Fuzzy-PID Controller On MPPT PV To Stabilize DC Bus Voltage

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***Abstract*— The energy generated by solar cells varies greatly depending on weather conditions and because the solar energy is changing at any time, the power generated is also changed and not maximum. To achieve high efficiency Maximum Power Point Tracker is used. In this paper we will use fuzzy PID method as MPPT controller on PV. Fuzzy logic is used to optimize the PID in the tracking of the maximum power point, so that the voltage or output power of the boost converter will always be stable. Fuzzy input is power and irradiation, while the output is the change of PID parameters to be used to set the boost converter. In this fuzzy design the intensity of solar energy from 1w / m2 to 1000 w / m2, while the solar cell power capacity from 1watt to 1000 watts and temperature temperature at 25 ° C. From the simulation results on the picture shows that the PID controller produces a larger overshoot when compared to the fuzzy PID controller, the overshoot generated by the PID controller is 15.14 percent with the rise time of 0.043 seconds. While the fuzzy PID controller produces 2.1 percent overshoot with 0.036 second rise time.**

Keywords—Boost Converter, Fuzzy-PID, MPPT

I. Introduction

The energy generated by solar cells varies greatly depending on weather conditions and because the solar energy is changing at any time, the power generated is also changed and not maximum. To achieve high efficiency Maximum Power Point Tracker is used. Efficiency and maximum power point on solar panels are based on their characteristics and are all comparable to the magnitude of irradiation and the incoming temperature (Martin and Vazquez 2015). Because the value of Maximum Power Point depends on weather conditions it is necessary algorithm that is able to maintain maximum operating point, based on voltage-current characteristics. From MPPT research to PV using PID fuzzy controller with buck converter aims to optimize incoming solar energy. The method is performed using Big Bang-Big Crunch algorithm. This method is quite effective and simple for MPPT. The methods performed are compared with perturb and observer methods. This method is able to work with different weather conditions (Dounis et al 2015). The fuzzy use of MPPT for PV arrays in the power system produces maximum PV array power by adjusting the duty ratio of the switching elements. From the simulation results show the PV model produces a curve similar to the PV panel curve. The boost converter output can reach the maximum point of power generated (Chujia et al., 2015). A research on controls that can track the maximum power point (MPP) of PV with different weather conditions, used several MPPT algorithms. In this case some methods are compared, such methods are perturbe and observe methods, PI control methods, fuzzy and neuro-fuzzy control methods, and backstepping control. . Four methods are able to track the maximum point quickly, but the backstepping control method produces the best efficiency (Martin and Vazquez 2015).

A PV panel can be modeled as an equivalence circuit and the problem is in determining the model parameters. A method of estimating PV parameters into parameter optimizations using Differential Evolution (DE) optimization techniques. Models used with standard test parameters (1000 W / m2, 250 C). The differential evolution (DE) method is efficient in estimating five equivalent circuit parameters (Sheraz and Abido 2014). The model was tested using FLC and produced better output compared to conventional methods (Sheraz and Abido 2014) (Pachauri and Chauhan 2014).

The fuzzy logic (FMPPT) MPPT capability is also tested when the weather is not bright, five PV modules are arranged in series to provide the output voltage according to load. The PV modules are given irradiated solar irradiation, especially during overcast weather. FMPPT is able to optimize the rapid changes of solar irradiation, resulting in more stable output power compared to conventional methods (Chin et al., 2013). MPPT based fuzzy logic is also used to optimize the input power of the inverter through boost converter. The use of non-linear loads affects the power quality on the grid, so the ability of FMPPT to optimize output power can help improve power quality. With temperature and irradiation changes the FMMPT method improves the power quality on the grid (Hamad, Fahmy, and Abdel-Geliel 2013) (Verma, Singh, and Shahani 2012). FMPPT is also capable of providing input power to multilevel inverters. Fuzzy logic controllers are more effective and flexible for non-linear loads than conventional controllers. The simulation results show that multilevel inverter provides stable voltage to the load, despite the change of temperature and irradiation of PV module (Heg et al., N.d.). Fuzzy logic controller is able to improve the I-V and P-V characteristics of the PV module, so that the output

