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Soft Computing Techniques FUZZY and ANN based MPPT for Grid Tied PV

Muhammad Shahid
Assistant Professor
Eee Department, Al-Falah University
Dhauj,Faridabad,India

Hawa Singh
Mtech(Power System) Student
Eee Department, Al-Falah University
Dhauj,Faridabad,India

***Abstract*— Photovoltaic system (PV) are affected by fast changing irradiation and due these characteristics, there is an operating point in which the maximum available power of PV is obtained. Artificial Neural Network(ANN) and Fuzzy logic controller (FLC) is the artificial intelligent based maximum power point tracking (MPPT) method for obtaining the maximum power point (MPP). This paper presents a detailed comparative study between ANN Controller and FLC in DC-DC boost converter. Both method is implemented using ANN and Fuzzy logic toolbox of MATLAB and detailed model and results is carried out in SIMULINK. The both proposed method is able to track the maximum power point in minimum time with small oscillations and the highest system efficiency . This investigation provides valuable results for all users who want to implement the reliable ANN and fuzzy logic subset for their works.**

Keywords*— *Maximum power point tracking; Artificial Neural Network; Fuzzy Logic Controller; Photovoltaic system, DC-DC Boost converter.

I. INTRODUCTION

Due to increase in global warming and depletion of fossils fuel, concern about alternate source of energy is the major goal of power sector research. Sun is the large source of energy for our mother earth. And with the invention of photovoltaic system, sun's energy can be directly transform into electrical energy. Photovoltaic is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity[1,2,4,5].

The main problems of PV systems is weather conditions such as dirt, changing irradiation, temperature variation and other factors. The change in irradiation have most effect on P-V and I-V characteristics photovoltaic(PV) system where P,V and I are PV output power, voltage and current. The crossing point between I-V curve of the PV panel and load-line in I-V characteristics is called operating point. The point of PV panel that power has maximum value is called maximum power point(MPP). Operating point is change due to fast change in irradiation. Due to MPPT controller MPP can be tracked in minimum time in order to minimize the power loss.[3]

The method to find MPP can be classified into two categories: Conventional method and soft computing method. Perturb and observe (P&O), Constant current (CI), Constant Voltage (CI), Incremental Conductance (IC) are conventional method and soft computing method include Fuzzy logic, Artificial neural network(ANN), Artificial Neuro fuzzy interference system(ANFIS),Particle swarn optimization(PSO), Genetic algorithm(GA), Biogeography based optimization(BBO) and so on[8,9,14,15].

The rest of the paper is organized as follows. In Section II mathematical modelling of PV cell and PV system array is discussed. 100KW PV array is connected with grid with inverter is discussed in section III. MPPT technique based on Fuzzy logic and ANN is described in section IV. In section V results based on both technique and their comparisons is discussed.

II. PHOTOVOLTAIC SYSTEM

The schematic diagram of a three-phase grid-connected PV system which is main focus of this paper is shown in Fig. 1. The considered PV system consists of a PV array, a DC link capacitor C, a three-phase inverter, a filter inductor L and connected to the grid with voltage e_a, e_b, e_c. In this paper, the main target is to control the voltage v_{dc} across the capacitor C and to make the input current in phase with grid voltage for unity power factor by means of appropriate control signals through the switches of the inverter. The mathematical model of the system is presented in the next subsections

