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Modeling and Simulation of Hybrid Solar Photovoltaic-Wind System Based on Artificial Intelligence

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ABSTRACT

Now a day's electricity is most needed facility for the human being. All the conventional energy resources are depleting day by day. So we have to shift from conventional to non-conventional energy resources. In this the combination of two energy resources is takes place i.e. wind and solar energy. This process reviles the sustainable energy resources without damaging the nature. Renewable energy sources have become a popular, the commonly used renewable sources are solar photovoltaic and wind energy systems have received agreat acceptance in field of power generation for pollution free performance, free availability and for great reliability. Further development and effective use of natural resources, the hybrid systems are developed. Hybrid power systems can provide a good solution for such problems because they integrate renewable energy along with the traditional power plants. Hybrid systems are characterized by containing two or more technologies of electrical generation, in order to optimize global efficiency of the processes. Basically this system involves the integration of solar, wind with battery storage device that will gives continuous power. A simple control technique which is also cost effective has been proposed to track the operating point at which maximum power can be coerced from the PV system and wind turbine generator system under continuously changing environmental conditions. In this Paper, the modeling of hybrid Solar Photovoltaic-Wind Stand-Alone Generation System is done by using MATLAB/SIMULINK software and results are presented.

Keywords- Hybrid Energy system, MPPT, Wind Energy, Solar Photovoltaic System Battery Storage, Matlab/Simulink

I. INTRODUCTION

Due to the critical condition of industrial fuels which include oil, gas and others, the development of renewable energy sources is continuously improving. This is the reason why renewable energy sources have become more important these days. Few other reasons include advantages like abundant availability in nature, eco-friendly and recyclable. Many renewable energy sources like solar, wind, and tidal are there. Among these renewable sources solar and wind energy are the world's fastest growing energy resources. With no emission of pollutants, energy conversion is done through wind and PV cells. Day by day, the demand for electricity is rapidly increasing. But the available base load plants are not able to supply electricity as per demand. So these energy sources can be used to bridge the gap between supply and demand during peak loads. This kind of small scale stand-alone power generating systems can also be used in remote areas where conventional power generation is impractical. The importance of hybrid systems grown as they appeared to be the right solution for a clean and distributed energy production. In this Paper, the modeling of hybrid Solar Photovoltaic-Wind Stand-Alone Generation System is modeled by using MATLAB/SIMULINK.

II. METHODS AND MATERIAL

1. Overview Of Hybrid Energy System

Solar-Wind hybrid Power system is the combined power generating system by wind mill and solar energy panel. It also includes a battery which is used to store the energy generated from both the sources.

Using this system power generation by windmill when wind source is available and generation from PV module when light radiation is available can be achieved. Both units can be generated power when both sources are available. By providing the battery uninterrupted power supply is possible when both sources are idle. The design process of hybrid energy

systems requires the selection and sizing of the most suitable combination of energy sources, power conditioning devices, and energy storage system together with the implementation of an efficient energy dispatch strategy. The selection of the suitable combination from renewable technology to form a hybrid energy system depends on the availability of the renewable resources in the site where the hybrid system is intended to be installed. In this proposed system solar, wind power with battery storage system is used for generating power. Solar and wind has good advantages than other than any other non-conventional energy sources. Both the energy sources have greater availability in all areas with lower cost.

2. Solar PV Energy

Solar energy is that energy which is gets by the radiation of the sun the sun. Solar panels are the medium to convert solar energy into the electrical energy. Solar panels can convert the energy directly or heat the water with the induced energy. PV (Photo-voltaic) cells are made up from semiconductor structures as in the computer technologies. Sun rays are absorbed with this material and electrons are emitted from the atoms. This release activates a current. Photovoltaic is known as the process between radiation absorbed and the electricity induced. Solar power is converted into the electric power by a common principle called photo electric effect. The solar cell array or panel consists of an appropriate number of solar cell modules connected in series or parallel based on the required current and voltage. The sun is the original source of almost all the energy used on earth. The earth receives a stock ring amount of energy from the sun, as much energy falls on the planet each hour is the total human’s population uses in a whole years.

3. Wind Energy

Wind energy is the energy which is extracted from wind. For extraction we use wind mill. The wind energy needs less cost for generation of electricity. Maintenance cost is also less for wind energy system. Wind energy is present almost 24 hours of the day. It has less emission. Initial cost is also less of the system. Generation of electricity from wind is depend upon the speed of wind flowing. Wind energy is a source of renewable power which comes from the air currents flowing across the earth's surface. Wind turbines are used to convert the wind power into electric power. Electric generator inside the turbine converts the mechanical power into the electric power. Wind turbine systems are available ranging from 50W to 3-4 MW. The energy production by wind turbines depends on the wind velocity acting on the turbine. Wind power is able to feed both energy production and demand in the rural areas. It is used to run a windmill which in turn drives a wind generator or wind turbine to produce electricity.

4. Battery Storage Device

The batteries in the system provide to store the electricity that is generated from the wind or the solar power. Any required capacity can be obtained by serial or parallel connections of the batteries. The battery that provides the most advantageous operation in the solar and wind power systems are maintenance free dry type and utilizes the special electrolytes. These batteries provide a perfect performance for long discharges.

A battery is a device that converts chemical energy directly to electrical energy. An electric battery is a device consisting of one or more electrochemical cells with external connections provided to power electrical devices. Each cell consists of three main parts: a positive electrode (terminal), a negative electrode, and a liquid or solid separating them called the electrolyte. When a battery is connected to an external circuit, a chemical reaction takes place in the electrolyte causing ions (in this case, atom with a positive electrical charge) to flow through it one way electrolytes are able to move as ions within, allowing the chemical reactions to be completed at the separate terminals and so deliver energy to the external circuit. It is the movement of those ions within the battery whichallows current to flow out of the battery to perform work. The energy storage device is used basically for three purposes, energy stabilization, ride through capability and dispatch ability. The energy stabilization permits the hybrid system to run at a constant stable level with the help of the energy storage devices, even if load fluctuations rapidly. The ride through capability is the capability of energy storage devices which provides the proper amount of energy to loads, when the hybrid system generators are unavailable. Since both wind and PVs are intermediate sources of power, it is highly desirable to incorporate energy storage into such hybrid power systems. The hybrid system is shown in Figure. 1. In the following sections, the model of components is discussed.

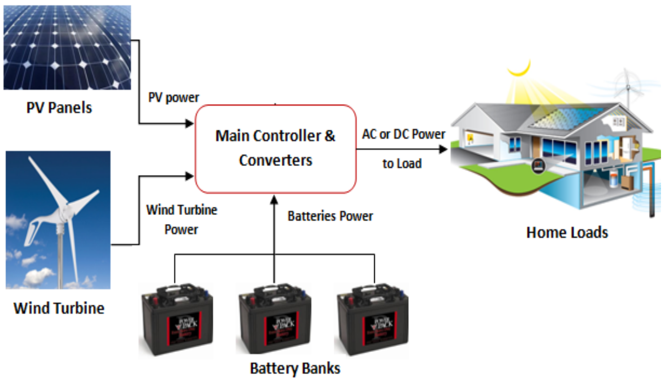

Figure 1. Block diagram of a hybrid power generation system

5. Modeling of Hybrid Energy System

✓ Modeling of PV Cell

The model of the solar PV cell can be realized by an equivalent circuit that consists of a current source in parallel with a diode as shown in Fig. 2 for ideal model R_s, R_p and C components can be neglected.

