Artificial Intelligence based Battery Power Management for Solar PV And Wind Hybrid Power System

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Abstract— This paper proposes an approach for the hybrid solar photovoltaic and wind power system in Battery management for stand-alone applications with Artificial Intelligence. In general, Solar and wind energy are utilized as leading sources of energy and battery unit is considered as storage element to meet out the load demand. Loads are considered based on the priority. Ratings of hybrid energy system components such as solar PV, wind generator, battery unit, power electronic converter, etc., are optimally selected based on the rating of load. Fuzzy logic and Neural network are the tools being used here to obtain the maximum utilization of battery. A simulation model with MATLAB/Simulink for the hybrid power system has been developed. Considering power supply variation in Solar and Wind Hybrid Power system (SWHP) caused due to disturbed power supply from wind turbine generator and solar cells, fuzzy-PID-NN control is brought into it. The main components model of SWHP is established and simulation of fuzzy-PID-NN control is being presented, analyzed and compared. The final result of simulation indicates an effective utilization of battery.

Keywords- fuzzy logic; neural network; solar photovoltaic; wind power; battery management

INTRODUCTION

Many Countries count on coal, oil and natural gas to supply most of their energy needs due to tremendous increase in population growth rate. But reliance on fossil fuels presents a big problem. Fossil fuels are a finite resource. Eventually, the world will run out of fossil fuels, or it will become too expensive to retrieve those that remain. Fossil fuels also cause air, water and soil pollution, and produce greenhouse gases that contribute to global warming. Renewable energy resources, such as wind, solar and hydropower, offer clean alternatives to fossil fuels. They produce little or no pollution and they will never run out. SWHP has a bright application to face electric demand in the near future. It can raise power supply reliability and reduce the system cost according to local environment condition and load characteristics of residents [1].

For stand-alone SWHP, lead-acid batteries play a vital role as an energy storage unit. Even though batteries are the weaker section in the overall system, they are in need of certain initial investment of equipment. As the management of charging/discharging in storage battery directly affects the quality of power supply in SWHP since electric energy from wind turbine generator and solar cells has obvious fluctuation. It makes the system great demand to electric power management. Therefore, it is significant to study power management of batteries in detail [2].

Conventional control theories do not have good performance for them. In this paper, the combination of fuzzy control and traditional PID control is presented along with Neural Network to solve the problem of battery management in Solar and Wind Hybrid Power system. And simulation result of the fuzzy and NN control system is compared at the end [3].

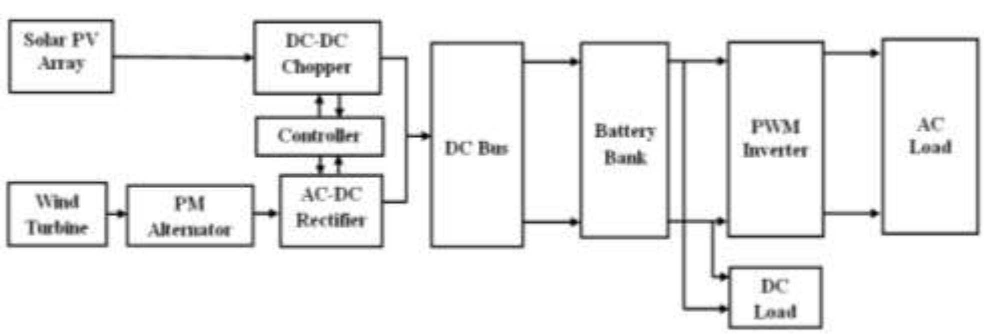


Fig. 1. Block Diagram of SWHP

SYSTEM DESCRIPTION

The SWHP is made up of solar photovoltaic array, wind turbine generator, controller with the combination of PID/fuzzy/Neural Network, storage batteries, Rectifier, chopper, inverter, etc. as shown in Fig. 1. Rectifier used in wind Turbine line is to convert AC into DC. Chopper used in Solar PV line is to convert variable DC into constant DC. Then it is connected to batteries through charge controller. Here battery will ensure reliability of the power system for all climatic conditions. Batteries will charge when the power generation from wind and solar PV system is in excess and it will discharge when the power generation from wind and solar PV is not enough to meet the load demand.

