DESIGN, MODELING AND SIMULATION OF HYBRID SOLAR-WIND-BATTERY-DG POWER SYSTEM

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Abstract

Hybrid Power Generation System is an excellent solution for electrification where grid connection is not enough to fulfill the electricity demand. In the present power generation system the use of renewable energy sources (RES) plays an important role in the hybrid power system to provide secure, reliable and pollution free power source for electrical power generation. Integration of hybrid renewable energy sources and power converters is required to meet the load demands and power quality problems. For utilization of hybrid renewable energy sources, modeling and simulation of three phase power converter is designed by Space Vector Pulse Width Modulation (SVPWM) technique. This paper focuses on the hybrid power generation system including renewable energy sources such as photovoltaic (PV) cell, wind energy system and energy storage system like battery in the proposed system. If the complete configuration is connected to the grid through VSI which can be capable to maintain the continuity and reliability of power. In the proposed system, the PV cell is considered as the primary power source to meet the load demands. The maximum power point tracking (MPPT) is used to capable of extracting maximum power from the PV array connected to each DC link voltage level through DC-DC converter. The wind energy system is to improve the efficiency, power rating, cost benefit effectiveness etc. The battery is provided as a high energy density device to maintain the DC bus constant. A phase locked loop (PLL) is provided for phase and frequency match. One of the main advantages of the proposed VSC is high level of integration such as bidirectional power flow in AC/DC micro-grids and independent control in both dc and ac parts. The Voltage Source Inverter (VSI) with SVPWM control technique is most suitable for building hybrid AC/DC grids incorporating multi-terminal HVDC systems. SVPWM based VSI technology is provided to control active power and at the same time reactive power at each terminal. The control technique is implemented for the Voltage Source Converter for smooth power transfer and for stable operation. All hybrid renewable energy sources and their power controllers are designed, modeled and simulated in Matlab/Simulink. The results of simulation show to verify the effectiveness of the proposed hybrid Simulink model with controller. The DG power system is in service when wind and solar power generation systems cannot satisfy the power demand.

Index Terms – Hybrid Power Generation System, Renewable Energy Sources, PV, WT, Battery, DG, VSI, SVPWM, MPPT, Boost Converter, Modeling, Simulation

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I. Introduction

In [1], a hybrid AC/DC MG which includes dispatchable generation units, PV generation systems, storage systems and controllable loads has been focused, and an advanced method of process control was proposed. The hybrid micro grid presented here comprises the DC and AC sub grid interconnected by an interlinking converter. The management of power flows among all the sources in two types of sub grids is achieved through droop control technique. The coordinated operation of DC sources and AC sources and interlinking converters are investigated for proportional power sharing in [2]. This work has provided a strong planning base to bring closer the vision of local power generation and consumption with large contributions from renewable sources while maintaining high reliability in [3]. In [4], a new control strategy for controlling the qZSI used in an AC/DC hybrid micro grid has been proposed. In this approach, the maximum constant boost (MCB) for the interconnected converter provided for both grid- connected and islanded modes of operation as well as during the transition of micro grid from islanded mode to grid connected mode and vice versa. A simple NDO-based dc-bus voltage control strategy was proposed in this paper, which is especially suitable for a hybrid ac/dc micro grid or a dc micro grid. With the proposed control strategy, high bandwidth communications between the dc source/loads and the dc–ac converter can be avoided, which is key for the system scalability and maintaining the plug-and-play feature of the DGs in [5]. In [6], real-time energy management of a hybrid DC micro grid supplied by a three phase generator and a super capacitor bank was proposed. The Energy management algorithm based on master-slave control for three modes of operation is defined to continuously supply the steady state and pulse load. A YD transformer was implemented between the generator and AC filter to isolate the hybrid DC micro grid. The test was performed for both isolated and non-isolated hybrid DC grid. In [7], Focusing on the interfacing converters between ac bus and dc bus, a dc-side hierarchical control system is designed and evaluated in this paper to analyze both standalone and grid-connected dc operation modes. An optimization-based multivariable PI controller has been presented for decoupling dq-current control of grid-tied voltage source converter using nonparametric models in [8].A hybrid micro grid is a small grid formed by banking multiple renewable energy sources together to enhance their independent advantages. The banked hybrid micro grid can be operated either in connection to main grid or isolated in [9]. In the proposed model of hybrid power system, the modeling and simulation of a VSI fed from hybrid energy sources has been presented. Solar and wind power are the two sources being used. The proposed model is used to reduce the voltage, current and THD and implement a hybrid renewable energy system. Solar and wind energy sources are the most popular types of grid connected renewable energy sources. In this paper, a new system configuration for interfacing the hybrid solar and wind energy system to the grid has been presented. This configuration is flexible and also allows solar and wind renewable energy sources to supply the load together or independently depending upon their availability. In [10], a single phase photovoltaic inverter topology with battery backup for grid connected pv systems with a novel control scheme has been presented. This control scheme controls the active and reactive power injected into the grid and implements a reliable grid connected hybrid renewable energy sources. A new control strategy improving power quality for four leg inverter based system has been described in [11]. In [12], a supervisory controller based on the state machine approach for an isolated hybrid AC/DC micro-grid is presented to satisfy load power demand in both the AC/DC micro-grids, while maintaining SOC of battery banks with fuzzy control. Based on the above review, the proposed model is focused on the development of a effective control scheme for power generation system management and also can be connected to the AC/DC micro grid for power flow quality and stability control.

