A New Control Strategy for PMSG Based Wind Energy Conversion System

T.Santhana Krishnan[1], C.Sharmeela[2]

Assistant Professor, Department of EEE, Rajalakshmi Engineering College, Chennai, India[1]

Assistant Professor, Department of EEE, College of Engineering, Anna University, Chennai, India[2]

ABSTRACT: In recent days, people migrated towards renewable energy sources to meet their power demand. Among all these renewable energy sources wind energy system is widely preferred because of its pollution free in nature, provides all time energy source and also occupies less space at ground level as compared to solar panels. Reliability and efficiency are two major factors in wind energy conversion system. A high gain Resonant Switched Capacitor (RSC) converter operates at high frequency will eliminate the switching losses and also reduces the size of the passive elements. PSO based MPPT controller can improve the accuracy of which the maximum power transmitted for the time varying wind speed. This method will reduce the time required for convergence and adaptive step size variation is achieved as compared to conventional Hill Climb Search based MPPT controller. The developed power will be applied to AC micro grid with the help of voltage source inverter. Micro grid is a local network supplied with the generated power from wind energy conversion system which eliminates long distance transmission losses and heat losses caused by the transmission lines. The simulation and analysis of the proposed system is carried out in MATLAB Simulink to obtain the system performance which validates its design and working.

KEYWORDS: Wind energy system, Particle Swarm Optimization (PSO), Maximum Power Point Tracking (MPPT), Resonant Switched Capacitor Converter (RSC), Micro grid.

I. INTRODUCTION

Wind is an attractive renewable energy source which has gained momentum recently. However the generated energy from wind is always fluctuating in nature which may leads to power quality issues and disturbances in loads connected with grid. Recent researches focused on use of Permanent Magnet Synchronous Generator as a wind generator because of its low cost, high efficiency and self-starting ability.

According to the topology concerned simple DC to DC boost converter is used in between diode rectifier and inverter. This topology will give efficiency of about 80% only. So that multilevel DC to DC converter is emerged which can give the efficiency of about 93% but it may lead to large size of components and high switching stress. The High gain Resonant Switched Capacitor (RSC) with multiple stages formed with series and cascade combination will result in efficiency of about 98%.

Various Maximum Power Point Tracking (MPPT) techniques for wind energy conversion system were evolved like Tip Speed Ratio (TSR), Power Signal Feedback (PSF) and Hill Climb Search (HCS) techniques to track the maximum power from the wind. But Particle Swarm Optimization (PSO) based MPPT technique will be more efficient than other techniques. The application of PSO in MPPT will have the advantage of reduced convergence time. This technique results in adaptive step size, so that the oscillation around peak 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 Micro grid station near the wind generation system. Micro grid is a small scale local network of energy distribution, it will have several loads connect to it. The Micro grid has the major advantage of improved efficiency because transmission losses get reduced.

II.OBJECTIVE

The main objective is to design, simulate and implement Particle swarm optimization technique based MPPT algorithm for wind energy conversion system with high gain resonant converter for micro grid applications. To compare the performance obtained by PSO based MPPT controlled wind energy system with conventional MPPT controlled wind energy system.

III. SYSTEM OVERVIEW

Fig.1 illustrates the schematic diagram of the wind energy conversion system. This system supplies to a micro grid and contains wind turbine, Permanent Magnet Synchronous Generator (PMSG), rectifier, high gain Resonant Switched Capacitor (RSC) converter, Particle Swarm Optimization (PSO) based Maximum Power Point Tracking (MPPT) controller and an inverter.
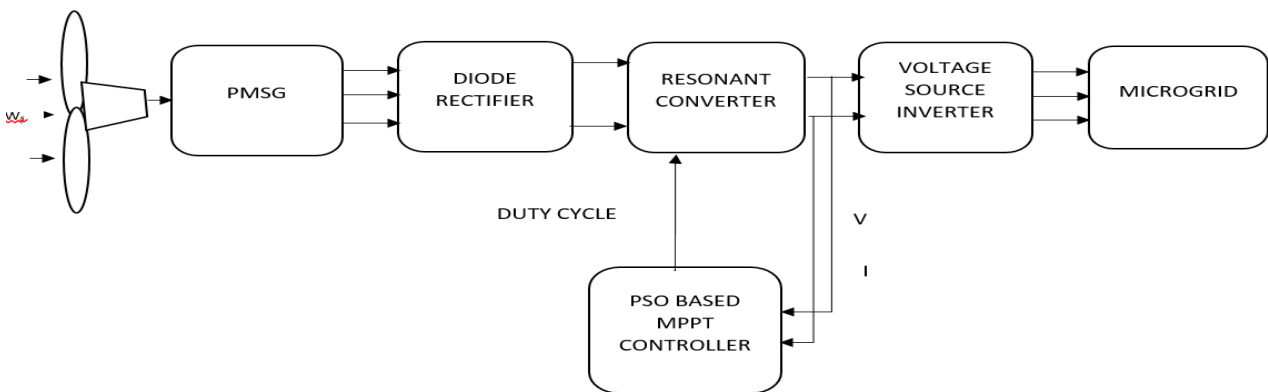

Figure 1 Block diagram of proposed system.

