

A WIDE RANGE FUZZY BASED MAXIMUM POWER POINT TRACKER FOR IMPROVING THE EFFICIENCY AND SIZING OF PV SYSTEMS

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Abstract: This paper presents a wide range maximum power point tracker (MPPT) using fuzzy logic controller for PV sizing and efficiency improvement. The MPPT consists of a buck boost converter, controlled by a fuzzy logic. The fuzzy has two inputs and single output. Inputs are voltage and current of the PV, while the output is duty cycle for the buck boost. The MPPT effectively tracks at average 97.3% of the peak power under wide range of solar irradiances and load resistances. Without MPPT, the PV output generates at average 67.7% of the peak power. A sizing method of PV system involving MPPT for supplying 2500 Watt load is also presented in this paper.

Key words: photovoltaic, MPPT, fuzzy logic controller, buck boost converter, sizing method

1. Introduction

Solar photovoltaic (PV) has widely been used as renewable generators in electric power systems [1-3]. Example applications of PV systems include PV street light, PV electric vehicle, and PV power supply for base transceiver station (BTS). Solar PV has relatively low conversion efficiency and produces a maximum output power at a specific load resistance. However, the equivalent load resistance is varied following behavior of consumers.

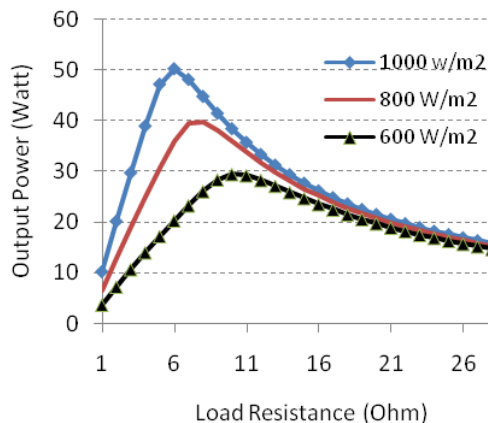


Fig.1. PV output power on various load resistances

Fig. 1 shows characteristics of a typical PV panel (50 Watt peak, 12 volt) when supplying various load resistances. As can be seen, the PV output is maximum at 50 Watt, when the irradiance is 1000 Watt/m². The load resistance in this condition is 6 Ohm. When the load resistance is changed, the output power reduces even the solar irradiance remaining 1000 Watt/m². At lower irradiances, the maximum output is below 50 Watt, while the matching load resistance is higher. Thus, a maximum power occurs at a specific resistance point only, otherwise the PV works at non optimum condition.

A maximum power point tracker (MPPT) is needed to solve this problem. MPPT works electronically to keep the output at maximum power, instead of mechanically changing the position of solar panels. It adjusts the output voltage, so that the power is always at the maximum point under circumstance conditions. Many methods have been proposed by researchers including hill climbing, open circuit voltage, short circuit current [4-9]. In addition, artificial intelligent based method is preferable since presented in software, flexible and hardly duplicated by others [6-9].

This paper presents fuzzy based MPPT for PV system sizing and efficiency improvement. Comparison sizing using conventional method, e.g. Fill Factor, is also presented in this paper.

2. Fuzzy Based MPPT

Fig. 2 shows block diagram of the proposed MPPT. It uses buck boost converter to adjust the output voltage of PV panel. Buck Boost is capable of step up or step down the output from the source voltage. The converter is controlled by fuzzy logic with 2 inputs and 1 output. The inputs are fed by voltage and current of the PV terminals, while the output provides duty cycle for the buck boost.

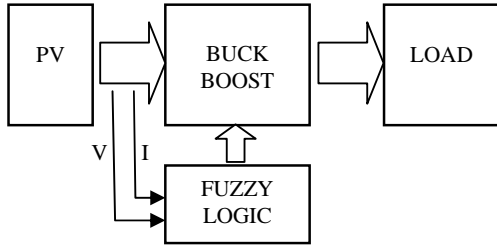


Fig.2. Block diagram of the proposed MPPT

Buck Boost converter, shown in Fig. 3, controls the output voltage, V_a , by varying the duty cycle, k , of the IGBT Q . Duty cycle refers to ratio of the conduction time (t_{on}) and the period (T) of the switching operation Q , as depicted in Fig. 4. During its operations, the semiconductor switch Q turns-on for t_{on} milliseconds, and turns-off for t_{off} milliseconds periodically.

