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Implementation of Hybrid Renewable Energy System for MPPT with Flyback Converter using PI Controller

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Abstract: Harnessing energy from alternative energy source has been recorded since early history. Renewable energy is abundantly found anywhere, free of cost and has non-polluting characteristics. However, these energy sources are based on the weather condition and possess inherited intermittent nature, which hinders stable power supply. Combining multiple renewable energy resources can be a possible solution to overcome defects, which not only provides reliable power but also leads to reduction in required storage capacity. Although an oversized hybrid system satisfies the load demand, it can be unnecessarily expensive. An undersized hybrid system is economical, but may not be able to meet the load demand. The optimal sizing of the renewable energy power system depends on the mathematical model of system components. This paper summarizes the mathematical modeling of various renewable energy system particularly PV, wind, hydro and storage devices. Because of the nonlinear power characteristics, wind and PV system require special techniques to extract maximum power by using PI controller. Hybrid system has complex control system due to integration of two (or more) different power sources. The complexity of system increases with maximum power point tracking (MPPT) techniques employed in their subsystems.

Keywords: PV, Wind Energy Conversion System, MPPT, PI Controller, Flyback Converter.

I. INTRODUCTION

At Present fossil fuels contribute as the world's major energy sources. The non-renewable nature of fossil fuel and increasing energy demand have made it scarcer than before and therefore its price is skyrocketing. On the other hand renewable energy such as wind and solar is omnipresent free and abundant in nature. Since the renewable energy technologies are improving, the electricity cost produced by renewable form is certainly going to decrease significantly in near future.1-3 Energy crisis, ever increasing oil prices, climate changes due to greenhouse gases and limitations imposed by Kyoto protocol in production of these gases have increased people's attention towards effective, efficient,4 sustainable and almost pollution free renewable energy systems.5 Even though renewable energy is novel, it is stochastic in nature. Its availability is sporadic and should be complemented by other power sources like batteries in most of cases.6-8 Due to intermittent nature of the renewable energy resources, system using single renewable energy source leads to oversized components and unnecessary operational and lifecycle cost.9 Two or more forms of energy resources can be combined to form a hybrid energy system that complements the drawbacks in each individual energy resources. Therefore, the design goals for hybrid power system are the minimization of power production cost, minimization of power purchase from grid (if it is connected to grid), reduction in emission, reduction of the total life cycle cost and increase in reliability of the power generation of system.2,10,11.

Integrated system of two or more renewable energy systems, also known as hybrid renewable energy system (HRES), is gaining popularity because the sources can complement each other to provide higher quality and more reliable power to customer than single source system.12,13 A HRES can be standalone or grid connected. Standalone systems need to have generation and storage capacity large enough to handle the load. In a grid connected system, the size of storage device can be relatively smaller because deficient power can be obtained from the grid. A grid connected HRES can supply electricity to both load. However, when connected to grid, proper power electronic controllers are required to control voltage, frequency, harmonic regulations, and load sharing. Based on the type of HRES, the operating mode of HRES can be classified into island mode where the generated electricity is consumed locally and grid connected mode where the renewable energy source is connected to the grid.12-14.

II. LITERATURE SURVEY

Diaf et al.15 proposed a hybrid PV-Wind system in which the AC power form the wind is directly supplied to the load via un-interruptible power supply (UPS). The excess power, if available, is used to charge the battery through an AC/DC converter. The power obtained from the PV is also used in charging the battery via a DC/DC converter. In case of peak load, power is supplied from battery to the load through a DC/ AC converter. Jeon et al.16 studied the characteristics of solar cell through various extreme environmental conditions.

Hashimito et al.17 discussed stand-alone wind-PV hybrid system with a secondary backup battery that ensures uninterruptable supply of electricity to a radio base station in an island. Their system consists of cylindrical PV modules mounted on wind generator pole to save installation space and cost. Relationship between system idle time and backup battery capacity was studied and battery bank was designed to bring the system idle time to zero. Sharaf and El-sayed18 discussed application of wind-PV hybrid system in a micro grid. Their system is consisted of a common DC and common AC collection bus interface. The system employs permanent magnet DC generator to convert the wind kinetic energy into DC power. The power obtained from PV, which is also DC, is connected to common DC bus.

