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Maximum Power Point Trackingfor single phase photovoltaic system using fuzzy logic

Mrs.P.S.Gotekar[1], Dr.S.P.Muley[2]
AsstProf , Professor,
Electrical Department
Priyadarshini College of Engineering
Nagpur, India
p_somkuwar@yahoo.com

Dr.D.P.Kothari[3]
Fellow (IEEE),
Dean (Research),J.D College of Engineering,
Nagpur,
India

***Abstract*—A modeling technique for maximum power point tracking using fuzzy logicof PV systemis presented in this paper. The main focus of this paper is to simplify modeling of single phase PV system. Then a fuzzy logic based maximum power point has been implemented. Thiswill help to track power efficiently.**

Keywords—FuzzyLogic,MPPT,PV model, MATLAB/SIMULINK.

I. INTRODUCTION

In India the application of solar energy is increasing rapidly. In 2017 the solar grid had a total output of 16.20 GW.India hasincreased its solar output to 12,289 MW on 31 March 2017[1-2]. Around 3 GW of solarenergy was added in 2016 and 5.525 GW in 2017.This is the highest solarcapacity added of any year.This is due to the reason that average price of solarelectricity dropped to 18% which is below the average price of its thermal power counterpart[3-5].

The main component of any solar system is photovoltaic module. The characteristic I-V equation, is a non-linear equation with number of parameters classified as follows: those provided by manufacturer,those known as constants and the ones which mustbe calculated. Sometimes, researchers develop simple methods. So the unknown parameters cant be calculated.They are assumed to be constant. For example, in [6] the series resistance Rs was included, butnot the parallel resistance. In some literature these two have been identified more accurately.

The main objective of this paper is to target the PVmodule in a complex system. In a PV cell apart from series and parallel resistance, ideality factor, photocurrent, diode current have also been considered. A PV module comprises of several PV cells connected in series /parallel or combination of both as per the required capacity.Aim is to obtain the maximumpower more accurately, which is the close to theexperimental result.

IIModelling of PV cell

A solar cell is the electronic device which converts sunlight into electricity. Combination of PV cells connected in series and parallel forms a PV module. A voltage of PV module is selected such that it is compatible with the voltage of the battery. Single diode model or a two diode model may be used to represent a PV cell. Due to simplicity single diode model has been selected in this paper.

A.Design of PV Cell

The five parameters on which the solar irradiation and cell temperature depends are Io, Rs, Rp, Iph, and ideality factor(refer Table1).

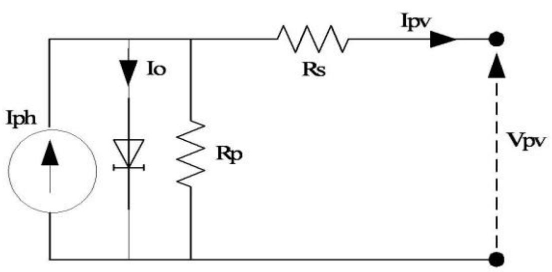

Fig.1. Single diode model of PV cell.

Figure 1 shows practical model of PV cell. This model is also called as five parameter model (Io,ideality factor,Rs,Rp,Iph) and has following properties:

* Rsis introduced in series to consider voltage drop and internal losses due to the flow of current.

* Rp is introduced to consider leakage current to ground when the diode is reverse biased.

B: Mathematical equations

To predict the behavior of the solar cell under varying atmospheric conditions mathematical modeling is required. The key factor that affects the accuracy of the simulation is the accurate representation of nonlinear characteristics of the PV system modeling .

$$I_{pv} = N_p * I_{ph} - N_p * I_o * [\exp(\frac{q * V_{pv} + I_{pv} * R_s}{N_s * A * K * T}) - 1] \quad (1)$$

PV saturationcurrent is given by,

$$I_o = I_{rs} * \left[\frac{T}{T_r}\right]^3 \exp\left[q * \frac{E_g}{Ak\left[\frac{1}{T_r} - \frac{1}{T}\right]}\right] \quad (2)$$