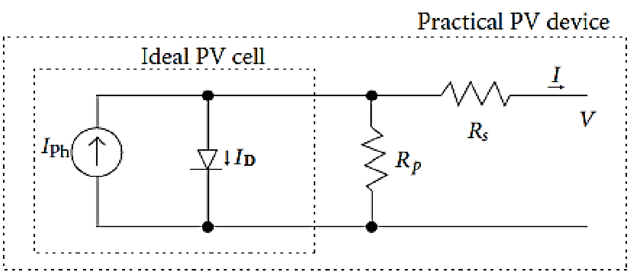

Figure 2. Equivalent circuit diagram of a solar pv cell

The diode is the one which determines the current-voltage characteristic of the cell. The output of the current source is directly proportional to the light falling on the cell. The open circuit voltage increases logarithmically according to the Shockley equation which describes the interdependent of current and voltage in a solar cell. An equation that represents I -V characteristics of a solar array is given by the following mathematical equation as: The power output of a single diode solar cell is given by (Villalva et al. 2009)

$$P = VI \qquad \text{----------} (1)$$

The photocurrent (I_{ph}) which mainly depends on the solar irradiation and cell temperature is described as (Villalva et al. 2009)

$$I_{ph} = [\mu_{sc}(T_c - T_r) + I_{SC}]S \qquad \text{---------} (2)$$

Where μ_{sc} is the temperature coefficient of the cell's short circuit current; Tr is the cell's reference temperature; Isc is the cell's short circuit current at a 25°C and 1kW/m^2; and S is the solar irradiation in kW/m^2. Furthermore, the cell's saturation current (Is) varies according to the cell temperature and can be described as (Villalva et al. 2009)

$$I = I_{ph} - I_s\left(e^{\frac{q(v+IR_S)}{mkT}} - 1\right) - [\frac{V+IR_S}{R_p}] \text{----}(3)$$

Equation (3.1) is used in computer simulations to obtain the output characteristics of a solar cell. To simulate the selected PV array, a PV mathematical model having N_P cells in parallel and N_s cells in series is used according to the following equation (neglecting shunt resistance):

$$I = N_P I_{ph} - N_P I_S\left(e^{\frac{q(v+IR_S)}{(mkTN_S)}} - 1\right) \text{-----}(4)$$

Assuming N_P the above equation can be rewritten as:

$$I = I_{ph} - I_S\left(e^{\frac{q(v+IR_S)}{(mkTN_S)}} - 1\right) \text{-----}(5)$$

In particular, the cell reverse saturation current, Is, varies with temperature according to the following equation as:

$$I_S = I_{S(T_1)} * \left(\frac{T}{T_1}\right)^{\frac{3}{m}} * e^{\frac{-qv}{mK}}\left(\frac{1}{T} - \frac{1}{T_1}\right) \qquad \text{--------} (6)$$

$$I_{S(T_1)} = \frac{I_{SC(T_1)}}{(e^{qvoc(T_1)/mKT_1} - 1)} \text{---------}(7)$$

The photo current I_{ph}, depends on the solar radiation (S) and the temperature (T) according to the following equation as:

$$I_{ph} = I_{ph(T_1)}\left(1 + K_0(T - T_1)\right) \text{-------}(8)$$

$$I_{ph(T_1)} = S * I_{SC(T_1,norm)}/S_{norm} \text{--------}(9)$$

Where $K_0 = (I_{S(T_2)} - I_{S(T_1)})/(T_2 - T_1)$ ------(10)

The series resistance of the cell is given as

$$R_S = \frac{dV}{dI_{voc}} - \left(\frac{I}{X_V}\right) \text{---------} (3.9)$$

Where $X_V = I_{0(T_1)} * q/mKT_1 * (e^{qvoc(T_1)/mKT_1}$------- (11)

The PV power, P, is then calculated as follows

$$P = N_P I_{ph} V - N_P I_S V\left(e^{\frac{q(v+IR_S)}{(mkTN_S)}} - 1\right) = VI \text{-----}(12)$$

where

V - output voltage of PV module,

I - output current of PV module,

R_s - series resistance of cell (Ω)

R_{sh} - shunt resistance of cell (Ω)

q - electronic charge ($1.602 * 10^{-19}$ C),

I_{sc} - light-generated current,

K - Boltzman constant ($1.38 * 10^{-23}$ J/k),

T_k - temperature (K), n_s number of PV cells connected in series,

N_p- number of PV cells connected in parallel,

I_o - reverse saturation current which depends on the ambient temperature

m - diode factor (usually between 1 and 2);

n_s: number of PV cell in series

n_p: number of PV cell in parallel

✓ PV Module and Array

The basic element of a PV System is the photovoltaic (PV) cell, also called a Solar Cell. A PV / Solar Cell is a semiconductor device that can convert solar energy into DC electricity through the Photovoltaic Effect • (Conversion of solar light energy into electrical energy). When light shines on a PV / Solar Cell, it may be reflected, absorbed, or passes right through. But only the absorbed light generates electricity. To increase their utility, a number of individual PV cells are interconnected together in a sealed, weatherproof package called a Panel (Module). To achieve the desired voltage and current, Modules are wired in series and parallel into what is called a PV Array. The flexibility of the modular PV system allows designers to create solar power systems that can meet a wide variety of electrical needs. Fig. 3 shows PV cell, Panel (Module) and Array. The cells are very thin and fragile so they are sandwiched between a transparent front sheet, usually and a backingsheet, usually glass or a type of tough plastic. This protects them from breakage and from the weather. An aluminum frame is fitted around the module to enable easy fixing to a support structure. To increase the power, the cells are connected in series-parallel configuration on a module. For photovoltaic systems, the PV array is the group of several PV modules which are connected in series and parallel circuits to generate the required voltage and current.

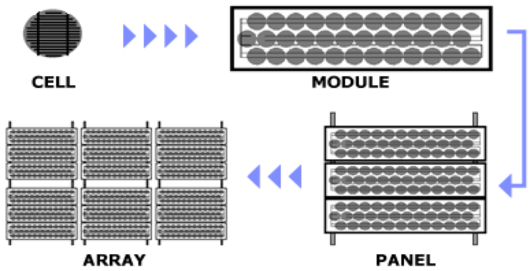

Figure 3. PV cell, module, and array

The equivalent circuit for the solar module arranged in *NP* parallel and *NS* series branches is shown in Figure. 4.

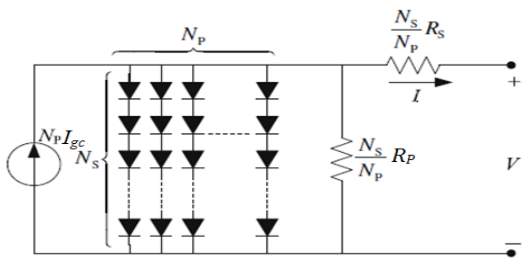

Figure 4. General equivalent circuit of PV module

The block diagram of the proposed model is implemented based on the mathematical equations of the PV cell and shown in Fig. 5 and corresponding I-V and P-V output characteristics of PV cell shown in Fig. 6.