A. Wind turbine Modelling

Wind turbine converts the kinetic energy of wind into mechanical energy. There are two major types of wind turbines Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). The HAWT is widely used for high power applications. Here fixed pitch variable speed wind turbine is modelled with parameters power coefficient (C_p) and tip speed ratio (λ). The power equation will be,

$$P_m = 0.5\rho A C_p (\lambda, \beta) V_w^3 \qquad (1)$$

Where Cp (λ, β) = power coefficient, λ = the tip speed ratio, and β = pitch angle fixed to 0°.
Tip speed ratio can be calculated as,

$$\lambda = R\omega_r / V_w \qquad (2)$$

Where ω_r is the angular speed, R is the turbine radius and V_w is the wind velocity. Power coefficient can be obtained as,

$$C_p (\lambda, \beta) = 0.5(116(1/\lambda)-0.4 \beta-5) e^{-(21/\lambda_i)} \qquad (3)$$

$$1/\lambda_i = 1/(\lambda + 0.08\beta) - 0.035/(1+\beta^2) \qquad (4)$$

Figure 2 C_p Vs λ characteristics
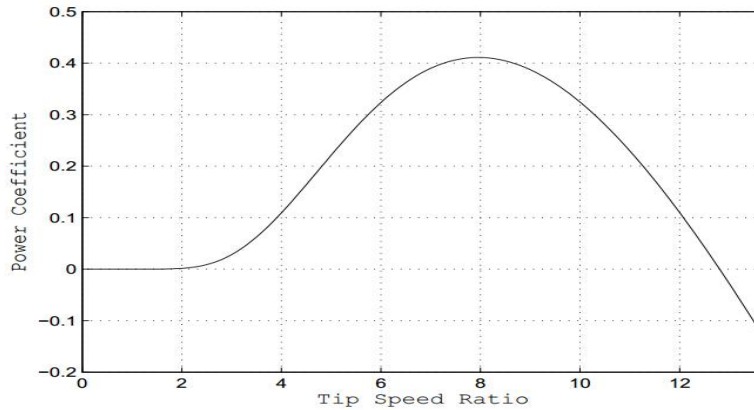
The dynamic equation of wind turbine is given as

$$d\omega_r / dt = (1/J) [T_m - T_L - F\omega_r] \qquad (5)$$

Where J is the system inertia, F is the viscous friction coefficient, T_m is torque developed by the turbine, T_L is the torque due to load.

B. PMSG modelling

Among various electric generators, PMSG is preferred due to its high efficiency, reliability, power density, gearless construction, light weight and self excitation features. This paper uses simplified model of the PMSG. The source EMF (e_w) is proportional to the generator speed (ω_m) and the equivalent resistance has a value of twice the per phase resistance of the generator.

$$e_w = K_w \, \omega_m \qquad (6)$$

Neglecting the damping and friction, the mechanical dynamics can be reduced to

$$J \, d\omega_m/dt = T_m - T_e \qquad (7)$$

$$T_e = P_e / \omega_m = e_w \, i_{dc} / \omega_m = K_w \, i_{dc} \qquad (8)$$

Where K_w is the generator EMF constant. T_m is the turbine mechanical torque and T_e is electrical torque.

C. Diode Rectifier

Diode rectifier is used to convert the three phase AC signal from the wind generator to DC signal.
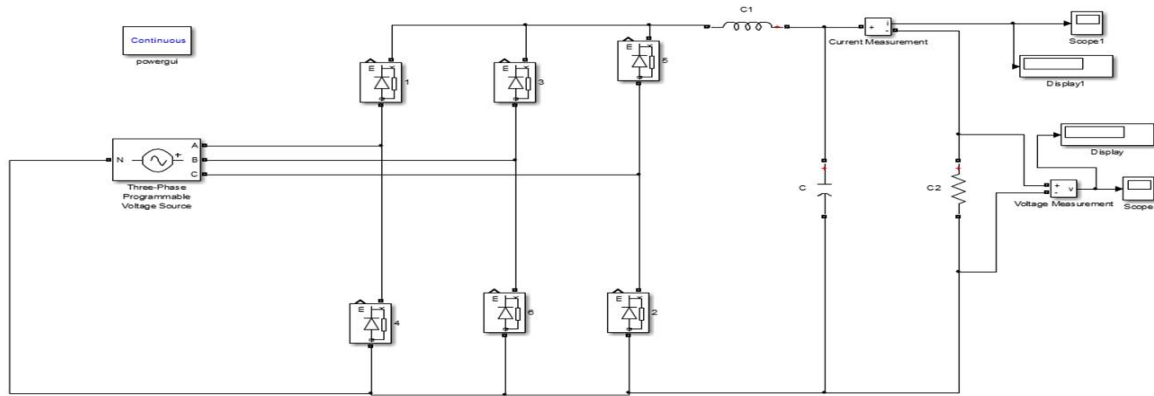
Figure 3 Simulation model of diode rectifier

D. Resonant Converter

This paper proposes a multistage resonant converter which offers higher voltage gain. Here the proposed converter is modelled based ZCS (Zero Current Switching) quasi resonant converter principle also known as Resonant Switched Capacitor (RSC) converter. Here three stage resonant converter is proposed.