I. Hybrid System Configuration

The system configuration used to be evaluated in the proposed model has a DC bus which combines the DC output of the PV module, the DC output of the WT, and the Battery bank. The AC bus of this system configuration combines the output of the inverter, the output of the backup DG and the load. "Fig.1" illustrates the block diagram of proposed model of hybrid power system configuration.

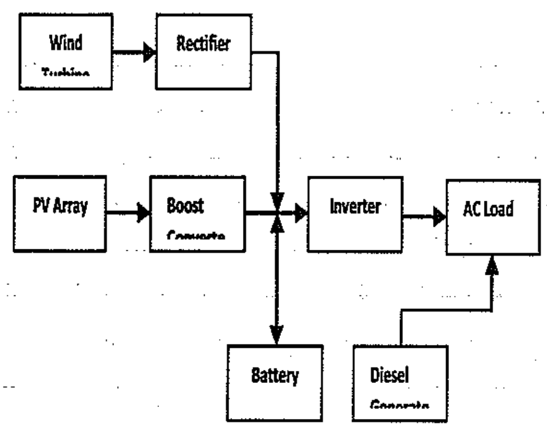

Figure.1. Block Diagram of a Hybrid Power System

The design of a hybrid system depends on the requirements of the load (isolated or not isolated, rural or urban, DC or AC) and on the power supply system. It is so important to determine the appropriate size of hybrid system components. The system shall not be oversized (expensive without increasing performance) or under sized (not capable to operate load). The proposed model of hybrid power system consists of three phase voltage source inverter, rectifier, MPPT, battery and also includes generation sources (PV, wind turbine and diesel generator). A suitable AC load is connected for the simulation purpose. Detailed description of each sub-system is considered under design details of each generation system. Proposed hybrid power system use DG with PV or WT, since diesel provides more predictable power on demand. Also batteries are used in addition to the DG. The batteries meet the daily load fluctuation, and the DG takes care of the long-term fluctuations.

II. Control strategy

Control strategy is the core problem of off-grid wind-solar hybrid power generation systems. The problem of power supply reliability is the one needed to be solved. It's necessary to make clear the operation modes before formulating the control strategy. DG can be reserve source of electrical power in poor conditions. However, it's difficult to transport and supply diesel for remote areas. So it's important to reduce the diesel consumption of DG.

Table 1. Operating Modes of Hybrid Power System

WT	PV	Load situation	Battery	Diesel Generator
ON	ON	Generation > Load	Charge	OFF
ON	OFF	Generation < Load	Discharge	OFF
OFF	ON	Generation < Load	Discharge	OFF
OFF	OFF	Generation < Load	Discharge	ON

Case 1: When WT and PV have output, battery and diesel generator are in standby mode.

Case 2: When only WT has output, the output power of WT is not sufficient, battery starts discharging and DG is in standby mode.

Case 3: When only PV has output, the output power of PV is not sufficient, battery starts discharging and DG is in standby mode.

Case 4: When WT and PV have no output, battery discharges almost fully and DG begins to operate.

IV. Design Calculation For Hybrid Power System

A. Design Procedure for 50 KW Hybrid Power System

One of the most important things for the design of a renewable energy based power system is to know the exact nature of energy consumption and renewable energy resources during a given period, as this information is important for demand side management.