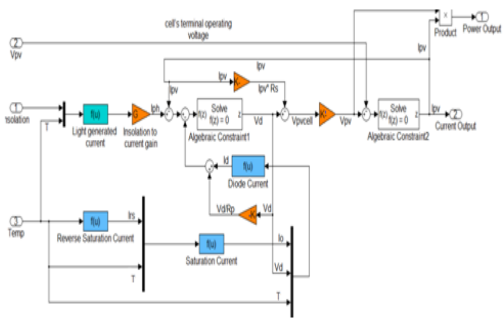

Figure 5.implementation of the PV model in Simulink

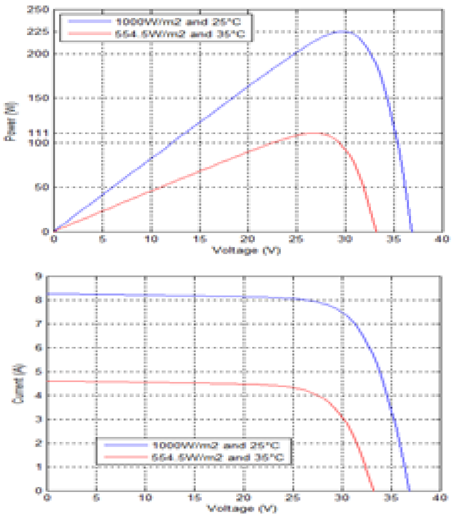

Figure 6. I-V and P-V output characteristics

- ✓ **Wind Generator Model**

Modeling the wind energy converter is made considering the following assumptions:

Friction is neglected; Stationary wind flow; Constant, shear-free wind flow; Rotation-free flow; Incompressible flow (ρ=1.22 kg/m^3); Free wind flow around the wind energy converter.

On the above condition the maximum physical achievable wind energy conversion can be derived using theoretical model that is independent of the technical construction of a wind energy converter.The flow air mass has certain energy. This energy is obtained from the air movement on the earth's surface determined by the difference in speed and pressure. This the main source of the energy used by the wind turbines to obtain electric power. The Kinetic energy W taken from the air mass flow m at speed v_1 in front of the wind turbines pales and at the back of the pales at speed V_2 is illustrated by equation (13):

$$W = \frac{1}{2} m({v_1}^2 - {v_2}^2)\text{-------------}(13)$$

The resulted theoretical medium power p is determined as the ratio between the kinetic energy and the unit of time and is expressed by equation (14).

$$P = \frac{1}{2}\frac{m}{t}({v_1}^2 - {v_2}^2) = \frac{1}{2}\frac{V\rho}{t}({v_1}^2 - {v_2}^2)\text{-----}(14)$$

Where:

V- air mass volume; t- time; ρ - Air density.

Assuming the expression of the mean air speed $V_{med} = \frac{1}{2}(v_1 + v_2)$

the mean air volume transferred per unit time can be determined as follows:

$$V_{med} = \frac{V}{t} = Av_{med}\text{---------------}(15)$$

The equation for the mean theoretical power is determined using equation (15)

$$P = \frac{1}{4}A\rho({v_1}^2 - {v_2}^2)(v_1 + v_2) = \frac{A}{4}A\rho {v_1}^3\left(1 - \frac{{v_2}^2}{{v_1}^2}\right)\left(1 - \frac{V_2}{V_1}\right)\text{------}(16)$$

We can conclude that an adequate choice of v_1/v_2 ratio leads to a maximum power value taken by the wind converter from the kinetic energy of the air masses, as shown by equation (17)

$$P_{max} = \frac{8}{27}A\rho {v_1}^3\text{-------------}(17)$$

This power represents only a fraction of the incident air flow theoretical power given by

$$P_{wind} = \frac{1}{2}A\rho {v_1}^3\text{--------------}(18)$$

Equations (17) and (18) leads to:

$$P_{max} = \frac{8}{27}A\rho {v_1}^3 = \frac{1}{2}A\rho {v_1}^3 = P_{wind} \, . \, C_P\text{---}(19)$$

Where C_p represents the mechanical power coefficient which express that the wind kinetic energy cannot be totally converted in useful energy. This coefficient, meaning the maximum theoretical efficiency of wind power. The electrical power obtained under the assumptions of a wind generator's electrical and mechanical part efficiency is given by

$$P_{ele} = \frac{1}{2}C_e A\rho {v_1}^3\text{--------------}(20)$$

Where C_e represents the total net efficiency coefficient at the transformer terminals.

The wind energy generator model was implemented by a module having configurable parameters based on the equation (20) and using the equivalent model of a generator. This model takes the following form and is shown in figure. 7

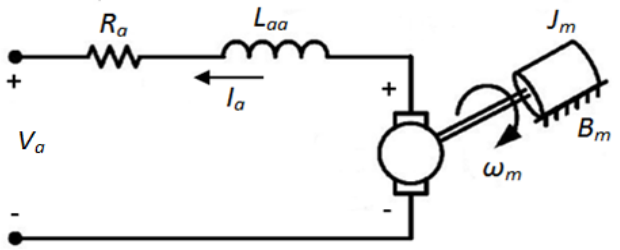

Figure 7. Equivalent circuit diagram of a small wind generator

In the equivalent circuit diagram of a small wind generator the notations are:

R_a - rotor winding resistance
Ex - generator separate excitation winding; current I_e through this winding generates the main field
V_e - induced voltage in the rotor (armature) V- terminal voltage , Kirchhoff's voltage law, the electrical side of the PMDC generator can be presented as follows,

$$V_a = K_m W_m - I_a R_a - L_{aa}\frac{dI_a}{dt}\text{--------------------(21)}$$

Where V_a is the generator output voltage (V), Km is the torque constant (N-m/A), ωm is the motor speed (rad/s), Ia is the armature current (A), Ra is the armature resistance (Ω), and L_{aa} is the armature inductance (H).

On the mechanical side, the electromagnetic torque (Te) developed by the DC machine is proportional to the armature current Ia, as shown below

$$Te = K_m I_a\text{---------------(22)}$$

The applied torque produces an angular velocity ωm according to the inertia Jm and the friction Bm of the machine and load. The relations are described by

$$J_m\frac{d\,\omega m}{dt} = Te - T_L - B_m\omega_m\text{-------(23)}$$

Where Jm is the total inertia ($Kg.m^2$), T_L is the load torque (N-M), Te is the electromagnetic torque (N-M), and B_m is the viscous friction coefficient (N-M-S).

The amount of power that a wind turbine can extract from the wind depends on the turbine design. Factors such as the wind speed and the rotor diameter affect the amount of power that a turbine can extract from the wind. The wind turbine was modeled using the mathematical equations. Figure. 8 shows the wind turbine model which adopted for this study . As illustrated, there are three inputs and one output. The three inputs are the generator speed, the pitch angle, and the wind speed. The output is the torque applied to the generator shaft.

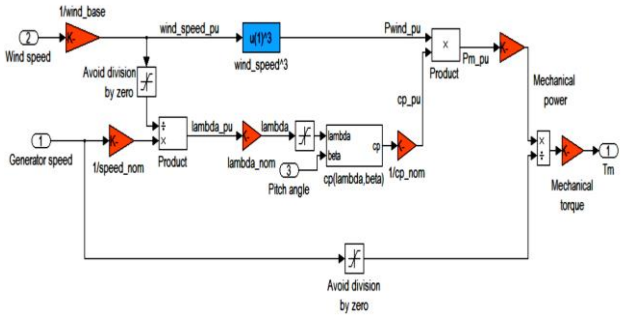

Figure 8.implementation of the wind turbine in Simulink

The built-in SimPower System block model of a DC machine is used as a power generator driven by the wind turbine (MathWorks 2012). As shown in Fig. 9, the rotor shaft is driven by the wind turbine which produces the mechanical torque according to the generator and wind speed values and the Figure. 10 shows the wind turbine characteristics.