$$k = t_{on} / T \quad (1)$$

$$t_{on} = k T \quad (2)$$

$$t_{off} = (1-k) T \quad (3)$$

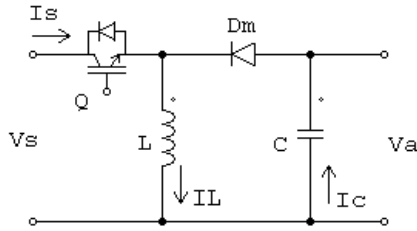


Fig.3. Power circuit of a Buck Boost converter

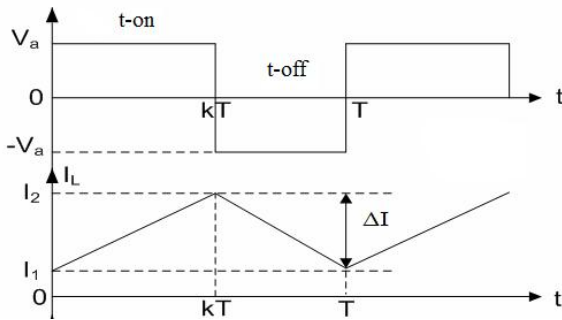


Fig.4. Switching operation and current flow

In the period of t_{on} , it is assumed that the current

flow in the inductor L is linear, from I_1 to I_2 . Thus, the converter source voltage is:

$$V_s = L \frac{I_2 - I_1}{t_{on}} = L \frac{\Delta I}{t_{on}} \quad (4)$$

During t_{off} , the output converter voltage is written as:

$$V_a = -L \frac{\Delta I}{t_{off}} \quad (5)$$

Substitution eq. (4) and (5), the output voltage corresponds the source voltage and duty cycle as follows:

$$V_a = \frac{V_s k}{1 - k} \quad (6)$$

By adjusting k at pre-defined value depending on the PV voltage and current, the output power of PV can be maintained at the maximum point. The value of k is determined by the fuzzy logic controller.

The design of fuzzy logic is based on characteristics of the PV panel. The voltage, current and power at maximum power points are investigated under various solar irradiances for references. Table 1 shows characteristics of typical single PV panel used for the proposed system.

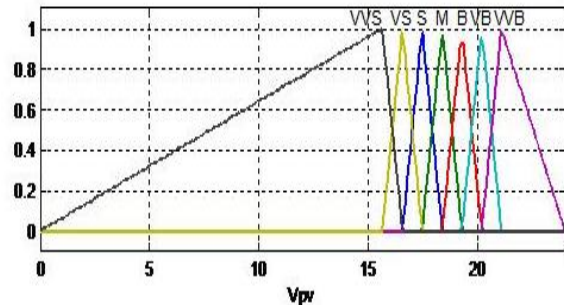


Fig.5. Fuzzification for the input voltage

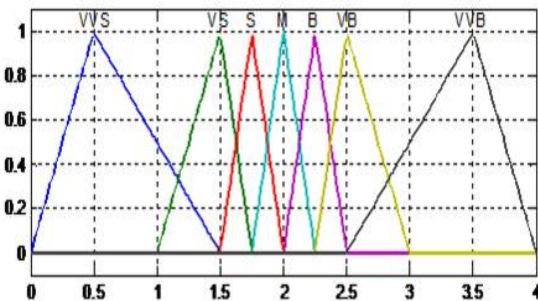


Fig.6. Fuzzification for the input current

The membership function of fuzzy logic is then derived considering parameters at the power point. Fig. 5 and 6 show the membership function of voltage and current as the inputs, respectively.

The inputs and output are determined in 7 membership functions. When the input voltage is very very small (VVS), and the input current is also VVS, then the output will be VVS. Similar conditions are applied for very small (VS), small (S), medium (M), big (B), very big (VB), and very very big (VVB).

The membership function for output of the fuzzy is depicted in Fig. 7.

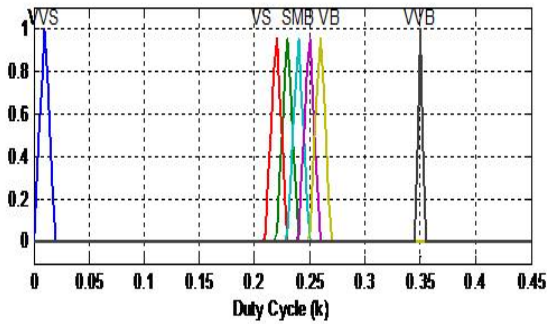


Fig.7. Membership function of the output

3. Result and Discussion

a. MPPT Performances

Simulation results of MPPT performances under 1000 W/m² irradiance are shown in Fig. 8. The MPPT can effectively track and remains working at the maximum power point when the load resistance reaches 5 Ohm and higher.