Reverse saturation current is given by,

$$Irs = \frac{Iscr}{\left[\exp\left(q\frac{Voc}{NsKAT}\right) - 1\right]} \quad (3)$$

PV photocurrent Iph is,

$$\mathrm{Iph} = [\mathrm{Iscr} + \mathrm{Ki}(\mathrm{T} - \mathrm{tr})] * \frac{\mathrm{S}}{1000} \quad (4)$$

A constant introduced is given by,

Co = Ns.K.A.T (5)

C. MATLAB/Simulink Implementationof PV module.

To implement the equations (1-5), differentmatlab functions have been used. Different blocks represent different mathematical equations for Iph, Ipv, Io and Co. Input parameters chosen are Np, Ns, temperature, while output parametersare output power of PV module, current and voltage of PV module. Figure 2 represents matlabsimulink model of PV module.

III. MPPT System

As the direction of the Sun changes there is change in insolation level therefore the output power of PV module also changes. The peak value of the product of voltage and current represents the maximum power point Pmax of the solar module. The solar module should always beoperated in this region so as to extract the maximum power for a given input conditions. For this purpose variouspower point algorithms are used. It is desirable that PV module operates near maximum power point.Many MPPT algorithms had been proposed in the past. Most commonly used algorithms are Perturb and Observe,Incremental conductance method, neural network and fuzzy logic method.

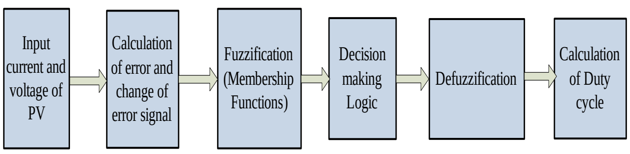

Fig 3. Block diagram of fuzzy logic controller.

The input parameters are chosen as : input current and voltage of PV module. The output will be the duty cycle.

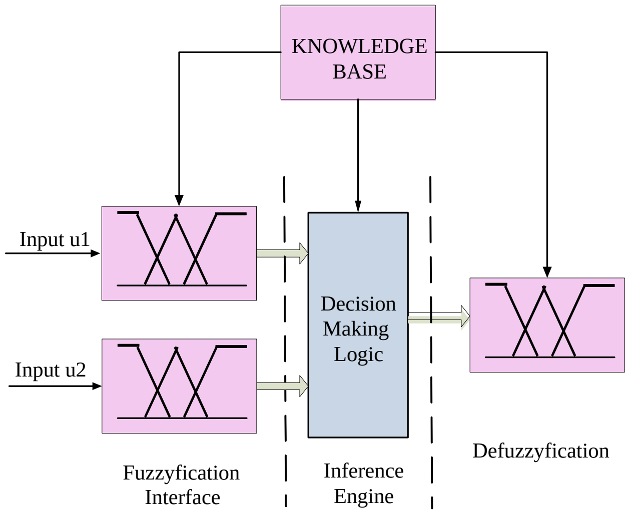

Fig 4. Fuzzy Logic algorithm

From fig 4 the basic concept of fuzzy algorithm is clear.
The equations associated with calculation of error and change of error have been given below.

Fuzzification and DecisionMaking logic:

