Power Management of Hybrid Source Fed Electric Drive for Electric Vehicle Application

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Abstract: *The paper proposes a hybrid energy system for electric vehicle charging integrating solar PV and wind turbine systems connected to the grid. The solar PV and wind system are used as the foremost energy sources to supply the load. In addition, a battery is used to fill up the need in case of uncertainties of power supply to load. A simple MPPT technique for extracting the maximum power from wind and solar photo-voltaic system, a control technique for grid side converter for grid side control and power interface is developed for the proposed hybrid system. The hybrid conversion system is developed in MATLAB/SIMULINK.*

Keywords: **Hybrid energy system, Electric vehicle, MPPT technique, Wind turbine system, Solar photo-voltaic system**

1. INTRODUCTION

In general, the vehicles that run on the non-renewable resources are conventional vehicles that not only emit harmful gases affecting the environment and causing global warming but also consuming fossil fuels at a very rapid pace that takes years to form. Thus, need for the use of electric vehicles came into being. The use of such vehicles emerged as they run on the renewable sources of energy and also store the excess energy in rechargeable batteries to drive themselves. These vehicles are not only efficient but also be in the service of reducing the pollution in the environment by ejecting no harmful gases unlike conventional vehicles.

A paper has presented off grid charging-station for electric and hydrogen vehicles [2]. Some studies have presented the modeling and the controlling of the hybrid system with solar pv, battery and wind supply systems [14,10,15]. A research has proposed the systematic review on the solar pv modules, the failure and their causes and effects [17,5]. Futhermore, various methodologies are being proposed to reduce the temperature of pv modules which affect the efficiency and the concept of multi-cooling for improving efficiency of the pv modules [8,9].

In this paper, a model and control scheme for Hybrid source fed system that would be beneficial for electric vehicle charging from ac as well as dc sources. A proper control mechanism for each portion is provided individually.

2. Hybrid System

The Figure.1 shows the topology of the proposed model comprising of wind turbine connected with a permanent magnet synchronous generator (PMSG) and solar PV system. Individual controls have been given to each part of the system. WTG system is connected to the grid through AC-DC-AC conversion system. WTG and PV are connected to the dc link which in-turn will transfer active power to the grid and reactive power will not be exchanged. MPPT is given to extract the maximum power from the system. Moreover, the uncertainties in the power can be eliminated with the use of the battery.

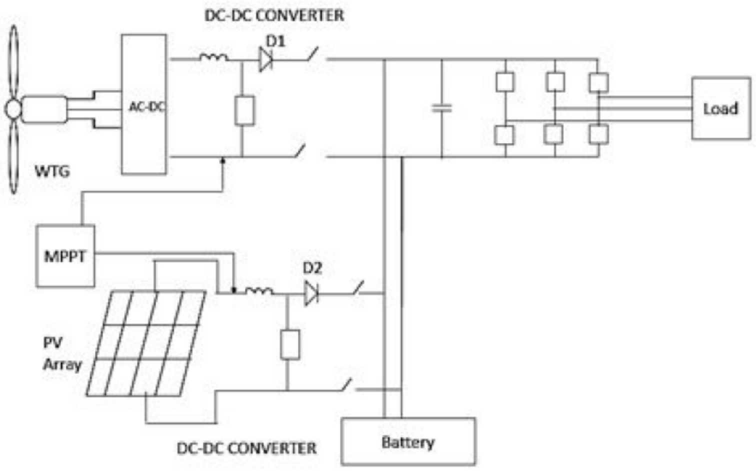

Figure.1 Proposed hybrid system model

2.1. Solar PV Model

The given below is the equivalent circuit of the solar pv cell and the pv cells can either be grouped in series or parallels to form the connections in order to form pv arrays that may be used in the generation of the high solar power to meet the need. These are connected electrically in series-parallel connection to obtain the amount of the current and voltage that is required. The paper has discussed modeling of the solar pv array step by step based on the characteristic equations of the solar pv [13].
The following characteristic equations of a solar cell are taken into account;

$$I_{ph}=[I_{sc}+k_i(T-298)]*I_{rr}/1000 \quad (1)$$

where; I_{ph} = photocurrent of module (A), I_{sc} = module short circuit current (A), k_i = cell short circuit current (A), T = operating temperature (K), Irr = solar irradiation (W/m^2)

$$I_{rs}=I_{sc}/[\exp(q*V_{oc}/N_sKnT)-1] \quad (2)$$

where; I_{rs} = reverse saturation current (A), q = charge of electron (C), Voc = open circuit voltage (V), N_s = number of cells in series, K = Boltzmann's constant, n = diode ideality factor

$$I_o=I_{rs}[T/T_r]^3\exp[q*E_{go}/nk(1/Tr-1/T)] \quad (3)$$

where; T_r = nominal temperature (K), E_{go} = semiconductor band gap energy

$$I=N_p*I_{ph}-N_p*I_o*[\exp((V/N_s+I*R_s/N_p)/n*V_t)-1]-I_{sh} \quad (4)$$

Also,

$$V_t=K*T/q \quad (5)$$

And,

$I_s=(V*N_p/N_s+IR_s)/R_{sh}$ (6)

where; N_p = number of modules in parallel, R_s = series resistance in ohms, R_{sh} = shunt resistance in ohms, V_t = thermal voltage of diode (V).

