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Modeling and simulation of Hybrid Energy Storage System (HESS): Integrated Renewable Energy Generation System (REGS) ForGrid

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ABSTRACT
This research article explores the qualitative issue of modelling in Energy Storage system with Renewable Power Generation for opting grid which provide the bulk power to industrial consumers as well as domestic load i.e. hilly and desert area. Objective of this research work is developing a model in MATLAB environment for feasibility assessment of the Energy Storage System integrated with Wind-Solar component operation which is helpful to develop a practical model. This integrated model uses statistical values to simulate power in utility grid. The utility grid load requirement is flexible so power interchange with grid is monitor by system controller. The load profile and control techniques of electric grid must be enhancing the quality of power. The proposed work is capable to solve the problem where conventional energy source is difficult to provide the power to consumer and also help in the green energy generation to country**.**
Keywords–Energy Storage System, Grid, Modeling, Renewable Energy Generation System, Utility Network

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I. INTRODUCTION

In present and past era, Power demand of the consumer mostly full fill by the conventional energy sources like oil, coal and natural gas etc. Because limited reserves of conventional sources and environmental point of view, Day by day increasing the importance and use of the Non-Conventional energy sources like Wind and Solar. Now a days the Wind Turbine Generators and photovoltaic panels are worldwide available for supplying customer in ever where as well as remote areas for Generation of Renewable Energy power System with no harm full to our environment, Power generation is done from this hybrid power generation system. Renewable energy has limited contribution in the power generation and this type of generation is difficult to control, this problem is solved by integration of this hybrid energy system with hybrid Energy Storage System. In the present research article, a proposed hybrid power generation system and ESS model issimulated in MATLAB and gives satisfactory result.

II. PROPOSED STATE OF ART

This hybrid technology consists of the Integration of Wind and Solar Energy Generation System with Energy Storage System (ESS) which provide smooth and reliable power to the loads and utility grid. A dc-dc boost converter is used for getting higher and maintained voltage at dc-link. In this proposed work WEGS, SEGS and ESS are connected as per block diagram with DC-Link. The work of DC-Link is to maintain constant output for Voltage Source Inverter (VSI) as input. A passive filter is used between VSI and grid to get ripple free voltage. A d-q based current control method is used to generate the pulse of Voltage Source Inverter. The Voltage Source Inverter gives the required AC output with the help of control circuit, which is fed to the consumer load and utility grid [1]. The basic diagram of research article as shown in figure 1.

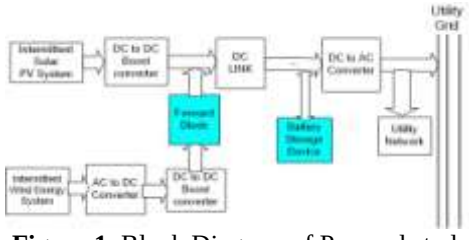


Figure 1. Block Diagram of Propesd study

III. MODELING OF WEGS

The wind air is free and in exhaustible form i.e. Renewable Energy, because of the uneven heating in the environment, the irregularities of earth surface and earth movement on his magnetic axis, wind is originated. The wind energy is converted into electrical energy through wind machine. The

much power produced by the rotor when generator rotating at maximum wind air velocity. Maximum velocity at which wind turbine produced power is called furling velocity. Beyond this velocity wind machine will stop. The components of wind energy generation systemare as following.

A. Wind Turbine:

Wind Turbine is to transform kinetic energy of windinto rotating power from turbine blades [2, 8]. The basic expression for the generated power by wind is

$$\mathbf{P_{WT} = \frac{1}{2}\,\rho\, A\, C_P\,(\lambda_{i,}\,\beta)\, V^3} (1)$$

Where,

P_{WT} = Power of WT

ρ = Air density in Kg/m^3 = $1.225kg/m^3$ at 15^{0c}

A = Swift area of the WT = πR^2

R = WT Blade length

λ = TSR = $\frac{\omega_t R}{V}$

β = Pitch Angle of blade

ω_t= WT Rotational velocity

V = wind speed

C_P = Power coefficient

The coefficient of wind power is the fraction of wind collected by WT. Betz Rule told the value of power coefficient will be about 60% or 0.59. The blade pitch angle β =0 degree maintain for obtaining maximum torque.