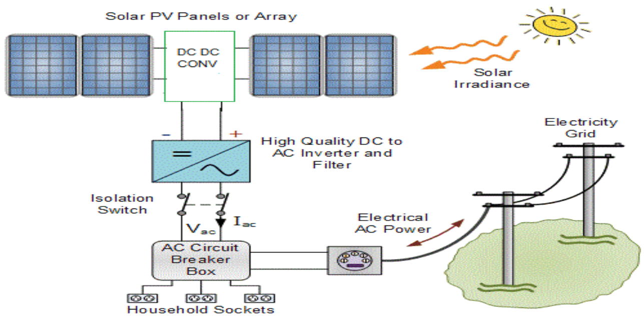

Fig 1.Three phase grid connected PV system

PV Cell and Array Modeling

PV cell is a simple p-n junction diode which converts the irradiation into electricity. Fig. 2 shows an equivalent circuit diagram of a PV cell which consists of a light generated current source I_L, a parallel diode, shunt resistance R_{SH} and series resistance R_S. In Fig. 2, I_{ON} is the diode current which can be written as

$$I_{ON} = I_S[\exp[\alpha(V_{PV} + R_S i_{PV})] - 1] \quad (1)$$

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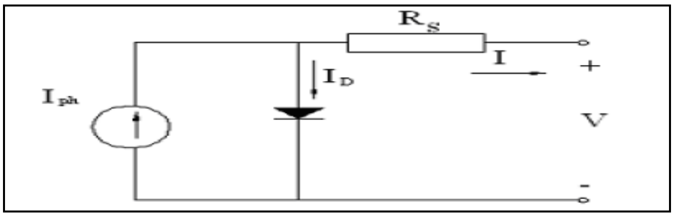

Fig 2 PV cell Equivalent Diagram.

where $\alpha=\frac{q}{AkT_c}$, k = 1.3807 × 10^{-23} JK^{-1} is the Boltzmann's constant, q = 1.6022 × 10^{-19} C is the charge of electron, Tc is the cell's absolute working temperature in Kelvin, A is the p-n junction ideality factor whose value is between 1 and 5, I_S is the saturation current, and V_{PV} is the output voltage of PV array which in this case is the voltage across C, i.e., v_{dc}. Now, by applying Kirchhoff's Current Law (KCL) , the output current (i_{PV}) generated by PV cell can be written as,

$$i_{PV}=I_L-I_S[\exp[\alpha(V_{PV}+R_S i_{PV})]-1]-V_{PV}+\frac{R_S i_{PV}}{R_{SH}} \quad (2)$$

The light generated current I_L depends on the solar irradiation which can be related by the following equation:

$$I_L=\frac{[I_{SC}+k_i(T_C-T_{ref})]S}{1000} \quad (3)$$

where, I_{SC} is the short circuit current, S is the solar irradiation, k_i is the cell's short circuit current coefficient and T_{ref} is the reference temperature of the cell. The cell's saturation current Is varies with the temperature according to the following equation [4]:

$$I_s=I_{RS}[\frac{T_c}{T_{ref}}]^3 exp\left[\frac{qE_g}{Ak}\left(\frac{1}{T_{ref}}-\frac{1}{T_c}\right)\right] \quad (4)$$

where, E_g is the band-gap energy of the semiconductor used in the cell and IRS is the reverse saturation current of the cell at reference temperature and solar irradiation.

Since the output voltage of PV cell is very low, a number of PV cells are connected together in series in order to obtain higher voltages. A number of PV cells are put together and encapsulated with glass, plastic, and other transparent materials to protect from harsh environment, to form a PV module. To obtain the required voltage and power, a number of modules are connected in parallel to form a PV array. Fig. 3 shows an electrical equivalent circuit diagram of a PV array where N_s is the number of cells in series and N_P is the number of modules in parallel. In this case, the array ipv can be written as

$$i_{pv}=N_pI_L-N_pI_S\left[\exp\left[\alpha\left(\frac{v_{Pv}}{N_s}+\frac{R_si_{Pv}}{N_P}\right)\right]-1\right]-\frac{N_P}{R_{sh}}\left(\frac{v_{Pv}}{N_s}+\frac{R_si_{Pv}}{N_P}\right) \quad (5)$$

