

Fuzzy Logic Based Maximum Power Point Tracking Controller

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Abstract: Solar power is environment friendly power source. It is characterized by being nonlinear, temperature dependent and also irradiation dependent to extract maximum power from the panel, the load resistance should be equal to internal resistance of the solar panel. To achieve this a power converter should be used and controlled in such a manner that the load resistance is always transformed into temperature and irradiation dependent panel internal resistance. This paper proposes a fuzzy logic based controller for a boost converter to achieve the above target. The input variables of this fuzzy controller are $\Delta P/\Delta V$ and ΔV . Its output variable is the change in the duty ratio ΔD . Its structure is simple and uses four rules.

The controller has been tested (at the reference condition) under different loading and also step load changes. It has exhibited an excellent tracking capability.

1. Introduction

Current trends in electric energy generation are moving towards the utilization of the environment friendly sources of energy, represented by the wind and solar energy ones as a supplementary energy resources. The solar based one is the more attractive because it is characterized by being free, incur no fuel cost, abundant, limited less, distributed all over the word, pollution free, and require little maintenances. The fore mentioned advantages are also accompanied by number of mishaps. These are the low conversion efficiency, temperature dependent, isolation dependent, ageing dependent, and finally the nonlinear I-V and P-V characteristics of the photovoltaic cells used to do the sun energy conversion. According to these mishaps, there is a unique maximum power point for each operating condition (temperature and light

intensity). Therefore, maximum power point tracking (MPPT) technique is highly required.

Many MPPT techniques have been developed and still are being developed. These range from conventional methods such as the Hill-Climbing Method and the Perturbation and Observe Method (Weidog & William, 2004; Carles et al. 2008), to the more intelligent Neural network (Premrudeepprreechacharm & Patanapirom, 2003), Fuzzy logic based control methods (Bogdar & Xangli, 2002; Neil et al., 2005; Cheikh et al., 2007; Lixin et al, 2008) and DSP based ones (Stone et al. 2008; Chiang et al. 2009).

In this paper, a Fuzzy logic based MPPT controller has been developed. This controller has four rules and uses the $\Delta P/\Delta V$ and ΔV as an inputs to the Fuzzy engine.

2. Photovoltaic Cell Operation and Characteristic

Photovoltaic cell consists of semiconductor material, which converts sunlight into DC current using the photovoltaic effect. The conversion process passes through two phases. In the first phase, absorption of sun light generates an electron-hole pairs. In the second phase, the electron and holes are separated (by the internal electric field) to the negative and positive terminal thereby generating electrical power (Hongpeng, 2009).

2.1 Photovoltaic Cell Equivalent Circuit & Mathematical Model

The most general model is the one so called one diode model. This model is shown in Fig1 (Masoum et al. 2007). It consists of current source (directly proportional to solar irradiation), diode (stands for the intrinsic P-N junction), shunt resistance (R_{sh}), and series resistance (R_s).

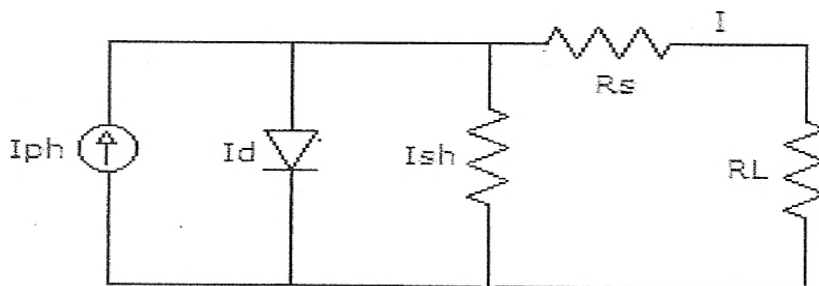


Fig.1 : The Equivalent Circuit of a Solar Cell

Where I and V stand for terminal current and voltage respectively of the solar cell, I_{ph} is the light generated current, I_d is the diode current, R_s and R_{sh} are the series and parallel resistances of the cell.