$$\mathbf{C_P\ (\lambda_i\ ,\ \beta)\ =\ 0.5176\ \left(\frac{116}{\lambda_i} - 0.4\,\beta - 5\right) e^{-21/\lambda_i} + 0.0068\,\lambda_i} (2)$$

$$\mathbf{\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}} (3)$$

The Torque on WT is calculated by the following formula:

$$\mathbf{T_{WT} = \frac{P_{WT}}{\omega_{WT}} = \frac{\rho\pi R^5}{2\lambda^3} C_P(\lambda_i,\ \beta)\omega_{WT}^2} (4)$$

The parameters of wind turbine which are used for simulation is shown in table 1.

Table 1. Parameters of wind turbine

Sr. No.	Name of parameters	Specifications
1	Nominal mechanical output power (Watt)	8500
2	Base power of Electrical Generator (VA)	9445
3	Base wind speed (m/sec)	12
4	Max. power at BWS (PU of NMP))	0.8
4	Base rotational speed (PU of BGS)	1
5	Pitch angle of blade	0 deg.

B. Induction Generator (PMIG)

A synchronous generatoris used to produce electricpower in large amounts from themechanical power obtained from the wind turbine. The magnetic field is received by using a permanent magnet. The PM induction generator (PMIG) give the better results as compared to other generators also reduction of cost and weight due to absence of gear box in such generator. The dynamic mathematical model of generator in the reference frame i.e. state equation form is given by eq^n (5) and (6). For synchronization between d-q reference frame and a-b-c three phase frame is done by phase locked loop [3].

$$\mathbf{\frac{di_d}{dt} = \frac{1}{L_{ds}+L_{ls}}\left(-R_s\, I_d + \omega_e\left(L_{qs} + L_{ls}\right)i_q + u_d\right)} (5)$$

$$\mathbf{\frac{di_q}{dt} = \frac{1}{L_{qs}+L_{ls}}\left(-R_s\, I_q + \omega_e[(L_{ds} + L_{ls})i_d + \Phi_f]\right)} (6)$$

Where d and q refer to the physical parameters that have been transformed in to d-q theory, R_s stator winding resistance in [Ohm], L_d and L_q inductances of the generator winding in d and q axis in [Henery], L_{ld} and $L_{lq}$is the leakge inductances of d and q axis theory in [henery],Φ is the flux in [Weber] and ω_e is the angular speed [rad/sec] of generator. The equation of electromagnet torque and emf isgiven by eq^n (7) and (8) which is useful in modeling of generator.

$$\mathbf{\tau_e = 1.5\ P\left((L_{ds} - L_{ls})i_d i_q + i_q \Phi_f\right)} (7)$$

$$\mathbf{E = 4.44 * f * \Phi * t} (8)$$

Here all symbols are representing in standard notation.

Parameters of wind generator are used in study of simulation is shown in table 2.

Table 2. Parameters of wind Generator

Sr.no.	Name of parameters	Specifications
1	Rated power (W)	280
2	Rated line voltage (RMS) V	60
3	Stator phase inductances [Ld(H), Lq(H)]	0.0082, 0.0082
4	Stator phase resistance (Ω)	0.425
5	Machine constants: (a) Flux linage, (b) Voltage constant (c) Torque constant	 0.433 392.68 3.24

III. MODELING OF SPVGS

In 1839 French physicist Alexander E. Becquerel discovered photo voltaic effect which involving conversion of solar power in to electrical power in semiconductor element. For bulk power generation, solar Cells are joint as series or parallel as need. High power watt rating is the key performance of SEPVS. The basic segment of PV array is PV cell, the below figure 2. shows the equivalent circuit of PV cell. Equivalent circuit has a current source, a diode parallel to it, a resistance in series describing an internal resistor to the flow of current and a shunt resistor which show a leakage current [3,4]. The current supplied to the load is given by eq^{n}(9)