Total power generation = 50 KW

Power Generation from Solar = 20 KW

Power Generation from Wind = 30 KW

Total Power Consumption = 20 KW

Total Energy Consumption = 200 KWh / day

Total energy needed from WT is = 120 KWh / day

Total energy needed from PV is = 80 KWh / day

Solar PV System Sizing :

Total appliance use = 80 KWh / day

Total Watt hours per day needed from the PV modules

= 80 KWh * 1.3 (energy lost in the system) = 104 KWh / day.

Size of the PV Panel :

Daily energy produced by the panel = 104 KWh / day

Solar hours = 7

Watts per hour = 104,000 / 7 = 14,857.14

Number of PV panels needed :

Watts per hour = 14,857.14

Panel capacity = 200 Watts = 14,857.14 / 200 = 74.2 panels

So the system needs at least 75 panels of 200 W_P

Inverter Sizing :

Total Watts of load = 50 kW

For safety, the inverter should be considered 25-30% bigger size.

The inverter size should be about 56 KW or greater.

Battery Sizing :

Battery Capacity (Ah) = (Total Watt-hours * Days of autonomy) / (Battery loss * DOD * Battery voltage)

Total appliances use = 200 KWh

Nominal battery voltage = 360 V

Days of autonomy = 1 days

Battery capacity = (200,000 * 1) / (0.85 * 0.7 * 360)

Total Ampere-hours required 933.71 Ah, and 1000 Ah can be considered for the design.

So the battery should be rated 360 V, 1000 Ah for 1 day autonomy

Solar Charge Controller Sizing:

According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array, and multiply it by 1.3

Solar charge controller rating = Total short circuit current of PV array * 1.3

Short circuit current (I_{SC}) = 8.21 A

Solar charge controller rating

= (10 strings * 8.21) 1.3

= 106.73 A

So the solar charge controller should be rated 110 A or greater.

B. PV Design Parameter Consideration

Below TABLE II. indicates the design parameters considered for 20 kW PV design.

Table II. PV Design Parameter

Type of Solar Panel	Polycrystalline
Total PV Output	20 KW
Number of PV Panels	100 Numbers
Each Panel Capacity	200 Watts
Cells per Module	54(9*6)
Maximum Power Voltage (V_{mp})	26.3
Maximum Power Current (I_{mp})	7.61

C. Boost Converter Design Parameter Consideration

Below TABLE III. indicates the design parameters considered for Boost converter module.

Table III. Boost Converter Design Parameter

Input Voltage	242.4 V DC
Output Voltage	360 V DC
Duty Ratio	0.3
Switching Frequency	1 KHz
Inductor Value	47e-3 H
Capacitor Value	2500e-6 F

D. Inverter Design Parameter Consideration

Below TABLE IV. indicates the design parameters considered for 50 KW inverter design.

Table IV. Inverter Design parameter

Input Voltage	360 V, DC
Output Voltage	415 V, AC
Output Current	110 A, AC
Switching Frequency	5 kHz

E. Power Calculation for 30 KW WT Systems

Power available in the air, P_{air} = 1/2 (ρ*A*V^3)

Air Density, ρ = 1.225 Kg/m^3

Wind Utilize Ratio, C_p = 0.42

Wind Speed, V = 3.5 m/s

Blade Diameter, D = 12 m

Blade Radius, r = 6 m

Area, A = πr^2 = 113.10 m^2

P_{air} = 1/2(1.225*113.10*3.5^3) = 2,970.11 Watts = 3KW

Power available in the wind turbine, $P_{wt} = C_p * P_{air}$

= 0.42*751.642 = 1247.45 Watts = 1.25 KW

Table V. Power Output of 30 Kwwt At Different Wing Speeds

Wind Speed (m/s)	P_{air} (KW)	P_{wt} (KW)
3.5	3.00	1.25
4	4.43	1.86
5	8.66	3.64
6	14.96	6.28
7	23.76	9.98
8	35.47	14.90
9	50.50	21.21
10	69.24	29.10
10.5	80.19	33.68

V. Simulation Model

The entire system has been modeled by MATLAB and Simulink [13 &14]. "Fig.2" shows the simulation model of hybrid system consists of PV, WT, DG and Battery. In this simulation, the PV/WT system is assigned to dispatch 50 kW power to the load. The PV, WT is delivering its maximum power of 20 KW and 30 KW and the battery discharges to provide the remaining power when any one of the source is not available. When there is no wind and solar power and the battery is completely discharged, the DG system is required to supply all the power required by the load. At light load conditions, the PV array can provide more power than the load demand, i.e. ($P_{PV} > P_{load}$), the excess energy from the PV array is utilized to charge the battery when the power is provided to the load simultaneously.

