ISSN (ONLINE): 2395-695X
ISSN (PRINT): 2395-695X

International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)
Vol.3, Special Issue.24, March 2017

Power management in standalone hybrid system using ANFIS and Fuzzy logic controller

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***Abstract*— In This paper a hybrid system consists of PV power module and wind driven Permanent Magnet Synchronous Generator feeds an isolated load through a Boost Converter was proposed. The output voltage Of PV module depends on solar irradiance as well as the output voltage and frequency of the PMSG is variable in nature due to non uniform wind velocities. The fluctuating output is rectified and kept constant by means of a boost converter. A neuro fuzzy logic controller is designed to extract the maximum power from PV also fuzzy logic controller is designed to set the duty ratio of the boost converter and to choose the moment to charge/discharge the battery and the moment to dissipate excess power in a dump load..This converter output is converted to three phase ac using a three phase PWM inverter. The proposed system has been demonstrated using MATLAB Simulink based simulations**

Keywords*—*Adapative neuro Fuzzy logic controller , Boost Converter, Permanent Magnet synchronous Generator

I.Introduction

THE WORLD has known the issues of global warming, and renewable energy is a solution to reduction of greenhouse emissions. The use of renewable energy sources gives a excellent potential for many applications, and particularly, off-grid stand-alone systems have many benefits. In remote areas, the energy storage units are needed in order to balance the electric power production and consumption within a system having a many number of renewable energy penetration also to increase the reliability of the system. Many studies have been done to make use of renewable energy sources (e.g. solar, biogas, wind, etc) that are stand alone. Among these, solar and wind energy are two of the most promising renewable power generation technologies.

The availability of renewable energy sources has daily and some have seasonal patterns which results in difficulties in regulating the output power production and the load is the major the drawback of standalone power systems .For example, the daily wind speed is not constant and solar irradiation cut-off at night and cloudy days, thus, the solar and wind system cannot supply the load throughout a day.

The solar power as well as wind power are available is not continuously for the entire day. solar or wind power systems alone cannot be used on remotely located areas which require constant guaranteed power. Alternative to this is the installation of hybrid energy systems. The hybrid Energy system must need a controller to monitor the power generation and load demand. And it to be performed the necessary action based on hybrid system operating condition.

In this paper, Adaptive Neural Fuzzy Inference System is used to extract the maximum power from the PV system. The P&O method is used to develop the MPPT of Wind turbine. Last a Fuzzy logic Controller is designed in such a way it selects the best available energy source(s) and to choose the moment to dissipate excess power in a dump load. MATLAB/Simulink software is used to model for designing of the proposed controller that optimize

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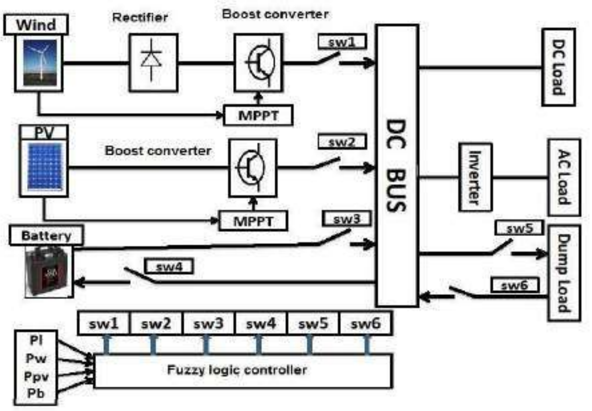
power generated and consumed and also manage the power of battery on PV-Wind hybrid system

II. Modeling of Hybrid System Components

In this section, the dynamic simulation model for the system is described. The system consists of various units, PV power and wind power units as primary sources of energy, battery bank unit as auxiliary source of energy, dc-dc and dc-ac converters, load unit and control unit.The function of controller unit is to ensure the management of the power, which is delivered by the hybrid system to satisfy the load and to charge the battery. The inverter unit is used to convert the DC generated power from renewable energy sources to feed the load with the required AC power. The excessive charge from the battery will be dumped to the dump load unit. The dump load in this case is the battery storage .

