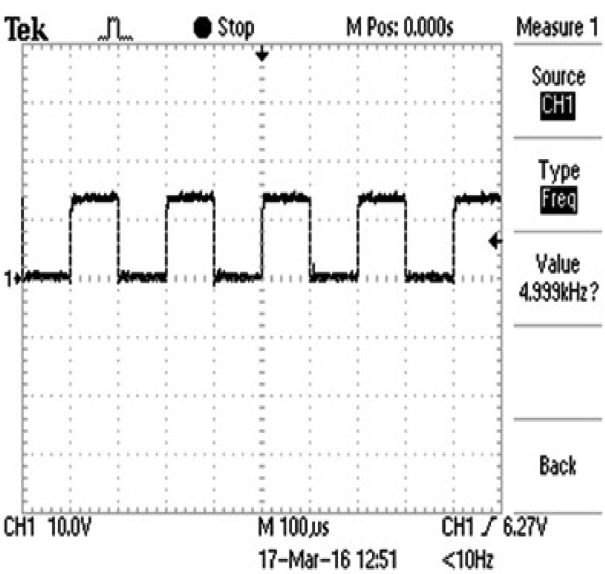


Fig. 15. PWM Pulse for MOSFET Switch of Resonant Converter.

The DC output voltage of resonant converter is shown in figure 16 which is 99.5 V. The resonant converter is capable of giving the 15 times the voltage gain. As the system is implemented for low power ratings, the hardware prototype is modelled for the voltage gain of 5 times only.

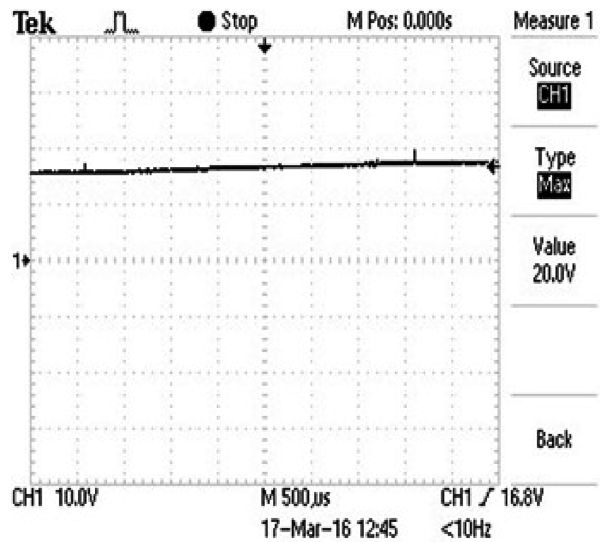


Fig. 16. Output Voltage for Converter Circuit

## 6. CONCLUSION AND FUTURE SCOPE

PMSG based WECS is widely preferred among other generators for variable speed wind turbine to achieve better efficiency since it can start generation at very low wind velocity. The high gain resonant converter is modelled in such a way that it will provide better efficiency of about 95.6% which is 13% higher than other multilevel DC to DC boost converters. The adaptive step change achieved by PSO based MPPT technique will result in less steady state oscillation as compared with conventional (P and O MPPT control) methods. Overall system efficiency is improved by this topology which is suitable for several applications especially standalone and Microgrid applications. The hardware model is fabricated and the results were observed and stored using Digital Storage Oscilloscope (DSO). The input, output voltages and the pulse generated using dsPIC30F4011 for resonant converter and inverter were displayed. Comparison was made between hardware results and simulation results.

Future work may include increasing the number of stages of resonant converter will give very high DC voltage which can be used for HVDC transmission systems. The hybrid renewable energy sources can be used for continuous power availability.

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