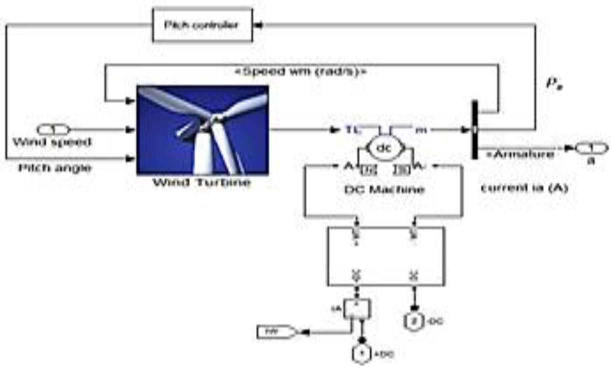

Figure 9. Implementation of the wind turbine DC generator model in Simulink

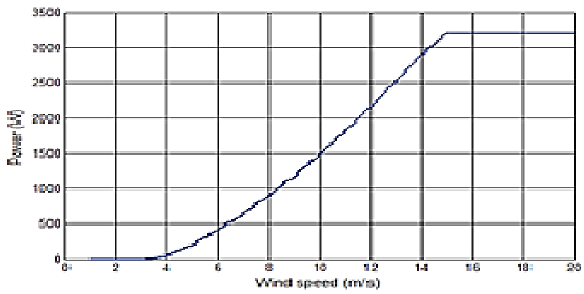

Figure 10.wind turbine characteristics

✓ **Battery Storage Model**

The battery is modeled using a controlled voltage source in series with a constant resistance, as shown in Figure. 11

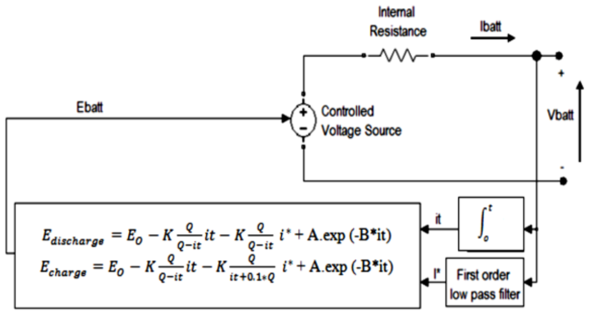

Figure 11. Battery model equivalent circuit

Discharge Model:

The Discharging battery model used is based on the Shepherd model (Shepherd 1965) but, it can represent accurately the voltage dynamics when the current varies and takes into account the open circuit voltage (OCV) as a function of state-of-charge (SOC). The OCV varies non-linearly with the SOC. Therefore, a term concerning the polarization voltage has been added $\left[K\frac{Q}{Q-it}it\right]$ to better represent the OCV behaviour. The battery voltage (V_{batt}) obtained can be described as (Tremblay &Dessaint 2009):

$$V_{batt} = E_0 - K\frac{Q}{Q-it}it - Ri - K\frac{Q}{0Q-it}i^* + A * \exp(-B\ it) \text{-- (24)}$$

Where E_o is the battery constant voltage4 (V), K is the polarization constant (Ah^{-1}), Q is the maximum battery capacity (Ah), it (∫ i dt) is the actual battery charge (Ah), R is the internal resistance (Ω), i is the battery current (A), i* is the low frequency current dynamics (A), A is the exponential zone amplitude (voltage drop during the exponential zone) (V), & B is the exponential zone time constant inverse $(Ah)^{-1}$.

Charge Model :

The battery charge behaviour, especially the end of the charge characteristic, is different and depends on the battery type. This phenomenon can be modeled by the polarization resistance term ($K\frac{Q}{it}$). The polarisation resistance increases until the battery is almost fully charged (it = 0). Above this point, the polarization resistance increases suddenly. Theoretically, when it = 0 (fully charged), the polarization resistance is infinite. This is not exactly the case in practice. Actually, experimental results have shown that the contribution of the polarization resistance is shifted by about 10% of the capacity of the battery (Tremblay &Dessaint 2009). Hence the polarization resistance of the charge model can be described as:

$$\text{Pol Resistance} = K\frac{Q}{0.1Q+it} \quad \text{------- (25)}$$

Similar to the discharge model, the exponential voltage for the Li-Ion battery is A*exp(-Bit) term. Hence, the battery voltage obtained can be described as (Tremblay &Dessaint 2009):

$$V_{batt} = E_0 - K\frac{Q}{Q-it}it - Ri - K\frac{Q}{0.1Q+it}i^* + A\exp(-B\ it) \quad \text{-- (26)}$$

For the fully charged voltage (V_{full}), the extracted charge is 0 (it = 0) and the filtered current (i*) is '0' because the current step has just started:

$$V_{full} = E_0 - (R * i) + A \text{----------------(27)}$$

In steady state the filtered current is equal to (i). Hence, the exponential zone voltage (V_{exp}) can be described as

$$V_{exp} = E_0 - K\frac{Q}{Q-Q_{exp}}\left(Q_{exp} + i\right) - Ri + A * \exp(-\frac{3}{Q_{exp}}Q_{exp}) \text{--(28)}$$

And the nominal zone voltage (V_{nom}) can be given by:

$$V_{nom} = E_0 - K\frac{Q}{Q-Q_{nom}}(Q_{nom} + i) - Ri + A * \exp(-\frac{3}{Q_{exp}}Q_{nom}) \text{---------- (29)}$$

The model of the is implemented in MatLab/Simulink based on the mathematical equations. as shown in Figure. 12 and 13 shows the typical charge characteristics of the battery.

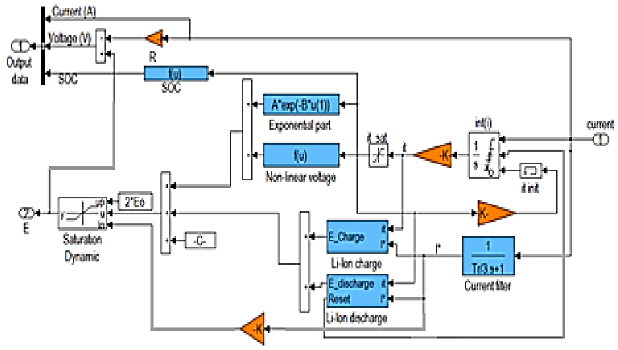

Figure 12.implementation of the battery model in Simulink

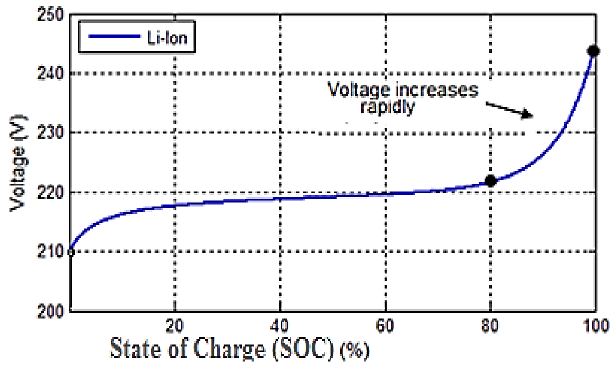

Figure 13. Typical charge characteristic

6. The Power Converter Models

Power electronics is the technology associated with efficient conversion, control and conditioning of electric power from its available form into the desired electrical output form. Power Electronics refers to control and conversion of electrical power by semiconductor devices, wherein these devices operate as switches. The main task of power electronics is to control and convert electrical power from one form to another. The four main forms of conversion are: AC-to-DC rectification, DC-to-AC conversion, DC-to-DC conversion, and AC-to-AC conversion. In the following discussion, we will explain the basic characteristics of DC/DC converter, and DC/AC inverter.