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is stable despite sudden environmental changes. The simulation results show with FMPPT algorithm and size incremental conductance method, parameter change from characteristic PV module can be stabilized at maximum power point (MPP). FLC is able to quickly find new maximum power points (Xiaoe, Jinmei, and Jinsong 2013). The purpose of this research is to improve MPPT performance with PV sources, to make the boost converter output more stable. The method used in this research is to determine the PV capacity, design the PID control, design the Fuzzy control, and design a hybrid control. In several previous studies, the use of combined control results in a more stable system output when compared to uncombed control.

In this paper we will use fuzzy PID method as MPPT controller on PV. Fuzzy logic is used to optimize the PID in the tracking of the maximum power point, so that the voltage or output power of the boost converter will always be stable. In chapter I contains the introduction, chapter II on the PV cell and boost converter model, chapter III on PID and fuzzy-PID controller theory, chapter IV on MPPT design with fuzzy-PID controller, chapter V on results and discussion, and chapter VI contains conclusions

II. PV Cell And Boost Converter Model

A. PV Cell Model

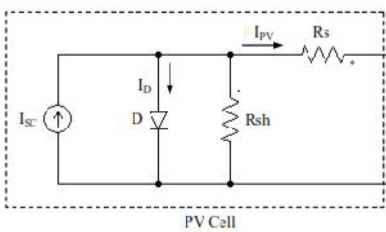

Fig. 1 PV cell model

The PV cell has non-linear characteristics, so PVs should be pursued for use only at the maximum power point. PV arrays can be made by arranging in series or parallel from the PV cell. In order to facilitate analysis in a raggaiaan PV cell is usually used an equivalent circuit (Pachauri and Chauhan 2014) (Dounis et al 2015). But in the characteristics of PV cells there are some unknown parameters that are in fact inconvenient for analysis or design (Xiaoe, Jinmei, and Jinsong 2013). The equivalence circuit equivalent of a PV cell according to fig. 1 can be expressed by equation 1. In the equivalence circuit two Rsh parallel resistors are added and the series resistor Rs.

$$I_{PV} = I_{SC} - I_D - \frac{V_D}{R_P}$$

$$I_{PV} = I_{SC} - I_0 (e^{V_D/V_T} - 1) - \frac{V_D}{R_P} \quad (1)$$

$$I_{PV} = I_{SC} - I_0 (e^{q\frac{V_{PV}+R_s I_{PV}}{\eta K T_C}} - 1) - \frac{V_D}{R_P} \quad (2)$$

In the equation the VPV is the PV cell voltage and I0 is the saturated current of the diode (in units A). K is the boltzmann constant (J / K), q is the electron charge (Coulomb), η is the ideal factor, and Tc is the temperature of the PV cell in K (Martin and Vazquez 2015). Tc can be expressed as the amount of temperature Ta and temperature Tb. Ta is the environmental temperature of PV cell and Tb is the PV cell temperature coefficient (Xiaoe, Jinmei, and Jinsong 2013).

$$T_c = T_a + T_b$$

If an equivalent PV cell circuit ignores Rsh, then the output voltage can be written in equation 3.

$$V_{PV} = V_D - R_s I_{PV}$$

$$V_{PV} = \frac{KT_C}{e} \ln\left(\frac{I_{SC} - I_D - I_{PV}}{I_D}\right) - R_s I_{PV} \quad (3)$$

The operating temperature of the cell PV depends on changes in the irradiation rate (S) and the environmental temperature (Ta). This will affect the voltage and current output of PV cell.

