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Solar photo-voltaic mathematical modeling and its maximum power extraction using P&O based FLC method

Ajay Kumar Pandey, Shashikant Tripathi, Anjaney Kumar Pandey

Mahatma Gandhi Chitrakoot Gramodaya Vishwavidyalaya, Chitrakoot, Satna, M.P

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Abstract

Objectives: This article presents the mathematical modeling of solar photovoltaic(SPV) and its maximum power point (MPP0 extraction from perturb and observe (P&O) based method. The maximum power is extracted from SPV in order to fulfill the load demand

Methods: The integration of solar photovoltaic with the DC microgrid causes the improper variation in voltage and power in the system. It begins with the modeling of solar photovoltaic cell and peak power is extracted from perturb and observ(P&O) method. Further P&O method is extended in the support of fuzzy logic controller(FLC). The two methods like P&O based FLC and P&O methods are used for realizing the change in power deviation and change in voltage deviation.

Findings: The research finds the change in power and change in voltage under the variable solar irradiations. The modeling of SPV helps to find the important parameters of the system. The maximum power is extracted from SPV with the assistance of P&O based FLC and P&O methods which will also use for switching of boost converter. The performance parameters like change in voltage and change in power have been improved a lot with P&O based FLC.

Novelty: The deviation in power and voltage are found to be minimum with P&O based FLC in contrast to P&O methods by extracting the maximum power from SPV.

Keywords: solar photovoltaic, boost converter, P&O based FLC, MPP, voltage deviation, power deviation

1. Introduction

In the past few years, solar photovoltaic systems have become increasingly popular as a highly effective source of energy for power generation all around the world. Utilizing photovoltaic (PV) panels to produce electricity is an easy way to harness the Earth's incredible daily energy potential. However, knowledge about a solar plant's effectiveness and efficiency is required before it is installed. In order to generate electricity with PV panels and maximize the use of solar energy, the layout of maximum power point tracking (MPPT) controllers is also crucial. For both of these uses, module parameters must be extracted with the least amount of precision, simplicity, and speed. [1]

The devaluation of conventional fossil fuel sources has resulted in a significant adoption of renewable energy sources. Since photovoltaics (PV) is environmentally benign, secure, harmless, lightweight, and free, it has garnered a lot of attention among all renewable energy sources. However, the current setup and manufacturing costs are high and will gradually decrease with further research and large-scale use. Environmental elements that observe changes in power under fluctuating operation conditions determine how much power is extracted from the PV module. As a result, it is imperative to integrate auxiliary power sources such as fuel cells, diesel generators, and batteries. Both diesel generators and batteries are limited in their ability to supply backup for specific durations and all load demands, respectively.[2]

2. Methodology

To permit operations at that moment and improve the PV system's overall effectiveness, the MPPT technique looks for the maximum power point and control system. The effectiveness and steady-state error of methods using MPPT have been the subject of substantial studies. Along with recently employed methods for failure mode evaluation of PV modules, the elements influencing PV module performance, PV module deterioration modes, stress factors that cause deterioration, rapid aging tests, and current PV panel certification standard testing are also covered. In order to discover gaps in knowledge for long-term PV module dependability and to improve the PV qualification criteria for different geographical and climatic circumstances, the study's primary goal is to review existing research on the efficiency and deterioration of PV modules during outdoor operations[3-4].

A thorough analysis of mathematical modeling for simulating photovoltaic (PV) module efficiency is presented in this paper. Additionally provided are the meteorological factors that affect PV module performance. Numerous approaches to mathematical modeling, both stochastic and predictable, have been studied. In order to promote the use of algorithms that can foresee the parameters with the highest level of accuracy, this article also discusses the metaheuristic techniques employed in parameter extract of diode models of the PV equivalent circuit. Soft computing techniques are anticipated to gain greater traction and overtake different algorithms as a result of the notable growth in the processing power of desktops and personal devices[5-7].