A. DC-DC Boost Converter

To connect a photovoltaic, wind turbine an external power system (e.g. DC load), it is necessary to boost their voltage or to increase their number. Therefore, a DC averaged switched model converter is needed to regulate the output voltage before being supplied to other electronic devices. There are many DC-to-DC converters including the step-down (buck) converter, the step-up (boost) converter, the buck-boost converter and many others. Most DC to DC converter circuits also regulate the output voltage. Some exceptions include high-efficiency LED power sources, which are a kind of DC to DC converter that regulates the current through the LEDs, and simple charge pumps which double or triple the output voltage. DC to DC converters developed to maximize the energy harvest for photovoltaic systems and for wind turbines are called power optimizers.

The following will evaluate the step-up (boost) converter which is shown in Figure. 14.

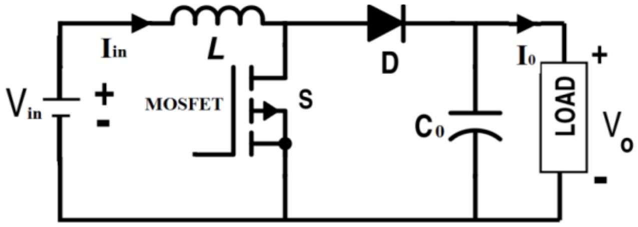

Figure 14. Boost Converter

Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since powermust be conserved, the output current is lower than the source current. which has boosting the voltage to maintain the maximum output power constant for all the conditions of temperature and solar irradiance variations. The MPPT uses the converter to regulating the input voltage at the PV MPP and providing load-matching for the maximum power transfer. The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. There are several different types of dc-dc converters, buck, boost, buck-boost topologies, have been developed and reported in the literature to meet variety of application specific demands .The topology used for DC to DC converter is boost converter. The boost converter is shown in fig. 6 when the switch S is on, the current builds up in the inductor L due to the positive inductor voltage is equal to the input voltage. When S is off, the voltage across L reverses and adds to the input voltage, thus makes the output voltage greater than the input voltage. For steady state operation, the average voltage across the inductor over a full period is zero. By designing this circuit we can also investigate performance of converters which have input from solar energy the boost converter output voltage can be calculated as follows:

$$\int_0^{T_s} V_L\,(t)dt = V_{in}(DT_s) + (V_{in} - V_0)(1 - D)T_s \text{ --- } (30)$$

Where $V_L$is the inductor voltage, $V_{in}$is the input voltage, Vo is the output voltage, $T_s$is the switching period and D is the switch duty cycle ($0 \leq D \leq 1$). Equal to zero and collect term:

$$V_{in}(1 + D - D) - V_0(1 - D)= 0 \text{ --------------- } (31)$$

Therefore, the voltage conversion ratio for the boost is:

$$R(D) = \frac{V_0}{V_{in}} = \frac{1}{1-D}\text{----------------}(32)$$

Consequently, from the above equations, a DC switch model converter is built and implemented using MatLab/Simulink. The proposed model is implemented as shown in Figure. 15

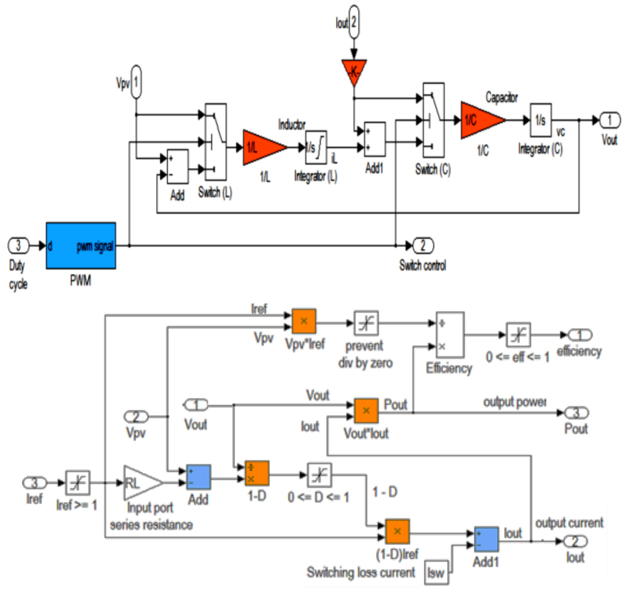

Figure 15. Subsystem implementation of the DC/DC converter model with (a) Duty cycle control (b) Input current reference (Natsheh&Albarbar 2011).

B. The DC/AC Inverters

A DC/AC switching inverter is developed, As shown in Figure. 16

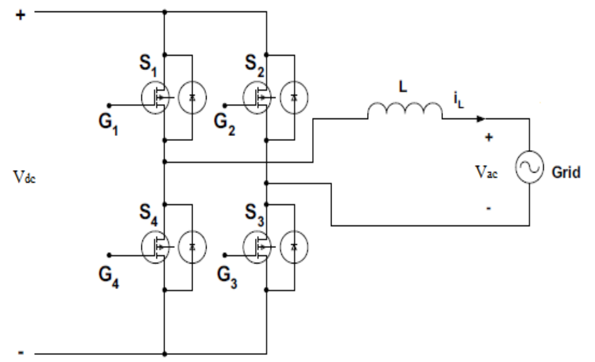

Figure 16. DC/AC switching inverter

The basic operation of the DC/AC switching inverter is to generate AC waveform from the DC signal, by operating each pair of switches S1-S3 and S2-S4 alternately with their duty cycle for each switching period. By applying net volt-seconds to the inductor over one switching period, the AC output voltage can be calculated as follow:

$$V_L = \frac{1}{T_S}\int_0^{T_S} V_L(t) = D(V_{dc} - V_{ac}) + (1 - D)(-V_{dc} - V_{ac})\text{--------}(33)$$

$$(2D - 1)(V_{dc} - V_{ac}) = 0 \text{ ------------}(34)$$

Therefore, the voltage conversion ratio for the inverter is:

$$\mathrm{R(D)} = \frac{\mathrm{V_o}}{\mathrm{V_{in}}} = 2\mathrm{D} - 1\text{---------------}(35)$$

With a voltage conversion ratio equal to (2*D*-1), an AC averaged switch model inverter is built and implemented using MatLab/Simulink (Natsheh&Albarbar 2012), to convert the direct current into alternating current, at a switching frequency greater than the AC line frequency (50Hz - 60Hz). Losses are included due to output-port series resistance and input-port switching loss current.