Further battery makes the voltage of power supply steady. Fuzzy intelligence and NN controller are used to switch and regulate working state of batteries, so as to operate alternately in the state of charging or discharging. Thus the stability and continuity of power supply is improved. For the AC loads, PWM inverter is used to convert DC from battery into AC.

SYSTEM MODEL

A. Wind turbine generator model

According to aerodynamics principle, output power characteristic of wind turbine is described as follows [1,2] considering the main components of a wind turbine for modeling purposes consist of the turbine rotor, a shaft and gearbox unit, an electric generator, and a control system.

$$P_i = \frac{1}{2}\rho\pi\lambda C_p(\lambda,\beta)v^3R^2 \quad (1)$$

Where C_P is a constant denotes wind power utilization coefficient, ρ is the density of air, v is the wind speed and R is the radius of wind turbine blades. The tip speed ratio of wind turbine is written as:

$$\lambda = \frac{R\omega}{v} \quad (2)$$

Where ω is the wind turbine angular speed and the aerodynamic torque can be expressed as:

$$T_a = \frac{1}{2}\rho\pi C_T(\lambda,\beta)v^2R^3 \quad (3)$$

Where $C_T(\lambda,\beta)$ is the torque coefficient which is given by

$$C_T(\lambda,\beta) = \frac{1}{\lambda}C_P(\lambda,\beta) \quad (4)$$

The fitting functions of $C_P(\lambda,\beta)$ is obtained by:

$$C_P(\lambda,\beta) = C_1(\frac{C_2}{\lambda_i} - C_3\beta - C_4)e^{\frac{C_5}{\lambda_i}} + C_6\lambda \quad (5)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (6)$$

Where C_1,C_2....C_6 are the undetermined coefficient according to characteristic of wind turbine.

B. Photovoltaic cells model

The equivalent circuit of solar cell, composed of photo-generated current source, internal series resistance and parallel resistance, is shown in Figure 2.

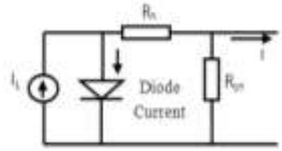


Fig. 2. Equivalent circuit of single photovoltaic cell

The relationship between the output voltage V and the load current I of a PV cell or a module can be expressed as

$$I = I_L - I_0(e^{\frac{q(V-IR_S)}{nkT}} - 1) - \frac{(R_S I + V)}{R_{sh}} \qquad (7)$$

Here I_L is the generated photocurrent under a given intensity, I_0 the saturation current of the diode, q the charge of an electron, K the Boltzmann's constant, n the ideality factor for a p-n junction, T the temperature rise, R_s and R_{sh} are the series and shunt resistance of the solar cell respectively.

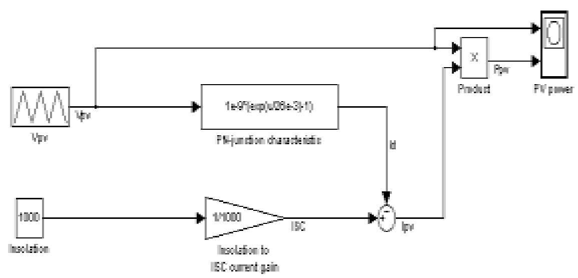
The saturation current I_0 varies with corresponding temperature according to equations:

$$I_o = C_D T^3 e^{(\frac{-eE_G}{nkT})} \qquad (8)$$

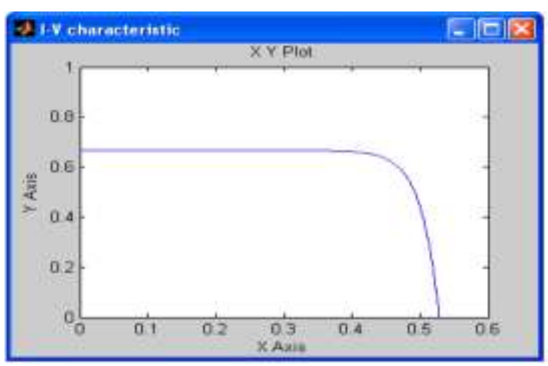
$$I = 5.46 * 10^{-3} E_{tp}[1 + 0.001(T - 298)] \qquad (9)$$

Where C_D represents the diffusion capacitance, E_G represents the band-gap energy of the semiconductor used in the PV panel and E_{tp} represents the intensity in mW/cm^2.