The characteristics of reference solar pv module parameters taken for the simulation are being given in the Table 1 below:

Table 1. Table Label

Rated power (V_mp)	200W
Voltage at max power (Vmp)	26.4V
Current at max power (Imp)	7.58A
Open circuit voltage (Voc)	32.9V
Short circuit current (Isc)	8.21A
Total cells in series (Ns)	54
Total modules in parallel (N_p)	1
Operating temperature(T) Range	-40 to 80^{o}C
Nominal temperature (Tr)	298 K
Reference operating temperature	25^{o}C
Solar Irradiation	1000W/m^2
Series resistance (Rs)	0.221
Shunt resistance (Rsh)	415.405
Boltzmann’s constant (K)	1.38e-23 J/K
Ideality factor (n)	1.3
Band gap of semiconductor (E_{go})	1.1eV
Electron charge (q)	1.6e-19 C

2.2. Wind Turbine Model

A wind turbine converts the energy of the wind into the electrical power using a force termed as aerodynamic force from the blades attached to the rotor. The rotor in turn is connected to the generator through rotating shaft. The aerodynamic force being converted into the rotation of the generator through rotor will give rise to electricity. A paper has suggested and developed a simulator to control the wind environment rates using DC motor to simulate the wind turbine model [3]. The characteristic equations from wind turbine is given as;

$P_m=1/2\ \rho AC_p3$ (7)

where; ρ = air density, A= turbine blades area, V_w = wind speed (m/s), C_p = power coefficient of aerodynamic power. Here, ρ and A are constant values and at the maximum value of $C_{p,}$ the wind turbine will generate maximum power.

$C_p(\lambda,\beta)=C_1[C_2/\lambda_1–C_3\beta–C_4]e^{-C_5/\lambda_1}+C_6\lambda$

(8) where; λ = tip speed ratio, β =pitch angle in degrees.

$$\lambda = \omega_t R / V_w \quad (9)$$

where; ω_t =angular velocity of turbine/ turbine speed, R = turbine radius, V_w = wind speed in m/s.

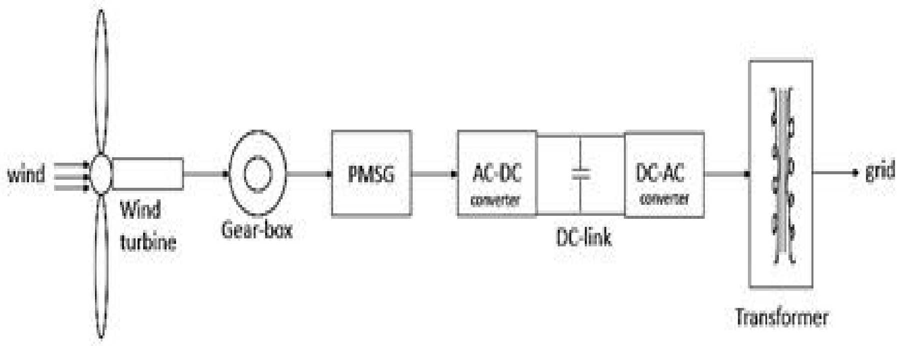

Figure.2 WTG connected to Grid

The research suggests control of variable speed turbines in high and low speeds [7]. PMSGs are used in the wind turbines because of them being less expensive than conventional wound rotors and also have more poles to drive the low speed drives. It has the ability of being small in size, efficient and without any gear system used, it can provide high torques at low speed operations.

2.3. Drive Train Model

Drive-train represents mechanical coupling of the generator with the turbine with the help of a rotating shaft. It comprises a turbine, a generator and a gear box. Only the generator inertia and the turbine inertia along with the damping coefficient and the stiffness of the rotating shaft be considered. Among all the three sources, the main are generator and turbine inertia. Although the inertia of the gearbox only comes up with a little amount of the whole contribution, therefore, the inertia of the gear-box is usually not taken into consideration most often but only the gear ratio may be taken equal to unity.

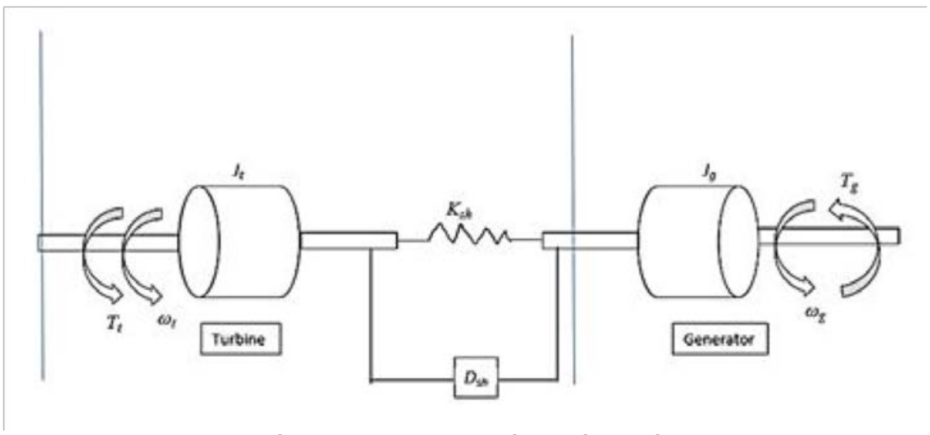

Figure.3 Two mass Drive train mode

The characteristic equations of the drive-train are given as;