The proposed model is implemented as shown in Figure 17

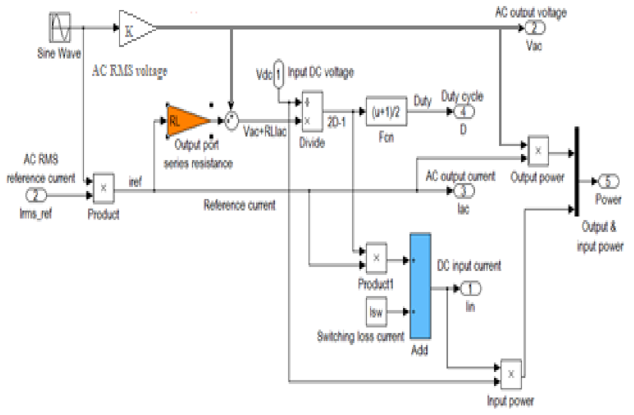

Figure 17. Subsystem implementation of the DC/AC inverter mode

7. Hybrid Power Systems Controller Based on Artificial Intelligence

Due to intermittent natural energy resources and energy resources seasonal unbalance, a PV-wind hybrid electrical power supply system was developed for many remote locations where a conventional grid connection is inconvenient or expensive. Due to the high nonlinearity characterizing the PV-Wind hybrid system it would be impractical to develop rigorous mathematical model and at the same time obtain a simple and effective controller Artificial intelligence (AI) techniques are becoming useful as alternate approaches to conventional techniques or as components of integrated systems. They have been used to solve complicated practical problems in various areas and are becoming more and more popular nowadays. Hybrid power systems with fuel cells and batteries have the great potential to improve the operation efficiency and dynamic response. In addition, the dynamic interaction between the load demand and the renewable energy source can lead to, critical problems of stability and power quality, that are not very common in conventional power systems. Therefore, managing flow of energy throughout the proposed hybrid system is essential to ensure the continuous power supply for the load demand.

This chapter will present an optimized adaptive management strategy for power flows in stand-alone hybrid power systems. The method offers an on-line energy management by a hierarchical controller between three energy sources comprises photovoltaic panels, wind turbine, and battery storage. The proposed method includes a MPPT controller in the first layer, to achieve the maximum power point (MPP) for different types of PV panels; two different techniques will be presented (P&O and neural network). In the second layer, an advance fuzzy logic controller will be developed to distribute the power among the hybrid system and to manage the charge and discharge current flow for performance optimization. Finally in the third layer, smart controllers are developed to maintain the stability of battery set points to reach best performance. Figure 18 shows the proposed control structure for the hybrid generation system. Hybrid Power Systems Based on Artificial Intelligence Each layer will be explained in detail later in this chapter, but before that an overview of Artificial Intelligence will be provided.

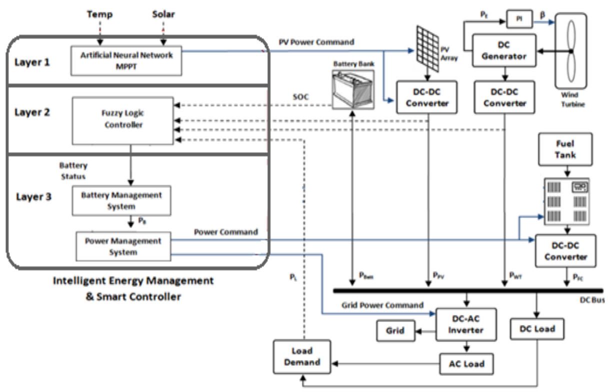

Figure 18. Block diagram of the proposed system

A. Overview of Artificial Intelligence

✓ **Artificial Neural Networks**

The artificial neural network (ANN), or simply neural network, is a machine learning method evolved from the idea of simulating the human brain. The data explosion in modem drug discovery research requires sophisticated analysis methods to uncover the hidden causal relationships between single or multiple responses and a large set of properties. The ANN is one of many versatile tools to meet the demand in drug discovery modeling. Artificial neural network has a form of multiprocessor computing system. It consists of a number of very simple and highly interconnected processors, called neurons, which are analogous to the biological neurons in the brain. Artificial Neural Networks (ANN) is a subject area that has recently emerged in the field of AI. ANN are biologically inspired, as is much of AI, based on a loose analogy of the presumed *workings* of a brain. However, if the workings of the human brain are to be simulated using ANN, clearly, drastic simplifications must be adopted. The basic model of a single neuron is shown in Figure 19.

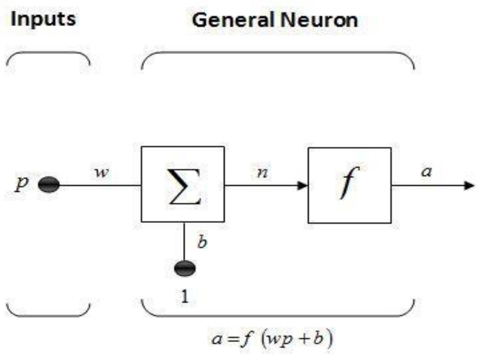

Figure 19. Architecture of a single artificial neuron

Figure 19 shows a single artificial neuron with an input vector *p* , a connection weight vector *w*, a bias *b* , an activation function *f* and an output *a* . The output (*a*) of this neuron is defined as follows (Haykin 1998):

$$a = f(\mathbf{p}\cdot\mathbf{w} - b) = f\left(\sum_{n=1}^{N} p_n \cdot w_n - b\right), \forall \mathbf{p} = \begin{pmatrix} p_1 \\ \cdot \\ \cdot \\ p_N \end{pmatrix}, \forall \mathbf{w} = \begin{pmatrix} w_1 \\ \cdot \\ \cdot \\ w_N \end{pmatrix}$$

The effect of the bias *b* on the activation function *f* is a shift to the left or the right, depending on whether it is positive or negative. The activation function *f* can be taken from a set of activation functions (as piecewise-linear function, hard limit function, sigmoid function). Some of the most popular activation functions are shown in Figure 20.

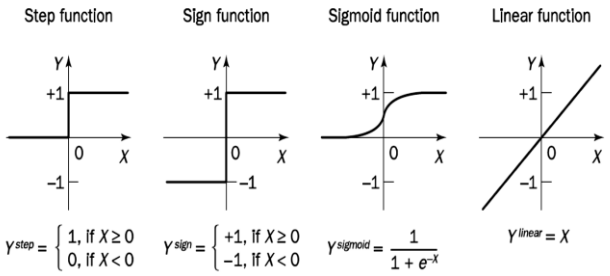

Figure20. Popular activation functions used in ANN

Using this basic model of a neuron as shown in Figure 19, different ANN architectures have evolved, among them feed-forward neural network. Feed-forward ANNs allow signals to travel in one way only; from inputs to outputs. They are extensively used in nonlinear system modeling (Hagan &Bemuth 1996). The earliest kind of neural network is a single layer perceptron network which consists of a single layer of output nodes; the inputs are fed directly to the outputs via a series of weights. In this way it can be considered the simplest kind of feed-forward network.

The next popular feed-forward model, as shown in Figure 21, is the multi-layer perceptron. It is a feed forward neural network model that maps sets of input data onto a set of outputs. It has more than two layers. The layers are fully connected. So that, every neuron in each layer is connected to every other neuron in the adjacent forward layer.