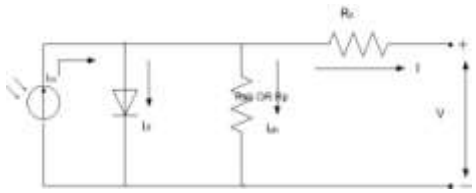


Figure 2. Circuit diagram of single PV cell

$$\mathbf{I = I_{PV} - I_d\left[\exp\left(\frac{V+IR_S}{aV_T}\right) - 1\right] - \left(\frac{V+IR_S}{R_P}\right)(9)}$$

Where
I_{Ph}–Photo current
I_d– Reverse steady state current,
V– Output Voltage in volt
a– Ideal factor constant
V_t –Heating voltage
R_{Se}– Series resistor in Ω
R_{sh}–Parallel resistor in Ω
Photo current, basically depends on the temperature &irradiations and it is expressed as equ^{n} (10)& (11).

$$\mathbf{I_{PV} = (I_{PV\_STC} + K_I\Delta T)G/G_{STC}}$$
(10)

$$\mathbf{I_O = I_{O_{STC}}\left(\frac{T_{STC}}{T}\right)^3 \exp\left[qE_g/aK\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right]}$$
(11)

Where
$\mathbf{I_{0STC}}$ – Saturation current
E_g – Band gap
The Reverse steady state current further enhanced as a temperature function as equ^{n} (12).

$$\mathbf{I_O = (I_{\_STC} + K_1\Delta T)/exp[(V_{\_STC} + K_V\Delta T)/aV_T] - 1(12)}$$

Where,
I_{STC} =short current at STC
Z_{STC}= short voltage at STC
K_V – Temp. Coefficient
This model has good result at different condition. The equation of the Solar array can be represented as eq^{n}(13) and figure 3. shows the complete module of circuit.

$$\boldsymbol{I = I_{PV}N_P - I_ON_P\left[exp\left(\frac{V+IR_S\left(\frac{N_S}{N_P}\right)}{aV_TN_S}\right) - 1\right] - \left(\frac{V+IR_S\left(\frac{N_S}{N_P}\right)}{R_P\left(\frac{N_S}{N_P}\right)}\right)(13)}$$

Where,
Number of cells use in series =Ns
Number of cells use in parallel =Np

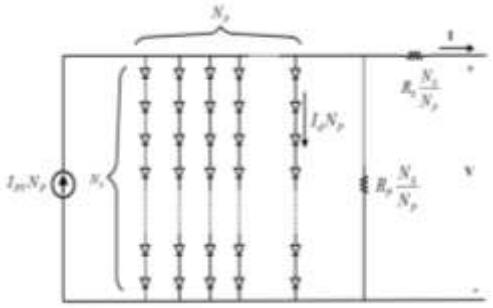


Figure 3. Complete PV Circuit for SEGS

The mathematical model representation of the Solar PV Generation as shown in equ^{n}(14).

$$\boldsymbol{I = I_{PV}N_P - I_ON_P\left[exp\left(\frac{V+IR_S\left(\frac{N_S}{N_P}\right)}{aV_TN_S}\right) - 1\right]}$$
(14)

Following Components are used for evaluate the performance by the V_{OC} andI_{sc}. Representation of maximum output asequ^{n} (15).

$$\boldsymbol{P_{MAX} = V_{MAX}I_{MAX}(15)}$$

The maximum photo voltage is generated under thiscondition when the ground leakage current with zero as following equation (16).

$$\mathbf{V_{OC} = \frac{AKT}{Q}log_n\left(\frac{I_L}{I_D} + 1\right)(16)}$$

The efficiency of SPVG is as defined as:

$$\boldsymbol{\eta = \left[\frac{Electrical\ Power\ Output}{Solar\ Power\ Raiation\ Intensity\ to\ the\ Cell}\right](17)}$$

Following parameters are used for the simulation of PV module which are shown in table 3.