The RSC converter is composed of six resonant capacitors (Crt1, Crt2, Crt3, Crb1, Crb2 and Crb3), two output filter capacitors (Cto and Cbo), six resonant inductors (Lrt1, Lrt2, Lrt3, Lrb1, Lrb2 and Lrb3), two output resonant inductors (Lto and Lbo), eight diodes (Dt1, Dt2, Dt3, Dto, Db1, Db2, Db3 and Dbo), and six switches (St1, St2, St3, Sb1, Sb2 and Sb3). In this paper, subscripts "t" and "b" represent the corresponding variables to the circuit components at the top and bottom cells, respectively. The switches (St1, St2, St3) and (Sb1, Sb2, Sb3) are controlled complementarily with a 50% duty cycle to minimize the conduction losses in the power devices and passive components.
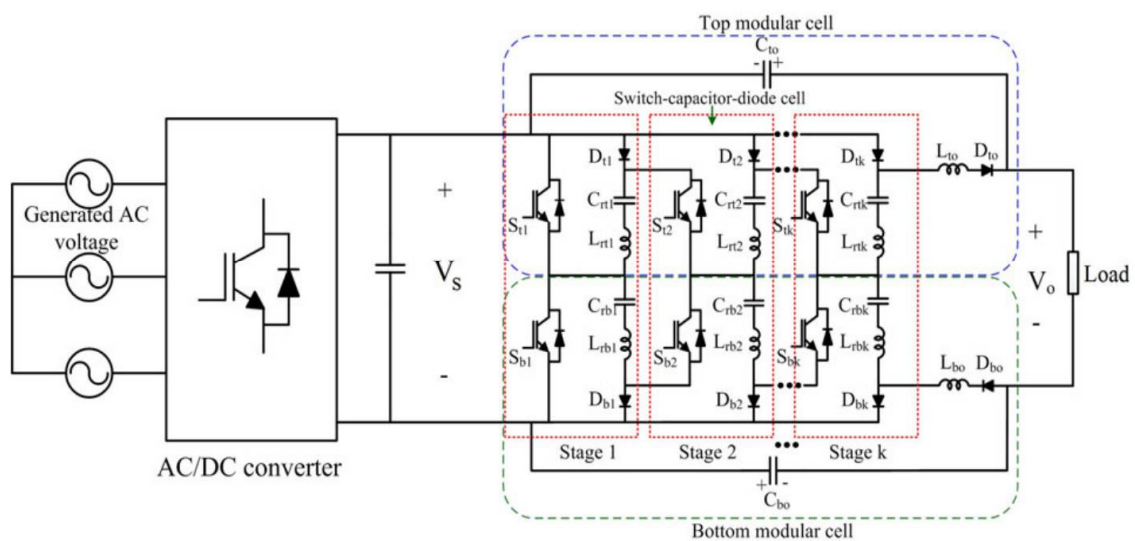

Figure 4 Three stage resonant converter

The gain is higher as the number of stages increased, the output voltage for k stage converter if given as

$$V_o = (2^{k+1} - 1)\, V_s \qquad (9)$$

For three stage converter the output voltage will be

$$V_o = 15\, V_s \qquad (10)$$

Mode I: Sb1, Sb2 and Sb3 are ON, whereas St1, St2 and St3 are OFF and the diodes Db1 Db2 and Db3 are reverse biased. The charging currents flow through Dt1-Sb1-Dt2-Sb2-Dt3-Sb3, Crt1, Crt2 and Crt3 are charged, whereas Crb1, Crb2 and Crb3 are discharged to Cbo in the bottom cell. Sb1, Sb2 and Sb3 can then be OFF under the zero-current condition

Mode II: In this mode, all the switches and diodes are turned OFF, Therefore, the inductor currents are equal to zero. The resonant capacitor voltages of Crt1, Crt2, Crt3 Crb1, Crb2 and Crb3 are unchanged. The output capacitor voltages of Cto and Cbo are discharged to the load.

Mode III: St1, St2 and St3 are turned ON, while Sb1, Sb2 and Sb3 are OFF.Crt1, Crt2 and Crt3 are discharged to Cto, whereas Crb1, Crb2 and Crb3 are charged. The charging currents flow through St1-Lrt1-St2-Lrt2-St3-Lrt3-Lto-Dto.

E. PSO based MPPT controller

A large number of MPPT techniques for WECS have been studied, they can be divided into three main methods: Hill Climb Search (HSC) control, Tip Speed Ratio (TSR) control and Power Signal Feedback (PSF) control.
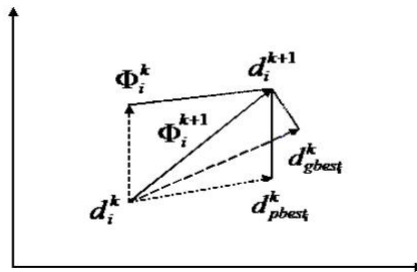

Figure 5 Modification of a searching point by PSO.

