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Operation and Control Strategy of Wind/Photovoltaic System with Battery Storage using Neural Networks

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ABSTRACT

This paper presents the design and operation of the multisource hybrid wind-photovoltaic system with energy management strategy using Neural Networks. Unlike conventional generation, the wind and sunrays are available at no cost and generate electricity pollution free and also it requires very low maintenance. The proposed energy management strategy was simulated in MATLAB/Simulink with the Neural Network controller. The optimal transfers of power from the sources are based on power, voltage and current control was done in order to regulate the DC bus voltage to a fixed value. The various models of the output waveforms are represented and discussed. The role of Neural Network controller is to interconnect the system for optimal performance based on expected wind, solar irradiations and battery voltage. The Neural Network controller takes the input from Solar (irradiation), Wind (speed) and the battery status of charge and controls the respective subsystem which formulates into different operational modes of energy management and the proposed system have very high accuracy and efficient operation which leads to a reduced operating cost.

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INTRODUCTION

In this new era, the recent technological invasions have propelled the development of the entire world to its new heights. These developments have transformed the world into its new dimensions through technological aspects & impact. This is the main reason for power demand. The rate of world development in geometric ratio catalyses the need of extracting power from renewable energy resources and also the funny fact as another reason is the available of conventional energy resources is only up to 60-70 years. Out of the renewable energy resources such as Wind, Geothermal, Solar, Ocean, Biomass and Chemical resources, the Wind and

Solar resources have its advancement due to its reliability, simplicity etc. Due to the frequent variation in the availability of these resources, the hybrid concept for power generation gains importance. Solar and wind power is an inexhaustible renewable energy source and they are widely available. Wind and solar power has a good application prospect in terms of development. The rational allocation of capacity for Wind Solar Hybrid Power System can increase reliability of power supply and reduce the system cost according to load characteristics of residential use and local environment condition. The production of pollution free electrical energy can be done and the advantage may extend up to the benefits of economics and developments. Battery units integrated with solar and wind sub systems can give a good reliability.

In this study, an optimal hybrid energy generation system which includes wind, photovoltaic and battery is designed. The aim of design is to reduce the cost of stand-alone system over its 20 years of operation. The optimization problem is within the economic and technical constraints. The generated power by wind turbine and PV arrays are depended on many parameters that the most effectual of them are wind speed, the height of WTs hub (affects the wind speed), solar radiations of PV panels. In certain region, the variables that are to be optimized are considered as the number of WTs, number of PV arrays, and installation angle of PV arrays, number of batteries, and height of the hub and sizes of DC/AC converter.

In stand-alone Wind Solar hybrid power system, the nickel-metal-hydride batteries play an important role as an energy storage component. Whereas charge/discharge strategies of battery storage directly affects the power supply quality in Wind Solar

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hybrid power system since electrical energy from solar and wind turbine generator has fluctuation. This causes a higher demand to electric power management system. Therefore, it has great theoretical significance to study and enhance the performance of power management of hybrid Wind-Photovoltaic system.

Modeling of Hybrid System:

The increasing energy demand and environmental concerns aroused considerable interest in hybrid renewable energy systems and its development. The generation of both wind power and solar power is very dependent on the weather conditions such that no single source of energy is capable of supplying cost- effective and power reliability. The combination of multiple power resources can be a viable way to achieve trade-off solutions. With the combined use of the renewable systems, thus the power fluctuations will be changed.

The hybrid system is shown in Fig.1. The various components of the hybrid system are discussed below.

Wind turbine:

The model used to calculate the output power generated by WTG is shown in Fig.2.

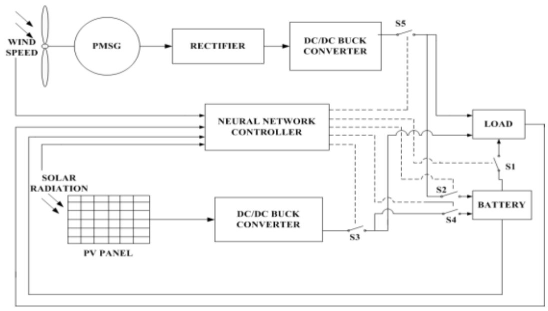

Fig. 1: Block diagram of proposed wind/photovoltaic system.