B. Boost Converter Model

One type of converter that is widely used for PV modules is the boost converter. The disadvantages of conventional converters, however, are the need for high voltages in the switching process and the large current capability of the components used, requiring modification of the converter (Kurohane et al., 2010). Conventionally to determine the output voltage of boost converter with duty cycle using equation 4, whereas to determine the magnitude of the inductor is expressed in equation 5. ΔIL denotes the change of ripple inductor current (Yamaguchi and Fujita 2017).

$$D = 1 - \frac{V_{out}}{V_{in}} \quad (4)$$

$$L = \frac{V_{out} x (V_{in} - V_{out})}{\Delta I_L f_s V_{out}} \quad (5)$$

$$L = \frac{D(1-D)^2 R}{2 f_s}$$

The value of the capacitor will affect the output voltage. If the magnitude of the output voltage ripple is 1% then the value of the capacitor can be expressed in equation 6 (Sahu and Verma 2016).

$$C = \frac{D}{R f_s (\frac{\Delta V_o}{V_o})} \quad (6)$$

$$C = \frac{D}{R f_s x 1\%}$$

Boost Converter can be adjusted output voltage using MPPT., So obtained the point of maximum power (Roy et al 2014) (Ram et al., 2016). By using boost converter, low input voltage can be increased according to load requirements (Sahu and Verma 2016).

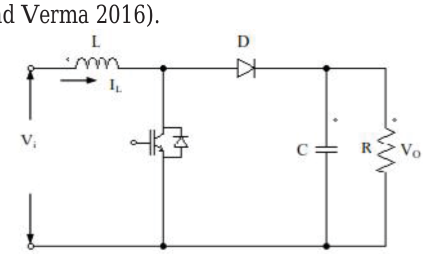

Fig. 2 Boost converter

A boost converter works with two modes of operation, ie when IGBT is on and off. IGBT is modeled with a switch.

When On

When IGBT on (0 ≤ t ≤ DT) corresponds to figure 1, then the current will flow through inductor L and IGBT. The magnitude of the inductor current is derived from the voltage equation 7.

$$V_i = L\frac{di_1(t)}{dt} \quad (7)$$

$$i_1(t) = \int_{-\infty}^{\infty} \frac{V_i}{L} dt$$

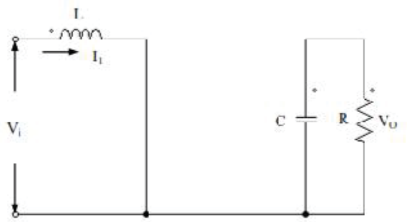

Fig. 3 Boost converter (when on)

Assume current when mode on turns to I2 (t = DT). I1 is the initial current in the first mode.

$$I_2 = \frac{V_i}{L} DT + I_1$$

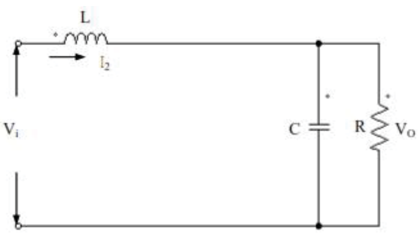

Fig. 4 Boost converter (when off)

<u>When Off</u>

When IGBT off (DT ≤ t ≤ T) then the current will flow will flow to the load R. The voltage equation at IGBT off is expressed in equation 8, I2 is the initial current when the mode off. Equation 9 is the final current equation of the off mode and is equal to I1 (i2 = (1-D) t).

$$V_i = Ri_2(t) + L\frac{di_2(t)}{dt} \quad (8)$$

$$i_2(t) = \frac{V_i}{L}\left(1 - e^{\frac{R}{L}t}\right) + I_2 e^{\frac{R}{L}t}$$

$$I_2 = \frac{V_i}{L}\left(1 - e^{-(1-D)\frac{TR}{L}}\right) + I_2 e^{-(1-D)\frac{TR}{L}} \quad (9)$$

Equation 8 and equation 9 can be expressed by equation 10 and equation 11.