$2H_t d\omega_t/dt = T_t \quad -K_{sh} \quad \theta_{sh} \quad -D_{sh} \quad (\omega_t - \omega_g)$
(10)

$$2H_g d\omega_g/d_g = K_{sh}\,\theta_{sh} - T_g + D_{sh}\,(\omega_t - \omega_g) \quad (11)$$

$$d\theta_{sh}/d_t = \omega_t - \omega_g \quad (12)$$

where, T_t = wind turbine torque, T_g = generator torque, ω_t = wind turbine speed, ω_g = generator speed, H_t = turbine momemt of inertia constant, H_g = generator momemt of inertia constant, K_{sh} = stiffness of shaft, D_{sh} = damping coefficient of shaft.

3. Power Electronics Interface

Power electronic converters produces the electronic power control mechanism. They exercise and deal with supplying the currents and voltages to fulfil the need or the requirement of the specified load and that which matches its speed torque characteristics. The proposed system has AC-DC-AC conversion through a DC link. The generator side is a diode rectifier and grid side converter has a VSC main controller for the control. Due to the presence of DC link, only active power will transfer to grid and reactive power will not be exchanged. It has separate DC-DC boost converter for solar PV, PMSG is connected to grid through AC-DC-AC system, and a Bi-directional DC-DC converter for battery for regenerative braking. A research has introduced the use of multi-input KY boost converter in the hybrid topology of pv and wind energy systems [6]. Another paper proposes a pv wind battery hybrid system using bidirectional converter and voltage inverter [11].

3.1. Boost converter topology

Boost converter is a dc-dc step up converter which regulates the voltage at the output. The output voltage will be more than the input voltage at the converter terminal. It regulates the dc voltage to recharge the battery.

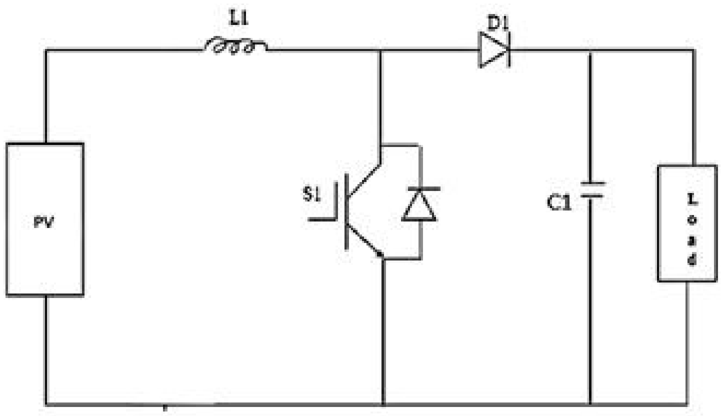

Figure.4 Boost converter topology

3.2 Buck-Boost Converter Topology

It is a dc-dc converter and the function of this converter is to step up or step down the voltage and can also inverse it. It hence is best suited for the battery for regenerative braking process.

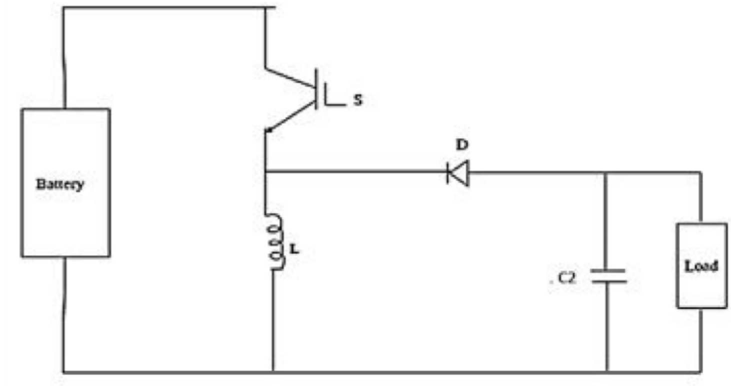

Figure.5 Buck converter topology

4. Battery Energy Storage System

The battery is connected to a dc bus. When SOC goes low, the battery would go in recharging mode and when SOC goes high, the battery would be in use. A bi-directional DC-DC converter is used to prevent the battery from excess discharging by the reverse current flow. In a paper, a hybrid pv wind with battery system to overcome the uncertainties using fuzzy logic for better power utilization has been proposed [1].