Dynamic models for the main components in the proposed hybrid system have been developed in MATLAB/Simulink platform. The developed model is utilized for a PV cell to investigate the system performance of intelligent power management strategy and it is shown in fig.3.



(a)



(b)

Fig. 3. Simulation of single photovoltaic cell (a) Simulation block diagram (b) I-V characteristic curve

C. Storage battery model

Thevenin Equivalent model of the storage battery is used in this paper as shown in Fig. 4. It comprises of voltage source Vs, battery internal resistance of R_s, equivalent parallel resistance and capacitance of R and C respectively between parallel plate electrodes. As all the parameters are constant, it may be an approximate battery model only.

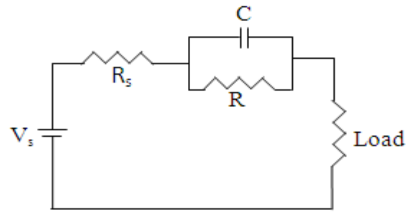


Fig. 4. Thevenin equivalent of battery circuit

FUZZY-PID-NN CONTROL

A. Control method

Closed-loop control system with double loop is used in battery charge/ discharge of SWHP. Inner- loop is taken as charge current loop, PI control is adopted. Outer-loop is taken as charge voltage loop. It brings to the whole system; fuzzy-PID-NN is used to control respectively realized by a switch. In an initial stage of charge, PID control is adopted for realize the large current and fast charge. But when 80% to 90% of the battery capability is reached, charge mode is fuzzy logic/Neural network, and charge voltage is invariable. Schematic control system diagram is as shown in Fig.5

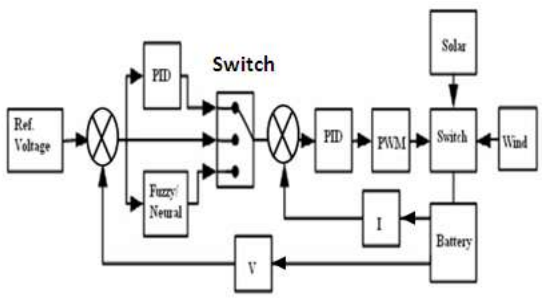


Fig. 5. Schematic control system diagram.

B. Design of Fuzzy controller

Fuzzy controller system is associated with artificial intelligence. Fuzzy variables of controller include the input variable e, Δe and the output U. e is taken as the deviation of reference and sampling voltage of batteries. Δe is taken as the change rate of change of e. U is taken as charge variable of batteries. Their domain is defined as follows:

$$e \in [-4,4],$$

$$\Delta e \in [-2,2],$$

$$U \in [20,24]$$

The corresponding fuzzy subset is as below:

$$e \in [NB, NM, NS, ZR, PS, PM, PB]$$

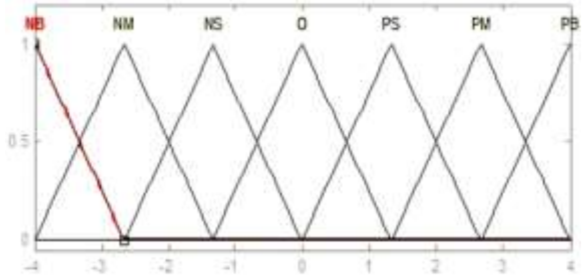
$$\Delta e \in [NB, NS, ZR, PS, PB]$$

$$U \in [NB, NM, NS, ZR, PS, PM, PB]$$

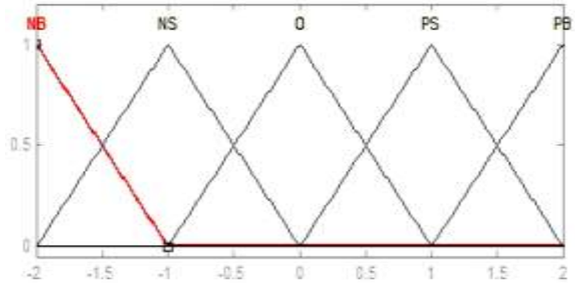
There are several methods to design a fuzzy controller. The design of fuzzy controller involves formation of membership function and rule base. Here, we have taken the rule base proposed by Mamdani for the simulation of the Fuzzy controller. These rules are shown in Table1. The table is read in the following way: If the error is negative small (NS) and the change of error is positive big (PB), then the control action is positive medium (PM).

