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Improvement of Power Output of PV based Microgrid System Using Fuzzy Logic Controller

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***Abstract*: Solar PV system has become the popular choice amongst Renewable Energy Sources (RES). With intermittent nature of solar insolation, the output of PV sys-tem is dynamic in behavior and the output is not remains constant at all time. Various Maximum Power Point (MPPT) techniques are proposed for making the output of PV system desirable at load side. Fuzzy Logic Control (FLC) system is one of the fast and reliable method to provide solutions of nonlinear problems. In the present paper we have compared two different methods of MPPT controller for buck boost type converter for DC load. The simulation model is developed in MATLAB environment and the results shows that FLC based controller has out-performed the P&O based controller.**

***Keywords*: Fuzzy logic control, Maximum power point tracking, Photovoltaic, Perturb and observation.**

1. Introduction

In view of requirement of closed loop control system for smooth operation of Soar PV system with optimized strategy involving latest and efficient technique must be investigated. MPPT controller is the technique to control the output of Solar PV sys-tem which optimize the output voltage of the PV characteristics and provide the point of maximum power at any operating condition. Artificial intelligent (AI) techniques like Fuzzy logic controller, Neuro-Fuzzy, Artificial neural network have proposed by many researchers as a better and faster approach of solving complex non-linear problems. Some optimization methods like genetic algorithm (GA), biological swarm optimization (PSO, ABC and GWO) to solve many different problems in different areas are also developed and utilized.

In MPPT of the solar PV most common method is Perturb & Observe (P&O) with simple approach and application. But the P&O approach shows oscillations near the peak point and takes times to settle down. Hence requirement of fast and reliable technique is arising. Fuzzy logic is amongst the oldest AI methods, which was developed by Zadeh in mid-60’s. It is one of the most efficient and significant technique in solving complex problems in non-linear area. The fuzzy inference works on uncertain situations by incorporating rules and using the rules in mechanism of decision making for various situations observed in daily life.

The output of the PV system is intermittent in nature as the input parameters are dynamic, but the load connected to the output of DC converter must be supplied with the maximum power available at time. The converter which is used to enhance the voltage level of PV output can control this power output during the dynamic conditions by controlling the Duty ratio (D). There are three types of DC-DC converters configurations namely; (a) Buck Converter known as step down converter produces average output voltage less than input DC voltage. (b) Boost Converter This converter is reverse in nature of Buck type converter; hence, the converter average output voltage is higher than the input voltage. Due to increase in the output voltage Boost type DC converter are very suitable for enhancing the output voltage of a Solar PV system. And (c) Buck-Boost or CuK converter it combines the circuitry of both Buck and Boost converter.

In this paper we have consider only Buck-Boost converter and compared the effect of MPPT controller with P&O and FLC based techniques. The simulation of the test system is done on variable operating conditions like irradiation level of 500 w/m2 and 1000 w/m2 and the temperature levels of 25 and 350 C.

The proposed study is presented in following sections, section 2 covers basic modeling of PV system with buck boost converter. Section 3 covers basics of FLC and P&O methods of MPPT and their mathematical modeling. Section 4 presents the simulation studies and finally section 5 presents the conclusions of the study.

2. Solar PV System and Buck-Boost Converter

For practical uses of the solar PV cell of any type, the parameters on which the performance of the cell depends, must be analyzed for getting the proper relation between current and voltage viz. I-V characteristics. In this context, the solar PV cell must be modeled in electrical equivalent circuit, which can be characterized for out-put equations of any module. Therefore, the electrical equivalent circuit is helpful to present the different characteristics in different operating conditions. Moreover, various methods for parameter extraction are available using different model of solar cells. In this way, the solar PV cell is presented in single diode Shokley model shown in Fig. 1.