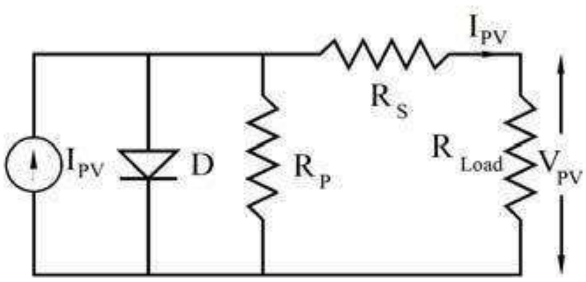
Fig. 1: Block diagram of PV-Wind Hybrid power systemwith controller



The Photovoltaic Module

The operation and the performance of PVgenerator depends to its maximum power,the models describing the PV module's maximum power output behaviorsare more practical for PV systemassessment. The following section describes the mathematical model for estimating the power output of PV. The equivalent circuit of a PV cell is shown in Fig 2. It includes a current source, a diode, a series resistance and a shunt resistance.

Fig. 2 The equivalent circuit of a PV cell



The current source Iph represents the cell photocurrent. Rsh
and Rs are the intrinsic shunt and series resistances of the
cell, respectively. Usually the value of Rsh is very large and
that of Rs is very small, hence they may be neglected to
simplify theanalysis. PV cells are grouped in larger units called PV modules which are further interconnected in a parallelseries configuration to form PV arrays. The photovoltaic panel can bemodeled mathematically as given in equations below:

Module photo-current:

Iph = [ISCr +Ki (T - 298)] *G / 1000 (1)

Where Iph is the light generated current in a PV module (A),ISCr is the PV module short-circuit current at 25oC and 1000W/m2, Ki is the short-circuit current temperature co-efficient at ISCr = 0.0017A=oC, T is the module operating temperature in Kelvin, G is the PV module illumination (W/m2) = 1000W/m2.

Module reverse saturation current - Irs:

$$Irs = \frac{Iscr}{\exp\left(\frac{qVoC}{NskAT}\right) - 1}$$

(2)

Where q is Electron charge = 1.610-19C, Voc is the open circuit voltage, Ns is the number of cells connected in series, k is Boltzman constant = 1.3805*10 -23J/K, A = B is an ideality factor = 1.6, The module saturation current I0 varies with the cell temperature, which is given by

$$Io = Irs\left[\frac{T}{Tr}\right]^3 \exp\left[\frac{q*Ego}{BK}\left[\frac{1}{Tr} - \frac{1}{T}\right]\right]$$

(3)

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Where Tr is the reference temperature = 298 K, Io is the PV module saturation current (A), Ego is the band gap for silicon = 1.1 eV.
The current output of PV module is

$$Ipv = Np * Iph - Np * Io\ [\exp\left[\frac{q*(Vpv+IpvRs)}{NsAkT}\right] - 1$$

(4)
Where Np is the number of cells connected in parallel, Vpv is output voltage of a PV module (V), Ipv is output current of a PV module (A), Rs is the series resistance of a PV module. Equations (1) - (4) are used to develop the PV model.

The Wind Turbine

There are two types of configuration for wind turbine exist, which is the vertical-axis wind turbine (VAWT) configuration and the widely used horizontalaxis wind turbine (HAWT) configuration. Wind turbines operate in two modes namely constant or variable speed. Advantages of constant speed turbine is that eliminates expensive power electronics such as converters and inverters. The main disadvantage is turbine cannot operate at its peak efficiency in all wind speeds. A relationship between the output power and the various variables constitute the mathematical model of the wind turbine. In this paper a model describing HAWT is proposed. For an object having mass m and velocity V under a constant acceleration, the kinetic energy W�is given by

$$Ww = \frac{1}{2} mv^2$$

(5)
The power �� in the wind is given by the rate of change of kinetic energy, i.e

$$Pw = \frac{dWw}{dt} = \frac{1}{2}\frac{dm}{dt} V_W{}^2$$

(6)
But the mass flow rate is given by

$$\frac{dm}{dt} = \rho A V_w$$

(7)
Where � is the swept area of the turbine, ρ is the density of air. With this expression equation (7) becomes

$$\frac{dm}{dt} = \rho A V_W{}^3$$

(8)
The actual mechanical power �� extracted by the rotor blades in watts is the difference between the upstream and the downstream wind powers [3], i.e.