The mathematical model which relates the various parameters of the equivalent circuit is given by the following expressions:

$$I = I_{ph} - I_d - I_{sh} \quad (1)$$

$$I_{ph} = I_{scr} \times [1 + \alpha \times (T_c - T_r)] \times (S/S_r) \quad (2)$$

$$I_d = I_o \times \{ \exp[q \times (V + I \times R_s) / A \times k \times T] - 1 \} \quad (3)$$

$$I_o = I_{or} \times (T/T_r)^{(3/A)} \times \exp\{ (q \times E_g / k \times A) (1/T_r - 1/T_c) \} \quad (4)$$

$$I_{sh} = (V + I \times R_s) / R_{sh} \quad (5)$$

$$I = I_{ph} - I_o \times [\exp\{ q \times (V + I \times R_s) / A \times k \times T_c \} - 1] - (V + I \times R_s) / R_{sh} \quad (6)$$

Assuming high R_{sh} , Equation 6 can be written as:

$$(I_{ph} - I + I_o) / I_o = \exp(q \times (V + I \times R_s) / A \times k \times T_c) \quad (7)$$

$$q \times (V + I \times R_s) / A \times k \times T_c = \ln[(I_{ph} - I + I_o) / I_o] \quad (8)$$

$$V = (A \times k \times T_c / q) \times \ln[I_{ph} - I + I_o] - I \times R_s \quad (9)$$

Where α is the current-temperature coefficient, T_c is the cell operating temperature, T_r is the reference temperature, S is the solar radiation, S_r is the reference solar radiation, q is the electron charge, A is the ideality factor, k is Boltzman constant, I_o is the diode saturation current, I_{or} is the diode reverse saturation current, and E_g is the band gap power.

2.2 Photovoltaic Array Mathematical Model

The photovoltaic array takes the structure shown in Fig(2). As it is clear, it consists of N_p parallel connected strings, where each string consists of N_s series connected photovoltaic cells.

Applying Kirshof's current law:

$$I = N_p \times I_{ph} - N_p \times I_d \quad (10)$$

$$I_d = I_{ph} - I/N_p \quad (11)$$

$$I_o \times [\exp\{q \times V_d / A \times k \times T_c\} - 1] = I_{ph} - I/N_p \quad (12)$$

$$I_o \times \exp\{q \times V_d / A \times k \times T_c\} = I_{ph} - I/N_p + I_o \quad (13)$$

$$q \times V_d / A \times k \times T_c = \ln[(I_{ph} - I/N_p + I_o) / I_o] \quad (14)$$

$$V_d = (A \times k \times T_c / q) \times \ln[(N_p \times I_{ph} - I + N_p \times I_o) / N_p \times I_o] \quad (15)$$

$$\text{But } V_d = V/N_s + I \times R_s / N_p$$

$$V = N_s \times (A \times k \times T_c / q) \times \ln[(N_p \times I_{ph} - I + N_p \times I_o) / N_p \times I_o] - I \times R_s \times N_s / N_p \quad (16)$$

$$V = (N_s \times A \times k \times T_c / q) \times \ln[1 + (N_p \times I_{ph} - I) / N_p \times I_o] - I \times R_s \times N_s / N_p \quad (17)$$

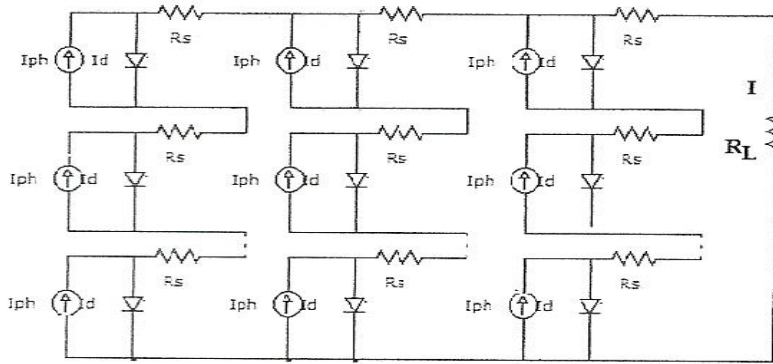


Fig.2: Photovoltaic Array Structure

2.3 Photovoltaic Cell Characteristics

From equation (2) and (17). It is seen that the PV characteristic is function of the level of solar irradiation and cell temperature.

Fig.(3) shows that the relationship between the PV terminal voltage and current is nonlinear, It also refers to the fact that says, to the left of the max power point, the PV cell behaves as if it were a current source and to the right of that point it behaves as if it were a voltage source.

Fig.(4) declares that the output power of the PV array increases as the solar irradiation increases. The open circuit voltage slightly decreases as the irradiation increases. The short circuit current is largely increases as the irradiation increases.

Fig.(5) shows the effect of temperature on the short circuit current, open circuit voltage, and maximum power, it says that the short circuit current is slightly increases as the temperature increases. The open circuit voltage is highly reduced as the temperature increases. The maximum power decreases as the temperature increase because of the high reduction in the voltage and minor growth in the current.