$$I_1 = \frac{V_i D \frac{TR}{L} e^{-(1-D)\frac{TR}{L}}}{R(1 - e^{-(1-D)\frac{TR}{L}})} + \frac{V_i}{R} \quad (10)$$

$$I_2 = \frac{V_i D \frac{TR}{L}}{R(1 - e^{-(1-D)\frac{TR}{L}})} + \frac{V_i}{R} \quad (11)$$

Therefore the current ripple of boost converter with R load can be expressed by

$$\Delta I = I_2 - I_1 = \frac{V_i}{L} DT \quad (12)$$

III. PID AND FUZZY-PID CONTROLLER

This section covers the basics of PID controller and the design of the controller as well. The basics theory of the PID controller will be presented in section A. The design for the system used in this paper woll be explained in section B.

A. PID Controller

PID controllers are actually a combination of three kinds of controllers, with the aim of improving control performance. In this way the weaknesses of each controller can be covered. Each controller has different characteristics. The P controller can reduce the rise time, but can not reduce the staedy-state error. In contrast controller I can reduce staedy-state error, but the resulting response is not good. D controller is able to reduce overshoot and can increase transient response (Chauhan and Rajpurohit, n.d.). The continuous PID control equation can be expressed in equation 13.

$$u(t) = K_p(e(t)) + K_i\left(\frac{1}{T_i}\int_0^t e(t)dt\right) + K_d\left(T_d \frac{de(t)}{dt}\right) \quad (13)$$

$$\tau_i = \frac{2\xi}{\omega_n}$$

$$\tau_d = \frac{1}{\tau_i \omega_n^2}$$

$$K_p = \frac{\tau_i}{\tau . K}$$

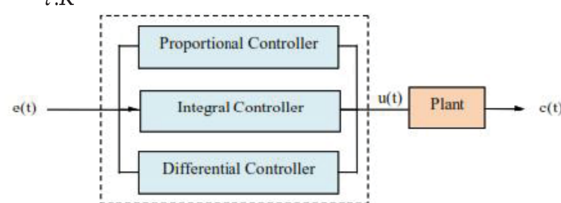

Fig.5 PID controlller

B. Fuzzy-PID Controller

This controller is a combination of fuzzy logic controllers with PID controllers. With this method, the fuzzy logic controller can adjust the parameter changes PID quickly and precisely, so that will occur process adapatasi parameters Kp Ti, and Td in case of interference from outside. Therefore the PID parameter equation in the presence of adaptation process can be expressed in equation 13.

$$K_p(t) = K_{p1}(t) + \Delta K_p \quad (13)$$

$$T_i(t) = T_{i1}(t) + \Delta T_i$$

$$T_d(t) = T_{d1}(t) + \Delta T_d$$

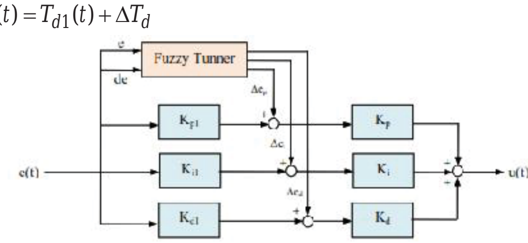

Fig. 6 Fuzzy PID controller

IV. DESIGN MPPT WITH FUZZY-PID CONTROLLER

1. Determine PV capacity
2. Designing a PID control
3. Designing Fuzzy controls

4. Designing a hybrid control system (Fuzzy-PID)

V. Design MPPT With Fuzzy-PID Controller

The main purpose of the fuzzy PID controller is to obtain maximum power from PV by tracking the maximum power point (MPP) quickly. With this method PV will output its maximum power in MPP area. This maximum power point may change due to changes in the intensity of irradiation and temperature. In accordance with the characteristics of PV (characteristic P-V or I-V) at the point MPP PV produces maximum power using MPPT. The MPPT design using the PID fuzzy controller is shown in Fig. 7.