$$P_{W} = \frac{1}{2}\rho A V_w\ (V_u{}^2 - V_d 2)$$

(9)
Where V� is the upstream wind velocity at the entrance of the rotor blades in m/s and V� is the downstream wind velocity at the exit of the rotor blades in m/s. From the mass flow rate, the equation can be written as

$$\rho A V_{w} = \frac{\rho A(V_u + V_d)}{2}$$

(10)
V� being the average of the velocities at the entry and exit of rotor blades of turbine. With this expression, equation (10) can be simplified and becomes

$$P_w = \frac{1}{2}\rho A V_w{}^3$$

(11)
Where �� is a fraction called the power coefficient. The power coefficient represents a fraction of the power in the wind captured by the turbine and has a theoretical maximum of 0.593.
�� is often called the Betz limit after the Germany physicist Albert Betz who worked it out in 1919. The power coefficient can be expressed by a typical empirical formula as

$$C_p = \frac{1}{2}(\lambda - .022\beta^2 - 5.6)e^{-0.17\lambda}$$

(12)
Where β is the pitch angle of the blade in degrees and λ is the tip speed ratio of the turbine, defined as

$$\lambda = \frac{V_{w(mph)}}{W_{b\,(rads^{-1})}}$$

(13)
Where W�is the turbine angular speed. Equations (5) - (13) describe the power captured by the turbine and constitute the turbine model.

Baterry storage system

ISSN (ONLINE): 2395-695X
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Unlike fossil and nuclear fuels, which are concentrated sources of energy that can be easily stored and transported, renewable forms of energy are highly dilute and diffuse.The

.lead-acid battery is proposed in this paper for energy storage. Moreover, their supply can be extremely intermittent and unreliable.When the state of charge(SOC) is below 80 percentage then the discharging switch is ON.

Based on the model given by Gu H et al [5] and incorporation of the diffusion precipitation mechanism studied by Ekdunge and Simonsson [6] in the reaction kinetics of the negative electrode, Kim and Hong [7] analyzed the discharge performance of a flooded lead acid battery cell using mathematical modeling. Bernardi and Carpenter [8] developed a mathematical model of lead acid batteries by adding the oxygen recombination reaction. Nguyen et al. [9] presented a model analogous to the flooded type and examined the dynamic behavior of the cell during discharge with respect to cold cranking amperage and reserve capacity. Bernardi and Carpenter [8] developed a mathematical model of lead acid batteries by adding the oxygen recombination reaction. Nguyen et al. [9] presented a model analogous to the flooded type and examined the dynamic behavior of the cell during discharge with respect to cold cranking amperage and reserve capacity.Extensive SOC determination methods have been introduced by Sabine Piller et al. [11]. During the charging process, when the total output of PV and wind generators is greater than the load demand, the available battery bank capacity at hour t can be described by [12.

$$C_{bat(t)} = C_{bat(t-1)} * (1-\sigma) + (E_{pv(t)} + E_{WG(t)} - \frac{EL(t)}{\eta inv})\, \eta_{bat}$$

(14)

On the other hand, when the load demand is greater than the available energy generated, the battery bank is in discharging state. Therefore, the available battery bank capacity at hour t can be expressed as

$$C_{bat(t)} = C_{bat(t-1)} * (1-\sigma) - (\frac{EL(t)}{\eta inv} - E_{pv(t)} + E_{WG(t)})$$

(15)

Where Cbat(t) and Cbat(t-1) are the available battery bank capacity (Wh) at hour t and t-1, respectively, ηbat is the battery efficiency (During discharging process, the battery efficiency = 1) σ is self-discharge rate of the battery bank. Epv(t) and EWG(t) are the energy generated by PV and wind generators, respectively; EL(t) is the load demand at hour t and ηinv is the inverter efficiency [%] At any hour, the storage capacity is subject to the following constraints:

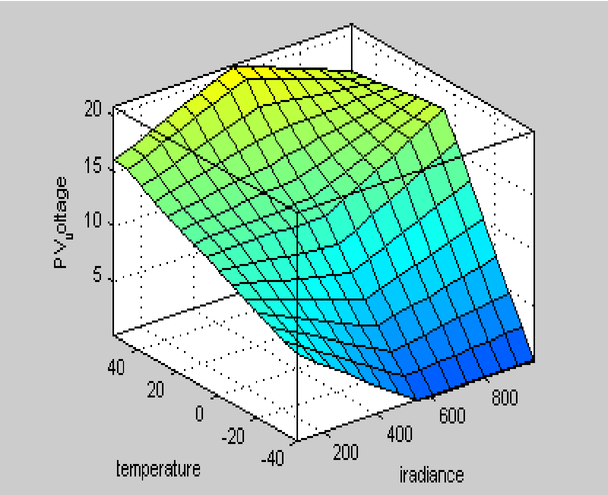
Cbatmin ≤ Cbat(t) ≤ Cbatmax (16)