Particle swarm optimization is a computational method that optimizes a problem by iteratively improves a candidate solution with regard to a given measure of quality. It starts with a group of random potential solutions, which are called particles. These particles fly around in a multidimensional search space searching for the optimum solution by adjusting their positions depending on their own experience as well as the experience of the other particles. To be realized as a MPPT algorithm, the particle position in PSO represents the duty-cycle, the velocity is the step-size of the duty-cycle and the objective function is maximizing the converter power. As depicted in Fig. 5, the particle position and velocity are updated iteratively based on the following two equations:

$$\Phi_i^{k+1} = w\Phi_i^k + c_1 r_1 \left\{ d_{Pbest_i}^k - d_i^k \right\} + c_2 r_2 \left\{ d_{gbest_i}^k - d_i^k \right\}$$
$$d_i^{k+1} = d_i^k + \Phi_i^{k+1} \qquad (11)$$

Where w is defined as the momentum factor, r1 and r2 are two random values between (0.1), c1 and c2 are positive constants known as acceleration constants.
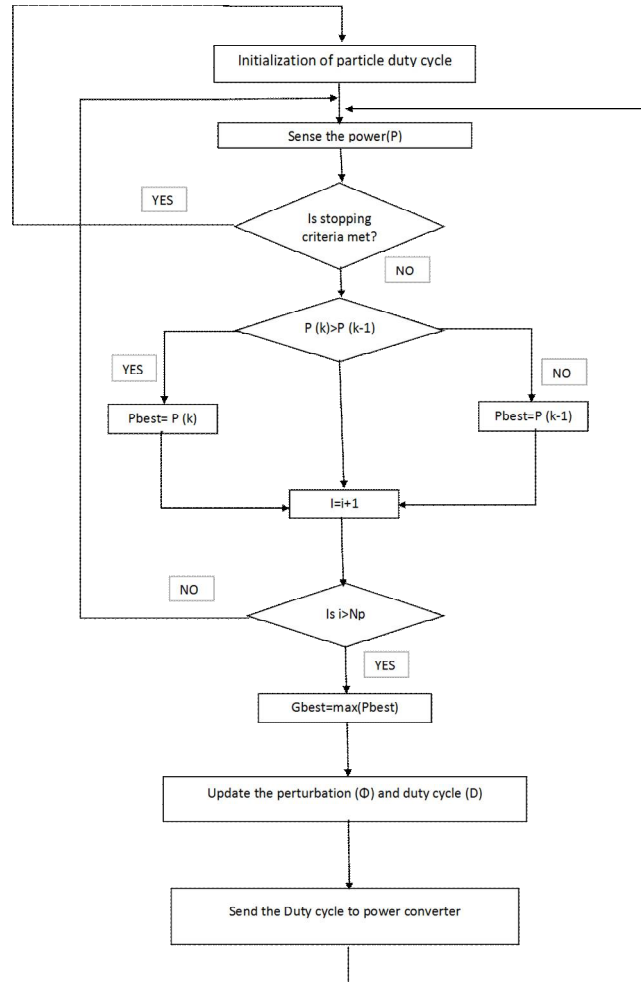
Figure 6 PSO based MPPT controller

F. Inverter Model

Voltage source inverter is used here for converting DC voltage from RSC converter to three phase AC voltage. For supplying the grid the design of inverter circuit is necessary, here the single phase or three phase inverter is required based on the load requirement at the micro grid.
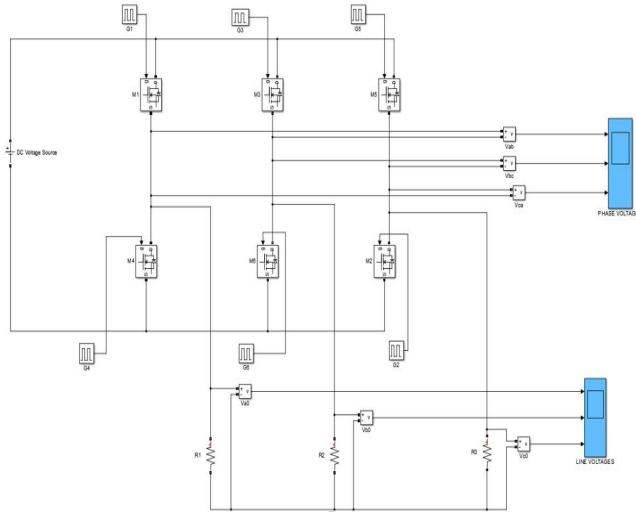
Figure 7 Simulation model of voltage source inverter

G. Micro grid Modelling

A new concept in power generation is a micro grid. A micro grid involves connecting several small alternative power sources in addition to the main grid on a particular site. Some examples where it could be used would be an office block, industrial site or shopping centre. Little is known about micro grid behaviour on the whole. Some models exist which describe the components of a micro grid, although to date a successful model of an entire micro grid system has not been developed.