To determine the highest possible power extraction circumstance, the connection between a direct-drive wave electricity converter's average generated power, its intrinsic mechanical resistance, and the generator's equivalent physical resistance is examined in the frequency field using a mechanical representation of direct-drive wave energy converters. Furthermore, the system's average output power curve under two-degree-of-freedom power regulation with regard to the control parameters are acquired. A maximum-power-point-tracking (MPPT) method is suggested depending on the curves' properties, and the MPPT is implemented using the hill-climbing method. Furthermore, the MPPT algorithm's flow of control and iteration formulas are given[8-10].

This study proposes a standalone hybrid power system. An smart power controller, a diesel engine, wind energy, and sunlight make up the system. The dynamic model was constructed and the whole thing was simulated using MATLAB/Simulink. An enhanced Elman neural network (ENN) for maximum power point tracking (MPPT) and a radial basis function network (RBFN) make up the smart controller, which provides a quick and steady reaction for actual power control. Our solar system uses RBFN, wherein the signal that comes out is utilized to regulate the dc/dc boost converters to produce the MPPT, while the wind turbine's pitch angle is controlled by the ENN[11-12].

This study describes the use of the firefly algorithm to construct a maximum power-point tracking (MPPT) technique for photovoltaic (PV) systems operating in partially shaded environments. Simple computing processes, quicker convergence, and low-cost microprocessor execution are the main benefits of the suggested approach. Under partial shadow, the suggested methodology is examined for two distinct PV array configurations, and its tracking efficiency is contrasted with that of the particle swarm optimization (PSO) method and the conventional perturb and observe (P&O) method under the same circumstances. Through simulation and practical research, the algorithm's enhanced tracking rapidity and effective efficiency is confirmed. Additionally, a study demonstrates how a PV system can produce more energy when partially shaded by using an artificial bee colony[13-14].

3. Modeling of solar photovoltaic cell

The effects of radiation on the solar PV array are the first step in the mathematical modeling of solar photovoltaic cells. Figure 1 depicts the solar PV array as a mix of a current source, diode, shunt resistance, & series resistance. The Solar PV array design & modeling formulae are taken from [15].

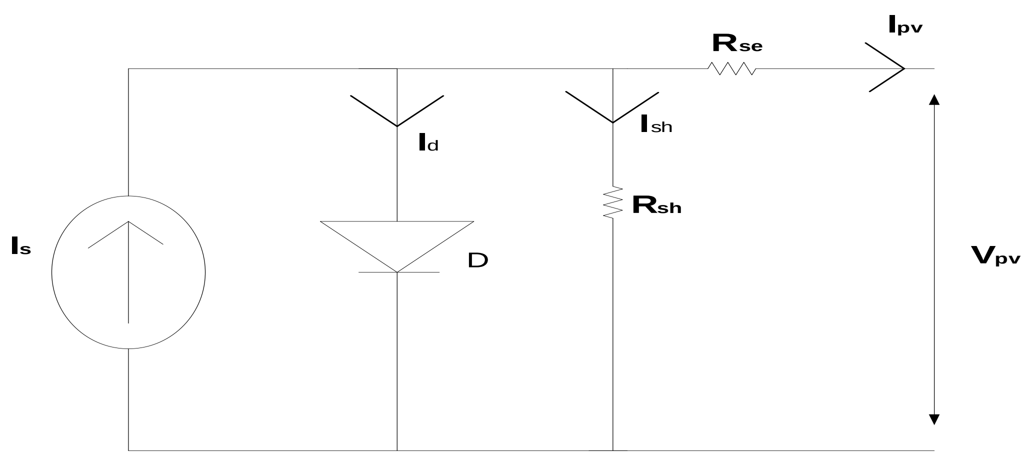

Fig.3.3 Equivalent model of Solar PV array[52]

From the Fig.1, It can be inferred that I_s is the photocurrent, I_d is the diode current, I_{sh} is the shunt resistance, I_{pv} is the output current of the solar photovoltaic cell, Rsh and Rse are the shunt and series resistance. The expression of solar PV output current is given as in Eq.1

$$I_{pv} = I_s - I_d - I_{sh} \tag{1}$$

The Eq.3.2 can be modified as shown in Eq.2

$$I_{pv} = I_s - I_o(e^{\frac{V_{pv}+I_{pv}R_s}{\eta kT}} - 1) - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \tag{2}$$

Whereas

$$I_d = I_o(e^{\frac{V_{pv}+I_{pv}R_s}{\eta kT}} - 1)$$

$$I_{sh} = \frac{V_{pv} + I_{pv} R_s}{R_{sh}}$$

Where η is diode ideality factor for SPV array, k= Boltzmann constant, T is the actual temperature of the cell in degree Celsius.