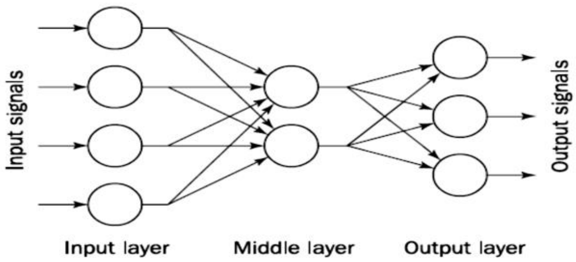

Figure 21. Architecture of a multilayer perceptron

A neuron determines its output in a way similar to Rosenblatt's perceptron (Negnevitsky 2004). First, it computes the net weighted input

$$\sum_{i=1}^{n} x_i w_i \; A - \theta \text{ ------36}$$

Where *n* is the number of inputs and *Θ* is the threshold applied to the neuron

B. Fuzzy Expert System

It is often suggested that the power of the human brain is a function of its ability to efficiently *process* imprecise information. To introduce this "fuzzy logic" to a computational setting, the critical elements are not numbers but fuzzy sets. Fuzzy sets allow for quick processing of information by association of vaguely similar patterns while providing the means to deal scientifically with subjectivity - a territory that traditional science has essentially ignored. Fuzzy logic is a type of logic that recognizes more than simple true and false values. It reflects how people think. It attempts to model our sense of words, our decision making and our common sense. Fuzzy logic is determined as a set of mathematical principles for knowledge representation based on degrees of membership rather than on crisp membership of classical binary logic (Zadeh 1965). In 1973, LotfiZadeh succeeded in outlined a new approach to analysis of complex systems (Zadeh 1973). He suggested capturing human knowledge in fuzzy rules. A fuzzy rule can be defined as a conditional statement in the form:

IF *x* is *A*
THEN *y* is *B*

Where *x* and *y* are linguistic variables, *A* and *B* are linguistic values determined by fuzzy sets on the universe of discourses *X* and *Y*, respectively.

In general, a fuzzy expert system incorporates not one but several rules that describe expert knowledge. The output of each rule is a fuzzy set, but usually we need to obtain a single number representing the expert system output.

To obtain a single crisp solution for the output variable, a fuzzy expert system first aggregates all output fuzzy sets into a single output fuzzy set, and then defuzzifies the resulting fuzzy set into a single number. Although there are several defuzzification methods (Cox 1999), the most popular one is the centroid technique. It finds the point where a vertical line would slice the aggregate set into two equal masses. Mathematically this centre of gravity can be expressed as (Negnevitsky 2004):

$$COG = \frac{\sum_{x=a}^{b} \mu_A(x)x}{\sum_{x=a}^{b} \mu_A(x)} \ldots\ldots\ldots\ldots\ldots 37$$

Where *x* is an element of the universe *X*, *A* is a fuzzy set of the universe *X*, and $\mu A(x)$ is the membership function of set *A*. In 1975, Mamdani built one of the first fuzzy systems to control a steam engine and boiler combination (Mamdani&Assilian 1975). He applied a set of fuzzy rules supplied by experienced human operators.

In general, the Mamdani-style fuzzy inference17 process is performed in four steps: fuzzification of the input variables, rule evaluation, aggregation of the rule outputs, and finally defuzzification.To shorten the time of fuzzy inference single spike, singleton, is used as the membership function of the rule consequent (Sugeno 1985). A singleton, or more precisely a fuzzy singleton, is a fuzzy set with a membership function that is unity at a single particular point on the universe of discourse and zero everywhere else. Sugeno-style fuzzy inference is similar to the Mamdani method. Sugeno changed only a rule consequent. Instead of a fuzzy set, he used a mathematical function of the input variable. The format of the Sugeno-style fuzzy rule is:

IF *x* is *A* AND *y* is *B*
THEN *z* is *f (x, y)*

Where *x*, *y* and *z* are linguistic variables, *A* and *B* are fuzzy sets on universe of discourses *X* and *Y*, respectively, and *f(x, y)* is a mathematical function.

The most commonly used zero-order Sugeno fuzzy model applies fuzzy rules in the following form:

IF *x* is *A* AND *y* is *B*
THEN *z* is *k*
Where *k* is a constant.

In this case, the output of each fuzzy rule is constant. In other words, all consequent membership functions are represented by singleton spikes.

The result (crisp output) is then obtained by finding the weighted average of these singletons.

It was found (Negnevitsky 2004) that Mamdani method is widely accepted for capturing expert knowledge. It allows us to describe the expertise in more intuitive, more human-like manner.

C. MPPT PV Control Systems

The fact that the output of the PV system is dependent upon the solar irradiance and temperature. In order to get maximum power from the solar panels the Maximum Power Point Tracking (MPPT) controllers can play an important role in photovoltaic systems, they have to operate at their maximum power point (MPP) despite the changes in the environment conditions. Maximum Power Point Tracking (MPPT) which significantly increases the efficiency of the solar photovoltaic System. There are different MPPT control methods used for solar PV systems, Incremental conductance(IC), Perturb and observe(P&O), Constant Current method, Constant Voltage method, Fuzzy Control, and Neural Network Control.

Furthermore, the solar irradiation is unpredictable, which makes the MPP of the PV module change continuously, as shown in Figure 22.

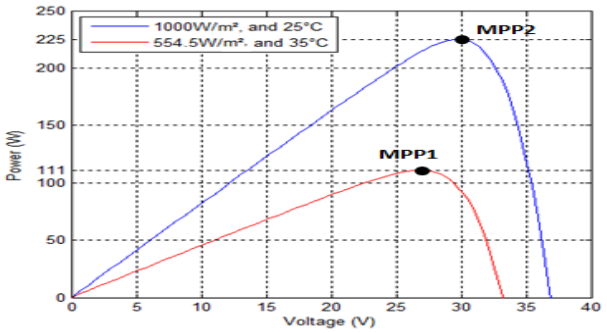

Figure 22. MPP of a PV module under different conditions

Hence tracking the maximum power point (MPP) of a photovoltaic array is an essential part of a PV system. As such, many maximum power point tracking (MPPT) techniques have been developed and implemented (Esram& Chapman 2007). 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 module characteristics and is easy to implement with analogue and digital circuits.In the literature there are two methods for implementing P&O algorithm: direct method (duty ratio perturbation) and indirect method (reference voltage/current perturbation). In the direct methods, the MPP is searched by continuously perturbing the duty cycle of the DC-DC converter. Although the simplicity is the main feature of this method, it has a slower transient response compared to the indirect method and worse performance at rapidly changing irradiance (Elgendy et al. 2012). In this section, intelligent control technique using artificial neural network is associated to an MPPT controller in order to increase the tracking response and consequently increase the tracking efficiency.

✓ Perturb and Observe Method

The problem considered by MPPT techniques is to automatically find the optimum voltage (*VMPP*) or current (*IMPP*) at which a PV array should operate, under a given solar irradiance and temperature. Perturb and observe method is the most commonly used technique because of its simplicity and ease of implementation (Natsheh&Albarbar 2011). It requires two inputs: measurement of the current (*Ipv*) and measurement of the voltage (*Vpv*). The P&O algorithm operates by periodically perturbing (incrementing or decrementing) the PV array terminal voltage or current, and comparing the PV output power with the previous one. If it is positive the control system moves the PV array operating point in the same direction; otherwise, it is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way. Figure 23 shows the flow chart of P&O algorithm. . The advantage of using this method to track MPP is that it is more efficient than the I&C method in a way that it is able to correctly locate the operating point of the PV array. There is a tradeoff between the power efficiency and reliability of tracking MPP. Since the I&C method will move away from the power operating point under rapidly changing light condition and not be able to go back the maximum operating point quickly, this will lead to the inefficient use of the PV array and hence this affects the whole system performance of tracking MPP.