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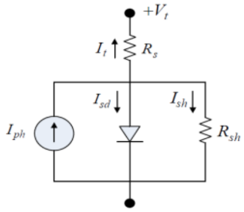

Fig. 1. Solar PV cell equivalent model Single diode module

In Fig. 1 PV cell is presented as single diode connected in parallel to the current source, which is representation of the photovoltaic current. This model has five unknown parameters, which has to be precisely determined for the performance analysis of the solar PV cell, where, I_{ph}, I_{sd}, R_s, R_{sh} and n namely solar PV cell output current, Diode saturation current, series resistance, shunt resistance and non-physical ideality factor, respectively. The maximum power output of the PV cell is expressed below,

$$P_{\max} = V_{oc} \times I_{sc} \tag{1}$$

$$P_{mpp} = V_{mp} \times I_{mp} \tag{2}$$

The output equation of single diode model is as under.

$$I = I_{PV} - I_0 \left[\exp\left(\frac{V + IR_S}{nV_T} \right) - 1 \right] - \left(\frac{V + IR_S}{R_{sh}} \right) \tag{3}$$

Where,

I_{PV} Output current of PV module, A
I_0 Diode saturation current, A
I_D Diode current, A
I_{Sh} Shunt current, A
R_S Series resistance, Ω
R_{Sh} Shunt resistance, Ω
V_T Thermal voltage, V
V Output voltage of PV array, V
I Output current of PV array, A
n_S No. of cells connected in series
n_P No. of cells connected in parallel
K Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K)
q Charge of Electron ($1.60217646 \times 10^{-19}$ C)
T Nominal cell Temperature, °C
n Fill factor (ideal=1)

On the basis of above equation, the simulation model of PV system is presented in Fig. 2.

Buck-Boost converter has an advantage of better output current characteristics due to presence of inductor at the output side. The equivalent circuit diagram is as shown in Fig. 3.

In this circuit, the diode 'd' in the circuit provides protection to the circuit from overheating due to switch operation and enhance the filtering of output. An inductor and capacitor combination makes a low pass filter, which attenuates the output voltage fluctuations. The operation of converter is controlled by the duty ratio 'D', which is the ratio of output to input of the converter (output voltage/input voltage). Duty ratio of a Buck converter is given by the expression as below.

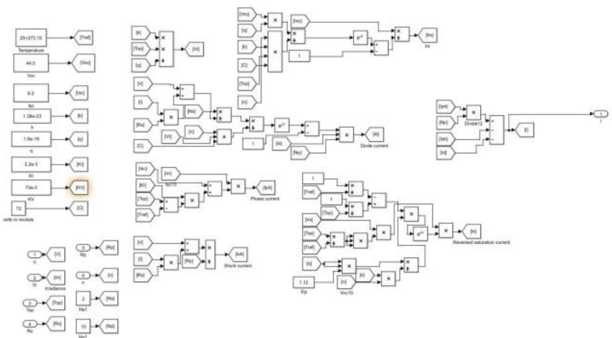

Fig. 2. Solar PV cell equivalent model Single diode module

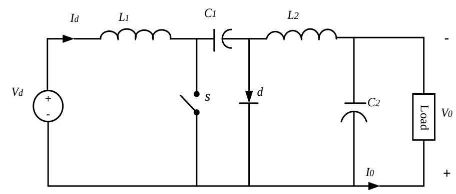

Fig. 3. Equivalent model of Buck-Boost type converter

$$D = \frac{V_{out}}{V_{in} \times \eta} \tag{4}$$

The MATLAB simulation model for Buck-Boost type converter is presented in figure below.

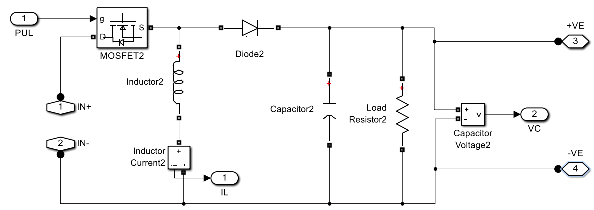

Fig. 4. Simulation model of Buck-Boost type converter

3. FLC and P & O MPPT Modeling

In the previous sections the mathematical modeling of PV system is done and the MATLAB/SIMULINK model is developed for study of dynamic behavior of the PV system under various operating conditions. The converter which is used to enhance the voltage level of PV output can control this power output during the dynamic conditions by controlling the Duty ratio (D).