Table 3. Parameters of the PV array at 27^0C, 1000w/m^2

Sr. No.	Parameters	Specifications
1.	Current at MPP (A)	7.612
2.	Voltage at MPP (V)	336
3.	Short circuit current (A)	8.27
4.	Rated Power (W)	5000
5.	Open circuit voltage (V)	406
6.	Series resistance (Ω)	0.055
7.	Parallel resistance (Ω)	550

IV. IMPORTANTCOMPONENTS

A. RECTIFIER: The main function of Rectifier in our proposed system is to convert the AC output voltage which received from wind machine to DC voltage. The three- phase bridge rectifier is commonly used in hybrid Wind-Solar Energy Generation System [5]. If $V_m$is the maximum value of phase voltage, the average and rms output voltage is calculated by the equation (18) and (19).

$$\mathbf{V_{DC}} = \frac{2}{2\pi/6}\int_0^{\pi/6}\sqrt{3}\mathbf{V_m}\ (cos\ \omega t)\ \mathbf{d(\omega t)} = \frac{3\sqrt{3}}{\pi}\mathbf{V_m} = \mathbf{1.654\ V_m (18)}$$

$$\mathbf{V_{rms}} = \left[\frac{2}{2\pi/6}\int_0^{\pi/6}\mathbf{3\ Vm^2\ cos\omega t d(\omega t)}\right]^{1/2}$$

$$= \left[\left[\frac{3}{2} + \mathbf{9}\frac{\sqrt{3}}{4\pi}\right]\right]^{1/2} \mathbf{V_m = 1.654\ V_m\ (19)}$$

B. **INVERTER:**In Renewable energy generation system, the main function of this power electronics device is to convert a DC input voltage into symmetric AC output voltage as required in grid application. A desirable AC voltage can be received by changing DC input which is collected from rectifier and maintained the gain of inverter constant. Researcher is applying various control techniques to three phase grid connected Voltage Source Inverter as PWM method and IGBT.

C. **DC-DC BOOST CONVERTER:**The DC-DCboost converter is commonly used for obtaining regulated DC power supply, but in our work the boost converter is capable to changes in dc output which obtained from the renewable energy generation system at DC link, but we know that the wind turbine generator produces AC output That is change to direct current voltage by application of power electronic circuit [5,6].The relation of regulated output voltage is determined by eq. (20).

$$\frac{\mathbf{V_o}}{\mathbf{V_i}} = \frac{\mathbf{T_s}}{\mathbf{t_{off}}} = \frac{\mathbf{1}}{\mathbf{1-D}}\ \ \mathbf{(20)}$$

Where,
V_i is input voltage in volt,
V_o is the output voltage in volts,
t_{on} is the switching ON period of Switch,
t_{off} is the off period of Switch.
T_s is switching period.
D is the duty cycle ratio.

V. ENERGY STORAGE SYSTEM (ESS)

As we know the power generation from renewable energy sources having more contribution in our country day by day, but this power output is highly variable due to environmental condition. To overcome this problem combination of Renewable Energy Generation System is used with Energy Storage System as a solution. In our work we use battery as energy storage device. The figure 4. functional block diagram of battery which is used in our work

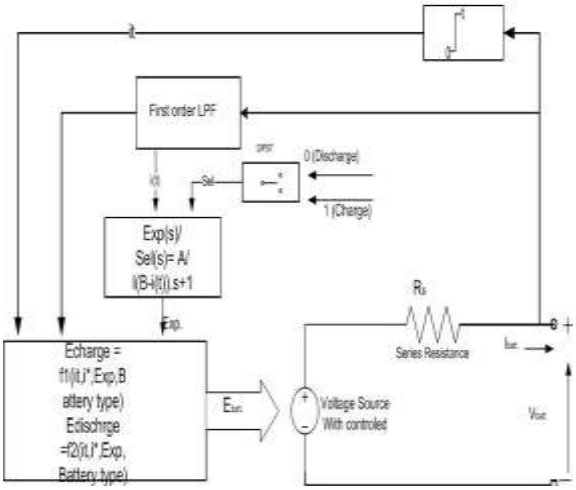


Figure 4. Represent a functional diagram of Battery

The table 4 is represent parameters which used in our simulation workEnergy Storage Device.