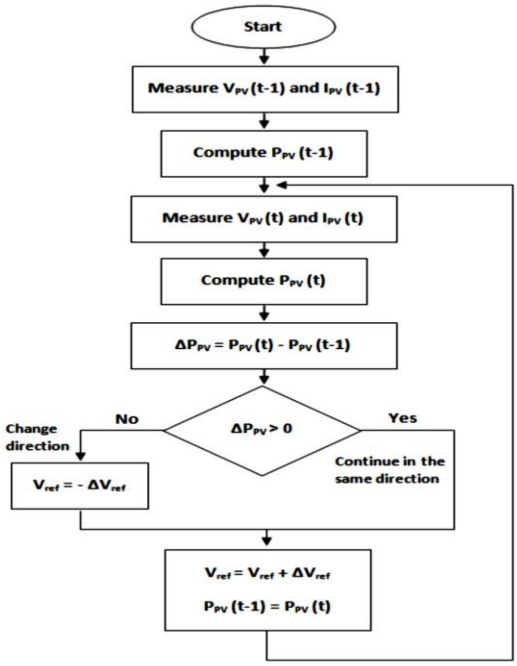

Figure 23. P&O algorithm flow chart

The main problem of this method can be seen when solar radiation rapidly change. As illustrated in Figure 24, starting from an operating point A, if atmospheric conditions stay approximately constant, the voltage perturbation (ΔV) will bring the operating point to B and the perturbation will be reversed due to a decrease in power.

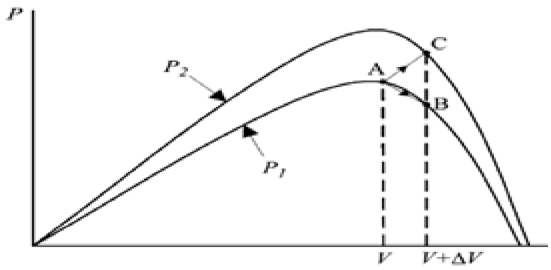

Figure 24. Divergence of P&O from MPPT

Furthermore, P&O technique may cause many oscillations around the MPP, and this slows down the response of the system. Hence, to remove power fluctuates and to keep the load voltage stable, different controller has been used along with the P&O.

✓ **Artificial Neural Network Method**

A neural network is an artificial representation of the human body that tries to simulate its learning process. In other words, ANN is an adaptive system that changes its structure based on internal or external information that flows through the network. The aim of using ANN here is to optimize the response of the MPPT, in order to increase the tracking efficiency. Figure 25 shows the structure of the proposed PV control system.

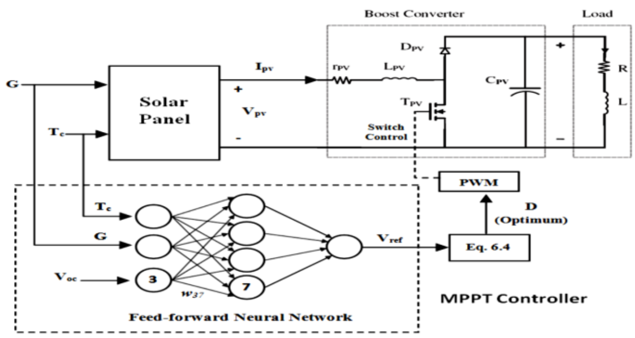

Figure 25. shows the structure of the proposed PV control system

As shown the neural network control (NNC) is used to estimate the PV array operating voltage (V_{ref}) which corresponds to P_{max}at any given solar radiation and cell temperature. It consists of three layers. The input layer is composed of three nodes in inputs that are; the solar radiation (S), cell temperature (T_c) and the cell's open circuit voltage (Vo_c) at a 25°C and 1kW/m^2. The hidden layer composed of four nodes whose function of activation is hyperbolic tangent sigmoid transfer function. The output Hybrid Power Systems Energy Management Based on Artificial Intelligence layer is composed of one node that is the optimum operating voltage (V_{ref}) whose function of activation is of linear type.

III. RESULTS & CONCLUSION

In this chapter the simulation results of the proposed hybrid system and its control strategy shown in Figure 18 will be discussed. Here, P&O algorithm is proposed MPPT controller system. The total power of the solar power plant and wind Turbine are shown in figure 26 (a) and (b).

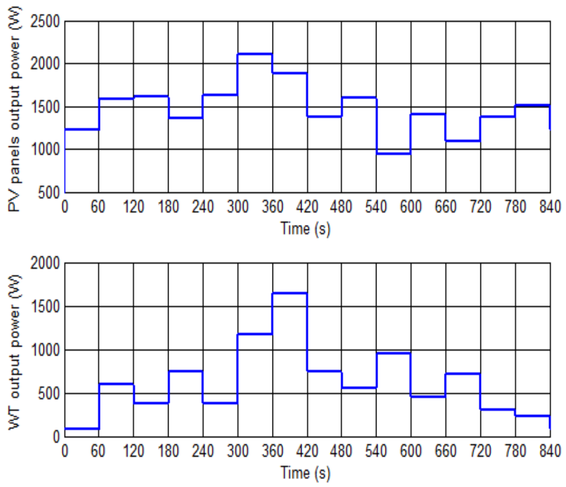

Figure 26 (a) Total power of the solar power plant (b) Total power of the wind Turbine

The figure. 27 and 28 illustrates the voltage waveform and current measured at the bus bar.

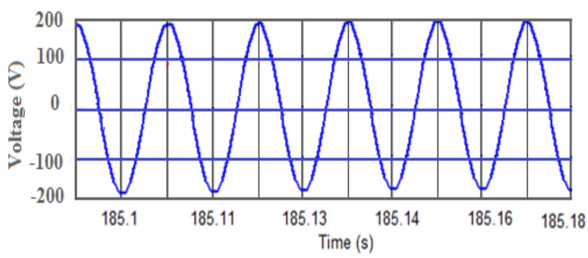

Figure 27. Voltage waveforms at load side

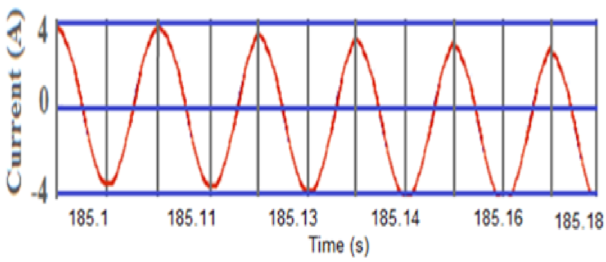

Figure 18. Current waveforms at load side

This paper presented the modeling of a hybrid solar-wind energy system with battery storage using Matlab/Simulink. This application is useful for analyze and simulate a real hybrid solar-wind energy system connected to a local grid. The blocks like wind model, solar energy model conversion and load are implemented and the results of simulation are also presented. Hybrid power generation system is good and effective solution for power generation. People should motivate to use the non-conventional energy resources. It is highly safe for the environment as it doesn't produce any emission and harmful waste product like conventional energy resources. It is cost effective solution for generation. It only need initial investment. It has also long life span. Overall it good, reliable and affordable solution for electricity generation

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