A bidirectional converter or a charge controller takes in SOC, current and the voltage of the dc link. It generates 3 PWM pulses depending upon these three measures, 2 of which will be sent to battery control switches and 1 PWM pulse is fed to the switch connected to the dc link.

5. Control for PV and WTG

PV is connected to WTG which is in turn connected to dc link. PV system is connected to boost converter to boost up the voltage to match that of the common bus voltage (set to constant line voltage). The output power from the PV and wind system is given to dc loads or it may be given to the 3_{ph} inverter to supply ac loads. Battery is connected to the system which will supply to dc loads in case of need or may supply to ac loads by discharging to inverter through discharge diodes. Some researches present solar pv system with MPPT techniques to reduce the losses [7,16]. To achieve MPPT, each source voltage is controlled individually.

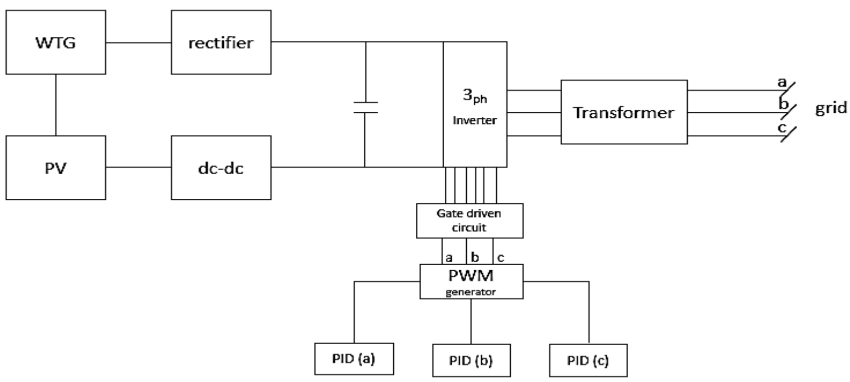

Figure.7 PV and Wind system

In the proposed system, A PWM mppt technique is used to extract maximum power from wind and PV systems. A PWM signal is formed by taking dc voltage signal and triangular waveform voltage signal as inputs. The comparator will compare the voltage signals and give the highest modulated voltage pulsed signals as the output. This technique has max power achieving capability, quick response, accuracy and high power factor. Also for low speed of generator, it provides the maximum torque.

6. Control for Grid-side Converter

The control scheme for grid side converter is to regulate the inverter output voltage. This scheme is based on d-q transformation technique. The 3ph output voltage from the dc-ac converter will be transformed from a, b, c to d-q variable frame. The 6 pulses to the 3_{ph} inverter is given via PWM generator to take the input from d-q output to abc conversion. PWM converter regulates the voltage by absorbing the reactive power and giving off the active power with lower THD. The frequency of PWM generator is taken in a range from 5-10 KHz. A paper presents control without PLL and such a concept applied to the type 4 wind turbine [4].

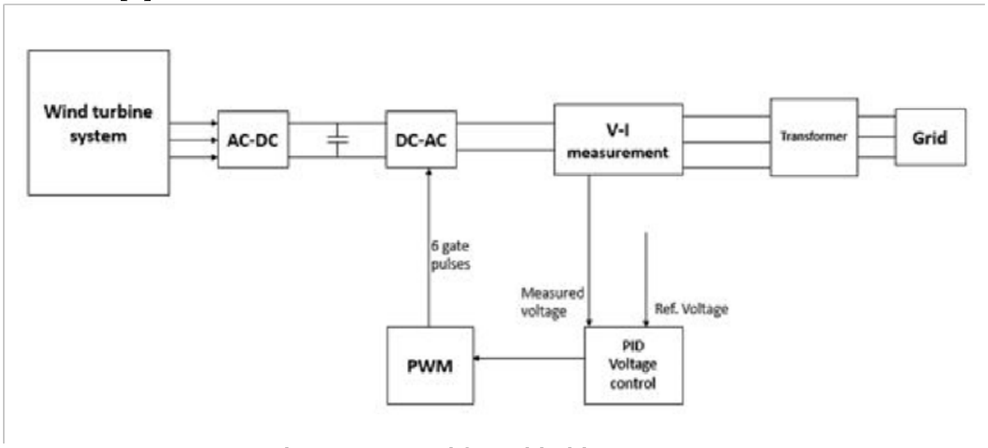

Figure.8 Control for grid-side converter

7. Simulation and Results

- Considering currents and voltages on a single plot keeping irradiance as same 1000W/m^2 and temperatures to be noted as varying at 25, 35, 45 degrees respectively.