Bakos19 performed the feasibility study of wind-pumped hydro storage system assisted by diesel generator in case of power shortage. The system is designed as a wind farm which supplies to the load first. Excess energy if available is used for pumping water from lower tank to the higher reservoir so that the excess energy is stored as hydro potential energy. When wind farm is incapable of covering the whole load, the hydro system is called into operation and energy is supplied from both wind and hydro. If further energy deficiency exists, then deficit power is supplied by the diesel generator. The water reservoir acts as an energy storage so it is designed based on energy autonomy days. Monte Carlo analysis considering the linear characteristic of wind energy system and undamaged hydro system has been performed to verify the feasibility. Bekele and Tedesse20 suggested a PV-hydro-wind hybrid system which can supply uninterrupted electricity for a village in Ethiopia. HOMER was used to optimize six small hydropower potentials together with wind PV systems. Due to the limitations of HOMER to handle more than one hydro resource at a time, optimization was performed by taking a nominal hydropower with total sum capacity of all small sites. Besides the primary purpose of lighting, they have considered electricity for cooking and running flour mills along with TVs and radio in their load calculation.

Ram Prabhakar and Ragavan14 discussed power management strategies in battery assisted PV-wind-hydro hybrid system. A control technique was developed, which estimates the load through energy balance model, DC-link voltage control and drop control. The system is capable of multi-mode operation i.e. wind-hydro-solar, wind-solar, hydro-solar, and wind-hydro owing to non-availability of any renewable energy resource. When weather is favorable, PV and wind are surplus. Then water is stored in reservoir for future use. The sequence of operation used in case of power scarcity is solar, wind, battery and hydro. Saheb-Koussa et al.21 presented results of techno-economic analysis of PV/wind/diesel hybrid system. For all the six sites they studied, they found out that stand alone PV is a better solution considering the economic aspects. But there would be deficit during the winter season, and using a hybrid system overcome this effect. Their study suggested that hybrid system would be reliable but is not economic. Fadaeenejad et al.22 studied PV-wind-battery hybrid and PV-wind-diesel-battery hybrid with aim of rural electrification in Malaysia. For optimization of HRES iHOGA software developed by Dr. Rodolfo, Dufo-Lopez has been used. This study suggested PV-wind-battery hybrid as a better option.

In a similar analysis, Goodbody et al.23 performed the study on integration of renewable energy systems in Ireland. System optimization was carried using HOMER, diurnal and seasonal variation of load was taken into consideration for optimization. This study has also considered space heating in the application of HRES and cost of fuel to do so, but the capital, maintenance or replacement cost is not taken into account due to limitations of HOMER. Ireland has high wind potential so wind energy was found to feature in most of stand-alone or grid connected hybrid systems. Biogas harvesting with large bio-digester was suggested to be cost-efficient for large community. Even though some regions simulated contains hydropower in the optimal design, the installation was found to be difficult in those regions because of the geographical constraints. Akikur et al.[24] carried a study on standalone solar and hybrid systems. Solar-wind hybrid, solar-hydro hybrid, solar-wind-diesel hybrid and solar-wind-diesel-hydro/biogas hybrid have been discussed, and viability and significance of solar energy (both in standalone and hybrid form) in global electrification have been shown in this study.