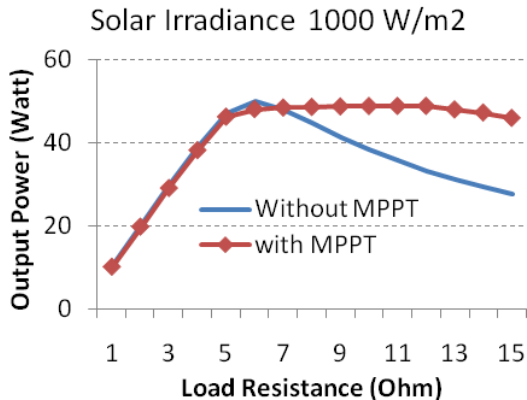


Fig.8. PV output power with and without MPPT

Fig. 9 shows the MPPT performances under various solar irradiances for a typical load. Under 700 W/m², the MPPT provides 94.2% of the maximum point, while under 1000 W/m² is 96.7%. The highest tracking efficiency is achieved as 99.2% when irradiance is 500 W/m². The average tracking efficiency is 97.3% of the peak power. Without MPPT, the average PV output power is 67.7% of the maximum point.

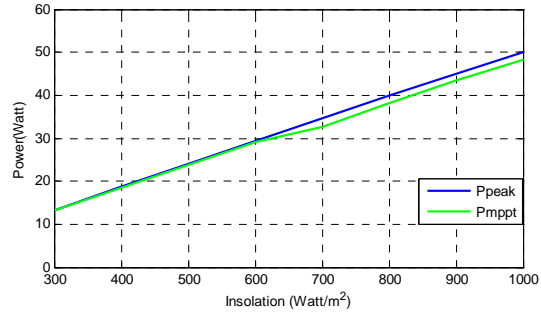


Fig.9. MPPT performance under various irradiances

b. Sizing Method of PV System

Sizing method of PV system considering the MPPT performances is discussed. The system consists of PV-battery and is assumed supplying 2500 Watts/ 48 volts constantly for 24 hours. The MPPT has a tracking efficiency as 97.3% of the maximum power. The sizing procedures follow the flow chart as shown in Fig. 10.

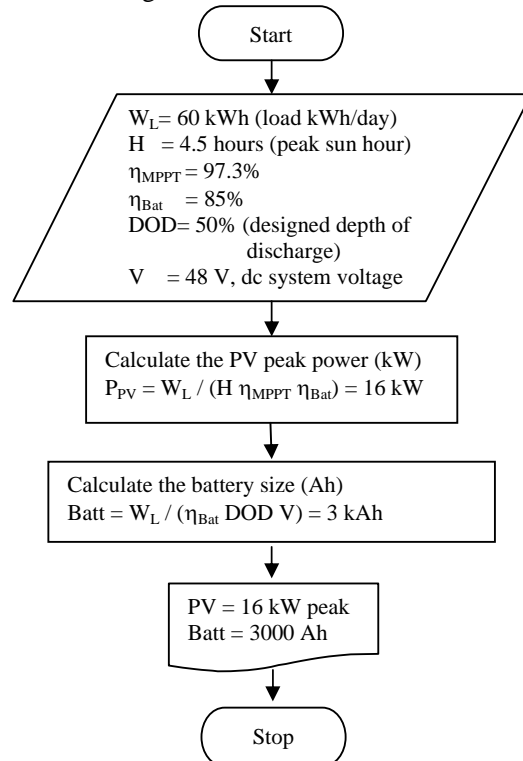


Fig. 10. Flow chart for sizing PV system with MPPT

The first step is to calculate the energy consumption per day, which is $2500 \text{ W} \times 24 \text{ hours} = 60 \text{ kWh}$. To determine the PV size considers:

- MPPT tracking efficiency ($\eta_{\text{MPPT}}=97.3\%$)
- battery efficiency ($\eta_{\text{Bat}}=85\%$)

The expected energy generated by the PV is found as 73 kWh per day. A peak sun hour conversion is used to calculate the PV peak power. The peak sun hour (H) refers the collected solar energy per day divided by 1000 Watt/ m^2 . In the site, the average peak sun hour is 4.5 hours. This is equivalent with receiving 4500 kWh energy from the sun per day. Thus, the PV peak power is $73 \text{ kWh} / 4.5 \text{ hours} = 16 \text{ kW}$. The number of parallel and series of PV panels can be chosen accordingly.