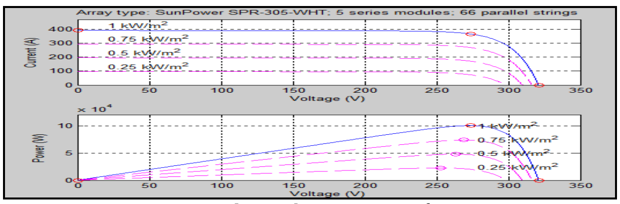

Fig 3. I-V and P-V characteristics of PV array

III . THREE-PHASE GRID CONNECTED PV SYSTEM AND DC-DC BOOST CONVERTER MODELING

For a control scheme to be effective for three-phase grid-connected PV system, some details of the system is essential. The details of any system can best be described by the mathematical model. In state-space form, Fig. 1 can be represented by the following equations [6]-[15]:

$$i_a=-\frac{R}{L}i_a-\frac{1}{L}e_a+\frac{v_{PV}}{3L}(2k_a-k_b-k_c) \quad (6)$$

$$i_b=-\frac{R}{L}i_b-\frac{1}{L}e_b+\frac{v_{PV}}{3L}(2k_a-k_b-k_c) \quad (7)$$

$$i_c=-\frac{R}{L}i_c-\frac{1}{L}e_c+\frac{v_{PV}}{3L}(2k_a-k_b-k_c) \quad (8)$$

where, k_a, k_b, and k_c are the input switching signals. Now, by applying KCL at the node where DC link is connected, we get

$$v_{PV}=\frac{1}{C}(i_{PV}-i_{dc}) \quad (9)$$

But the input current of the inverter i_{dc} can be written as [15], [20]

$$i_{dc}=i_ak_a+i_bk_b+i_ck_c \quad (10)$$

which yields,

$$v_{PV}=\frac{1}{C}i_{PV}-\frac{1}{C}(i_ak_a+i_bk_b+i_ck_c) \quad (11)$$

The real power delivered to the grid can be written as

P=3/2EdIq (13)

DC-DC Boost Converter

The boost converter is a famous switched-mode converter where its produced output voltage is bigger than dc input voltage in extent. The ideal and simple form of this converter is shown in Figure 4 that is including switch and diode for switching the system.

When the switch is ON (first subinterval) diode, capacitor, and load are connected to ground and the inductor is charged through the input voltage source (V_g). In this subinterval, load is supplied by capacitor and the inductor current is increased. When the switch is off (second subinterval), the load is supplied by inductor current and additionally recharges the capacitor.

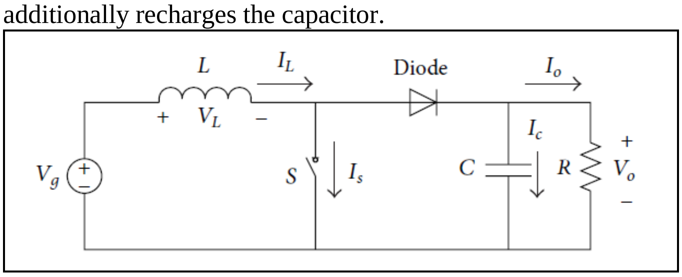

Fig 4 DC-DC Boost converter

Using the principles of voltage and ampere second balance [3], the voltage conversion ratio M(D) and the converter elements values are obtained. The voltage conversion ratio is defined as a proportion of the output voltage to input voltage of boost converter [3]:

$$M(D)=\frac{V}{V_g}=\frac{1}{1-D}$$

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where V_g and V are the input and output voltages of the boost converter and D is duty cycle that is defined as a ratio of the ON duration to the switching time period and it is adjusted by controller.

It can be noticed that when the boost converter is connected to PV panel, by increasing the duty cycle, the input voltage and current are decreased and increased, respectively, and it leads to shifting the operating point to the left side of the P-V curve of the PV panel. In a similar manner, by decreasing the duty cycle, the input voltage and current are increased and decreased, respectively, and it leads to shifting the operating point to the right side of the P-V curve of the PV panel.

IV. MPPT CONTROLLER

MPPT techniques employing new FLC and ANN are modeled and simulated in MATLAB/SIMULINK.