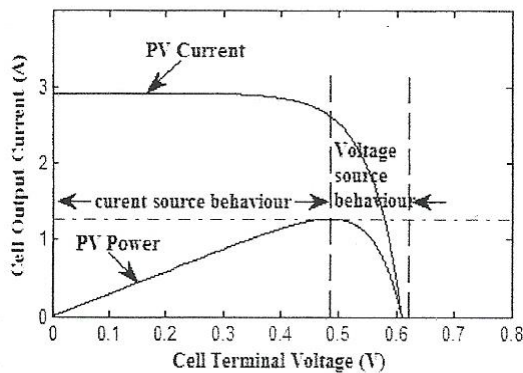


Fig.(3): I-V characteristics and P-V characteristics

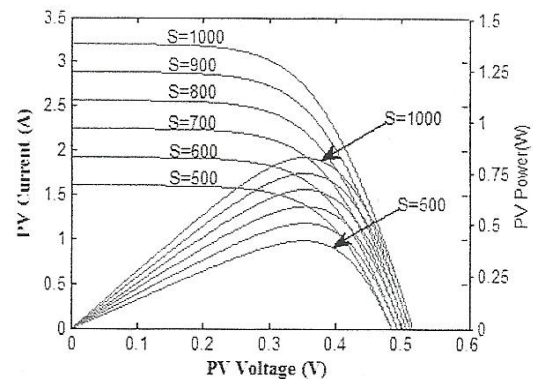


Fig.(4): I-V characteristics and P-V characteristics under different

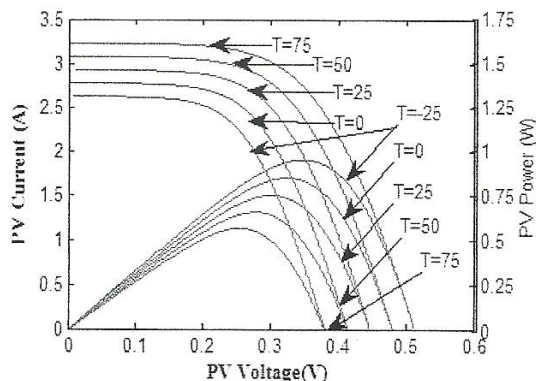


Fig.(5): I-V characteristics and P-V characteristics under different

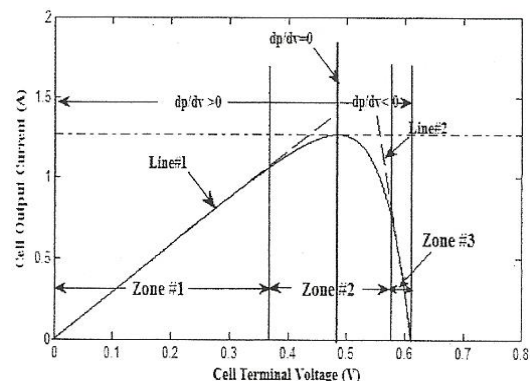


Fig.(6): Different Zones of the P-V characteristics

3. Proposed MPPT Controller

For each irradiation and temperature, there is a unique I-V curve like that drawn in Fig.(3). Each curve like that has one and only one maximum power point. For different operating points, there are different maximums, so to get the maximum power from PV array, MPPT controller has to operate the PV array at these maximum power points.

Close look to Fig.(6), one can observe the followings:

- 1- The zone to the left of the bold vertical line ($dp/dv=0$) is characterized by having $dp/dv>0$.
- 2- The zone to the right of the bold vertical line is characterized by having $dp/dv<0$.
- 3- In zone#1, the power curve has a slop equals that of line#1.
- 4- In zone#3, the power curve has a slop equals that of line#2.
- 5- In zone#2, the power curve has a varying slop taking +ve value to the left of the bold vertical line and -ve value to the right of that line.
- 6- In zone#3, the slop is -ve and sharp as compared to the +ve one in zone#1.

From the fore mentioned points, it is clear that zone#1 and #3, dp/dv cannot refer to the departure of the operating point from the optimum one. At these zones, the magnitude of dp/dv has no meaning but its sign refers to the location of the operating point. +ve sign indicates positioning to the left of the vertical line. -ve sign indicates right positioning.

The cooperation of the magnitude and sign of dv with +ve, zero, and -ve values of dp/dv can give a rich information about the departure and its direction with respect to the maximum power point. These observations have been adopted in the selection of the membership functions of the fuzzy controller input variables.