4. Maximum power extraction solar photovoltaic cell

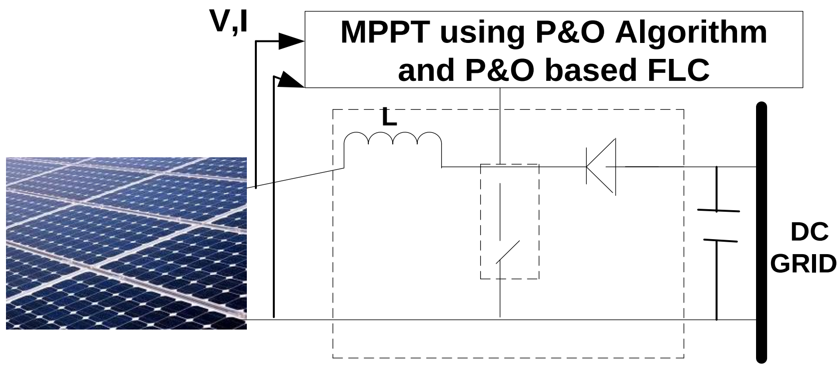

Fig.2 MPPT based boost converter

After the solar PV array has generated its maximum power, it is found that its output voltage is not enough to meet the load requirement, necessitating the installation of a boost converter to raise the output voltage. The boost conversion is connected in series with the solar PV array's output, as shown in Fig. 2. The next topic discussed is the boost converter's design.

4.3.1 Design of boost converter:

Figure 2 shows the structure of the DC-DC booster. An extra 142 V is added to the output voltage using a DC-DC boost converter. Equation 3 displays the DC-DC boost converter's design requirements.

$$L_b = \frac{V\text{pv} * D}{2 * \Delta i * fsw} \qquad (3)$$

where duty cycle (D) = 1-(Vin/V b) is represented by D. The connection Vin=V pv/1- yields an estimated D of 0.3.D is the PV output voltage from a solar PV array, fs = 10 kHz is the switching frequency, and 1.5 mH for inductance (Lb) is the input ripple current Δi, which is calculated as 10% of the input current for converter design. Equation 3 yields an inductance (Lb) value of 1.5 mH.

The output capacitor C_{dc} for this DC-DC boost converter which is given in Eq.4

$$C_{dc} = \frac{I_{ob} * D}{\Delta v * f_{sw}} \qquad (4)$$

when Iob=(Pob / Vb) is the output current. The maximum voltage output of the DC-DC boost converter is known as apparent oscillation, and its power output is known as pob. The output voltage, Vb, is 3% Vb, and the measured resultant current, Iob, is 31.25 A. The voltage that results is Vb. 700μF is the measured output condenser value (Cdc).

The minimum dc bus voltage should be twice as high as the system's phase voltage is given as in Eq.5

$$V_{dc=}\frac{2\sqrt{2}}{\sqrt{3}} * V_{in} \qquad (5)$$

The design of inductance (L_f) of VSC is given in Eq.6

$$L_f = \frac{\sqrt{3}m*V_{dc}}{\Delta i*12*h*f_s} \qquad (6)$$

If the ripple is a current value, and the value thereof is 5%, the ripple frequency f_s is switching and the voltage of the bus is 10 kHz (V dc) DC and the voltage of the bus v dc is 700 V. The L_f is 4.97 mH was measured.

There are two methods for extracting the maximum power from SPV which are discussed here one by one

4.1 MPPT from P&O algorithm

One sort of hill climbing technique is the Perturb and Observe (P&O) algorithm. The converter duty cycle, the voltage at the PV-panel output, & the voltage at the converter's standard terminals are all disrupted by the DC connection voltage in P&O. In this process, the indicators of the prior disturbance and increments are used to assess the current interruption. The course of the disruption must be altered to provide the impression that it is originating from an energy reduction, but the interruption should climb when the pull from the prior disturbance increases.