A. Fuzzy Logic Controller(FLC)

Fuzzy logic control is a range-to-point or range-to-range control. The out of a fuzzy controller is derived from fuzzifications of both inputs and outputs using the associated membership functions. It deals with imprecise inputs therefore it does not need an accurate mathematical model for handling nonlinearity.

The FLC uses two inputs such as error E and change in error CE at sample time k, which are defined by equations (17) and (18) and while the output of FLC is the duty cycle D.

$$E(K) = \frac{P(K)-P(K-1)}{V(K)-V(K-1)} \quad (14)$$

$$CE(K) = E(K) - E(K-1) \quad (15)$$

The FLC can be divided into four categories which include fuzzification, fuzzy interference, rule base and defuzzification as shown in fig below:

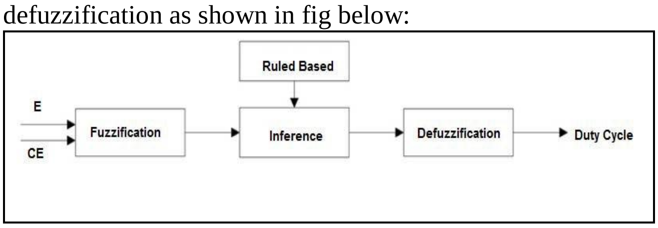

Fig 5. Fuzzy Logic Controller

1. Fuzzification

The process of making crisp values fuzzy based on knowledge base, by computing their membership to all linguistic terms of fuzzy sets. These linguistic terms are expressed in different fuzzy levels: PB (positive big), PS (positive small), ZE (zero), NB (negative big), NM (negative medium) and NS (negative small). The fuzzy set of input variable E, CE and output variable D is presented in Fig. 8, 9 and 10.

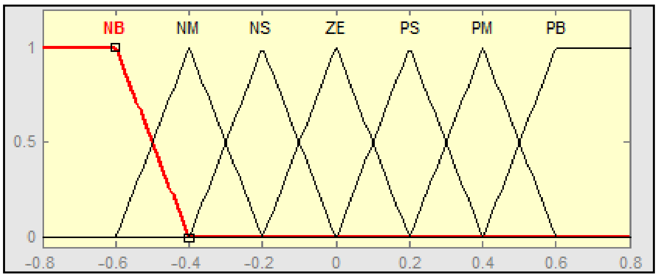

Fig. 6. Membership function for input variable E

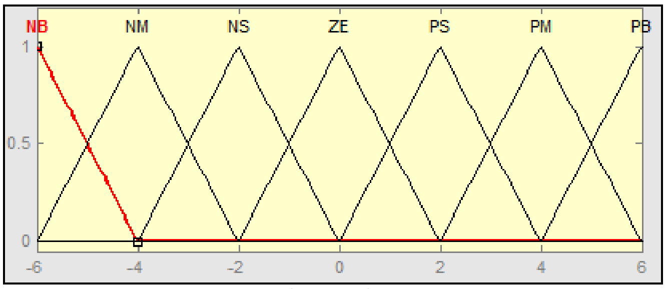

Fig.7.Membership function for input variable CE

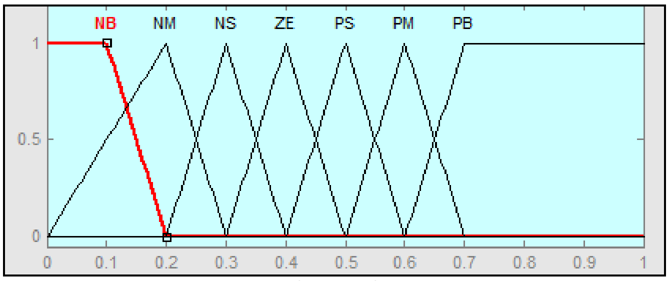

Fig. 8. Membership function for output variable D

2. Rule base and Inference Engine:

Rule base are if-then rules that associates the fuzzy output to the fuzzy input based on the operator's intelligence to achieve a good control. The fuzzy subset on forty nine rules with different membership functions is shown in Table II. The fuzzy inference is the process of mapping an input space to an output space by computing the firing strength of each rule based on the degree of match of the defined fuzzy sets by using "max-min" inference technique. In this study Mamdani's fuzzy inference method has been used.