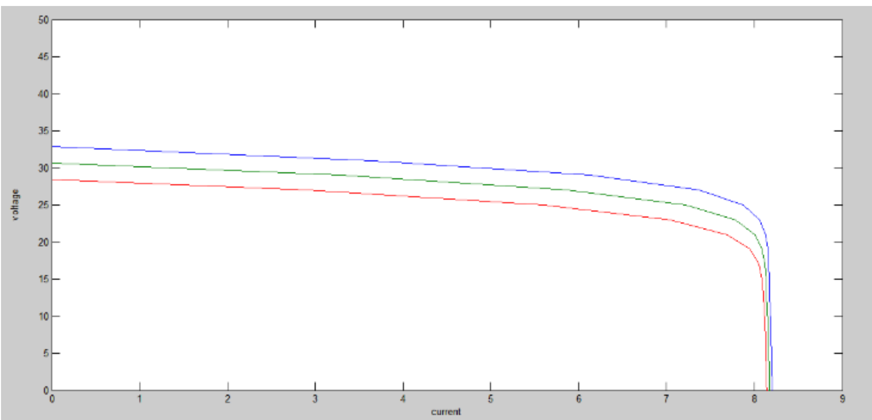

Figure.9 I-V graph with constant irradiation and varying temperature

- Considering voltages and power values on a single plot keeping irradiance as same 1000W/m^2 and temperatures to be noted as varying at 25, 35, 45 degrees respectively.

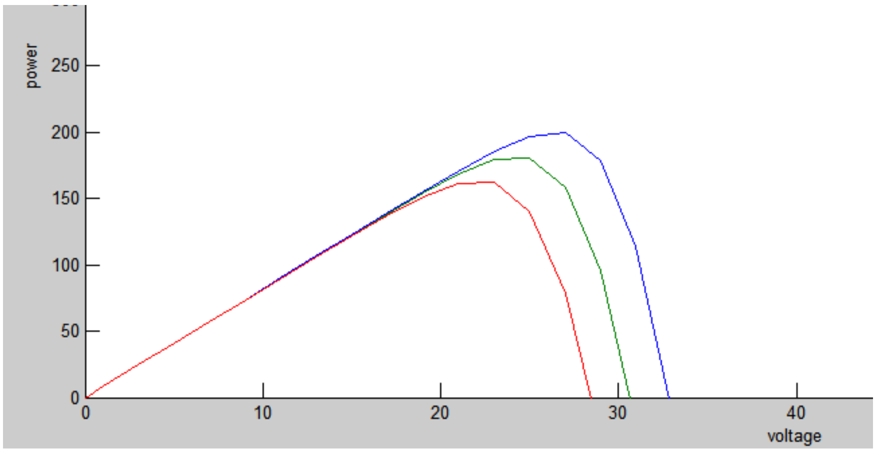

Figure.10 P-V graph with constant irradiation and varying temperature

With the decrease in the temperature, the current reduces and a rise in the current is seen. Thus, the power will also increase with the reduction in the temperature. Give below are the graphs for the solar PV system current, voltage and the power output.

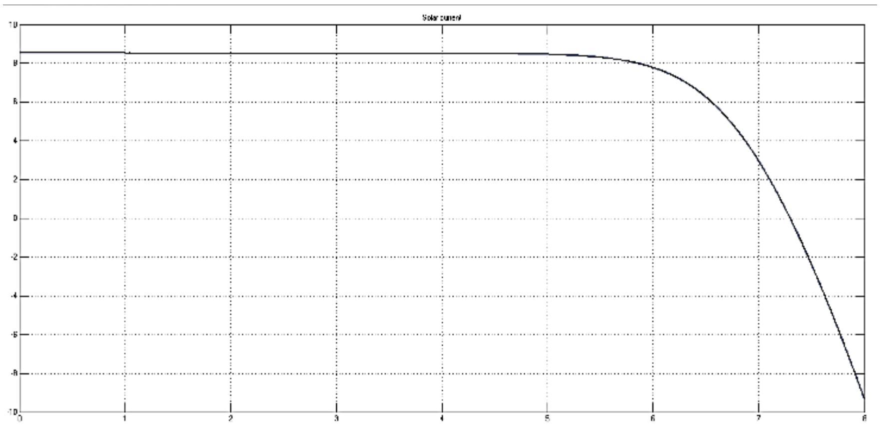

Figure.11 Solar PV system current (A)

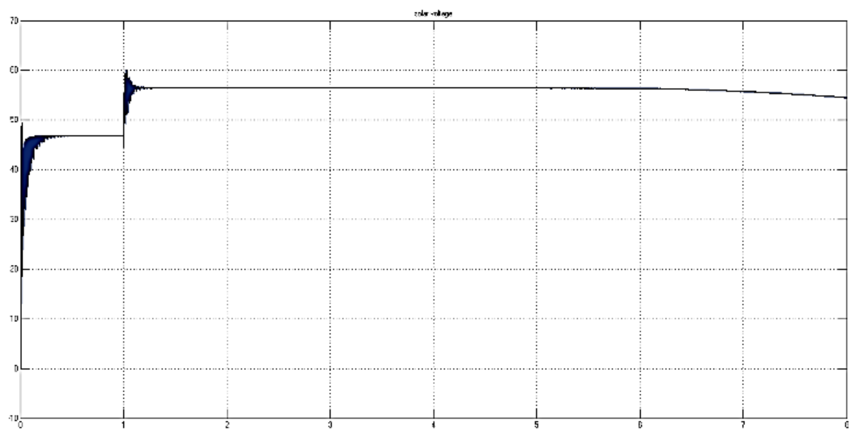

Figure.12 Solar PV system voltage (V)