Djamel and Abdallah[25] discussed power quality control of grid connected wind-solar hybrid system that employs a battery connected in the common DC bus. Though the system is said to be grid connected much has not been discussed. A fixed speed wind turbine has been employed so power control on high wind speed has been done by stall control. Power control in PV has been done by employing MPPT tracking that uses perturb and observe (P&O) method. Meshram et al.[26] proposed a hypothetical grid connected solar-hydro hybrid system. As solar energy is abundant in summer, grid connected solar system supplies the power while hydro system is cutoff during operation. Similarly during rainy season when water is abundant, grid connected hydro system is brought in operation and solar system is cut off. During other season the system operates in hybrid mode. The proposed system has 10kW solar capacity and 7.5 kW hydro capacity. 11 kV AC line is used to transmit the electricity form production site; it is then connected to 132 kV, 2500 MNA grid line through step down transformer, before supplying to customer supply; it is stepped down to 415 V for household usage. Ismail et al. performed a feasibility study and techno-economic analysis of a PV system with batteries and micro turbine- micro turbine acting as backup supply in the system. Component sizing and optimization have been performed by iterative method to minimize cost of energy (COE) production. Comparison of standalone PV, micro turbine and hybrid system is also performed in this study.

The study found that COE of standalone micro turbine was cheaper with very small difference. Sensitivity analysis of the system has also been performed by considering project life time, cost of natural gas, PV panels, battery bank, bidirectional inverter and charge regulator. The sensitivity analysis result showed hybrid system as the better alternative.

In similar study Daud and Ismail[28] designed and analyzed a PV-wind-diesel hybrid system for a family house in Palestine considering efficiency, reliability along with the dumped electric power. A software that is capable of changing the variable of hybrid energy system was developed to perform the analysis. High quantity of dump energy was found during the simulation because the system is designed for the worst case. In order to utilize the dump energy power supply to street light, water pumping has been suggested. Economic analysis of this system in terms of COE hybrid system lags behind purchasing grid electricity. The study concludes that if remote location, subsidy levels, cost of renewable energy equipment and environmental effects are taken into account then hybrid systems justify their use. In another study, the same authors[29] analyzed PV-battery-diesel hybrid system which concluded the hybrid system as best alternative when the diesel generator is used as backup source. Kalantar and Mousavi[5] also performed similar kind of study and proposed wind-solar-micro turbine-battery hybrid system. In their system the micro-turbine and battery act as a backup power supply during energy deficiency.

Menshsari et al.[30] discussed the optimization of hydro-wind-solar-fuel cell hybrid using ant colony algorithm. PV, wind and electrolyzer are connected through a common DC bus which in turn is connected to AC bus via DC/AC transducer. The hydroelectric generator is also connected to the AC bus which is then used to supply to the load. System reliability was also evaluated using loss of power supply probability (LPSP). This system has been optimized for cost and reliability. On different application of hybrid systems, Vitali and Ricci installed the solar wind hybrid system for street lighting system that employs 3 Savonius rotors along with PV panels placed at the top of the lamp post. Two different types of rotors; a 2 stage (90 degree staggered) straight rotor and helical rotor with 105^o maximum section rotation were tested. Helical rotor was found to have better performance with coefficient of performance, C_p values reaching maximum of 0.21. A hybrid controller that can cut-out during high speed and low speed conditions, disconnect load at low battery condition and switch off renewable energy source when the battery is fully charged is also employed in this system.

Saha et al. proposed a hypothetical hybrid system that employed wind-solar-biogas-micro hydro hybrid as major energy sources and also used diesel generator as emergency backup source. Micro hydro was modeled to supply constant base load while peak power was supplied by solar, wind biomass, and diesel generator. Biogas gives freedom to control the output power thus it helps in balancing the energy deficit from solar-wind and reduces output fluctuation. The optimum combination of weather dependent non-conventional energy sources- solar and wind, and weather independent energy source like biomass and hydro will completely eliminate the weather dependency of the renewable energy source and also ensures least cost of production. The power production cost form hydro is the least so designing it to supply for the base load significantly decreases the cost of production of electricity. The sequence of operation of these power sources in case of power deficiency is: hydro, wind, PV, battery, biogas and diesel engine. Hour by hour analysis of the proposed system has been simulated in MATLAB though the analysis does not consider the synchronization of the different power system.