Table 4. Parameters of Battery Storage System

Sr. No.	Parameters	Specifications
01	Type	NMH
02	Nominal voltage (V)	300
03	Rated capacity (Ah)	6.5
04	Initial State of Charge (%)	60
05	Battery response Time (sec.)	30

VI. CONTROL TECHNIQUES FOR OUR STUDY

A. **WEGS:** Wind output curve respect to velocity is shown in figure 5.

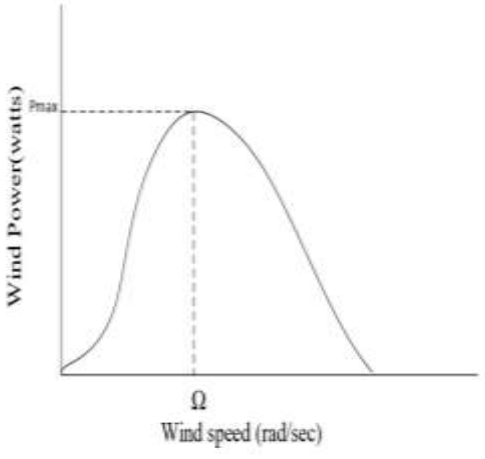


Fig 5. Wind Power vs. Speed Characteristics of WT

It is clear that from above figure for maximum power,

$$\frac{dp}{d\Omega} = 0$$

From chain rule

$\frac{dP}{d\Omega} = \frac{dP}{dD} \times \frac{dD}{dV_W} \times \frac{dV_W}{d\Omega_e} \times \frac{d\Omega_e}{d\Omega}$

Where

P – Wind power

Ω – Rotor speed

Ωe – Generator angular speed.

V_W – Rectifier output voltage

D – Duty cycle of converter

For buck-boost converter

$V_O = \frac{D}{1+D} V_W$

Where

V_O – Output of buck-boost converter

V_W – Input of buck-boost converter

From equation (1) we can write

$\frac{dD}{dV_W} = -\frac{D^2}{V_O} \neq 0$

It is clear that $\frac{dD}{dV_W}$ is negative value of velocity of turbine.

$\Omega_e = p.\Omega$

$\frac{d\Omega_e}{d\Omega} = p > 0$

Where

p – Number of pole pairs

From above relation we say that $\frac{d\Omega_e}{d\Omega}$ is positive and non-zero. The output voltage of generator can be written as $V_{ph} = 4.44.f.\Phi.t$

So $\frac{dV_{ph}}{d\Omega_e} > 0$ As$V_{ph} \propto V_W$

$\frac{dV_{ph}}{d\Omega_e} \approx \frac{dV_W}{d\Omega_e} > 0$

Where,

V_{ph} = Generator output in volt

f = Frequency of rotor in Hz

Φ = Flux per pole in wb

t = Number of turns from above relation, we see that $\frac{dD}{dV_W}, \frac{d\Omega_e}{d\Omega}, \frac{dV_W}{d\Omega_e}$ non-zero. So $\frac{dp}{d\Omega} = 0$ can be obtained if and only when $\frac{dP}{dD} = 0$

And $f \propto \Omega_e$

B. **SOLAR ENERGY SYSTEM:**In our Solar system, control technique uses as a Maximum PPT by Perturbation & observation method. It is a technique that control solar parameter with the help of power custom devises so that collect the maximum power from PV array solar system [8].

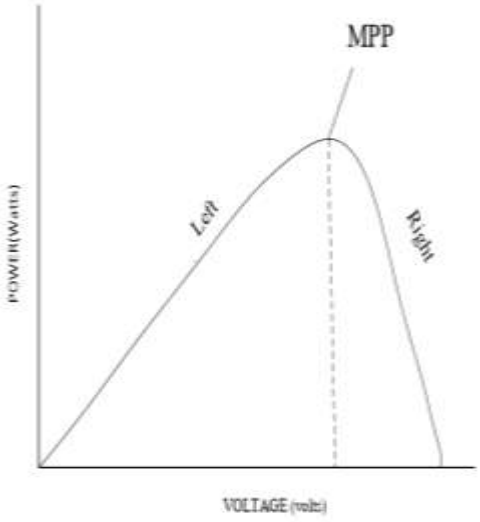


Fig. 6. Solar PV curve for P&O

VII. SIMULATION RESULTS

The following simulation results have been carried out for 3 second from my study work. The figure 7 represent constant voltage at input terminal of VSI which received from HPGS.