E				CE			
	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	ZE	ZE	NB	NB	NB	NB
NM	ZE	ZE	ZE	NM	NM	NM	NM
NS	NS	ZE	ZE	NS	NS	NS	NS
ZE	NM	NS	ZE	ZE	ZE	PS	PM
PS	PM	PS	PS	ZE	ZE	ZE	ZE
PM	PM	PM	PM	ZE	ZE	ZE	ZE
PB	PB	PB	PB	ZE	ZE	ZE	ZE

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3. Defuzzification:

The process of conversion of fuzzy set to a crisp output value that best represents the linguistic result obtained from the fuzzy inference process.

B. Artificial neural network controller

An artificial neural network consists of a number of interconnected processing elements called neurons. These neurons are connected by links of adjustable weights to pass signals forward to other neurons. They are best suited for the approximation of nonlinear photovoltaic systems [6].Neural network used for this work is Feed-Forward network shown in Fig. 4. The proposed ANN is using the PV voltage and PV current as the input of ANN, the output is the duty cycle at which PV module tracks the MPP. Three layers of input, hidden and output layers are used in this network shown in Fig. 5. Hidden layer has twenty neurons uses tangent sigmoid activation function, while output layer uses linear activation function. The net is obtained by training (supervised) with trainlm function-Levenberg-Marquardt algorithm.

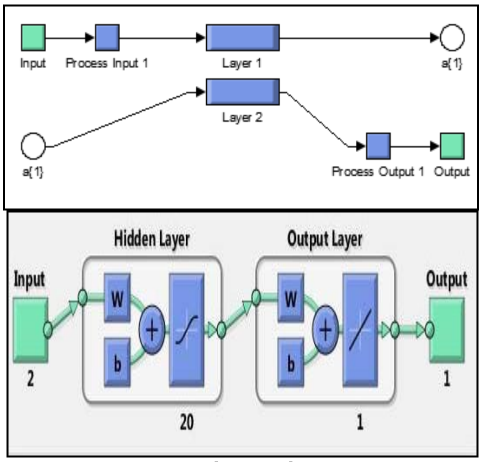

Fig. 5. Neural Network Structure

Performance function of the network is mean square error (MSE) which is given by equation (16) as below [1]:

$$E_{mse} = \sum_{k=1}^{N} \frac{1}{2}[t(k) - o(k)]^2 \qquad (16)$$

where t(k) denotes the target at sample k, o(k) is the output at sample k and N denotes the number of training patterns. The best validation performance Mean Squared Error (MSE) obtained is 0.0106 epoch 1000 is shown in Fig.

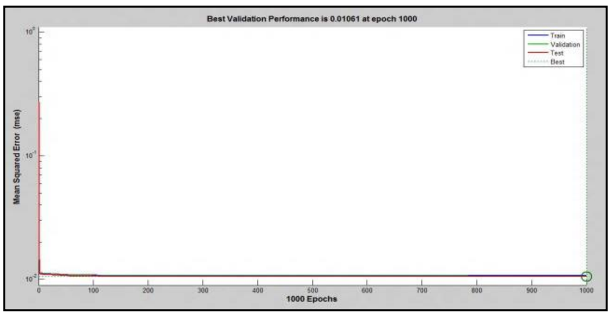

Fig. 6. Results of training error of ANN based controller

V. SIMULATIONS AND RESULTS

The MATLAB /SIMULINK model of the MPPT system consists of the PV module, MPPT controller, three phase inverter and grid. Simulation works were carried under constant and changing irradiation conditions with FLC and ANN based controller.