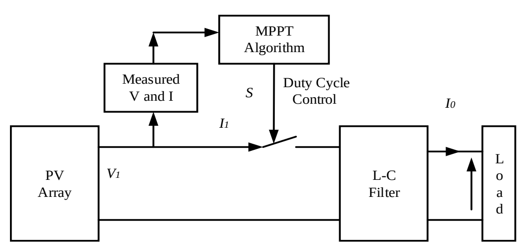

Fig. 5. Block diagram of MPPT control method

In this section the controlling of D is done with the help of Maximum Power Point Tracking (MPPT) and mathematical and simulation model is developed using two methods. The basic block diagram of MPPT is presented in Fig. 5.

PV system output mainly depends upon three factors; Irradiance, ambient temperature and the load impedance. For the PV cell as discussed in previous section output equation is function of irradiance and temperature.

$$P_{PV}(t) = F(V_{PV}(t), I_{PV}(t), \Upsilon(t)) \quad (5)$$

Where,

$P_{PV}(t)$ is the output power of PV system
$V_{PV}(t)$ is the output voltage of PV system
$I_{PV}(t)$ is the output current of PV system

Υ all parameters depending upon climatic conditions.

From above expression the concept of MPPT is developed in expression below,

$$\frac{dP_{PV}}{dV_{PV}} = 0 \quad when\ V_{PV} = V_{MPP} \quad (6)$$

$$\frac{dP_{PV}}{dV_{PV}} > 0 \quad when\ V_{PV} < V_{MPP} \quad (7)$$

$$\frac{dP_{PV}}{dV_{PV}} < 0 \quad when\ V_{PV} > V_{MPP} \quad (8)$$

A. *P & O Modeling*

The operation of P & O is basically described as increasing or decreasing the reference voltage value or duty ratio of the converter and observes its effect on the value of the power output from the system. Now if the value of the k^{th} power *P(k)* is higher than $(k\text{-}1)^{th}$ value *P(k-1)* than it keeps the same direction and if not than it reverses the direction of change. The change is given by perturbation and its effect is given by observation. The duty cycle of DC-DC converter is continuously varied with change of load condition and source output to match peak point of power till the maximum power is obtained.

The main disadvantage of P & O technique is, PV array voltages perturbed every MPPT cycle and at the MPP the output power oscillate around the maximum power point which results in power loss occurring in solar PV system. The MATLAB /SIMULINK block diagram for the P&O MPPT control unit is shown in figure below.

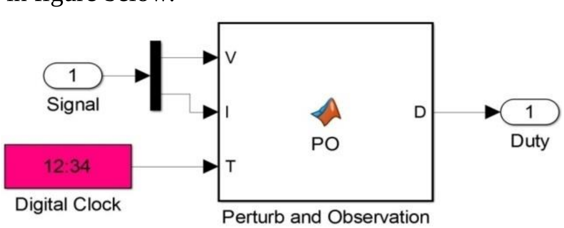

Fig. 6. Block diagram of MPPT control method

B. *Fuzzy Logic Controller*

FLC based MPPT need not to be a precise mathematical model; it deals with uncertain and noisy inputs. Due to the heuristic nature, simplicity and accuracy FLC technique are applicable to both linear and nonlinear systems. Therefore, in the PV sys-tem where the system parameters are highly nonlinear FLC provides a robust system as compared to conventional methods. FLC has basic three elements as below.

- Fuzzification and Rule base
- Inference engine
- De-fuzzification

The inputs to the FLC based MPPT are error (E) and change in error (dE) at some time instant k. The expression for the E and dE are given as below.

$$E(k) = \frac{P_{PV}(k) - P_{PV}(k-1)}{V_{PV}(k) - V_{PV}(k-1)} \quad (9)$$

$$dE(k) = E(k) - E(k-1) \quad (10)$$

The linguistic variable or the membership function of the FLC is as shown in figure below.