$$\mathrm{E(k)} = \frac{\Delta \mathrm{P}}{\Delta \mathrm{I}} \quad (6)$$

$$C\mathrm{E(k)} = \mathrm{E(k)} - \mathrm{E(k-1)} \quad (7)$$

$$\Delta \mathrm{I} = \mathrm{I(k)} - \mathrm{I(k-1)} \quad (8)$$

$$\Delta \mathrm{V} = \mathrm{V(k)} - \mathrm{V(k-1)} \quad (9)$$

$$\Delta \mathrm{P} = \mathrm{P(k)} - \mathrm{P(k-1)} \quad (10)$$

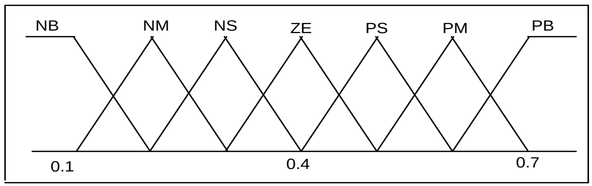

Figure 6: Membership function for error

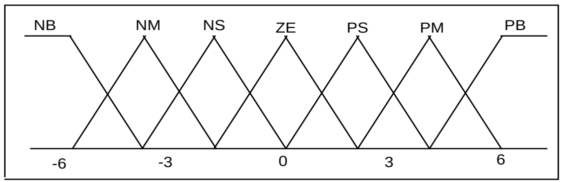

Figure 7 : Membership function for change of error

For the input variables, error and change of error and duty cycle, triangular membership functions have been chosen..

Rules for MPPTfor the fuzzy logic controller have different subsets. In all forty nine rules are written to operate the fuzzy logic controller. For the improvement in accuracy of the system forty nine rules are used.

Design of Boost Converter

The input to the boost converter is through photovoltaic panel. Fig.8 indicates basic circuit of boost converter. Vpv is input voltage, L is inductor, D is diode and load resistance is R. The equation to calculate duty cycle is given by ,

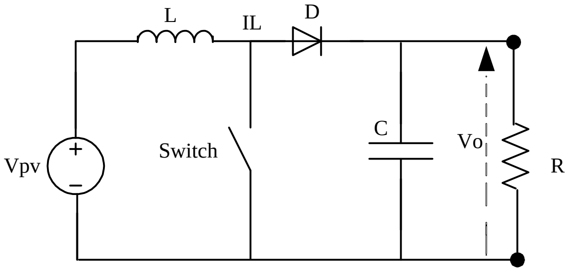

Fig 8. Basic circuit of Boost Converter

M= Vo/Vpv (11)

Simulation and Results

The complete system includes collecting data pertaining theirradiation. Irradiation between 200W/m2 to 1000 W/m2 was considered.A PV module and fuzzy based MPPT to obtain maximumpower output is designed.The versatile and efficient modeling technique of PV modulemodeling and to implement the fuzzy technique in a simple way to control the output with a fuzzy logic based MPPT system has been implemented. In all forty nine rules were designed to increase power output. The rules are indicated by table 2.The main objective here was to reduce the complexity of PV system.

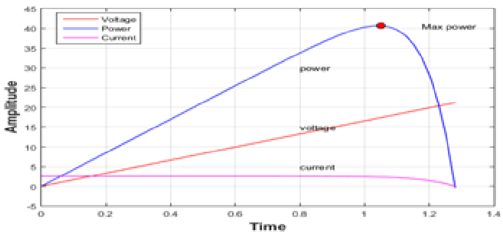

Fig 9.Variations in current, voltage and power, I(pv), V(pv), P(pv)

This paper presents a method used to optimize theenergy extraction in a photovoltaic (PV) power system. The maximum power of a PV module changes with temperature, solar irradiation. To increase efficiency, PV systems use a Maximum Power Point Tracker (MPPT) to continuously extract the highest possible power and deliver it to the load. It is observed that the system completes maximum tracking point successfully. Figure 9 and 10 gives response for variation in current, voltage and power with respect to time for irradiation of 1000W/m^2 and 800 W/m^2. With the increase in irradiance the poweroutput increases.