III.ENERGY MANAGEMENT AND CONTROL SYSTEM

ANFIS Based PV MPPT

A typical solar panel can converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. Therefore the MPPT of a photovoltaic array is an essential part of a PV system. Among these techniques, hill-climbing MPPT such as perturb and observe (P&O), which is a simple algorithm that does not require previous knowledge of the PV generator characteristics and is easy to implement with analogue and digital circuits.In this technique, first the PV voltage and current are measured and hence the corresponding power is calculated. The peak power point is recognized and hence the corresponding voltage can be calculated [13] [14]. The major drawbacks of P&O/hill-climbing are occasional deviation from the maximum operating point in case of rapidly changing atmospheric conditions, such as broken clouds. Also, correct perturbation size is important in providing good performance in both dynamic and steady-state response [15]. MPPT achieved very good performances, fast responses with no overshoot, and less fluctuations in the steady state for rapid temperature and irradiance variations [19]. For MPPT, ANFIS input can be PV array parameters like PV voltages and currents, environmental data like irradiance and temperature, or any combination of these, whereas the output signal is the identified maximum power or the duty cycle signal used to drive the electronic converter to operate at the MPP. The ANFIS input and output data are obtained from experimental measurement or model-based simulation results. After learning relation of with temperature and irradiance, ANFIScan track the MPP online [17]. The operating temperature is varied from 15 C to 65 C in a step of 5C and the solar irradiance level is varied from 100 W/m2 to 1000 W/m2 in a step of 50 W/m2, to get the training data sets for ANFIS.

Table 1 : ANFIS Training Data



FLC BASED WIND MPPT

The amount of power produced by a wind turbine is expressed as shown:

$$PT = 0.5c_p\rho AV^3 \quad (1)$$

where ρ is the air density A is the cross sectional area of the turbine V is the wind velocity The coefficient of power(cp) is a value dependent on the ratio between the turbine rotor's angular velocity, (ωT) and the wind speed (V). This ratio is known as the Tip speed ratio (TSR), and is represented by λ. TSR is given by:

$$\lambda = \omega T R \quad V \quad (2)$$

where R is the radius of the turbine. A wind turbine is generally characterised by its cp versus λ curves obtained for different wind speeds, and usually takes the shape. From the relationship between TSR and cp, it is possible to devise a control strategy that ensures that the wind turbine operates around or at the peak point of the curve. Such strategies are commonly referred to as Maximum Power Point Tracking (MPPT) techniques. MPPT techniques fall into two broad categories: • Techniques that employ known turbine characteristics • Techniques that allow optimization without knowledge of turbine characteristics.

FLC Based Power Management

The Fuzzy Logic Controller is used to control the power generated by wind source, PV source, Battery and dump load. It will control the battery state of charge (SOC) by activating the charger control switch when there is excess power from primary sources and activates the discharging switch in case of primary sources do not meet the load demand. The controller has four inputs named as Load Power (Pl), Wind turbine power (Pw), Solar PV Power (Ppv) and Battery Power (Pb). The outputs for controller are Wind power switch (SW1), PV power switch (SW2), Battery power switch (SW3), Charger controller switch (SW4), dump load charging switch (SW5) and dump load discharging switch (SW6). All four inputs has three(3) triangular membership function such as Low, Medium and High L,M,H and all output have two membership function (ON and OFF).