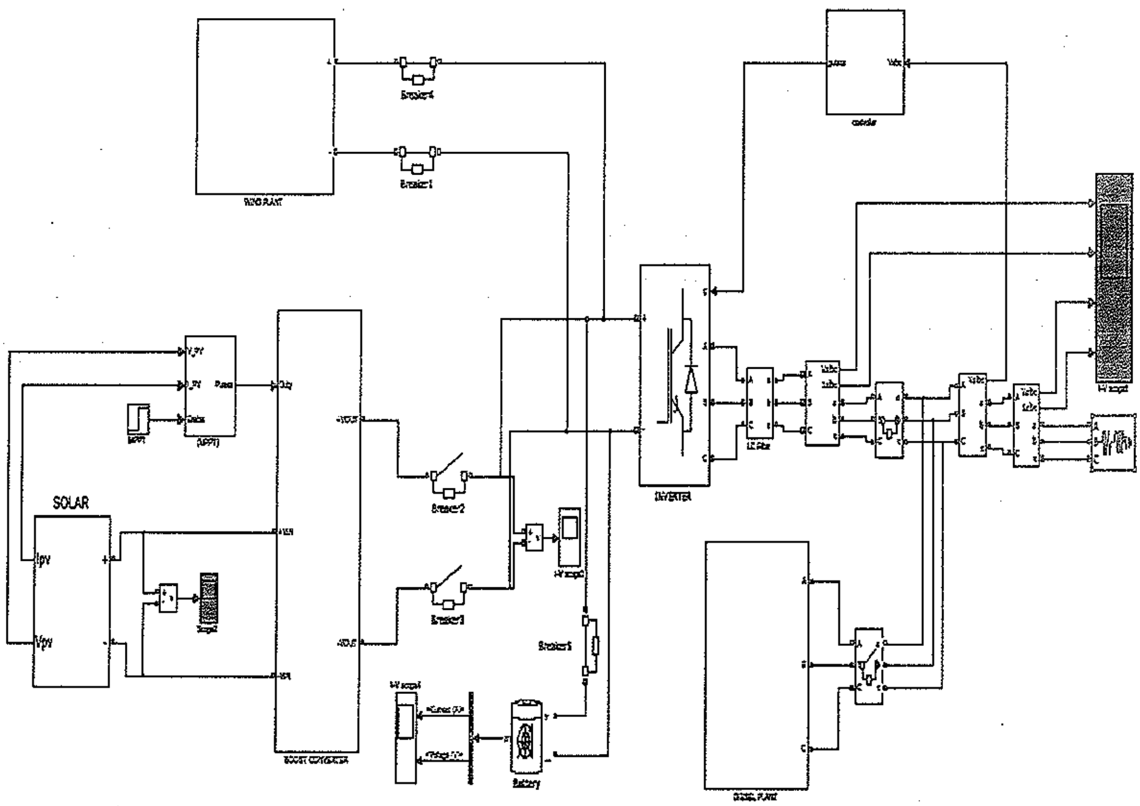

Figure 2. Simulink Model of a Hybrid System

The block diagram of the solar PV panel is as shown in "Fig.3". The inputs to the solar PV panel are temperature, solar irradiation, number of solar cells in series and number of solar cells in parallel. These models are simulated under standard test conditions, therefore the irradiance nominal value is set to 1000 W/m² and the temperature nominal value is set to 25°C. Since the unit of temperature for the system is Kelvin (K), a constant value of 273.15 is added to the Celsius temperature. The photovoltaic output voltage is the boost converter input. The inductance and the capacitor need to be specified. The MPPT controller is provided for obtaining the switching command of the transistor. In photovoltaic array, the voltage and current are the inputs, and the duty cycle is the output. The duty cycle is compared to a triangle wave signal for generating the PWM. The triangle wave frequency is the pulsation frequency of the boost converter. In the proposed model I used incremental conductance method for MPPT. When the instantaneous conductance equals the conductance of the solar then MPP is reached. MPPT controller is a fully electronic operated system which varies the electrical operating point of the modules so that the modules can able to deliver maximum available power. Harvested additional power from the modules is then made available as battery charge current is increased. MPPT controller is in conjunction with a mechanical tracking system, but the two systems are entirely different. The output pulses are the gate pulse for boost converter.

