

Modeling and Simulation of Hybrid Wind Solar Energy System using MPPT

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Abstract: The proposed system presents power-control strategies of a grid-connected hybrid generation system with versatile power transfer. This hybrid system allows maximum utilization of freely available renewable energy sources like wind and photovoltaic energies. For this, an adaptive MPPT algorithm along with standard perturb and observes method will be used for the system. Also, this configuration allows the two sources to supply the load separately or simultaneously depending on the availability of the energy sources. The turbine rotor speed is the main determinant of mechanical output from wind energy and Solar cell operating voltage in the case of output power from solar energy. Permanent Magnet Synchronous Generator is coupled with wind turbine for attaining wind energy conversion system. The inverter converts the DC output from non-conventional energy into useful AC power for the connected load. This hybrid system operates under normal conditions which include normal room temperature in the case of solar energy and normal wind speed at plain area in the case of wind energy. The simulation results are presented to illustrate the operating principle, feasibility and reliability of this proposed system.

Keywords: Hybrid Generation System, Battery Energy Storage.

I. INTRODUCTION

With increasing concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations. Other than hydro power, wind and photovoltaic energy holds the most potential to meet our energy demands. Alone, wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable. However, by combining these two intermittent sources and by incorporating maximum power point tracking (MPPT) algorithms, the system's power transfer efficiency and reliability can be improved significantly. The integration of renewable energy sources and energy-storage systems has been one of the new trends in power-electronic technology. The increasing number of renewable energy sources and distributed generators requires new strategies for their operations in order to maintain or improve the power-supply stability and quality. Combining multiple renewable resources via a common dc bus of a power converter has been prevalent because of convenience in integrated monitoring and control and consistency in the structure of controllers as compared with a common ac type. Dynamic performance of a wind and solar system is analyzed. There are some previous works on hybrid systems comprising of wind energy, photovoltaic and fuel cell have been discussed in [1]-[8]. All the energy sources are modeled using MATLAB software tool to analyze their behavior. A simple control method tracks the maximum power from the wind/solar energy source to achieve much higher generating capacity factors. The simulation results prove the feasibility and reliability of this proposed system.

II. PROPOSED HYBRID ENERGY SYSTEM

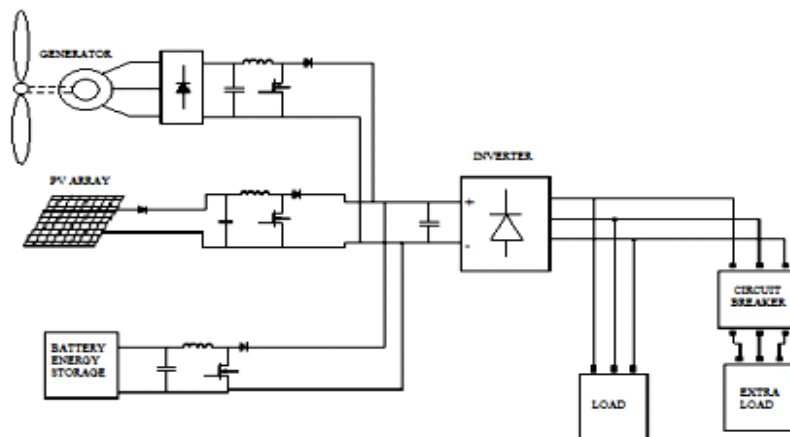


Figure 1: Configuration of Hybrid Energy System

The wind turbine captures the wind's kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The equation describes the mechanical power captured from wind by a wind turbine [4] can be formulated as:

$$P_m = 0.5 \rho A C_p v^3$$

The theoretical maximum value of the power coefficient is 0.59. It is dependent on two variables, the tip speed ratio (TSR) and the pitch angle. The pitch angle refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis. *TSR* is defined as the linear speed of the rotor to the wind speed.

Fig.2 shows a typical "*C_p* Vs. λ " curve for a wind turbine. In practical designs, the maximum achievable ranges *P* from 0.4 to 0.5 for high speed turbines and 0.2 to 0.4 for slow speed turbines. Fig.2 shows that has its maximum value (*C_{pmax}*) at λ_{opt} . Which results in optimum efficiency and maximum power is captured from wind by the turbine.