The second step is to calculate the battery size. It is determined considering 3 parameters:

- the daily load energy, $W_L = 60 \text{ kWh}$
- the battery efficiency ($\eta_{\text{Bat}}=85\%$)
- the designed depth of discharge (DOD)
- the dc voltage of system, 48 Volts

DOD is the depth for discharge of the battery. It is assumed that the battery cycle (charged and discharged) occurs one per day. The designed DOD is set 50%. This implies that the battery capacity is twice than the energy demanded per day. In case the sunlight is unavailable, the system can still meet the load for 2 days. The battery size is found as 3000 Ampere hours (Ah). Cell types, the number of batteries in series and parallel can be selected based on the size and the system voltage.

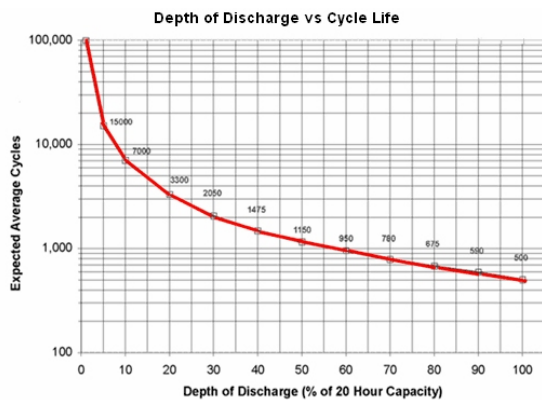


Fig.11. A typical battery cycles

Once the battery type was selected, the battery replacement period can be determined. It provides important data for economic analysis steps. An example of typical battery cycles is presented in Fig. 11. The curves show number of cycles as function of

DOD. When the battery DOD is selected as 50%, the number of cycles found as 1.150. Since one cycle is equivalent with one day, the battery life will be 1150 days or approximately 3 years.

A conventional method to size the PV using Fill Factor (FF) is presented for comparison. FF refers the ratio of the maximum power (P_{mpp}) and multiplication of open circuit voltage (V_{oc}) and short circuit current (I_{sc}). FF is the mismatched power between the nameplate and the estimated peak condition of the PV.

$$\begin{aligned} \text{FF} &= P_{\text{mpp}} / (V_{\text{oc}} I_{\text{sc}}) & (7) \\ &= 50 / (21 \times 3.74) \\ &= 0.637 \end{aligned}$$

Since FF is the mismatched power, the value of FF is then used to replace the tracking efficiency of MPPT. The PV sized is found as 24.6 kW peak, or 8.5 kW larger than using MPPT.

Since the PV size is larger, the battery capacity shall also be bigger than the calculation results shown in flow chart Fig. 10.

4. Conclusion

Fuzzy Logic based maximum power point tracker was presented. It effectively tracks the maximum power point at average 97.3% under wide range of solar irradiances and load resistances. Without MPPT, the PV works at average 67.7% of the maximum power point. By using the MPPT, the output power increases by 29.6%. This tracking efficiency was included in PV sizing calculations, resulting in saving 33% of PV size than using conventional Fill Factor method.

5. Acknowledgement

Authors would like to thank Institut Teknologi Sepuluh Nopember (ITS), Surabaya – Indonesia and Dikti (Higher Education Direktorat General) – the Ministry of National Education of Indonesia, for supporting this activity through the research funding.

Authors also express the gratitude to Department of Electrical Engineering - ITS and all undergraduate students who support this research.

Table 1. A typical PV characteristics used for the research

No.	Irradiation (W/m ²)	Temp. (°C)	I at max power point (Amp)	V at max power point (Volt)	P max (Watt)
1	250	25	0.6418	16.84	10.8086
2	300	25	0.7678	17.35	13.3217
3	400	25	1.0805	17.35	18.7474
4	500	25	1.3910	17.35	24.1334
5	600	25	1.6987	17.35	29.4717
6	700	25	2.0031	17.35	34.7534
7	800	25	2.3036	17.35	39.9683
8	900	25	2.5997	17.35	45.1051
9	1.000	25	2.8906	17.35	50.0000

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