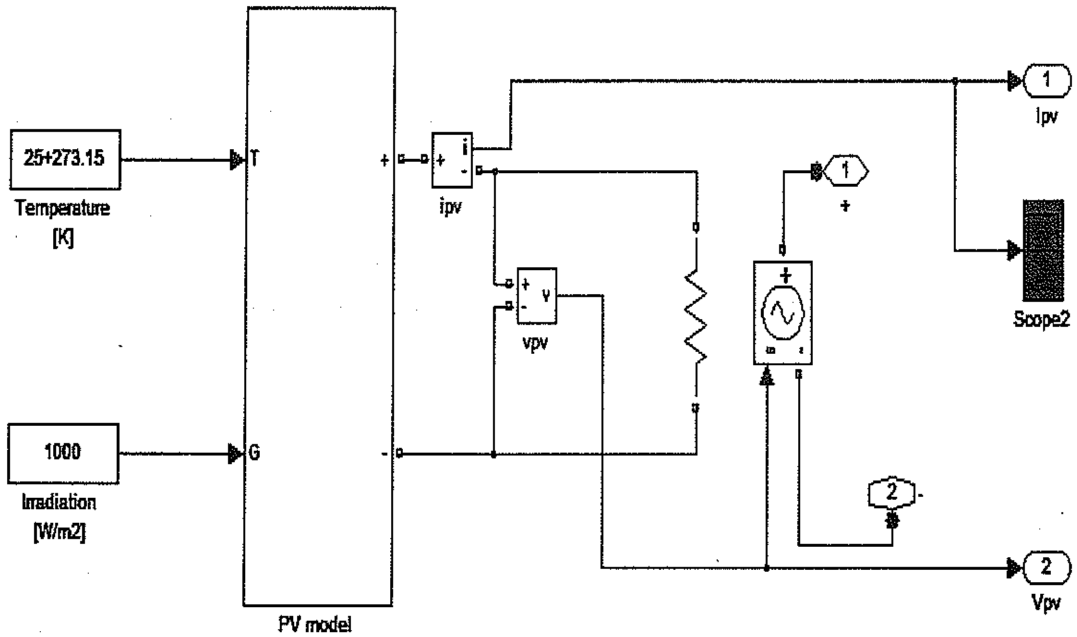

Figure.3. Simulink Model of PV System

The WT Power System consists of a WT model and a PMSG block. The proposed model of WT System is modeled according to the steady-state power characteristics of the turbine as shown in "Fig.4". The drive train stiffness is infinite and both the friction factor and inertia of the turbine must be added with the generator coupled to the turbine. The varying wind speed was the input into the WT. Mechanical torque produced by the WT will then directed to PMSG that converts mechanical energy from WT into electrical energy.

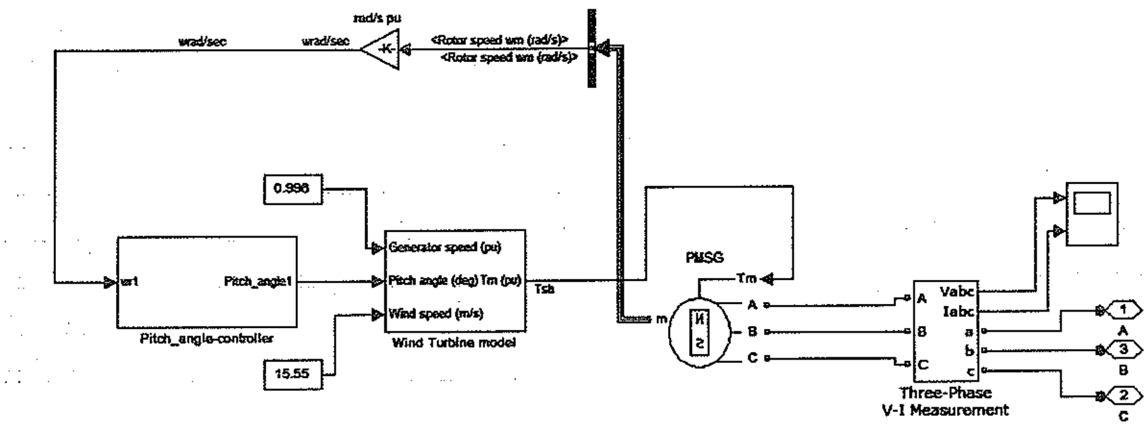

Figure 4. Simulink Model of WT System

The numerical modeling scheme used for the simulation of a DG in isolated regime has been presented in "Fig.5". The generator set, the electric load, the normally open switch, and the measurement blocks can be distinguished. The generator set block is composed of the diesel internal combustion engine and the synchronous generator models and the voltage and speed regulation systems.