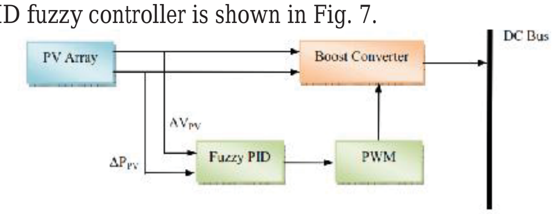

Fig.7 Block fuzzy control PID diagram

In Figure 7, solar energy is converted using PV Array into a DC voltage and as an input boost converter. To increase DC voltage and maximize PV Array output, the boost converter is controlled using MPPT based on Fuzzy-PID control. The DC boost converter output voltage is entered on the DC Bus.

The parameters to be used for fuzzy design are power changes and changes in PV output voltage, according to PV characteristics. The designed Fuzzy logic has two inputs and three outputs. The rule rule in fuzzy is the whole rule as a result of a combination of two inputs and based on observations when the system is interrupted to achieve the goal value, then evaluates the degree of membership of each membership function of the fuzzy set. Fuzzy logic has input ΔPPV and ΔIPV, while the output is the change of Kp, Ki, and Kd values. The input and output values are based on the upper and lower limits of the value, then quantized into a membership function. The purpose of using fuzzy logic is to set the value of PID in achieving the value that is chosen, so that fuzzy logic can change the PID parameter during system failure. The fuzzy PID controller generates PWM waves as an IGBT trigger on the boost converter. The final step of fuzzy logic is the defuzzification process with the centroid method. In this design the fuzzy logic input variable has five membership functions, namely NN (Negative Negative), NP (Negative Positive), Zero (ZO), PN (Positive Negative), PP (Positive Positive). For outputs Kp, Ki and Kd each have seven membership functions, namely NH (Negative High), NN (Negative Positive), NN (Negative Negative), Zero, PN (Positive Negative), PP (Positive Positive), PH (Positive High).

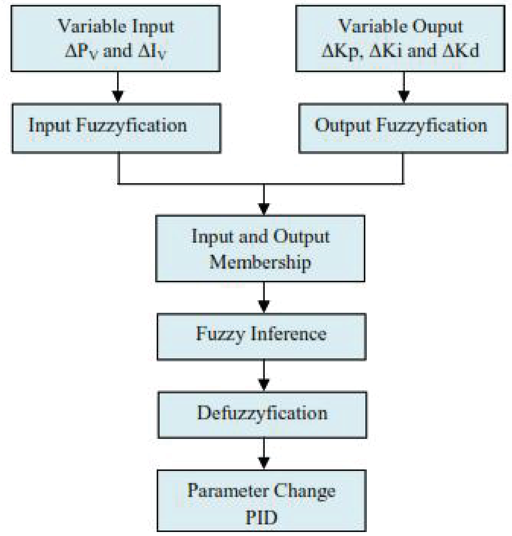

Fig.8 Flowchart fuzzy PID

Table 1. Rule base for input

ΔP_V / ΔI_V	NN	NP	ZO	PN	PP
NN	NN	NN	NP	NP	ZO
NP	NN	NP	NP	ZO	PN
ZO	NP	NP	ZO	PN	PN
PN	NP	ZO	PN	PN	PP
PP	ZO	PN	PN	PP	PP

Table 2. Rule Base for PID

ΔE / E	NH	NN	NP	ZO	PN		PP	PH
NH	NH	NH	NH	NN	NN		NP	ZO
NN	NH	NH	NN	NN	NP		ZO	PN
NP	NH	NN	NN	NP	ZO		PN	PP
ZO	NN	NN	NP	ZO	PN		PP	PP
PN	NN	NP	ZO	PN	PP		PP	PH
PP	NP	ZO	PN	PP	PP		PH	PH
PH	ZO	PN	PP	PP	PH		PH	PH