Suha Yazici et al. proposed PV/wind/fuel cell hybrid power system for powering amenities in a recreational vehicle (RV) with studio type living facilities called as H_2EkoKaravan. Wind and solar are the primary energy sources of the system which supplies to load and charge batteries. Excess energy, if available, would be used for electrolysis of water which can be used to power the fuel cell or can be burnt as fuel in hydrogen cooker. In case of power deficiency following hierarchy is used for power supply: solar, wind, battery and fuel cell. The system has been designed for three days of autonomy. Vertical axis control and MPP tracking has also been employed in the solar panel. PV panel positions automatically according to GPS date and time data. Component sizing is done by using a software called HOGA which considers daily load profile, solar and wind data, equipment options, price, and control strategy. The usability of this vehicle has been displayed as a mobile medical center for remote areas, as an emergency response vehicle, relief co-ordination hub or communication center when grid power is unavailable. Bhandari et al. proposed two tri-hybridization processes and implemented one of the process for rural electrification. The tri-hybrid system includes hydro-wind and PV systems.

III. MATHEMATICAL MODELING

A hybrid energy system might consist of various renewable energy conversion component like wind turbine, PV array and hydro turbines as well as conventional non-renewable generators like diesel generators, micro turbine and storage device like battery. A hybrid energy system might have all or part of it. In order to correctly select the components and subsystems for optimal sizing of the entire system, the first step is the modeling of individual components. Modeling process enables to identify and assists in knowing the components' characteristics and supports in decision making. The details of modeling is reflected by its correct prediction of performance, however it is too complex or extremely time consuming to design a perfect model. A sufficiently appropriate model should be tradeoff between complexity and accuracy. Performance of individual component is either modeled by deterministic or probabilistic approaches.[35] General methodology for modeling energy system is described below:

A. PV System

PV Potential Assessment: Power output of a PV array is based on solar irradiance and ambient temperature. The power output in this model is calculated as[15]

$$P_{PV} = \eta_{Pvg} A_{Pvg} G_t \quad (1)$$

Where η_{pvg} is PV generation efficiency, A_{pvg} is PV generator area (m^2), and G_t is solar irradiation in tilted module plane (W/m^2). η_{pvg} is further defined as,

$$\eta_{Pvg} = \eta r \eta_{PC}[1 - \beta(T_C - T_C ref) \quad (2)$$

Where η_{PC} is power conditioning efficiency which is equal to one when MPPT is used, and β is temperature coefficient

((0.004-0.006) per°C), and η_r is the reference mode efficiency, and T_{emf} is reference cell temperature in°C. Reference temperature (T_{ref}) can be obtained by relation

$$T_C = T_a + \left(\frac{NOCT-20}{800}\right)G_t \quad (3)$$

where T_a is ambient temperature in °C, NOCT is nominal operating cell temperature in °C, and G_t is solar irradiation in tiled module plane W/m^2. The total radiation in the solar cell considering normal and diffuse solar radiation can be estimated as[36]

$$I_T = I_b R_b + I_d R_d + (I_d + I_d) R_r \quad (4)$$

B. Wind Power System

Wind Potential Assessment: The fundamental equation governing the mechanical power of the wind turbine is given by

$$P_W = \frac{1}{2} C_P(\lambda, \beta)\rho A V^3 \quad (5)$$

Where ρ is air density (kg/m^3), C_P is power coefficient, A intercepting area of the rotor blades (m^2), V is average wind speed (m/s), λ is tip speed ratio. The theoretical maximum value of the power coefficient C_P is 0.593, also known as Betz's coefficient.

The tip Speed Ratio (TSR) for wind turbine is defined as the ratio or rotational speed of the tip of a blade to the wind velocity. Mathematically,

$$\lambda = \frac{R\omega}{V} \quad (6)$$

Where R is radius of turbine (m), is angular speed (rad/s), V is average wind speed (m/s).