e Δe	NB	NM	NS	ZR	PS	PM	PB
NB	NB	NB	NB	NB	NS	ZR	PS
NM	NB	NB	NB	NM	NS	ZR	PS
NS	NB	NB	NM	NS	ZR	PS	PM
ZR	NB	NM	NS	ZR	PS	PM	PB
PS	NM	NS	ZR	PS	PM	PB	PB
PM	NS	ZR	PS	PM	PB	PB	PB
PB	ZR	PS	PM	PB	PB	PB	PB

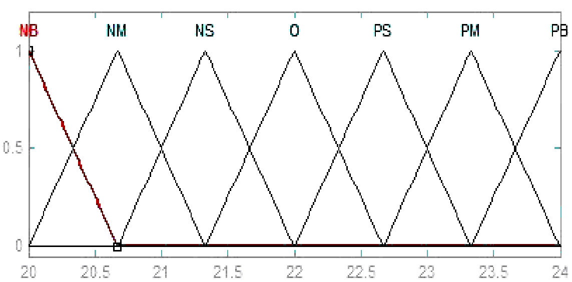
Table I: Rule base Fuzzy Controller (Mamdani)



Input variable **"e"**



Input variable **"Δe"**



Output variable **"U"**

Fig.6. Membership function of fuzzy linguistic variables
(a) Membership function of e
(b) Membership function of Δe
(c) Membership function of U

In Matlab/Simulink, fuzzy variables, domain and fuzzy control rule are written in Fuzzy Logic Toolbox. The fuzzy inference system is Mamdani. The membership function of fuzzy variables is shown in Fig. 6.

C. Design of Artificial Neural Network

The Neural networks used here are basically layers of neurons connected in cascade, with one input layer, one or more hidden layers and one output layer. The input layer is the sensory organ for the Artificial Neural Networks. Each neuron in a layer is connected to an adjacent neuron layer with different weights. Each neuron, except for the neurons of the input layer, receives signals from the neurons of the previous layer, weighted by the interconnect values between neurons. Consequently the output layer produces an output signal.

The choice of the number of hidden layer nodes is a compromise between efficiency and accuracy. Satisfactory results are obtainable if the number of hidden layer nodes is equal to the number of output nodes. NN structure is utilized to compute the maximum battery power utilization by developing MATLAB/Simulink for solar and wind energy sources, which consists of solar PV, wind turbine coupled to a permanent magnet DC generator, battery storage unit, PID controller and PWM inverter.

Feed forwarded NN is trained to compute the efficient battery utilization of hybrid model of SPV and Wind Turbine for the given solar radiation and wind velocity. Fig 7 shows the trained ANN in MATLAB/Simulink environment.

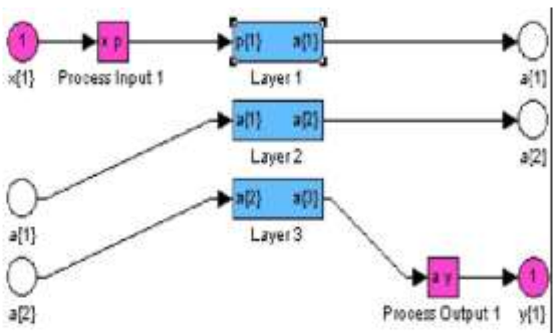


Fig 7. Trained NN model with Input, hidden and output Layer for SPV and wind Turbine system in MATLAB/Simulink platform

SIMULATION RESULT

A series of simulation results are presented in this section based on the developed mathematical model of hybrid power systems using both Fuzzy logic and Neural network. The simulation parameters are listed in the Table II of Appendix. Simulink of the whole control system using fuzzy logic & Neural network is shown in Figure.8&9 respectively. The simulation results of hybrid system with fuzzy and Neural network is given in Figure. 10. It illustrates the output AC line voltage & rectified DC voltage of wind turbine generator and MOSFET gating input pulse of battery charge/discharge for a particular time period. From the figure, we understood that output AC line voltage & DC voltage of wind turbine is same for fuzzy logic as well as Neural network. But we can see the difference in gating input pulse of battery charge/discharge for fuzzy logic and NN.