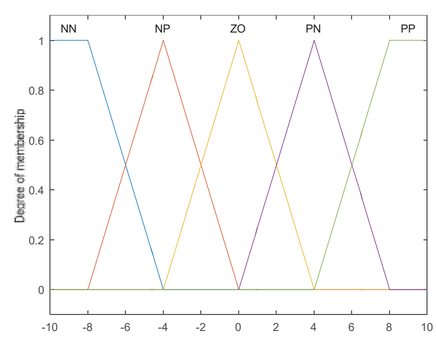

Fig 9. P_{PV} membership function

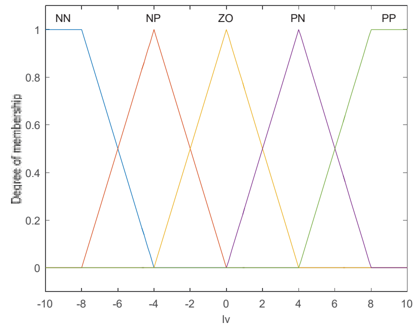

Fig. 10 V_{PV} membership function

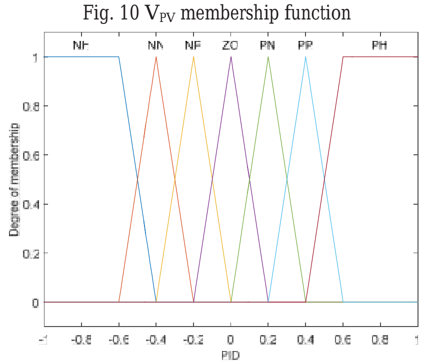

Fig. 11 Output membership function

VI. Results And Discussions

In this fuzzy design the intensity of solar energy from 1W / m^2 to 1000 W / m^2, while the solar cell power capacity from 1watt to 1000 watts and temperature temperature at 25 °C. From the simulation results on the picture shows that the PID controller produces a larger overshoot when compared to the fuzzy PID controller, the overshoot generated by the PID controller is 15.14 percent with the rise time of 0.043 seconds. While the fuzzy PID controller produces 2.1 percent overshoot with 0.036 second rise time. Comparison of output voltage boost converter or DC bus voltage of 24 V DC, shown in the figure. From the simulation result of PID fuzzy controller is very effective to stabilize voltage on DC bus.

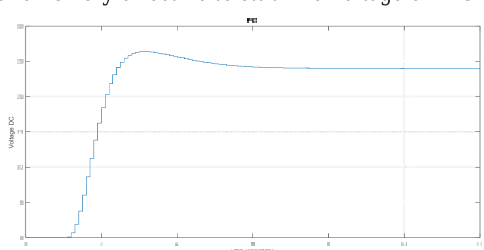

Fig 12. Voltage on DC bus with PID controller

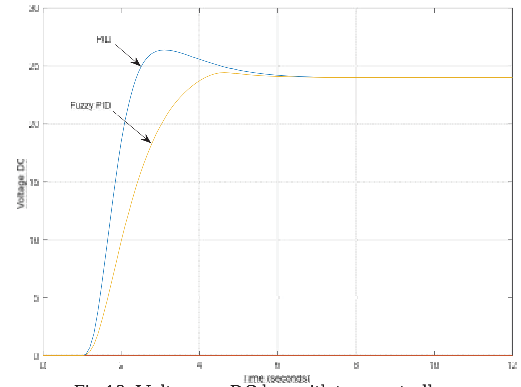

Fig 13. Voltage on DC bus with two controllers

VII. Conclusion

Fuzzy PID controller proved to improve the performance of boost converter in providing a more stable voltage of 24 V DC, when compared with conventional PID controllers. In the fuzzy mamdani design PID parameters can be generated system correctly. The fuzzy PID controller produces a lower overshoot with a lower rise time.

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