Efficiency of conventional grid is very low as compared to Micro grid because large amount of energy in the form of heat is wasted in conventional grid. Three load to be implemented for micro grid are Battery, PMDC motor, Heater.
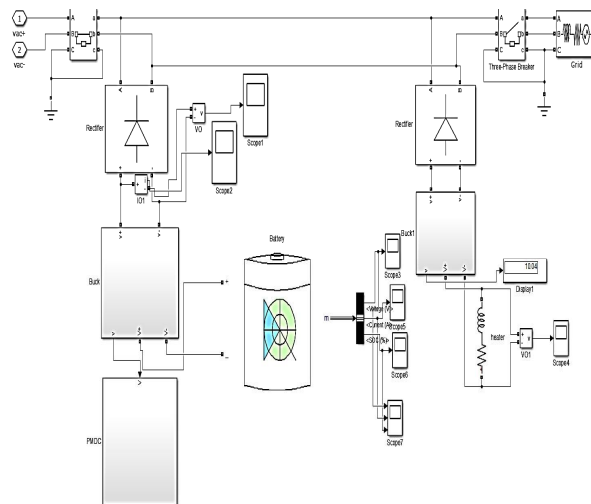

Figure 8 Micro grid Modelling

IV.SIMULATION RESULTS AND DISCUSSION

The simulation results of this section are generated using MATLAB/Simulink simulation software.

TABLE I

Components	Symbols	Values
1.WIND TURBINE		
Radius of turbine	R	2.3m
Air density	ρ	$1.08 kg/m^3$
Inertia	J	$0.01 kg.m^2$
2. PMSG		
Winding resistance	R_w	4.2Ω
EMF constant	K_w	10.48V.s/rad
3.RESONANT CONVERTER		
Resonant capacitors	Crt1-Crt3	$200\mu F$
Resonant capacitors	Crb1-Crb3	$200\mu F$
Output Capacitors	Ct0 and Cb0	$200\mu F$
Resonant inductors	Lrt1-Lrt3	$14\mu H$
Resonant inductors	Lrb1-Lrb3	$14\mu H$
Output inductors	Lt0 and Lb0	$14\mu H$
4.PSO		
Momentum factor	w	0.15
Positive constants	c1 and c2	0.5 and 1.6

The proposed RSC converter was implemented on a 2kW PMSG to verify the theoretical developments presented previously. The proposed converter was designed to boost a 100V input to the maximum output voltage of 1500 V. The switching frequency is about 2.8 kHz. Table I lists the specifications of the capacitors and inductors.
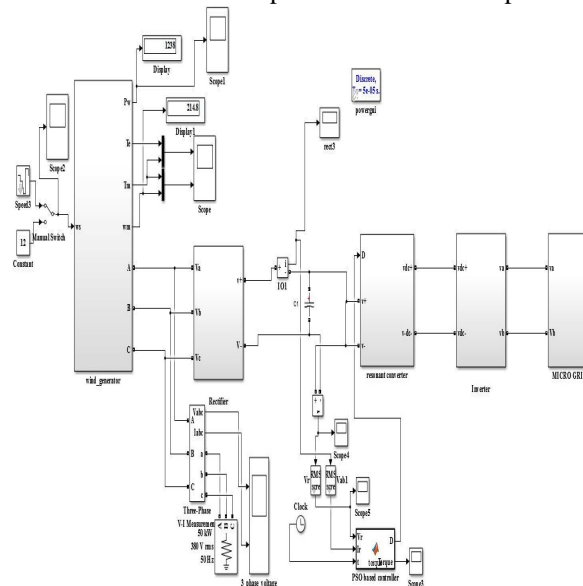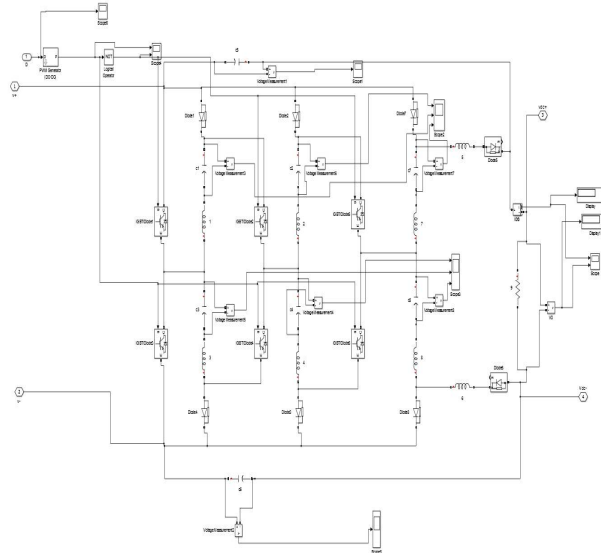