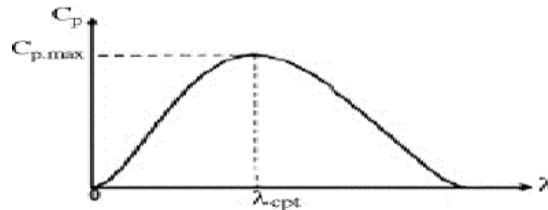


Figure 2: Power coefficient Vs Tip Speed Ratio

A solar cell is the most fundamental component of a photovoltaic (PV) system. The PV array is constructed by many series or parallel connected solar cells to obtain required current, voltage and high power [8]. Each Solar cell is similar to a diode with a p-n junction formed by semiconductor material. When the junction absorbs light, it can produce currents by the photovoltaic effect. The output power characteristic curves for the PV array at an insolation are shown in Fig. 3. It can be seen that a maximum power point exists on each output power characteristic curve. The Fig. 4 shows the (I-V) and (P-V) characteristics of the PV array at different solar intensities. The equivalent circuit of a solar cell is the current source in parallel with a diode of a forward bias. The output terminals of the circuit are connected to the load. The current equation of the solar cell is given by:

$$I = I_{ph} - I_D - I_{sh}$$

$$I = I_{ph} - I_0 \left[\exp\left(\frac{qV_D}{nkT}\right) \right] - \frac{V_D}{R_{sh}}$$

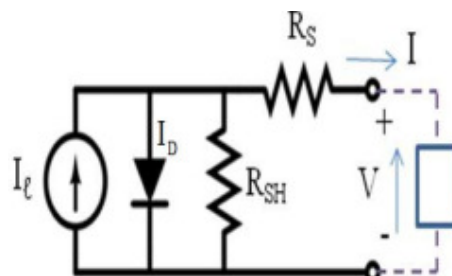


Figure 3: Equivalent circuit of PV Module

The power output of a solar cell is given by $P = V * I$

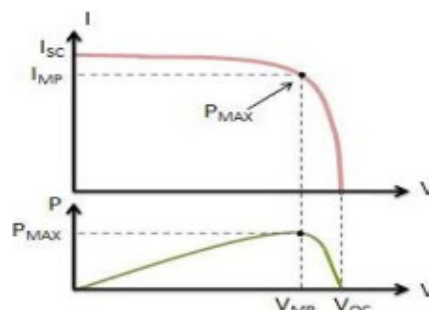


Figure 4: Output characteristics of PV Array

A. Battery Energy Storage

Battery energy storage system (BESS) includes batteries, control system and power electronic devices for conversion between alternating and direct current. The batteries convert electrical energy into chemical energy for storage. Batteries are charged and discharged using DC power, regulates the flow of power between batteries and the energy systems is done by a bi-directional power electronic devices. Different types of batteries have various advantages and disadvantages in terms of power and energy capabilities, size, weight, and cost. The main types of battery energy storage technologies are: Lead-Acid, Nickel Cadmium, Sodium Sulfur, Nickel Metal Hydride and Lithium-Ion. Lead-Acid batteries, achieve high discharge rates by using deep-cycle batteries. Low energy density, non-environment friendly electrolyte and a relatively limited life-cycle are the limiting factors to its dominant use in urban renewable energy systems [14]. Overall, with low maintenance requirements, relatively low self-discharge rates, Lead-Acid batteries offer a competitive solution for energy storage applications. Sodium Sulfur batteries have high energy density, high efficiency of charge/discharge and long cycle life. Nickel Cadmium (NiCd) batteries achieve higher energy density, longer cycle life and low maintenance requirements than the Lead-Acid batteries. But, which include the toxic-heaviness of cadmium and higher self-discharge rates than Lead-Acid batteries. Also, NiCd batteries may cost up to ten times more than a Lead-Acid battery [15], making it a very costly alternative. Nickel Metal Hydride (NiMH) is compact batteries and provides lightweight used in hybrid electric vehicles and tele-communication applications.

According to [16], NiMH batteries can substitute NiCd batteries in communications. They also provide equivalent cycle life characteristics, are environmentally friendly and can provide for an additional capacity ranging from 25 to 40% [16]. Lithium-Ion technology has the highest energy density amongst all types of batteries [17]. They are currently used in cellular phones, computers, etc. and development of this technology is used in distributed energy storage applications. But, high cost [17] and limited applications of technology. With the high rate of progress in development of lithium-ion technology, it has dominated the electronics market. Because of the sizes it is used in small, medium and large scale renewable energy systems. During coupled operation, Changes in the wind and solar PV generation output will cause an immediate change in the BESS output and BESS must neutralize by quick changes in output power. Rate variation control (or ramp rate control) and it is applied for smoothing real power fluctuations from an associated coupled system. Allowable ramp rates are typically specified by the utility in kilowatts per minute (kW/min), and are a common feature of wind and solar power purchase agreements between utilities and independent power producers. The information is processed by the Battery Energy System controller estimates the state of charge (SOC) of each battery cell and capacity of each battery cell, and protects all the cells operate in the designed SOC range.

The technical and economic advantages of energy storage systems on a smaller scale are as follows:

- Greater use of generally cleaner and more efficient energy sources.
- Improvement of reliability and quality of electricity supply.
- Provision of backup power for critical loads.