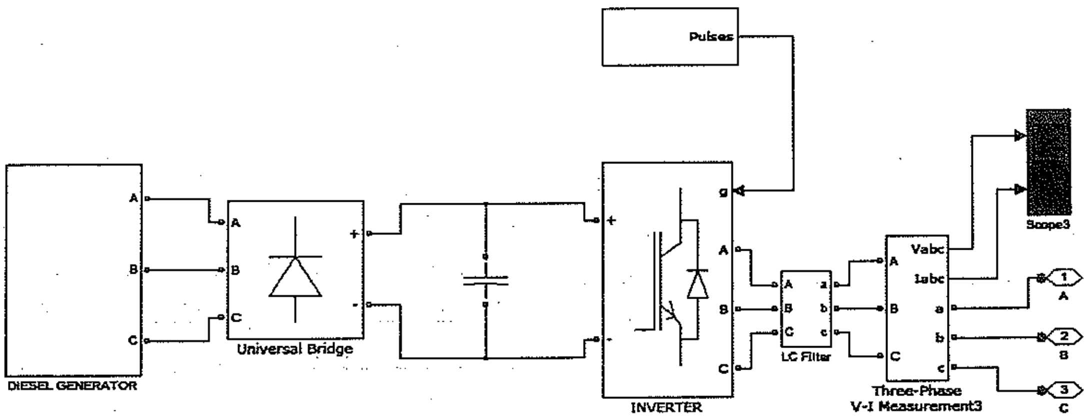

Figure 5. Simulink Model of DG System

VI. Simulation Results And Discussions

Initially (0 to 1 second) PV and WT is connected, battery is open circuited and after a second PV is open circuited. The WT & Battery (1 -2 seconds) will supply the required power to the load. During the photovoltaic model simulation, the temperature parameter was set at constant value 25°C and the irradiance parameter was set at 1000 W/m^2 respectively. The PV output voltage and current waveforms are shown in "Fig.6" and "Fig.7". The total output voltage from PV array is 242.4V, output current is 82.2A. So, total output power we are getting is around 20 KW.

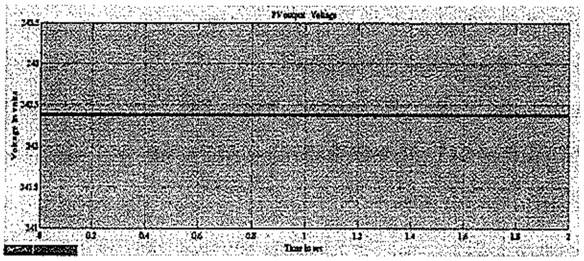

Figure 6. Output Voltage Waveform of PV Array

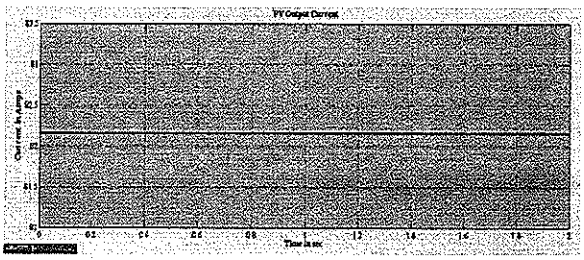

Figure.7. Output Current Waveform of PV Array

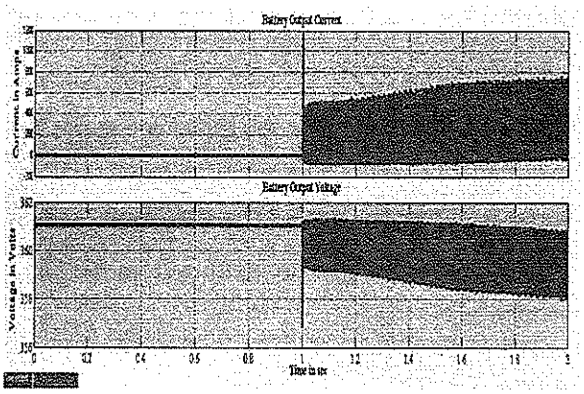

Figure 8. Output Voltage and Current Waveform of Battery

"Fig.8" shows the output current and voltage waveform of battery. Initially 0 to 1 second PV and WT give the required power to the load, the battery is in open circuit condition. So the battery current is zero, and battery voltage is 360V. After 1 sec WT and Battery are connected, the battery current is started to increase while battery voltage starts to decrease. "Fig.9" shows the output voltage and current waveform of PMSG in the 30KW WT system. The output AC voltage is 275V and output AC current is 100A. The hybrid system with battery will be operated in DC voltage. Therefore rectifier is needed to convert the AC voltage generated by the wind system into DC voltage. The rectified output voltage of WT is 360V.