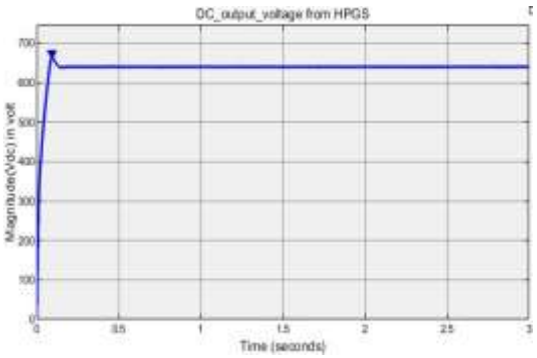
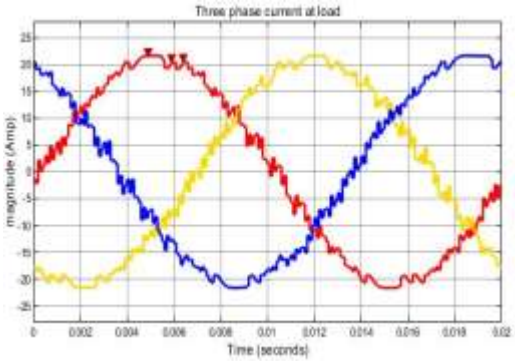


Figure 7. DC Output Voltage at DC link

The figure 8 represent Three phase ac voltage and current which received from voltage source converter and it supplied to utility network as well as utility grid and it is recorded for one cycle.



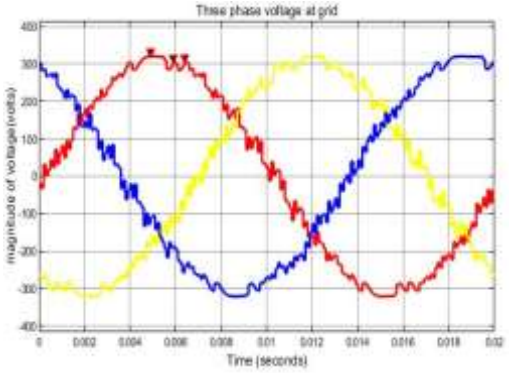


Figure 8. Three phase ac output voltage and current

Figure 9 represent Line voltage and Phase voltage which are gotten from our proposed Simulink model and which supplied to utility network as well as grid when renewable power surplus.

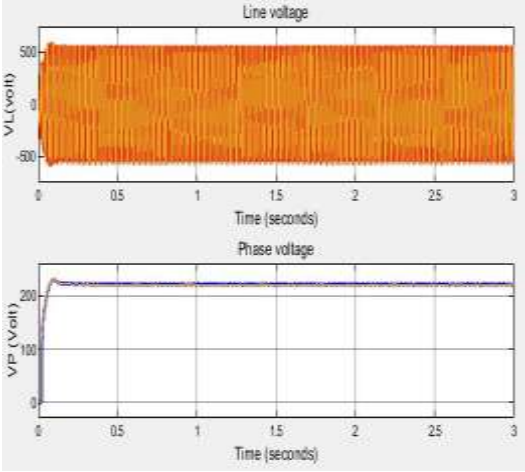


Figure 9. Line and Phase voltage

Figure 10 and 11 shows the THD present in output voltage and current signals which are received from Simulink model and it supplied to utility network.