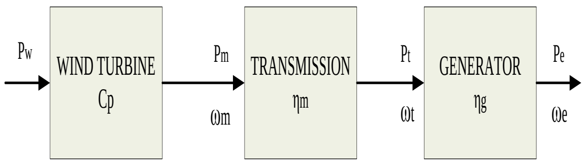

Fig. 2: Block diagram of wind energy system.

Where; P_W - wind power, P_m - turbine output power, P_t -generated input power and P_e - generator power output. C_P- coefficient of performance of the turbine, m - transmission efficiency, η_g- generator efficiency and η_m- turbine angular velocity.

The electrical output power can be calculated as,

$$P_e = C_P * \eta_m * \eta_g * 0.5 * \rho \quad (1)$$

The characteristics of power output from WTG can be described by the following formula, (De Bore, A.M., 1999)

$$P_e(V) = \begin{cases} 0 & : v < V_c \\ C_P * \eta_m * \eta_g * 0.5 * \rho * A * v^3 & : V_c \leq v \leq \\ C_P * \eta_m * \eta_g * 0.5 * \rho * A * v^3 & : V_r \leq v \leq \\ 0 & : v < V_f \end{cases} \quad (2)$$

Where; v- wind speed in m/sec, P_{rated} is the rated power in kW, A is the effective swept area in m^2, V_c - The cut-in speed of the WTG in m/s, V_r - rated wind speed of the WTG in m/s, V_f - cut-off speed of the WTG in m/s.

The coefficient of performance is the ratio of the mechanical power at the turbine shaft to the wind power. This factor is not constant and it varies with tip speed ratio, λ as (De Bore, A.M., 1999)

$$\lambda=(r_m*\omega_m)/v \quad (3)$$

where r_m is the radius of swept area in meters.

Photovoltaic array:

Solar energy is one of the most significant renewable energy sources that world needs. The main applications of solar energy can be classified into two categories: solar thermal system which converts solar energy to thermal energy, and photovoltaic system which converts solar energy to electrical energy. The model ling of PV arrays is described below.

The electrical power generated and terminal voltage of PV module depends on solar radiation and ambient temperature. The equivalent circuit describing the solar cells array used in the analysis is shown in Fig.3.

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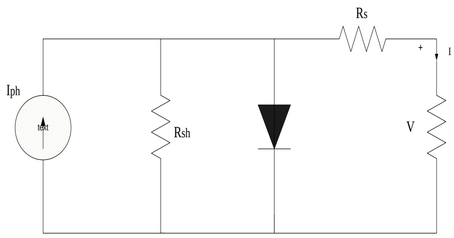

Fig. 3: Equivalent circuit of PV solar cells array.

For calculating the output electric power of PVs radiation is needed. When horizontal and vertical solar radiation is available, radiation can be calculated by (4).

$$G(t,\theta_{PV}) = G_V(t) * \cos(\theta_{PV}) + G_H(t) * \text{sir} \qquad (4)$$

Where, $G_V(t)$ and $G_H(t)$are the rate of vertical and horizontal radiations in the t^{th} step time (W/m^2), respectively. The radiated solar power on the surface of each PV array can be
calculated by (5)

$$P_{pv} = \frac{G}{1000} * F \qquad (5)$$

where, *G* is perpendicular radiation at the arrays' surface (W/m^2).$P_{pv,rated}$ is rated power of each array at G=1000(W/m^2) and is the efficiency of PV's DC/DC converter and Maximum Power Point Tracking(MPPT).

Battery storage:

Since both wind and PVS are intermediate power sources, it is highly desirable to the incorporate energy storage into such hybrid power systems. Energy storage can smooth out the fluctuations of wind and solar power and improve the load availability.

When the power generated by WGs and PVs are greater than the load demand, the additional power will be stored in the storage batteries for future use. On the other side, when there is any power deficit in the renewable sources, the power stored will be used to supply the load. This will improve the system reliability.