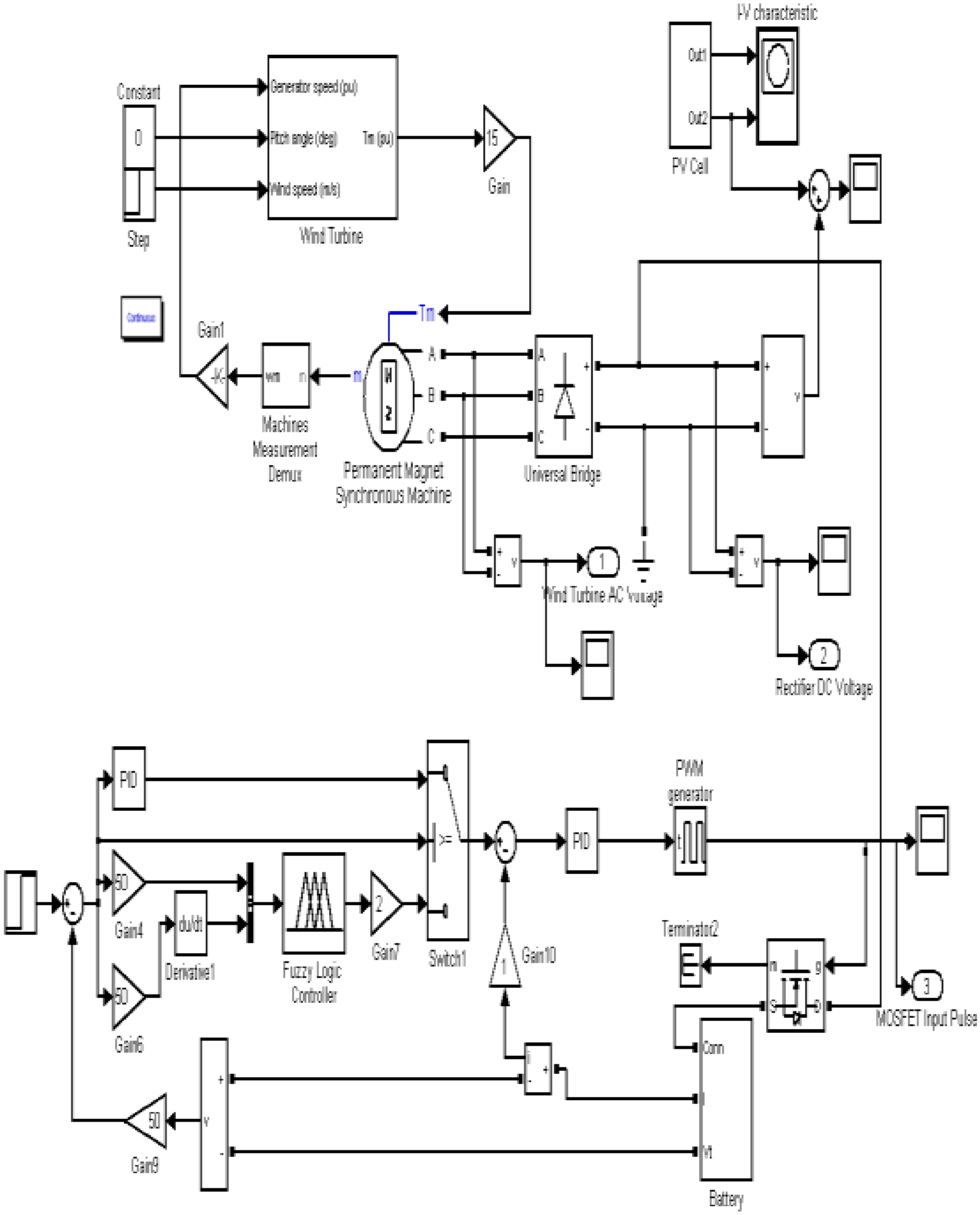


Fig. 8. Simulink of the whole control system using fuzzy logic

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