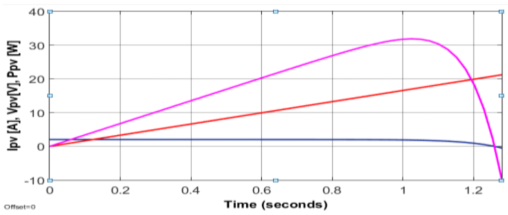

Fig10.Variations in current, voltage & power, I(pv),V(pv), P(pv)

TABLE I: NOMENCLATURE

Sr. No	*Symbols*	*Description*
1	Vpv	Output voltage of PV module
2	Tr	Reference temperature
3	Iph	Light generated current in a PV module
4	A	Ideality factor =1.6
5	q	Electron charge = 1.6 x 10^{-19} C
6	Iscr	Short circuit current
7	Ki	Short circuit current temperature coefficient
8	Eg	Band gap for silicon =1.1 eV
9	Kv	Open circuit voltage temperature coefficient
10	Ipv	Output current of a PV module
11	T	Module operating temperature in Kelvin
12	Io	PV module saturation current
13	k	Boltzman constant =1.3805 x10^{-23} J/K
14	Rs	Series resistance of PV module
15	Rp	Parallel resistance of PV module
16	S	PV module illumination (W/m^2)
17	Ns	Number of cells in series
18	Np	Number of cells in parallel
19	Voc	Open circuit voltage

TABLE II:THE FORTY NINE SET OF FUZZY RULES

E	CE						
	NB	NM	NS	ZE	S	M	B
NB	ZE	ZE	ZE	ZE	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	S	M
S	M	M	S	S	ZE	ZE	ZE
M	M	M	M	ZE	ZE	ZE	ZE
B	B	B	B	ZE	ZE	ZE	ZE

TABLE III:POWER OUTPUT

Sr. no	**Irradiance [W/m^2]**	**I [A]**	**V [V]**	**P[W] observed**	**P [W] calculated**
1	200	0.47	14.83	7.04	6.97
2	400	0.93	16.11	15.05	14.98
3	600	1.41	16.53	23.35	23.30
4	800	1.83	16.95	31.85	31.69
5	1000	2.34	17.38	40.68	40.66