In the state of charge, amount of energy that will be stored in batteries at any hour (t) is calculated:

$$E_B(t) = E_B(t-1) + \left((P_w + P_{pv})(t) - \frac{P_{Load}(t)}{\eta_{inv.}}\right)\eta_{Bat} \qquad (6)$$

In addition, (7) will calculate the state of battery discharge at any hour (t):

$$E_B(t) = E_B(t-1) + \left(\frac{P_{Load}(t)}{\eta_{inv.}} - (P_w + P_{pv})(t)\right)\eta \qquad (7)$$

Where, $E_B(t)$, $E_B(t-1)$ are the stored energy of battery at any hour (t) and (t-1). P_w, P_{pv} are the generated power by wind turbines and PV arrays, $P_{Load}(t)$ is the load demand at any hour (t) and η_{Bat} is the efficiency of storage batteries.

Operation Control Strategy:

There are three modes of operation:

- *Mode 1:* If the total power generated by PV arrays and WGs are greater than load demand, the additional energy is stored in the batteries until the full energy is stored.
- *Mode 2:* If the total power generated by PV arrays and WGs are less than load demand, shortage of power would be provided from batteries. If batteries could not provide the total energy that load demanded, the load will be cut.
- *Mode 3:* If the total power generated by PV arrays and WGs are equal to the demanded load, the storage capacity remains unchanged and all of the generated power will be consumed at the load.

Artificial Neural Network:

An Artificial Neural Network is defined as a data processing system consisting of a large number of simple highly interconnected processing elements in an architecture inspired by the structure of the cerebral cortex of the brain.

A neural network can have any number of layers, units per layer, network inputs, and network outputs.

Feed Forward Neural Network:

In a feed forward neural network information flows in one direction forward from the input layers via the hidden layers to the final output layers. There is no feedback loops or cycles in the network that means the output layer does not affect that same or preceding layer.

Fig.4 shows the structure of the proposed three layers neural network as shown in above figure. X1 , X2, X3, X4 and t are the five-input training matrix which represent DC output voltage from PV system and WTG system, battery storage, load demand, and time. The weight matrices are represented $W^{(1)}$and $W^{(2)}$.The network consists of five input layers, ten nodes in hidden layers and five nodes in output layer which sigmoid transfer function.

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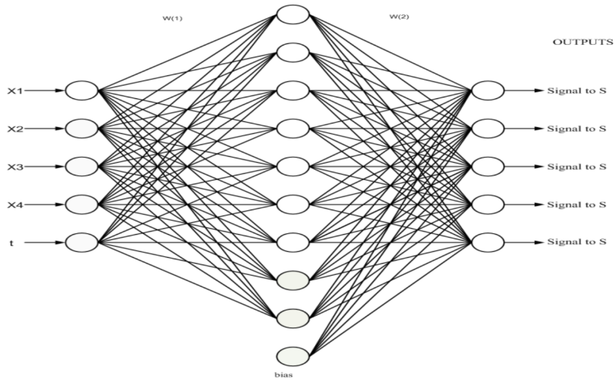

Fig. 4: Structure of the proposed three layers ANN used to interconnect PV/WTG /BS HPGS.

Supervised Learning and Training Process:

Here the back propagation technique with sigmoid transfer function is used as the training algorithm. Back propagation is a common method of training artificial neural networks so as to minimize the objective function. During learning phase, the network learns by adjusting the weights so as to be able to predict the correct class label of the input tuples.

Simulation Results:

The Fig.5 shows overall simulation diagram using neural network.

The Solar subsystem consists of Photovoltaic panel which has the input parameters of Irradiation level, temperature and the voltage. The energy management is designed for the irradiation level varying from 900 w/m^{2}to 1400 w/m^2 during day time.

The Photovoltaic panel produced an output of 80V DC voltage and it is given to the DC/DC buck converter. The DC/DC buck converter used to step down the voltage to the proposed DC bus voltage 48V.