The energy generated by wind can be obtained by

$$Q_w = P \times (Time)\,[kWh] \quad (7)$$

Sometimes because of various factors the velocity of wind at any particular height cannot be obtained by direct measurement. In that case the data at any reference height can be interpolated or extrapolated to find the wind speed at any particular height. The wind velocity is measured at a lower height can be error prone due to vegetation, shading and obstacles in the vicinity.[20]

$$v(z)\ln\left(\frac{Z_r}{Z_0}\right) = v(Z_r)\ln\left(\frac{Z}{Z_0}\right) \quad (8)$$

Where Z_r is reference height (m), Z is the height where wind speed is to be determined, Z_0 is the measure of surface roughness (0.1-0.25 for crop land), v(z) is wind speed at height z (m/s), and $v(z_r)$ is wind speed at reference height z (m/s).

Cut-in speed is a very low wind speed at which the turbine first starts to rotate and generate power. Cut-out speed is the high wind speed at which the forces on the turbine structure are high as a result there is a risk of the damage to the rotor. To prevent damage, braking system is employed to bring the rotor to stand-still. Rated output speed is the wind speed between cut-in speed and cut-out speed where the power output reaches the maximum limit that the electrical generator is capable of and is called rated power output. The power output in terms of wind speed can be estimated using,

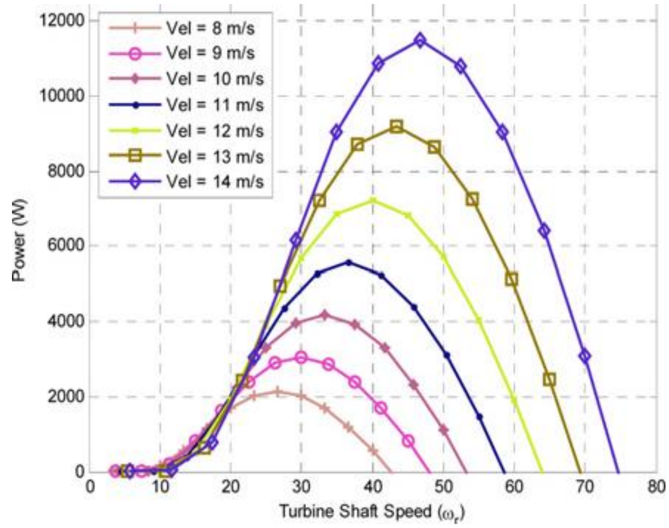

Fig.1. Wind Turbine power curve.

$$P_w(v) = \begin{cases} \frac{v^k - v_C^k}{v_R^k - v_C^k} \cdot P_R & v_C \le v \le v_R \\ P_R & v_R \le v \le v_F \\ 0 & v \le v_C \text{ and } v \ge v_F \end{cases} \quad (9)$$

Where P_R is rated power, v_C is cut-in wind speed, v_R is rated wind speed, v_F is rated cut-out speed, and k is the Weibull shape factor. Kalantar and Mousavi[5] used value of k as 1 while Daif et al.[15] and Yang et al.[44] used the value of k as 2, Chedid et al. Took the value as 3.

For the fixed size of rotor blade, and the power generation changes V is with change in wind velocity as shown in Fig. 1. So, with the change in wind velocity the optimum generator speed corresponding to max power should be determined for the changed velocity. The angular speed of generator must be changed in order to extract the maximum power, and this process is known as maximum power point tracking (MPPT). The next section is dedicated for MPPT. When the blade pitch angle is zero, the power coefficient is maximized for an optimum TSR.[5]

The optimum rotor speed is given by:

$$\omega_{opt} = \frac{\lambda_{opt}}{R} V_{wn} \quad (10)$$

Which gives

$$V_{wn} = \frac{R\omega_{opt}}{\lambda_{opt}} \quad (11)$$

Where ω_{opt} is optimum rotor angular speed in rad/s, λ_{opt} is optimum tip speed ratio, R is radius of turbine in meters and V_{wn} is wind speed in m/s.