The block diagram of the over all system is shown in Fig.(7).

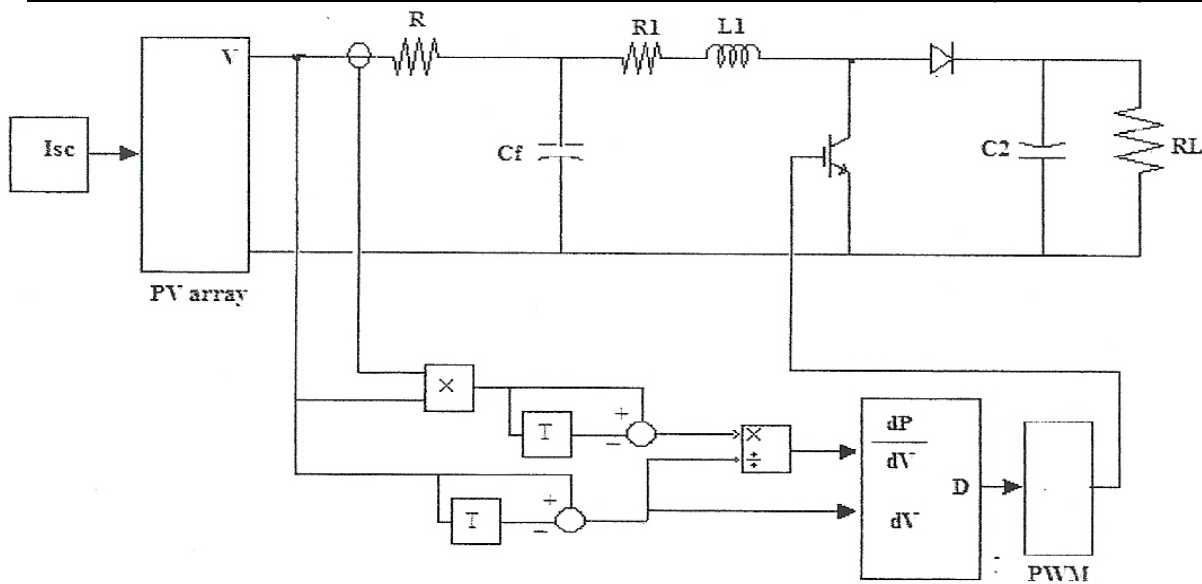


Fig.7: Proposed Fuzzy logic based controlled PV system configuration.

3.1 PV array

The specifications of the PV array model used in simulation are listed in Table 1 [12].

Table 1: Specifications of the PV model array used					
Ns	Np	$R_s(\Omega)$	$I_{sc}(A)$	$I_o(A)$	$A(A/C\bullet)$
35	1	0.0277	2.926	0.5×10^{-4}	0.002086

3.2 Boost DC/DC converter

This part of the system forms the interface between the PV power source and the load. Its function is to match the load resistance to that of the input source by the virtue of the commands issued by the fuzzy logic based controller.

The various parameters of this converter are listed in Table 2:

Table 2: Boost converter parameters					
$R(\Omega)$	$C_f(\mu F)$	$R_1(\Omega)$	$L_1(H)$	$C_2(\mu F)$	$R_L(\Omega)$
0.001	2200e-6	0.1	8e-3	2200e-6	25

3.3 Fuzzy logic based MPPT Controller

The proposed controller is shown in Fig.(8). It has two inputs and one output variables. The two inputs are the dPdV and dV where :

$$dPdV = [P(k) - P(k-1)] / [V(k) - V(k-1)]$$

$$dV = V(k) - V(k-1)$$

The output variable is the amount of correction of the duty ratio (ΔD). The membership functions of the input variables are shown in Fig.(9) and the fuzzy rules of the inference engine are tabulated in Table 3.