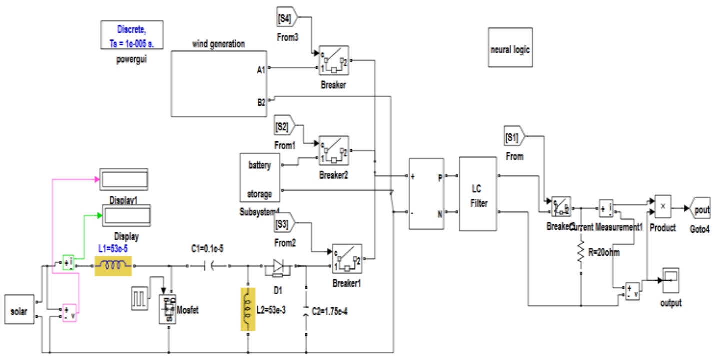

Fig. 5: Overall simulation diagram.

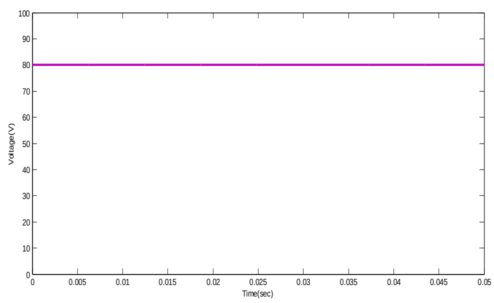

Fig. 6: Simulation waveform of PV side DC bus voltage.

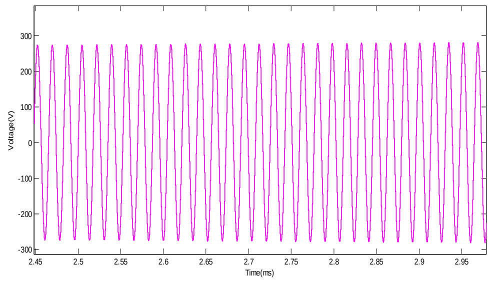

Fig. 7: Simulation waveform of wind energy system.

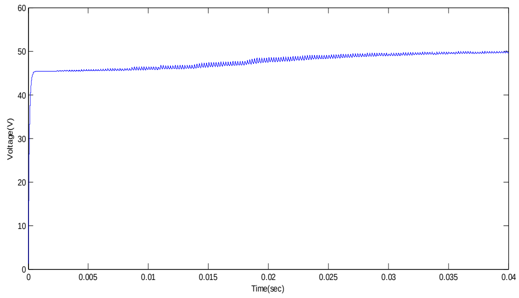

Fig. 8: Simulation waveform of DC bus voltage.

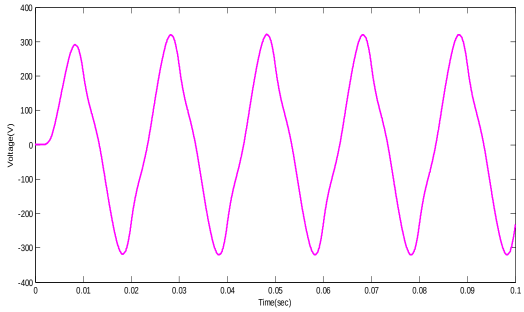

Fig. 9: Simulation waveform of entire proposed system using Neural Network.

Conclusion:

This paper presents mainly investigates the design and energy management of WES/PV/BS System. The entire hybrid system is composed of the interconnection of the photovoltaic panel and wind turbine generator with power electronic based interfaces for optimal transfer of DC power was analyzed. The major advantage of these components is that when it used together, the reliability of the system is improved. Also, the size of storage systems can be reduced as there is less reliance on one method of power generation. Often, when there is no sun, there is plenty of wind and vice versa. In this study, the batteries are employed as the energy storage system.

Artificial Neural Network is proposed here to achieve the optimal operation and control of WES/PV/BS/HPGS. This ANN is used here to feed the load demand. The whole hybrid wind-photovoltaic micro-generation system has been numerically simulated for different mode of operation derived in the energy management strategy. The results show good performance of the designed system and confirm the effectiveness of the proposed hybrid energy management strategy for any operating modes condition as the Neural Network controller makes fast and have very high accuracy.

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