C. Hybrid Power System

The first step in hydro modeling is to calculate the flow rate. The flow rate can be calculated if the catchment area of river is known in addition to the rainfall data (monthly, daily, and hourly). Catchment areas are the areas from which rain water flows into the river. The above procedure is for run off river type of hydro system. The hydro potential of a site is given by

$$Q_{site} = K \left[\frac{A_{site}}{A_{gauge}}\right] Q_{gauge} \quad (12)$$

Where A_{site} is catchment area of power plant (m^2), A_{gauge} is catchment area of gauge (m^2), Q_{site} is discharge at site (m^3/s), Q_{gauge} is discharge at gauge (m^3/s), and K is scaling constant or function.

The mechanical power generated by the turbine is given by

$$P = \eta_{total} \rho g Q H \quad (13)$$

Where P is mechanical power output produced at the turbine, η_{total} hydraulic efficiency of the turbine, ρ is density of water (1000 kg/m^3), g is acceleration due to gravity (9.81 m/s^2), and H is effective pressure head (m).

IV. MPPT TRACKING

When it comes to power control, solar and wind show a special feature; unlike other power systems power generation cannot be controlled by controlling the fuel inflow rate or the amount of energy applied to the generator thus solar and wind demand for a special control system. The amount of energy that can be extracted from the wind does not only depend upon the wind speed but is mainly governed by tip speed ratio (TSR). In order to extract maximum energy from wind in a varying speed condition the rotational speed should be varied to maintain optimal value of TSR all the time. In the similar way, the power generated by solar array depends upon insolation and temperature. The voltage-current relation and voltage-power relation are non-linear. Maximum power point (MPP) should be tracked for efficient extraction of solar energy in PV system during varying insolation conditions. Maximum power from a wind-PV hybrid system can be extracted when maximum power point tracking (MPPT) is done on each of them. Since the variable for MPPT of wind and PV system is different, individual tracking system should be implemented for each system. Maximum power point tracking (MPPT) not only maximizes the system's efficiency but also minimizes the return period of the installation cost.

A. MPPT Tracking In Wind

Wind turbine can operate in two different modes: fixed speed and variable speed. Fixed speed turbine generator can be directly connected to grid or load while in a variable speed turbine power electronic device are used to convert variable frequency, variable power to constant frequency and power. The use of variable speed wind turbine has made possible to continuously adapt the rotational speed of the wind turbine relative to wind speed in a way the turbine operates at higher efficiency and decreases power fluctuations. Annual production increases by 5-10% in a variable speed turbine compared with in a fixed turbine. Maximum power point can be captured in a varying wind speed by keeping the tip ratio in its optimal value in a variable speed generation system. Maximum power output of the wind turbine is difficult to maintain at all wind speed conditions due to nonlinear characteristics of the wind turbine. So, there are various control strategies to track the maximum power of the wind turbine systems. Some techniques track maximum power by observing the change in power produced while some techniques need mechanical sensors that measure the wind speed to calculate the value of generator speed that forces it to operate in maximum power point thus they are sensitive to modeling uncertainties and become insensitive in some cases.

B. MPPT Tracking in PV System

The characteristic of solar cell is dependent upon the insolation, temperature and array voltage. Thus it is necessary to implement MPPT in order to move the operating voltage close to maximum power point under changing atmospheric conditions. MPPT in solar is important because it reduces the solar array cost by decreasing the number of solar panels needed to obtain the desired output. The output characteristic of PV array is shown in Fig 2. It shows MPP tracking during varying weather condition.