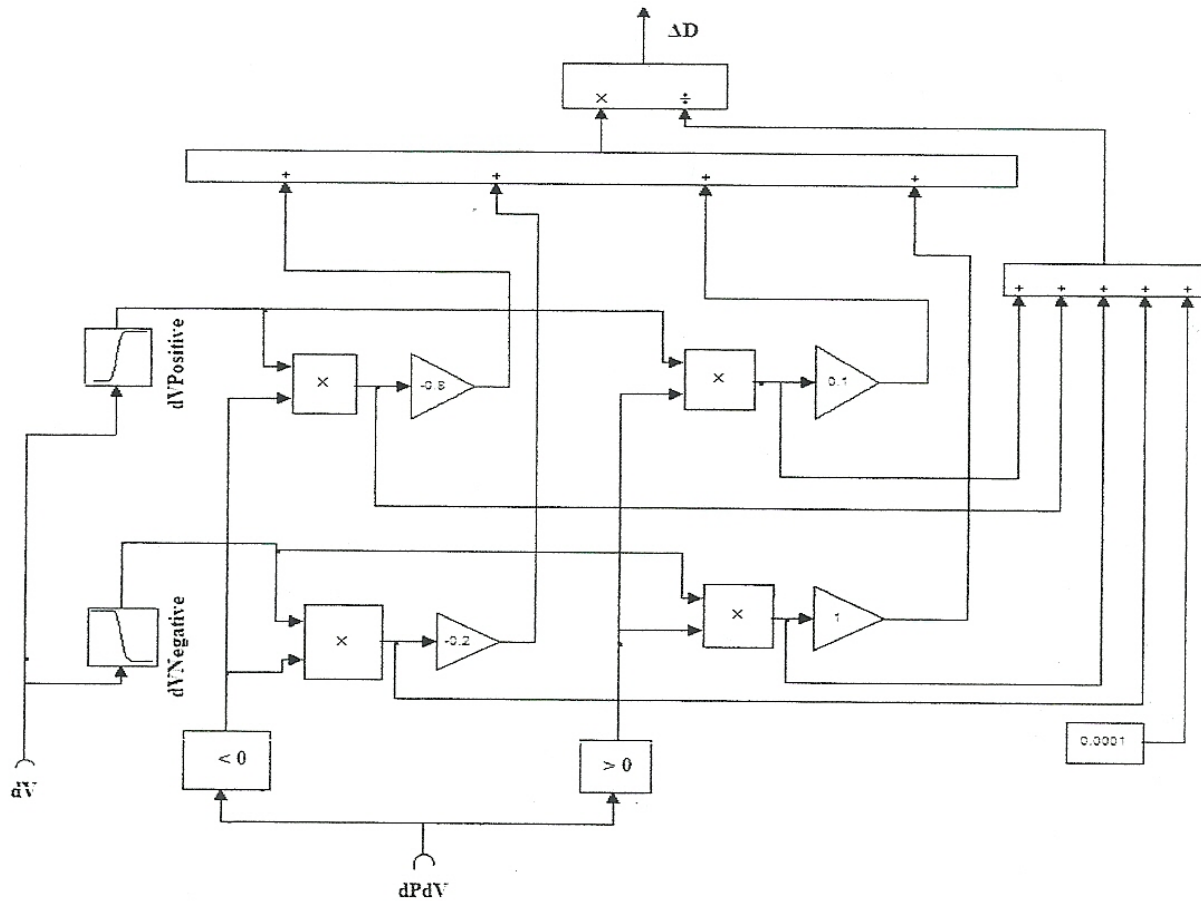


Fig.8: Matlab/Simulink modeling of the Proposed controller

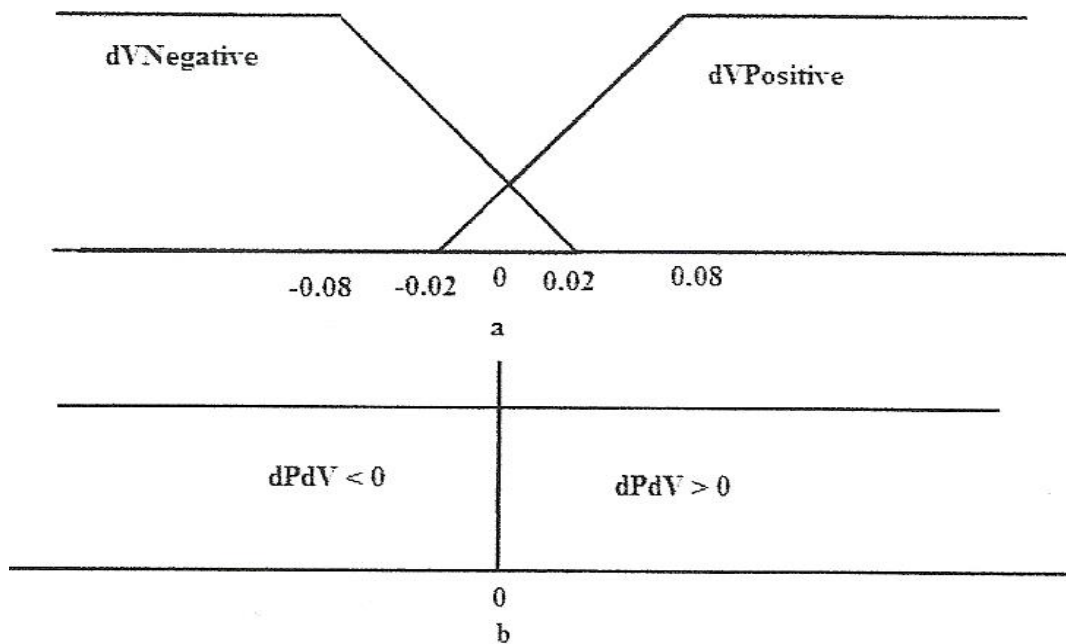


Fig. 9: Fuzzy controller membership functions:

A: voltage change; b: dP/dV change

Table 3 : Rules set of the Proposed controller			
		dV	
		dV_{Negative}	dV_{Positive}
$dPdV$	<0	-0.2	-0.8
	>0	1	0

4. Simulation results and discussion

The relation between the solar irradiation (in term of short circuit current) and the power at the maximum power point has been calculated and shown in Fig.(10). The simulation pictures the linear relationship between these two quantities at a given temperature.

The system depicted in Fig.(7) has been simulated using SIMULINK software to evaluate the performance of the proposed fuzzy logic based MPPT controller.

The results of this simulation under the reference condition have been plotted in Fig.(11), Fig.(12), and Fig.(13) where:

Fig.(11) displays the PV voltage and current responses under different loading with and without the proposed controller.