B. Maximum Power Point Tracking

Maximum power point tracking technique is used to improve the efficiency of both the solar panel and wind turbine and they adjusted to operate at their point of maximum power. There are different techniques for maximum power point tracking (MPPT) methods have been developed and implemented. Few of the most popular techniques are: Perturb and Observe (hill climbing method), Incremental Conductance method, Fractional short circuit current, Fractional open circuit voltage, Neural networks, Fuzzy logic. The MPPT Technique depends on the initial reference rotor speed for the wind turbine and an initial reference voltage for the photovoltaic array. The corresponding output powers of the two systems are measured. If this power does not correspond to their maximum powers, then their initial reference values are incremented or decremented by one step. If this adjustment leads to an increase in their output powers then the next adjustment is made in the same direction and vice-versa. The above steps are repeated till the maximum power points of the wind turbine and photovoltaic array are reached. Fig. 4 shows the characteristic power curve for a PV array. The problem considered by MPPT techniques is to automatically find the voltage V_{MP} or current I at which a PV array should operate to obtain the maximum power output P_{MP} under a given temperature and irradiance.

III. SIMULATION RESULTS

Simulation study was carried out to analyze the dynamic performance of the proposed hybrid energy system design with the complete system is simulated using SIMULINK software. A 10-kW wind/PV/BESS hybrid system was considered. The system parameters used in the simulation study are presented below.

All the three energy sources are accurately modeled in SIMULINK so as to predict their actual characteristics.

A. Simulated Graphs

- The load demand to fulfill is 10 KW throughout the time scale except at 4 to 5 sec when it increases to 14 KW.
 - Solar energy drops its irradiance to 15 % from 2 sec.
 - Wind turbine initially rotating at 5m/s excels to base speed 12m/s after 0.5 sec. It's rotating speed is decreased to 25 % of its base speed.
 - All these conditions are clearly observed in the below graph.
- The Maximum Voltage of PV Array is observed at around 640 V. the curve below explains that the varying irradiance is the deciding factor of the maximum voltage derived.

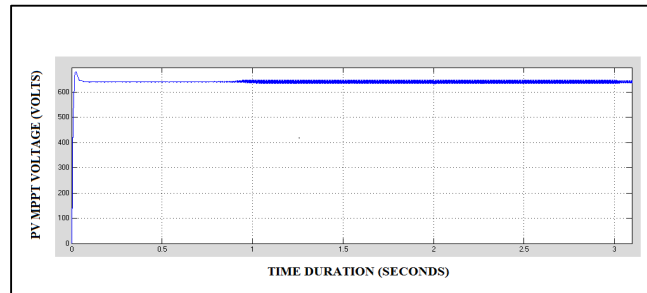


Figure 5: Phase Voltage observed at the PV array

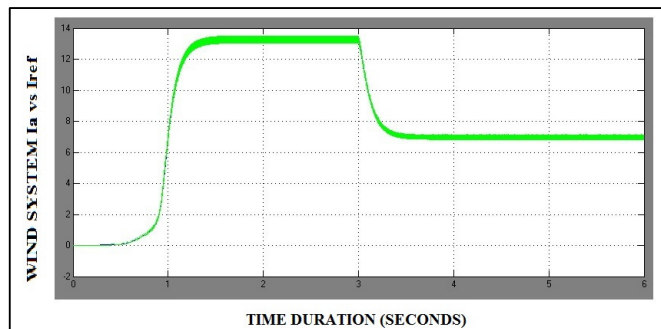


Figure 6: The relative variation curve of Actual Current (I_a) and Reference Current (I_{ref})

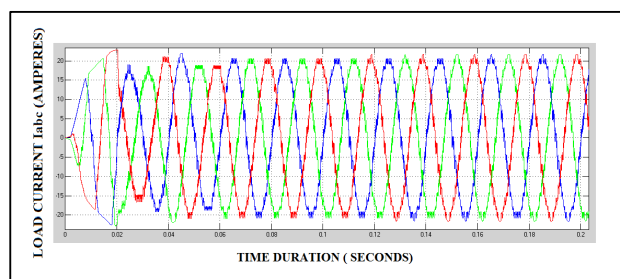


Figure 7: The load current supplied to the load is sinusoidal in nature as depicted in the simulation

IV. CONCLUSION

In the thesis load demand is met from the combination of PV array, wind turbine and the battery. An inverter is used to convert output from solar & wind systems into AC power output. Circuit Breaker is used to connect an additional load of 5 KW in the given time. This hybrid system is controlled to give maximum output power under all operating conditions to meet the load. Either wind or solar system is supported by the battery to meet the load. Also, simultaneous operation of wind and solar system is supported by battery for the same load.

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