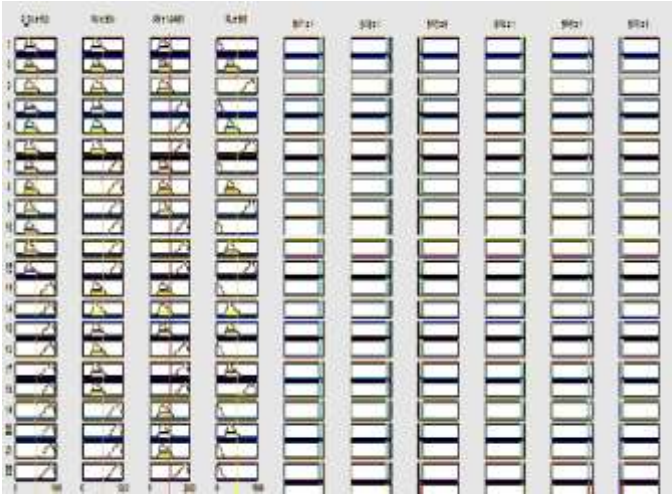
For the inputs low is defined from 0-200W, medium range from 200-600W and high considered to range from 600-1000w. All selector switches will be ON when any of the sources is low. The battery state of charge is limited from 20% to 80% which means the battery charging switch will be ON only when the state is below 80% and the discharging switch will be ON only when the SOC is above 20%. This paper proposes Sugeno type of fuzzy inference system.

IV Simulation results and discussion Evaluation of proposed MPPT

The proposed PV MPPT model has been designed and simulated by MatLab/Simulink software Simulation model of PV-Wind hybrid system with battery storage and Fuzzy Logic controller is developed using MATLAB/Simulink software.
Table2 : Rating of hybrid system components

Component	Rating(w)
Wind Power	1000
PV Power	1000
Battery Power	2000
DC Load	500
AC Load	500

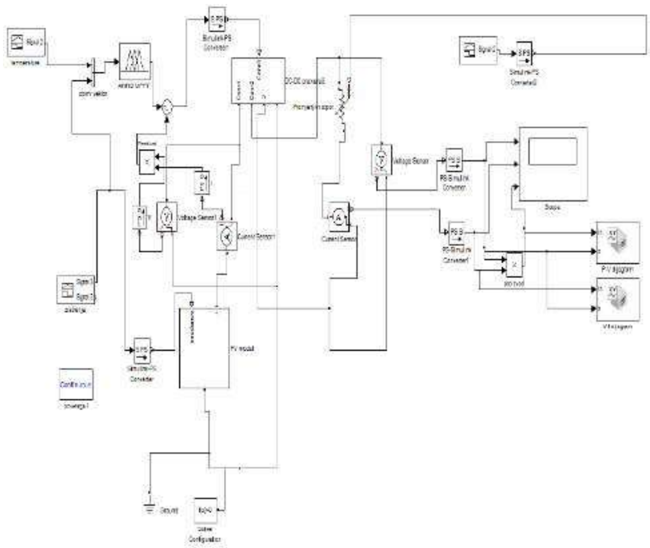
Fig.10 Simulink model for the ANFIS MPPT



Case 1

Consider the case where all of the renewable sources are sufficient to run the load. The solar selector switch SW1, the wind selector switches SW2, charge control switches (SW4 and SW5) are activated and the other selector switches are turned off. The fuzzy rule that satisfies this condition is:

If (Pl is L/M/H) and (Ppv is M/H) and (Pw is M/H) and (Pb is M/H) then (SW1 is ON) and (SW2 is ON) and (SW3 is OFF) and (SW4 is ON) and (SW5 is ON) and (SW6 is OFF). Table 4 show fuzzy rules formed that satisfies this condition.



Case 2

Consider the case where all of the renewable sources are insufficient to run the load. The discharge selector switch (SW3) is activated and the other selector switches are turned off. The fuzzy rule that satisfies this condition is:

If (Pl is L/M/H) and (Ppv is L) and (Pw L) and (Pb is M/H) then (SW1 is OFF) and (SW2 is OFF) and (SW3 is ON) and (SW4 is OFF) and (SW5 is OFF) and (SW6 is OFF).

Case 1 :Fig .11 shows the output of controller when PV and wind supplies load (1=ON , 0 = OFF).

V. Conclusion

The photovoltaic and wind hybrid power system is simulated using MATLAB/Simulink software. ANN and FLC MPPT Control is applied for solar and wind sources to make the system efficient. The performance of the MPPT was compared with the classical P& O technique. Results indicate that the ANFIS-based model developed in this work can predict the MPP for a PV panel with high accuracy. Moreover the simulation results of the developed Fuzzy logic based Power Management shows that the controller provides uninterrupted power, effective utilization of sources, minimizing usage of battery and hence improve battery life. It was found that the hybrid topology exhibits excellent performance under various operating conditions, and maintain the battery SOC between 20 – 80%. It can be concluded that the controller can satisfactory manage energy supply in a PV-Wind hybrid power system.

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