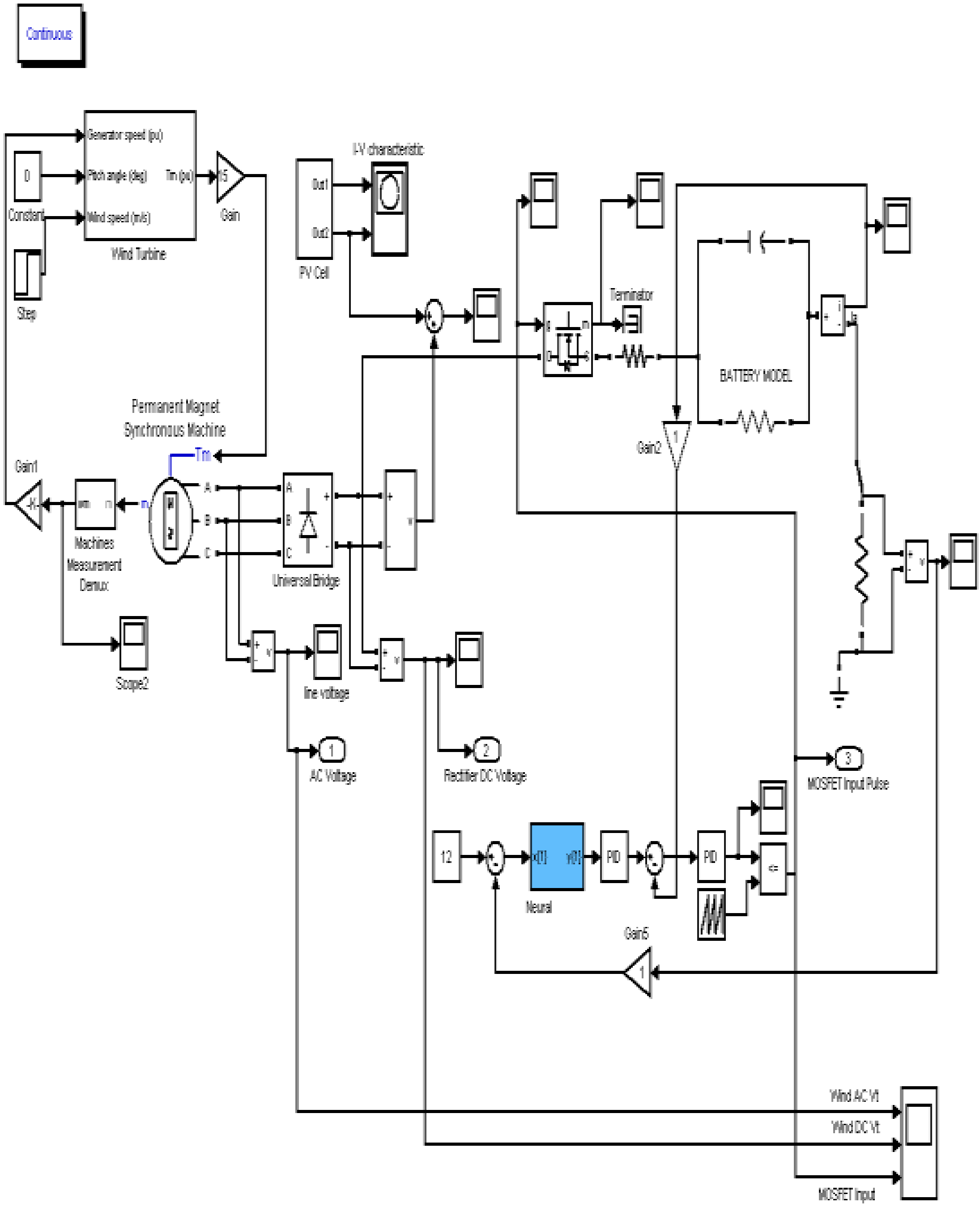
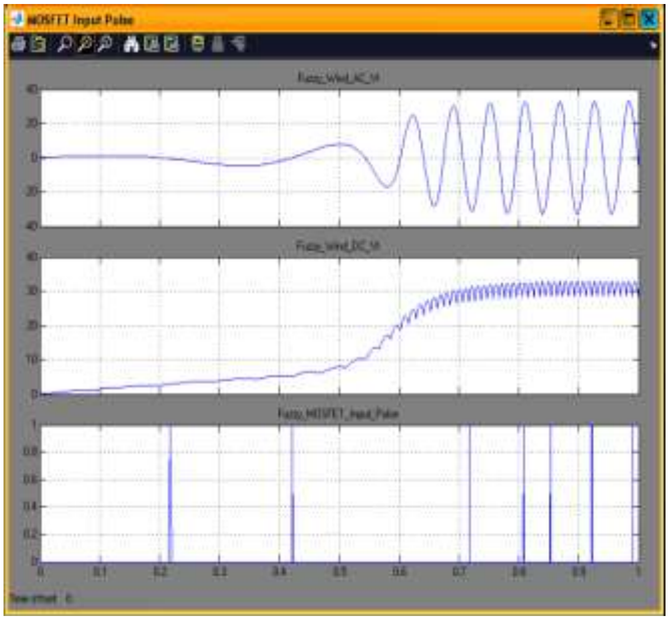
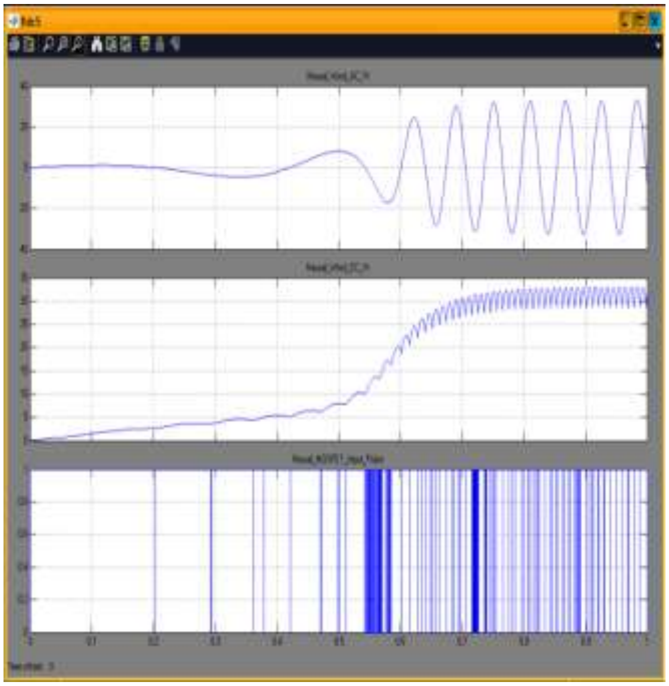