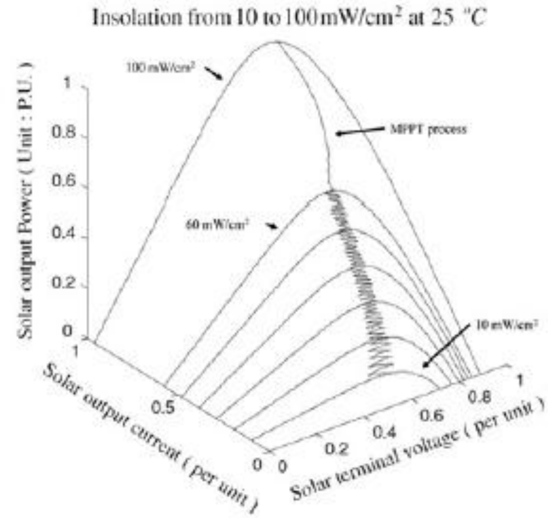

Fig.2. Maximum power tracking when insolation changes.

V. BATTERY MODELING

Batteries have a significant role in off grid HRES and have large share in initial cost. Batteries are used as a backup option to store the power when the power production excesses the demand. The supply from the battery is needed during peak hours when power demand is higher than the production. In some model of HRES batteries are used as a storage buffer, and all the electricity is supplied through battery. Batteries used in RES have different performance characteristics compared with batteries used in traditional application and in electric vehicles. Because of the stochastic nature of the renewable energy resources the battery may experience frequent deep cycles and irregular charging patterns. Also due to seasonal variations the battery may experience a low state of charge (SOC) for extended period. This inconsistency in charging and discharging causes decrease in the battery life. The diminished battery life causes significant impact in the overall life cycle cost of the HRES. If we consider a standalone PV system batteries can account for more than 40% of the life cycle cost. This can give us an idea on the share of the battery in the total life cycle cost. Increasing the lifecycle of the battery will result in the significant improvement in reliability and decrease in the lifecycle cost. Battery's lifetime depends upon the rate of energy consumption from the system. The easiest way is to increase the battery life could be decreasing the battery consumption rate – which is not always practical in case of HRES. During the period of high consumption the effective capacity of battery degrades and therefore decreases the life. During period without energy consumptions the battery can recover some of its lost capacity so the life is lengthened.

VI. SIMULATION AND RESULTS

A. Operation of Hybrid Energy System

The dynamic interaction between the power electronics interface of renewable energy sources leads to problems of stability and power quality in the system, which makes HES control difficult and complex. A hybrid energy system can be standalone or grid connected. Standalone systems need to have generation and storage large enough to handle the load while in a grid connected system the storage device can be relatively smaller as deficient power can be obtained from the grid. A grid connected hybrid can supply electricity to both load and the utility grid. However, when connected to grid, proper power electronic controllers are required to control voltage, frequency and harmonic regulations, and load sharing. The performance analysis of HES can only be evaluated after performance analysis of individual system. MPPT tracking is to be done for individual subsystems as found in literature. During operation hybrid wind-solar system is subjected to fluctuating wind speeds and solar insolation as well as to varying load demand. Hence a controller is essential to determine how much energy is available from each component and how much to use of it.

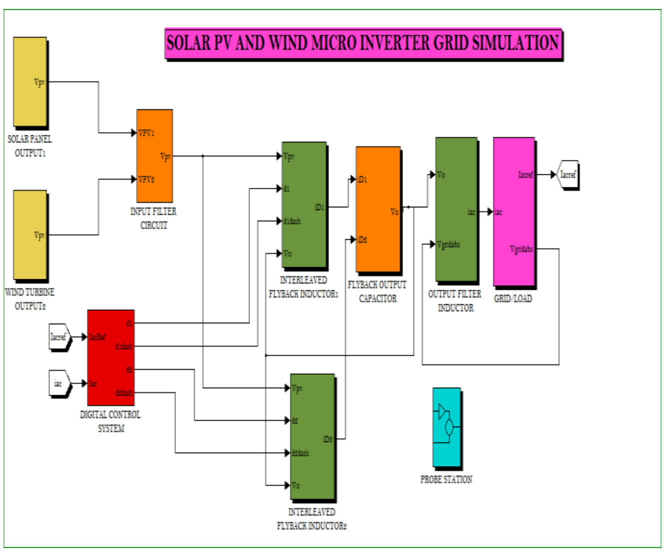

Fig.3. Simulation circuit of Hybrid Renewable Energy System.