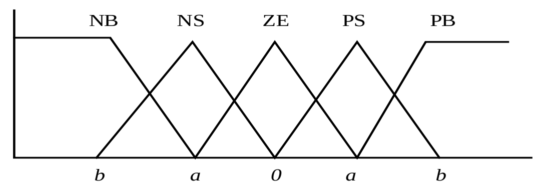

Fig. 7. Membership function of FLC based MPPT

The fuzzy inference engine consists of the rule base and implication sub blocks. Input parameters as fuzzified in above section are now fed to the fuzzy inference engine and the rule base is applied. The table below shows the Fuzzy inference.

Table 1
Fuzzy Inference for MPPT

dE / E	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

Defuzzification:

The duty ratio *D* as an output of the FLC controls the PWM of the DC converter and varies the voltage as per the MPP for the PV system.

$$D = \frac{\sum_{j=1}^{n} \mu(D_j) - (D_j)}{\sum_{j=1}^{n} (D_j)} \quad (11)$$

Below is the MATLAB model of FLC based MPPT.

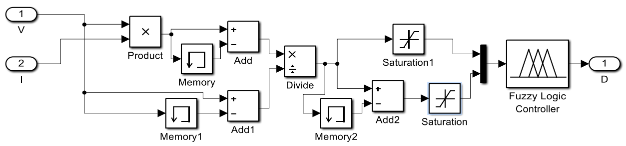

Fig. 8. MATLAB model of FLC based MPPT

4. Simulation Results

On the basis of model developed in above sections the comparative simulation results are shown as below for 500 and 1000 w/m^2 with 25 and 35 ^{0}C.

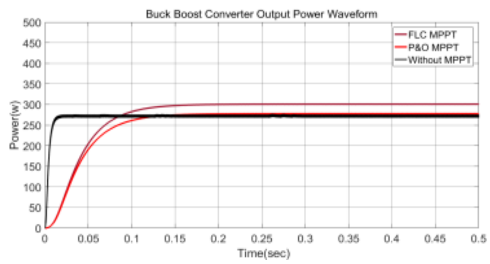

Fig. 9. Comparative results of Buck-Boost converter at 500 w/m^2 and 25 ^{0}C

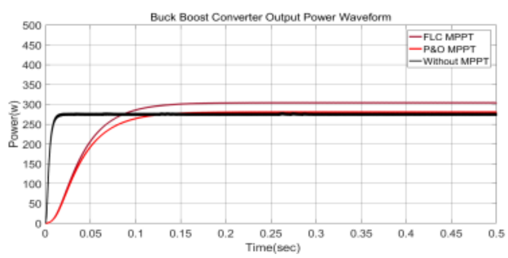

Fig. 10. Comparative results of Buck-Boost converter at 500 w/m^2 and 35 ^{0}C

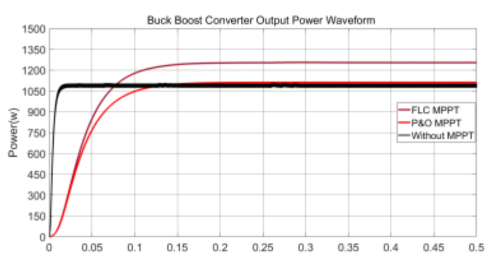

Fig. 11. Comparative results of Buck-Boost converter at 1000 w/m^2 and 35 ^{0}C

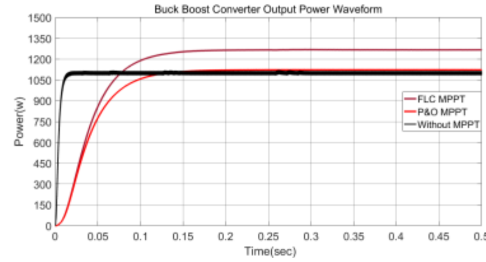

Fig. 12. Comparative results of Buck-Boost converter at 1000 w/m^2 and 35 ^{0}C

5. Conclusion

In this study a simulation model of PV system based on single diode equivalent model along with Buck-Boost converter model is developed. For comparison convention-al method P&O with Intelligent method FLC for MPPT is presented. The simulation results show remarkable improvement with the use of FLC as compared to P & O.

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