Fig. 9. Simulink of the whole control system using Neural network



(a)



(b)

Fig. 10. (a) Simulation results of Fuzzy logic Control (b) Simulation results of Neural network System

CONCLUSION

The simulation results of fuzzy-NN control based intelligent battery power management is discussed. Comparatively Neural network shows an improved version, compared to fuzzy logic in battery power management in the way of charging/discharging for a particular time period in SWHP. The proposed scheme can be applied to other similar power generation systems. It may be an approximate simulation as the model of battery is quite complicated. The simulation results will be more ideal if the model of battery is improved. Simulation result achieved from MATLAB/Simulink platform shows the effectiveness of the developed utilization of battery with improved charging/discharging characteristic to meet large demand of industry/ domestic load.

APPENDIX

TABLE II. SPECIFICATIONS OF SWHP COMPONENTS

Wind Turbine	
Parameter	Value
Ratted output power	300 W
Ratted wind speed	12 m/s
Pitch angle	0
Solar PV	
Light intensity	100 mW/cm^2
Atmospheric temperature	25 ^0C
n	1.11
Rs	0.141 ohm
Rsh	2000 ohm
C_D	10
Eg / eV	1.13
200 Ah discharge Lead –Acid Battery	
Nominal capacity	200 Ah
Nominal voltage	12 V
Max charging current	60 A

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