The disturbances continue until the MPPT is attained. Throughout the disruption and monitoring process, power is assessed using voltage and current sensors. Limits are displayed and the voltage is calculated using the Nth instant. By gently increasing the duty cycle numbers, the voltage & current information are evaluated at the (N+1)th instant. Between the Nth and the (N+1)th, the energy cost will be displayed. If there is a constructive shift in authority, the strategy is on the correct track.

The duty cycle has been slightly improved, thus the strategy will be applied once again in the near future. If the voltage intensity is low, the strategy takes the negative route after peak energy. If this occurs, the service cycle is reduced and the parameters for the next operation have been changed.

Case I

$\frac{dP}{dV} = 0$ The slope of the features is therefore null. At the highest level of government, the procedure is carried out. In that instance, there is no need for correction because the power delivered is the maximum value.

Case II

$\frac{dP}{dV} > 0$ The direction of the device is positive, To maximum energy use, the current and voltage readings are estimated and the duty cycle of the converter is enhanced.

Case III

$\frac{dP}{dV} < 0$ In that case, the features' slope is negative. It is now operating below its peak power.A converter's operating time will be decreased in order to get the highest energy production. They will also measure the voltage and current in order to calculate the energy. Additionally, this energy will continue for the next runs in accordance to the previous price. The process of P&O is explained through flowchart is shown in Fig.3