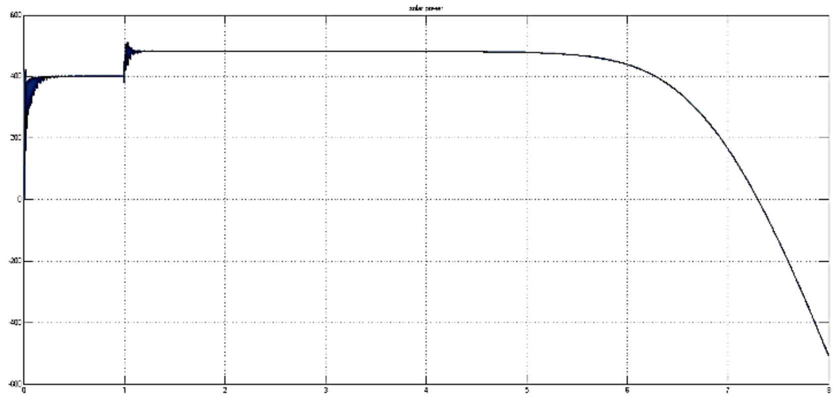

Figure.13 Solar PV system power (watts)

- For the extraction of maximum power from the Wind and PV systems and for the control of the dc system voltage, a pwm MPPT technique has been followed, given PID control for each current and output for the three phases. The Dc voltage is regulated all over the system at constant according to the load requirements. The dc voltage waveform is given as in the Fig.14. below:

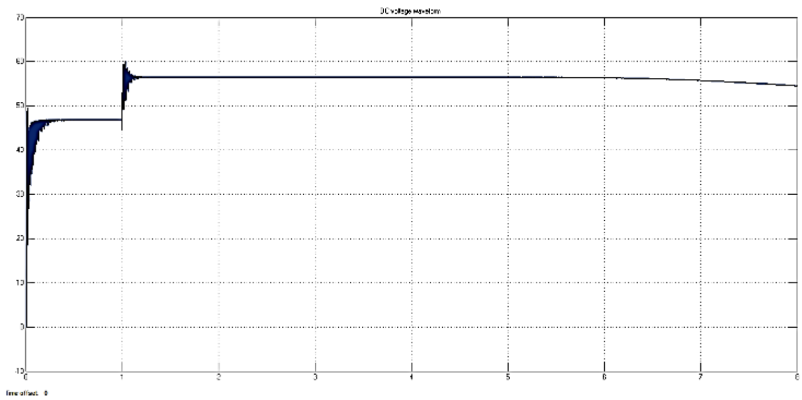

Figure.14 DC voltage waveform

- Figure.15 gives the rotor speed of the generator in p.u., Figure.16 gives the waveform for Torque and Figure.17 gives the mechanical power output.

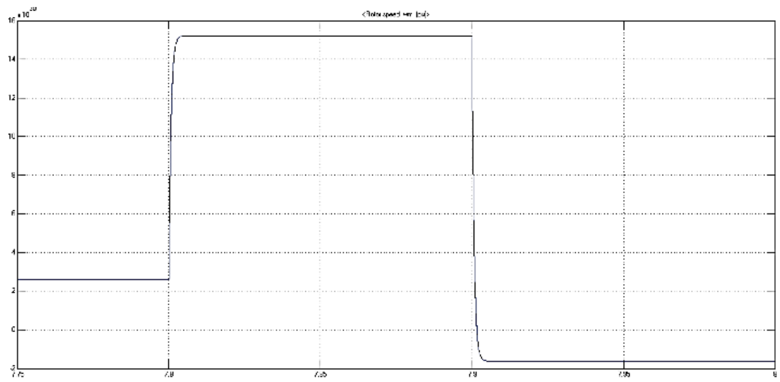

Figure.15 Rotor speed in p.u.