Figure 9 Overall Proposed simulation circuit

Figure 10 Simulation circuit of three stage resonant converter

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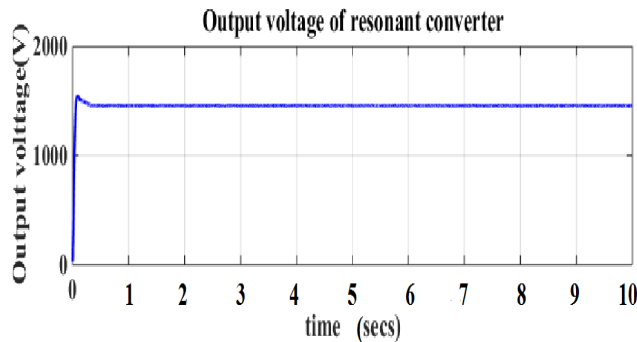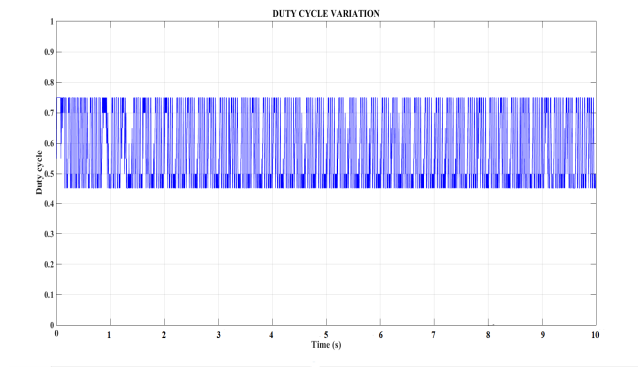

Figure 11 Output of resonant converter for 100V input

The conventional MPPT control algorithm results in variation in duty cycle with fixed step size as shown
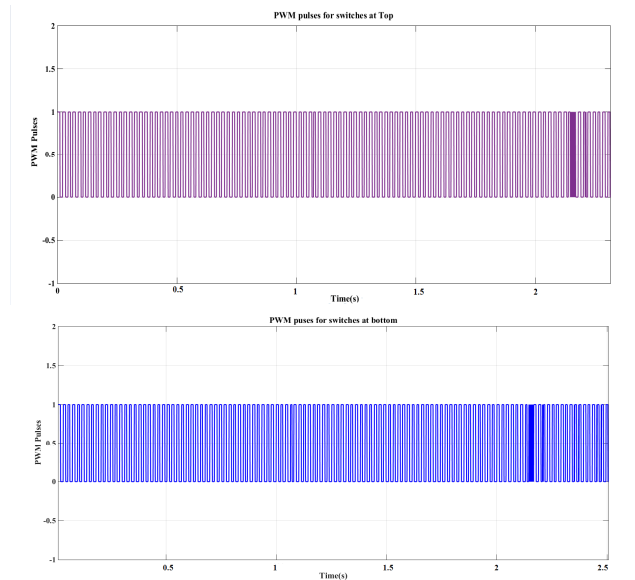
Figure 12 Duty cycle variation by simple P and O algorithm and corresponding PWM pulses

Whereas PSO based MPPT controller will result in adaptive step change in duty cycle which is shown in comparison with conventional method as,
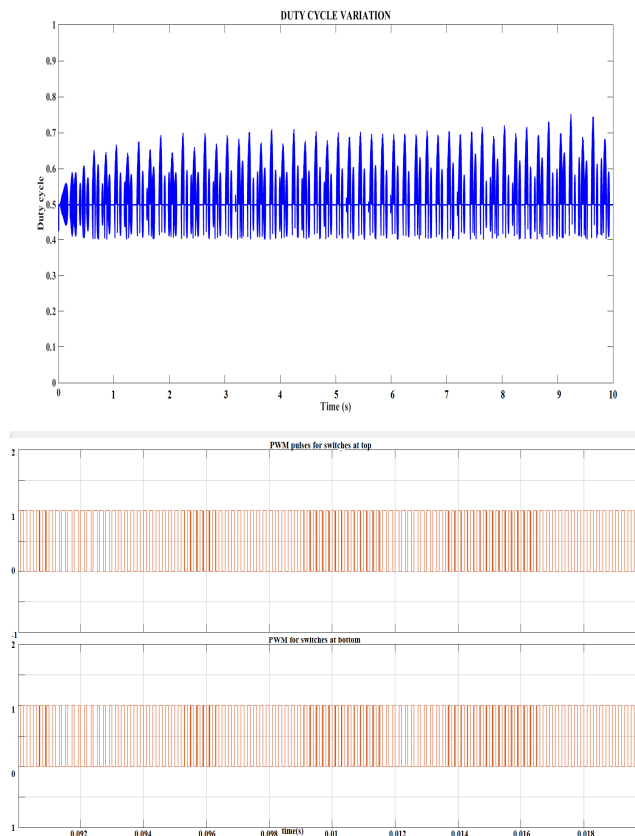

Figure 13 Proposed PSO based controller duty cycle variation and corresponding PWM pulses