The operation policy for autonomous wind-solar hybrid system should employ the available energy from the wind turbine and solar panel in each sub period to use first and excess energy to be stored in batteries. If the renewable energy is not sufficient to supply the load in a given sub period then energy is drawn from battery storage first and then through diesel generator (if available). In case of systems where diesel generators are available, batteries act as fuel saver as batteries are used prior to diesel engine. The operation policy in case of grid connected hybrid system should exploit renewable energy first and excess energy if available should be stored in batteries. However if excess energy is not sufficient to supply the load in a given sub period then batteries should be employed first and grid electricity should be used if deficiency still exists. The battery in grid connected system store the surplus power from power generation system, so only small power from the grid is needed. The simulation circuit as well the outputs are as shown in Fig.3and the output grid current and current reference can be shown in Figs.4 and 5.

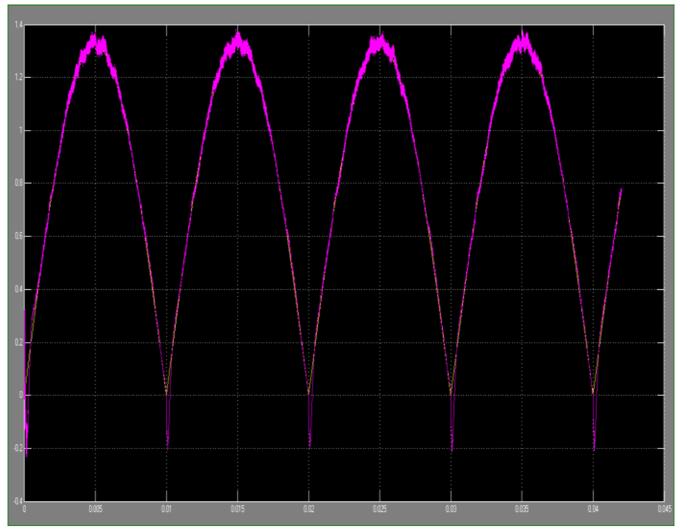

Fig.4. The output grid current and the reference current.

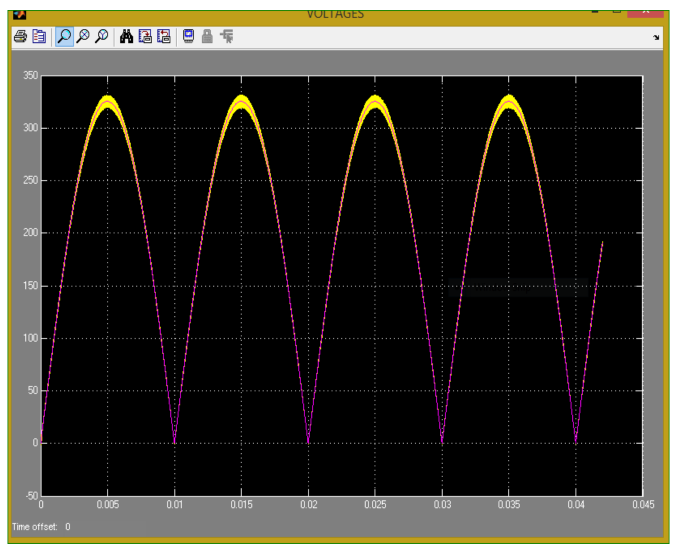

Fig.5. Output voltage waveform.

VII. CONCLUSION

Approximately one-fifth of the global populations are living without electricity in the world. In developing countries of Asia, it is estimated that almost one third of total population are deprived of electricity. An alternative to the grid connected power is the renewable energy based off-grid power system. Focusing on the top most used renewable energy sources, we have presented simulation modeling of hybrid renewable power systems. Non-linear characteristics of wind power system and PV system such as power, voltage and current are summarized for maximum power point tracking.

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