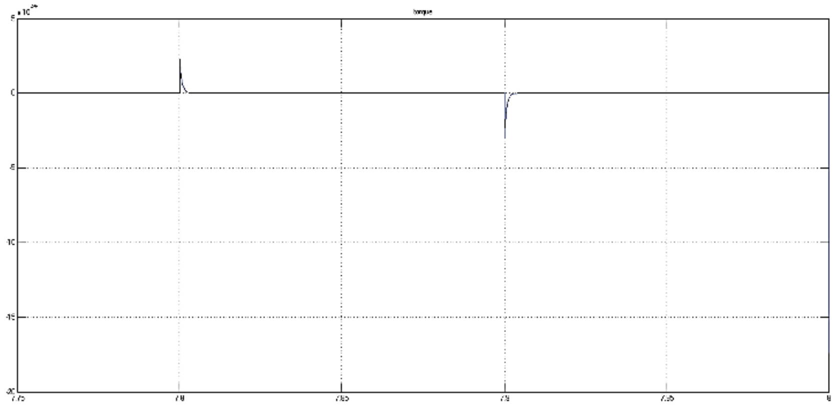

Figure.16 Torque

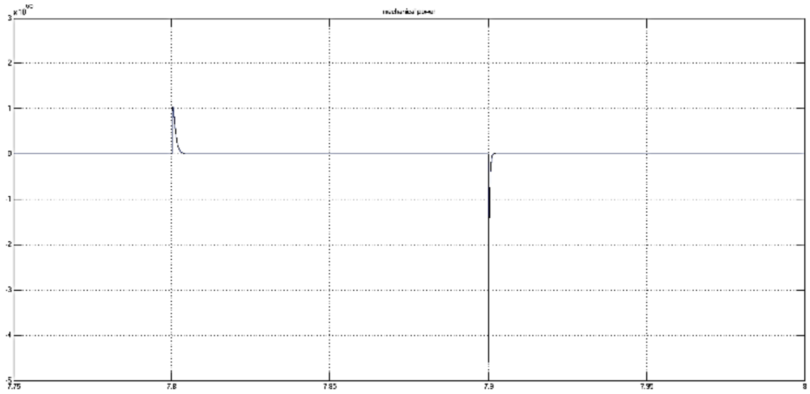

Figure.17 Mechanical power output

- Results for the 3 phase transmission currents and voltages using grid-side converter control.

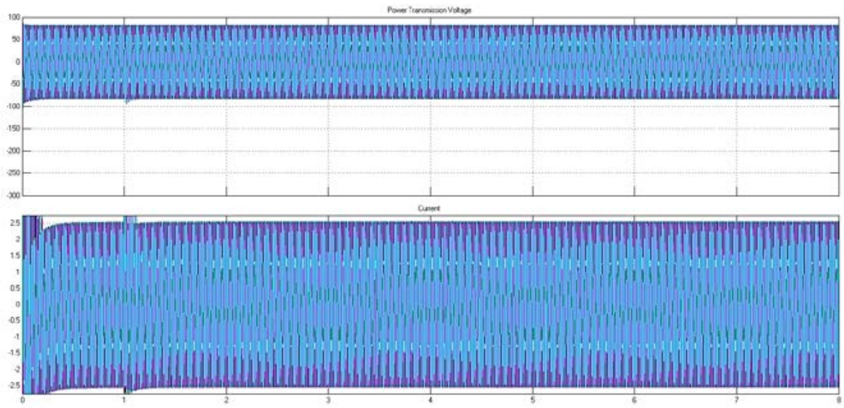

Figure.18 Output currents and voltages for 3 phases using Grid-side converter control

- The THD from the use of the VSC control of the 3 phase inverter becomes visibly less using LC filters and the PWM generator pulses, the power factor will be improved and the harmonics in the system be reduced which determines the strength of the control scheme used, shown in the Figure.19.

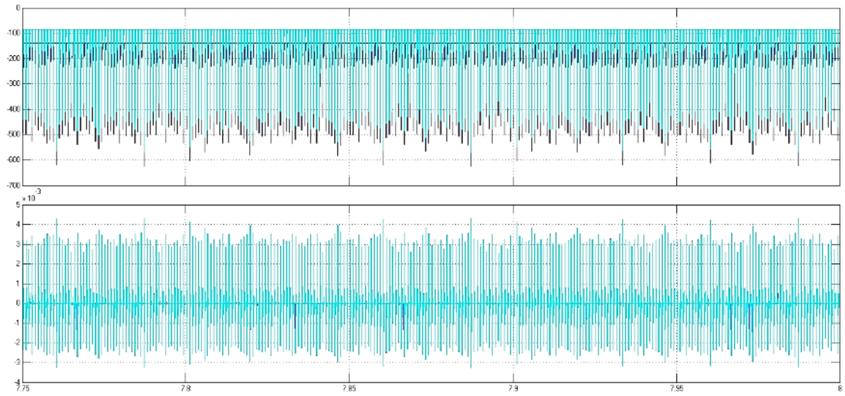

Figure.19 Harmonics and pf of grid side using VSC

- The 3 phase grid side transmission currents and voltages from utility 3ph source side, from distributed parameter line system and from using 3ph step-up transformer in Figure.20 a), b) and c) respectively.

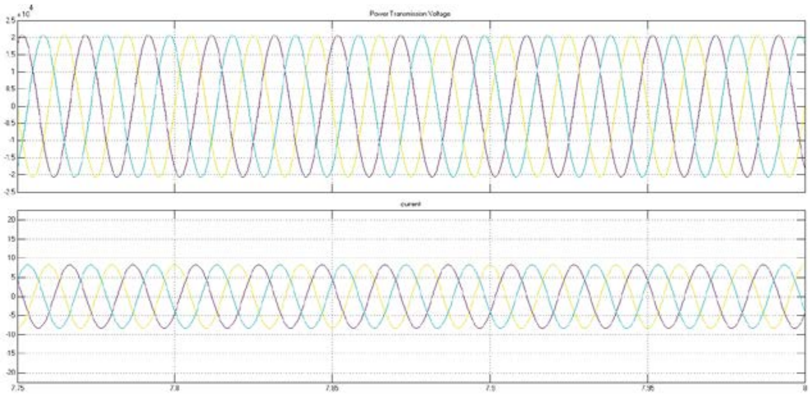

Figure 20.a) Power transmission currents and voltages from grid side from 3ph source side