Table 1 Duty cycle variation with P and O and PSO algorithm

S.No	Duty cycle variation with P and O algorithm		Duty cycle variation with PSO algorithm	
	Time (s)	Duty Cycle	Time (s)	Duty cycle
1	0.0002	0.75	0.0002	0.54
2	0.0003	0.75	0.0003	0.54
3	0.01	0.65	0.01	0.53
4	0.03	0.55	0.03	0.527539
5	0.05	0.45	0.05	0.466231
6	0.0865	0.6	0.0865	0.540641
7	0.0866	0.45	0.0866	0.457063
8	0.0867	0.45	0.0867	0.459011
9	0.0868	0.7	0.0868	0.540085
10	0.087	0.5	0.087	0.456671
11	0.0875	0.5	0.0875	0.459663
12	0.088	0.65	0.088	0.538993
13	0.09	0.75	0.09	0.539386
14	0.095	0.65	0.095	0.539412
15	0.1	0.75	0.1	0.541255
16	0.15	0.7	0.15	0.546128
17	0.16	0.6	0.16	0.536886
18	0.17	0.75	0.17	0.546886
19	0.18	0.5	0.18	0.452548
20	0.19	0.55	0.19	0.549236

Table 1 represents the values of duty cycle variations with P and O and PSO based controller.

By this control technique we can obtain constant voltage range for time varying input wind speed. The output waveform without MPPT controller will be
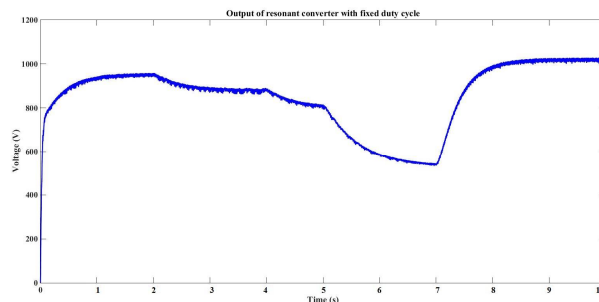

Figure 14 DC output waveform without MPPT

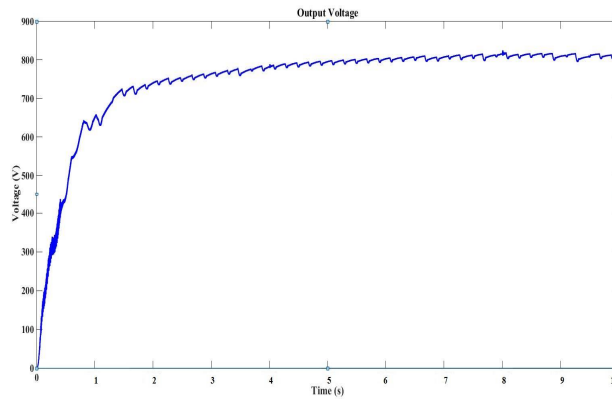Whereas the output with MPPT controller will results in

Figure 14 DC output waveform with PSO based MPPT

The power variation curve is obtained with P and O controller and PSO controller is compared with the uncontrolled system is shown in figure 15 as ,
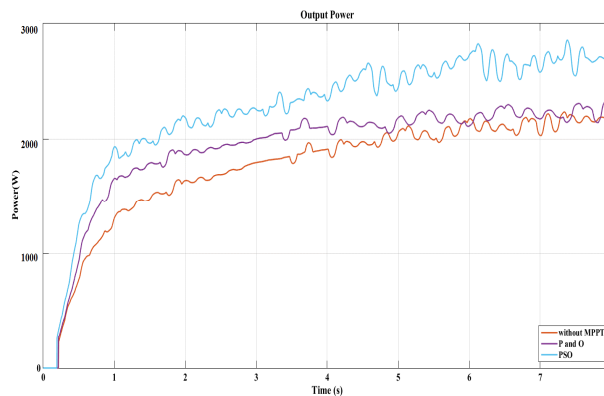

Figure 15 Comparison of output power

The efficiency comparison table is shown in Table 2 with percent improvement in efiiciency without any controller

Table 2 Ouput power comparison with efficiency

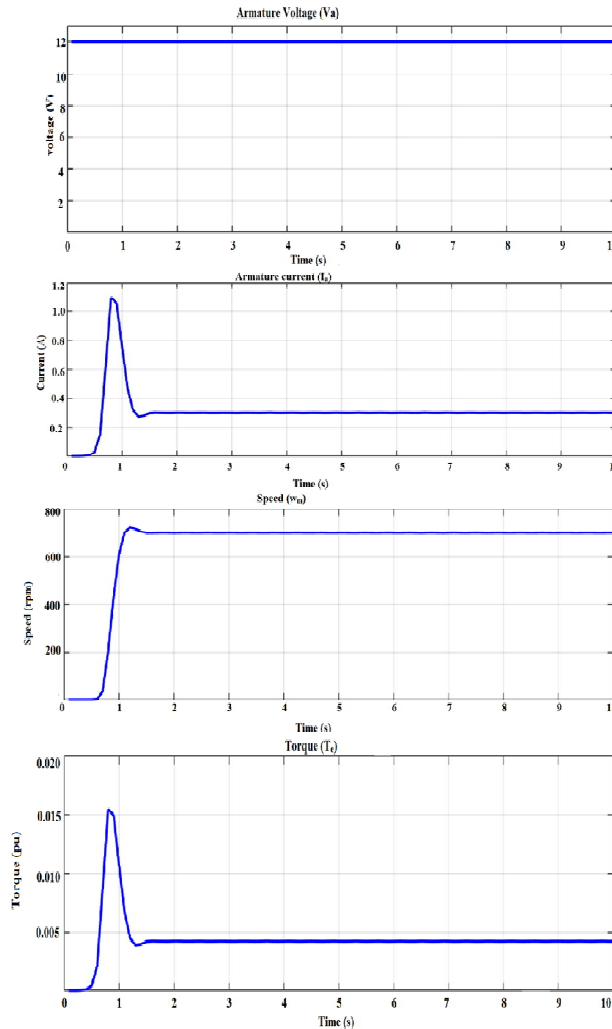| Method	Efficiency (%)	Percent improvement
Without MPPT	84.8	-
With HCS Based MPPT	91.56	6.76
PSO based MPPT controller	96.31	11.51