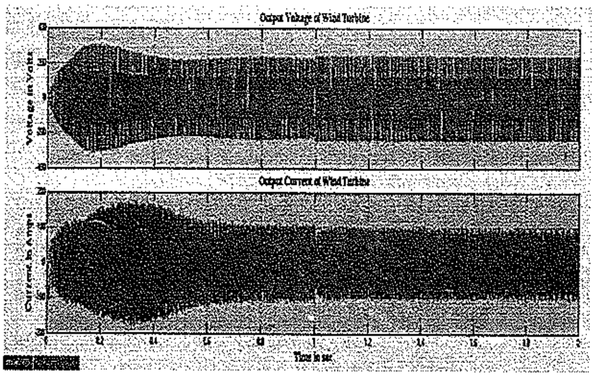

Figure 9. Output Voltage and Current waveforms of WT

"Fig.10" shows the inverted output voltage and current waveforms of PV/DC/battery. The output voltage of PV and battery is the input voltage to the inverter that is 360V. The output voltage of the inverter is 430V, current is 110A. The same output voltage and current we are getting from the DG / battery.

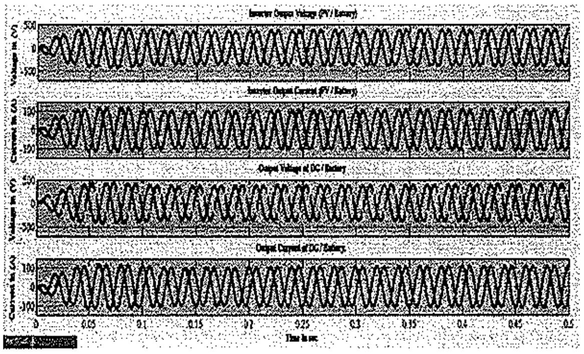

Figure10. Outputs Voltage & Current Waveforms of Inverter and Diesel Generator

The four combinations has been analyzed and summarized for electrical output as shown in TABLE VI. As load demand increases size of each renewable energy source also is increased, then grid contribution is decreased based on the renewable energy source combinations.

Table VI. Percentage cotribution of each renewable energy source with different combination

Combination	Grid	PV Array	Wind Turbine
Grid	100%	0%	0%
Grid + PV Array	33%	67%	0%
Grid + Wind Turbine	41%	0%	59%
Grid + PV Array + Wind Turbine	18%	49%	34%

VII. Conclusion

In proposed model of hybrid power system, emphasis has given to power the remote village by generating 50kW through the hybrid system which consists of PV, wind, battery and diesel generator. The hybrid grid can provide a reliable, high quality & more efficient power to the consumer. Simulation results show that hybrid system has greater reliability compare to standalone system because it is based on more than one type of electric generation source. When either anyone of the generation system is not operated with its full capacity due to inconsistent energy source, another system will operate and meet the extra load demand. In addition of this, the hybrid system can also be able to produce a higher output voltage compare to standalone system. MPPT technique is considered to maximize the efficiency of PV array system. The output current and voltage of the PV array can be used to compute the MPPT error. The output voltage generated by boost converter by SVPWM control technique. After analyzing the simulation, the main benefits of a proposed hybrid renewable power system model are as below:

- The possibility to join two or more renewable energy sources, based on the natural local potential of the users.
- Environmental protection especially in terms of CO_2 emissions reduction.
- Low cost – wind and also solar energy sources can be competitive with nuclear, thermal and gas energy sources especially considering possible future cost trends for fossil and nuclear energy.
- Diversity and security of supply. Rapid deployment - modular and quick to install.
- Fuel is abundant, free and inexhaustible.
- Costs of system are predictable and not influenced by price of fuel fluctuations although fluctuations in the price of batteries will be an influence where these are incorporated.

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