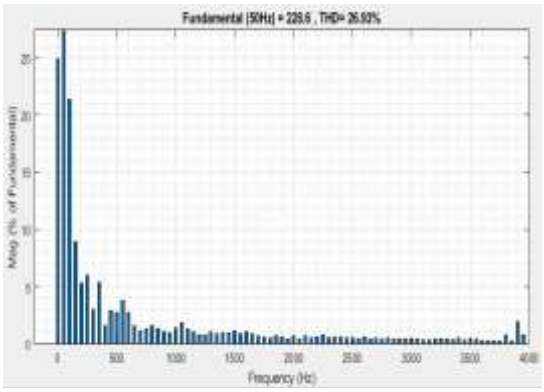


Figure 10. THD Analysis of voltage signal which received from our model

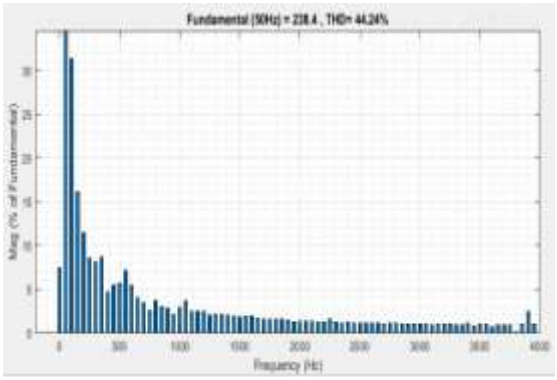


Figure 11. THD Analysis of current signal which received from our model

Figure 12 Shows the simulation results of output power which is received from Hybrid power at separate sources.

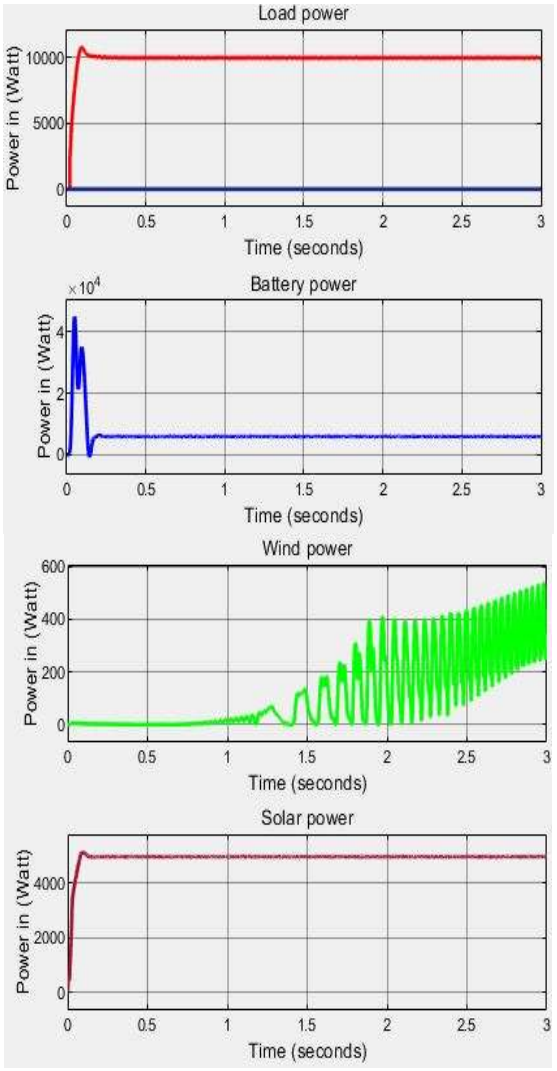


Figure 12. Shows the power from Solar, Wind, Battery and consumed by load

VIII. CONCLUSIONS

In the present scenario, The Renewable Energy Generation SystemwithEnergy Storage System isintegrated with grid is used for distribution generation system and hilly or desert areas where conventional power not available. But synchronization between Hybrid REGS with Electric grid is the main problem.Renewable Energy system such as PV and wind are highly variable Sources which depends on weather condition, Due to this cause, most of time these RE sources are not work. Because of this because RES has limited contribution in generation and it is also difficult to be maintained. To overcome this problem of REGS by use of Hybrid power Storage System.

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