Figure 16 Micro grid output

Figure 16 represents the output of PMDC motor, one of the loads connected with micro grid

V.CONCLUSION AND FURURE SCOPE

Various WECS were modelled to meet the power demand whereas PMSG based WECS is widely preferred for variable speed wind turbine to achieve better efficiency. The high gain resonant converter is modelled in such a way that it will provide efficiency of about 98% at steady state as compared to other converters. The adaptive step change achieved by PSO based MPPT technique will result in less steady state oscillation in output waveform as compared to other methods. Accuracy and reliability is achieved by this overall system.

Future work may include implementation of Genetic algorithm based MPPT controller and comparison is made with PSO based MPPT controller. Increasing the number of stage of resonant converter will give very high DC voltage which can be used for HVDC transmission systems. The smart grid topology can be implemented with obtained output power to obtain better control.

REFERENCES

1. Abdullah .M. A, Yatim A.H.M, Tan C.W, Samosir   A.S,"A review of maximum power point tracking algorithms for wind   energy systems," Renewable and Sustainable Energy Reviews, vol. 16, pp. 3220-3227, December 2014
2. Amir Parastar, Jul-Ki Seok, "High-Gain Resonant Switched-Capacitor Cell-Based DC/DC Converter for Offshore Wind Energy Systems", IEEE transactions on power electronics, vol.30, no.2 February 2015,
3. Ian Laird, Ian Laird and Dylan Dah Chuan Lu, "High Step-Up DC/DC Topology and MPPT Algorithm for Use with a Thermoelectric Generator" IEEE Transactions on Power Electronics, vol 28, no 7, July 2013.
4. Ishaque .K, Johor Bahru, Salam .Z, Amjad .M, Mekhilef .S," An Improved Particle Swarm Optimization (PSO) based MPPT for PV with Reduced Steady State Oscillation," Power Electronics, IEEE Transactions on, vol. 26, Issue 8, September 2014.
5. Kaiqin Yan, Jai Hou, Xiaoyong Ren,and Xinbo Ruan, "Self-Oscillating Contactless Resonant Converter With Phase Detection Contactless Current Transformer", IEEE transactions on Power Electronics, vol.29, no. 8, August 2014.
6. Melícioa .R, Mendes V.M.F , Catalão J.P.S,"Power Converter Topologies for Wind Energy Conversion Systems: Integrated Modelling, Control Strategy and Performance Simulation" Received 24 October 2008; received in revised form 13 February 2010
7. Z. Qian, O. Abdel-Rahman, H. Al-trash, and I. Batarseh,(2010) "Modeling and control of three-port DC/DC converter interface for satellite applications, *IEEE Trans. Power Electron.*, vol. 25, no. 3, pp. 637–649, March 2010.
8. Zhijun Qian, Osama Abdel- Rahman and Issa Batarseh,(2010)"An Integrated Four-Port DC/DC Converter
9. Renewable Energy Applications,"*IEEE Trans. Power Electron.* vol.25, no.7, pp.1877-1887, July 2010
10. Thanh Hai Nguyen, Dong-Choon Lee and Chan-Ki Kim, "A Series-Connected Topology of a Diode Rectifier and a Voltage-Source Converter for an HVDC Transmission System", IEEE Transactions on Power Electronics, Vol.29, no. 4, April 2014.
11. Yu-Seop Park, Min-Mo Koo, Seok-Myeong Jang, Jang-Young Choi, and Dae-Joon You, "Performance Evaluation of Radial- and Axial-Flux PM Wind Power Generators With Mechanical Energy Storage
12. System", IEEE Transaction on Energy Conversions, vol. 30, no. 1, March 2015
13. Wu Chen , Nanjing, Xiaogang Wu, Liangzhong Yao and Wei Jiang, "A Step-up Resonant Converter for Grid Connected Renewable Energy Sources," IEEE Transaction on Power Electronics, IEEE Transactions on Vol.30 , Issue: 6 ,no. 1, pp. 331–339, October 2015
14. Zhou Tianpei, Sun Wei," MPPT Method of Wind Power based on Improved Particle Swarm Optimization," TELKOMNIKA, Vol. 11, No. 6, June 2013