The important factors used to analyze performance of MPPT algorithms are oscillations, settling time, overshoot efficiency, stability and time taken to track MPP.

PV module used in this work is SunPower module (SPR- 305). The data sheet of the reference model under standard test conditions (STC) is shown in

Table III
Standard test conditions (STC)

Maximum power (Pmax)	*100.7 kW*
Voltage at MPP	54.7V
Current at MPP	*5.58 A*
Open-circuit voltage (Voc)	*64.2V*
Short-circuit current (Isc)	*5.96*
Number of cells connected in series	96

In ANN PV voltage and PV current are used as inputs while in FLC error and change in error are used as inputs and output is duty cycle which is used to drive the boost converter close to the MPP. Fig. 12 shows changing irradiation level for comparison of ANN and FLC algorithm

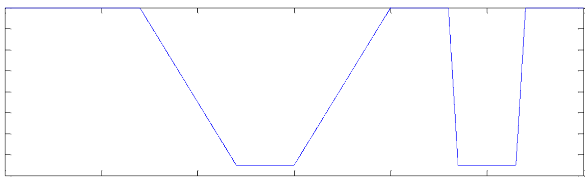

Fig11. Changing Irradiation

At constant irradiation 1000W/m2 from time 0.0s to 0.7s, ANN tracks maximum power of 100.57 kW at 0.14 s with duty cycle 0.453 while FLC tracks maximum power of 96 kW at 0.2 s with duty cycle 0.5. At constant irradiation 250w/m2 ANN tracks maximum power of 22.6 kW with duty cycle 0.485 whereas FLC tracks maximum power of 22 kW with duty cycle 0.5.

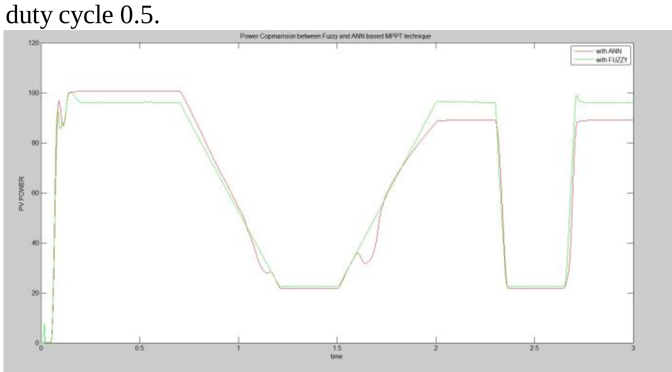

Fig 12. PV Power comparison with FLC and ANN Controller

The results discussed above is from graph shown above in fig 12.The comparison Table between FLC and ANN based on power tracking is shown in Table IV below:

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MPPT Algorithm	*Oscillations (s)*	*Settling time(s)*	*fficiency (%)*
ANN	0.138	0.132	**99.86**
FLC	**0.196**	**0.180**	**95.48**

MPPT Algorithm	*Time taken to track MPP (s)*
ANN	**0.14**
FLC	**0.20**

VI. CONCLUSIONS

In this paper artificial neural network (ANN) and fuzzy logic controller (FLC) algorithms of single-ended primary inductor converter are designed and presented. Wide range of irradiation level, constant, slow and fast changing has been discussed which contributes to the uniqueness of this work. The performance analysis of maximum power tracking (MPPT) algorithms on the basis of time taken to track maximum power point (MPP) and various important factors such as efficiency, stability, oscillations, settling time, overshoot in power and voltages before reaching MPP are done so that accurate results are obtained. This analysis shows that the response of the system when we use ANN is better than FLC as it is fast and precise in tracking MPP but with more overshooting in voltage and duty cycle during changing irradiation level. Efficiency of ANN controller is 99.86% and 98.93 kW power delivered to the grid while FLC has efficiency of 95.48% and 94.47 kW power delivered to the grid.

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