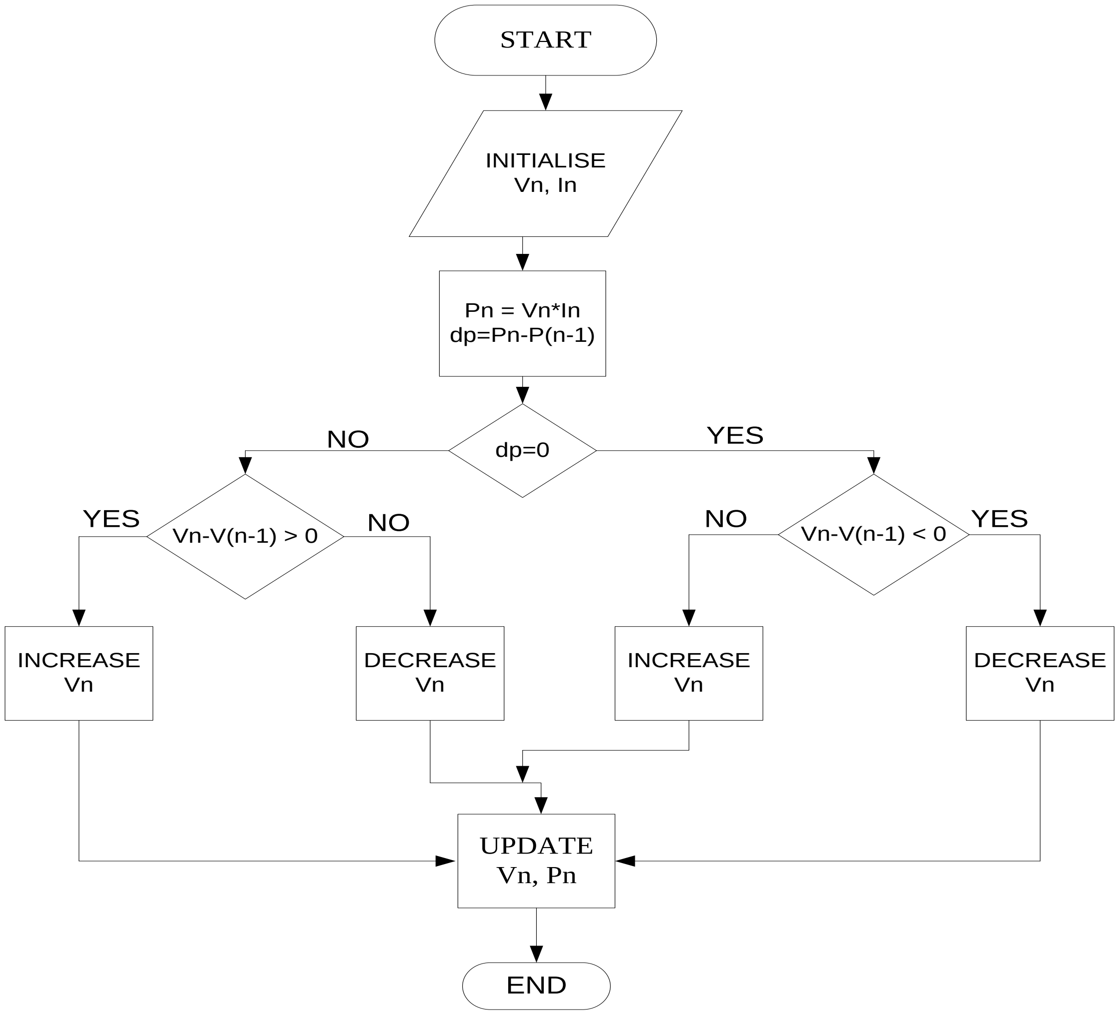

Fig.3 Flow chart of Perturb and Observe (P&O) control method

4.2 MPPT from P&O based FLC algorithm

The two inputs of FLC are error(e) and change in error(Δe) are shown in Eq.7 and Eq.8

$$e=\Delta V(t) \quad (7)$$

$$\Delta e=\Delta V(t)-\Delta V(t-1) \quad (8)$$

Table.1 fuzzy rules between two inputs

e/Δe	**NB**	**NS**	**NM**	**ZS**	**PM**	**PS**	**PB**
NB	NM	NB	NB	ZS	PB	PS	PS
NS	NM	NB	NS	ZS	PM	PM	PS
NM	NB	NS	NM	ZS	PB	PS	PM
ZS	ZS	ZS	ZS	ZS	ZS	ZS	ZS
PM	PM	PM	PB	ZS	NB	NB	NM
PS	PS	PS	PM	ZS	NM	NM	NS