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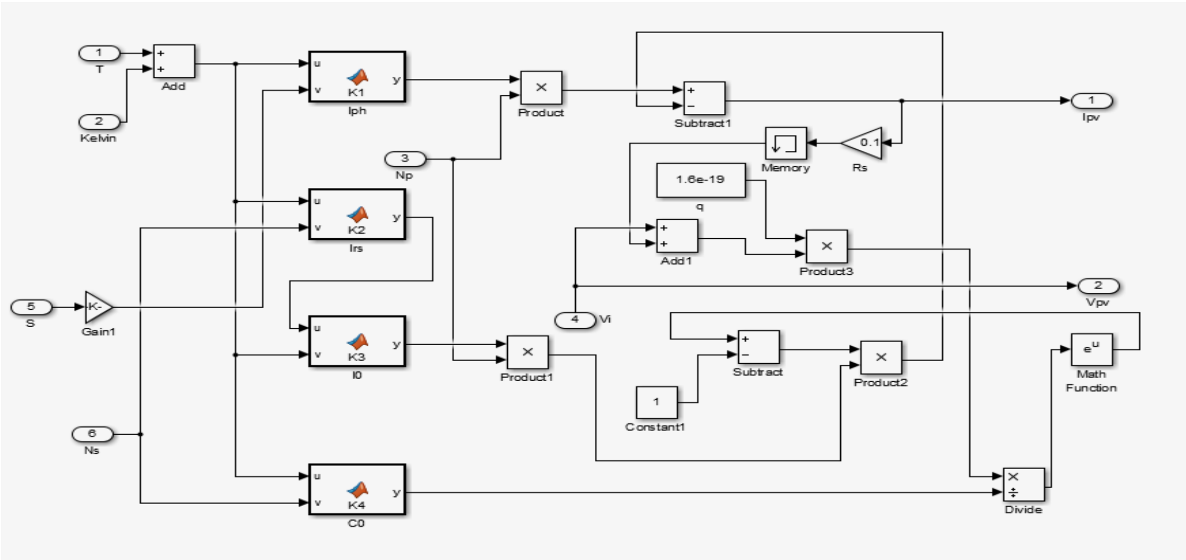
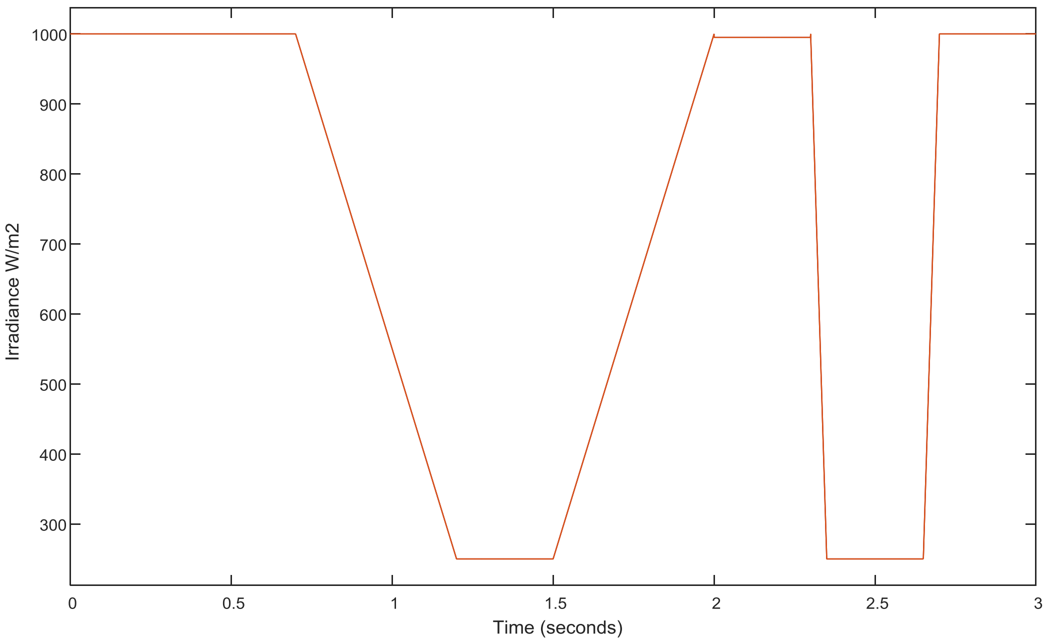
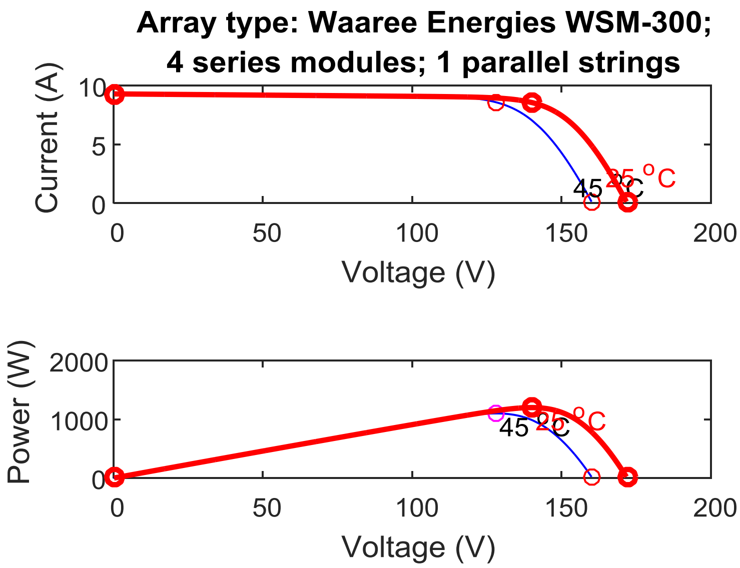


Fig.2. Simulink model of PV module


Irradiance W/m2
Time (seconds)
1000
900
800
700
600
500
400
300
0
0.5
1
1.5
2
2.5
3


Array type: Waaree Energies WSM-300;
4 series modules; 1 parallel strings
Current (A)
Voltage (V)
Power (W)
Voltage (V)
45 °C
25 °C
0
50
100
150
200
10
5
0
2000
1000