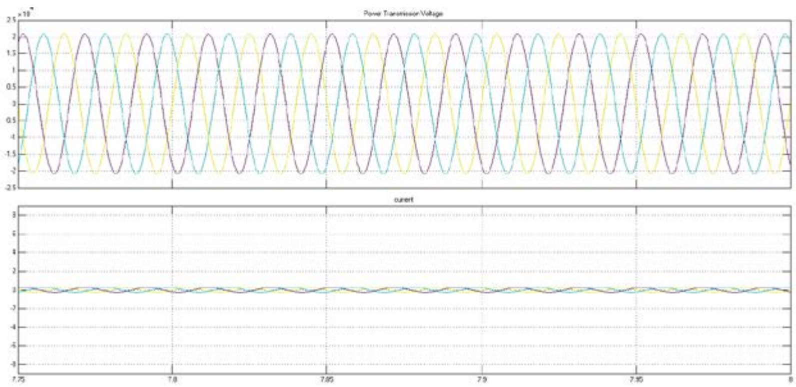

Figure 20.b) Power transmission currents and voltages from grid side from distribution side

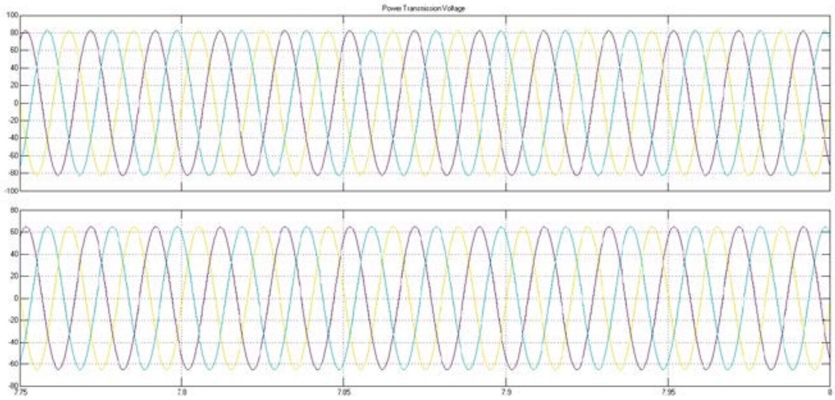

Figure 20.c) Power transmission currents and voltages from grid side with step up transformer

- The battery SOC, battery current and battery voltages are shown in the figure below. Keeping SOC constant, if the state of charge (SOC) is less than the predetermined value, the battery will be connected to the source (charging mode); if SOC is greater than the predetermined value, the battery will be disconnected from the source (discharging mode).

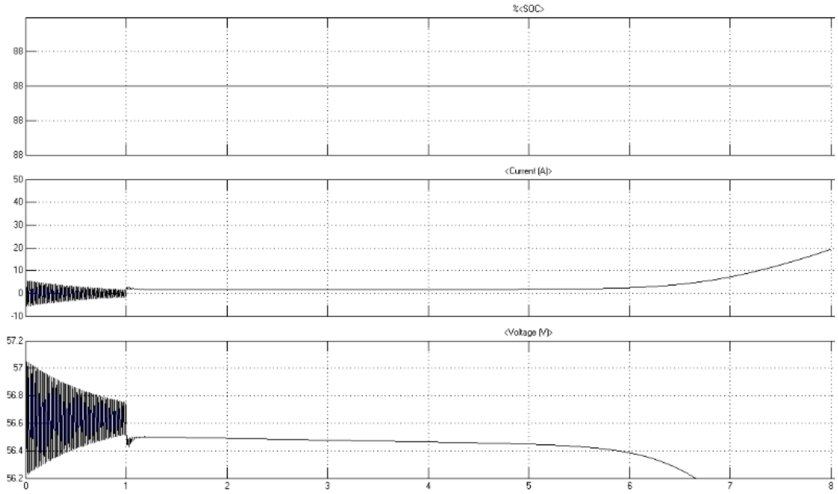

Figure.18 Battery SOC, Current, Voltage

7. Conclusion

This paper has provided the modeling and control scheme for the power control in hybrid source system using renewable energy combining PV with wind system and battery as a backup source. A pwm MPPT technique has been used for PV and wind system to extract maximum power and control the dc output voltage. A control scheme for grid side converter is also given. Therefore, a complete discussion and simulation results have been provided to make it feasible for other possibilities. In this proposed model, there might be lack of control mechanisms properly done or some other measures that are more resourced and with better technologies may be introduced. There is also scope for cost and parameter analysis. We could have also provided multiple resources and far more intelligent methods to make it more reliable and inexpensive and the power control with their proper management might also be adjusted to have better and better outcomes for a world like today.

Acknowledgments

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