PB	PM	PM	PS	ZS	PB	PS	NS

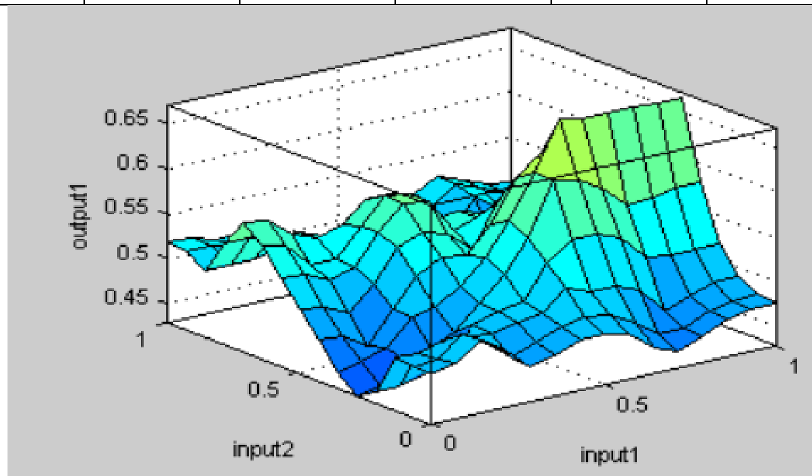

Fig.4 Surface view of fuzzy rules between inputs and output

5. Results and Discussion

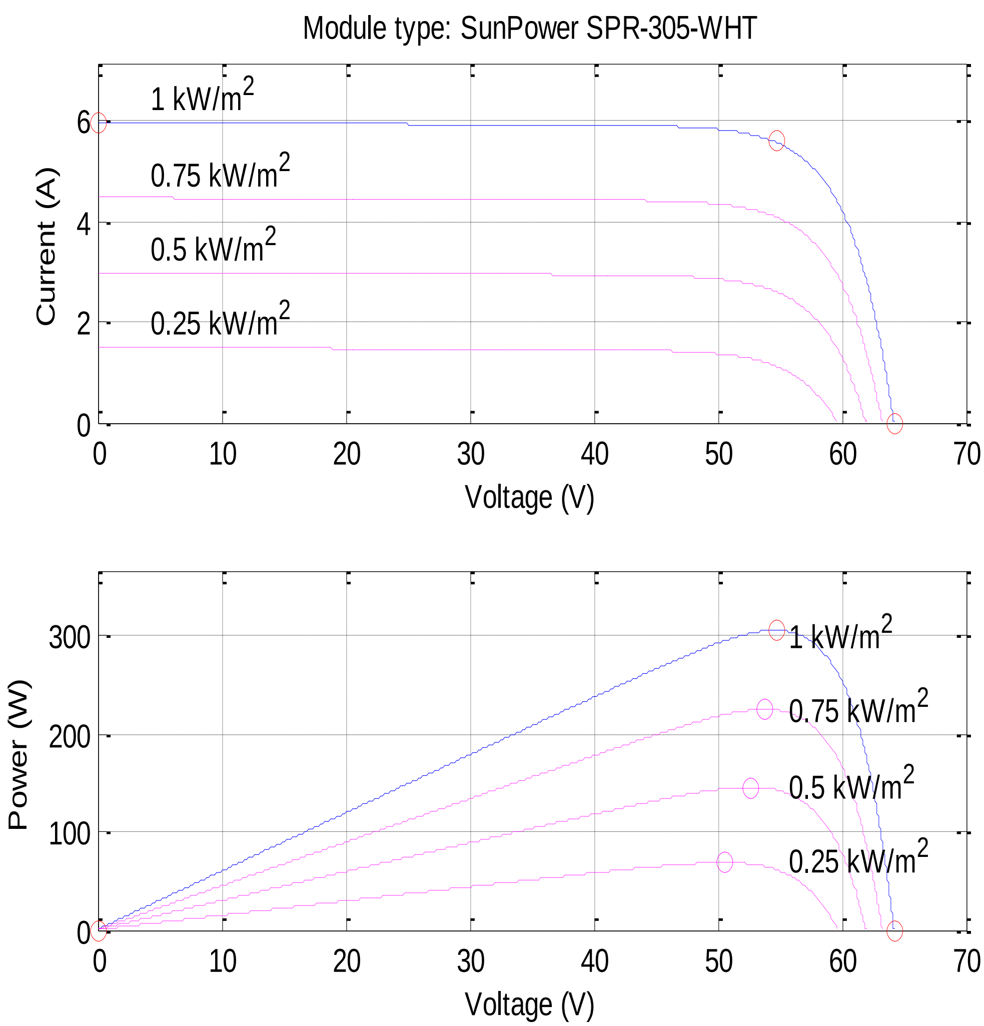

Fig.5 Current voltage and power voltage characteristics of single module of solar PV array

Table.2 Deviations of voltage(%) at different radiations

Irradiations	P&O based FLC	P&O
0.25 kW/m^2	3.6	9.1
0.5 kW/m^2	4.5	12.8
0.75 kW/m^2	2.3	11.7
1 kW/m^2	3.4	9.8

Table.3 Deviations of power(%) at different radiations

Irradiations	P&O based FLC	P&O
0.25 kW/m^2	3.6	9.8
0.5 kW/m^2	4.1	10.6
0.75 kW/m^2	5.2	10.2
1 kW/m^2	4.7	11.8

The various characteristics of current and power for single module is shown in Fig.5. The deviations of voltage and power for various irradiations are shown in Table.2 and Table.3 which shows that least deviation in power and voltage has been attained with P&O based FLC in contrast to P&O method for variable solar irradiations.

4. Conclusion

The maximum power point (MPP0) of solar photovoltaics (SPV) and its mathematical modeling are presented in this article. The method is based on perturb and observe (P&O). When solar photovoltaics are integrated with a DC microgrid, the system's voltage and power fluctuate improperly. First, the solar photovoltaic cell is modeled, and the perturb and observe (P&O) approach is used to derive peak power. The fuzzy logic controller (FLC) is supported by an extension of the P&O approach. The two techniques, such as P&O-based FLC and P&O approaches, are employed to determine changes in voltage and power deviation.By drawing the greatest power from SPV, P&O-based FLC is proven to have the least power and voltage deviation when compared to P&O approaches.

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