With the proposed controller, the operating voltage of the PV array is constant and equals 13.4V for $R_L=10\Omega$, 15Ω , 20Ω , and 25Ω . Also the operating current of the array equals 2.51A for $R_L=10\Omega$, 15Ω , 20Ω , and 25Ω .

Without any controller, the operating voltage increase as the load resistance increases (for $R_L=10$, $V=13.65V$ and for $R_L=25$, $V=18.2$). the current decreases as the load resistance increases (for $R_L=10$, $I=1.6A$ and for $R_L=25$, $I=0.72A$)

Fig.(12) shows that the proposed controller keeps the power taken from the PV array (under different loading) equals to the optimum one (33.75W).with the absence of the controller, the power taken decreases as the load increases (for $R_L=10$, $P=26.5W$ and for $R_L=25$, $P=13W$).

Fig.(13) plots the dynamic behavior of the proposed system when subjected to hard step changes in the load. It shows the ability of the proposed controller in keeping track with the optimum point.

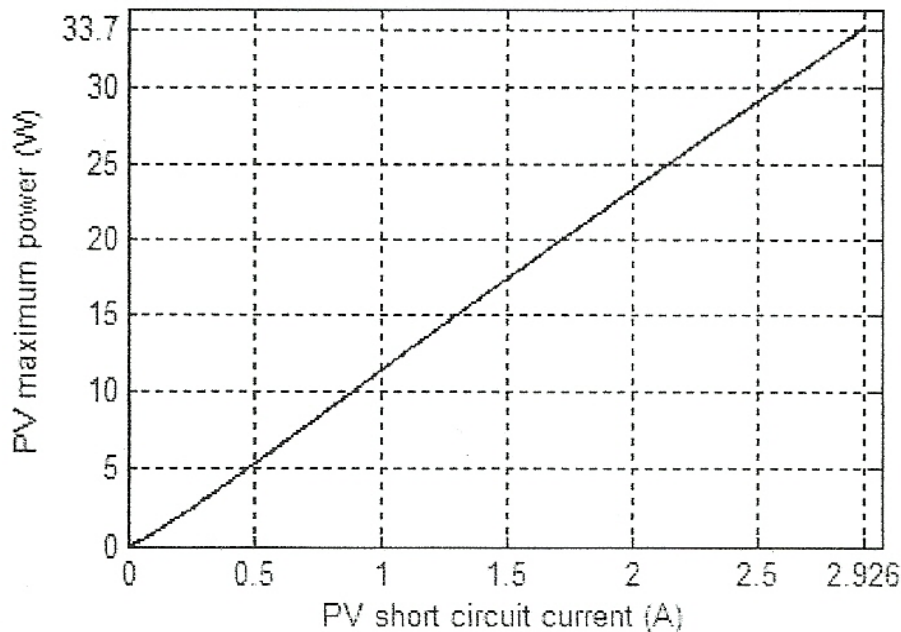


Fig.10: Maximum generated power

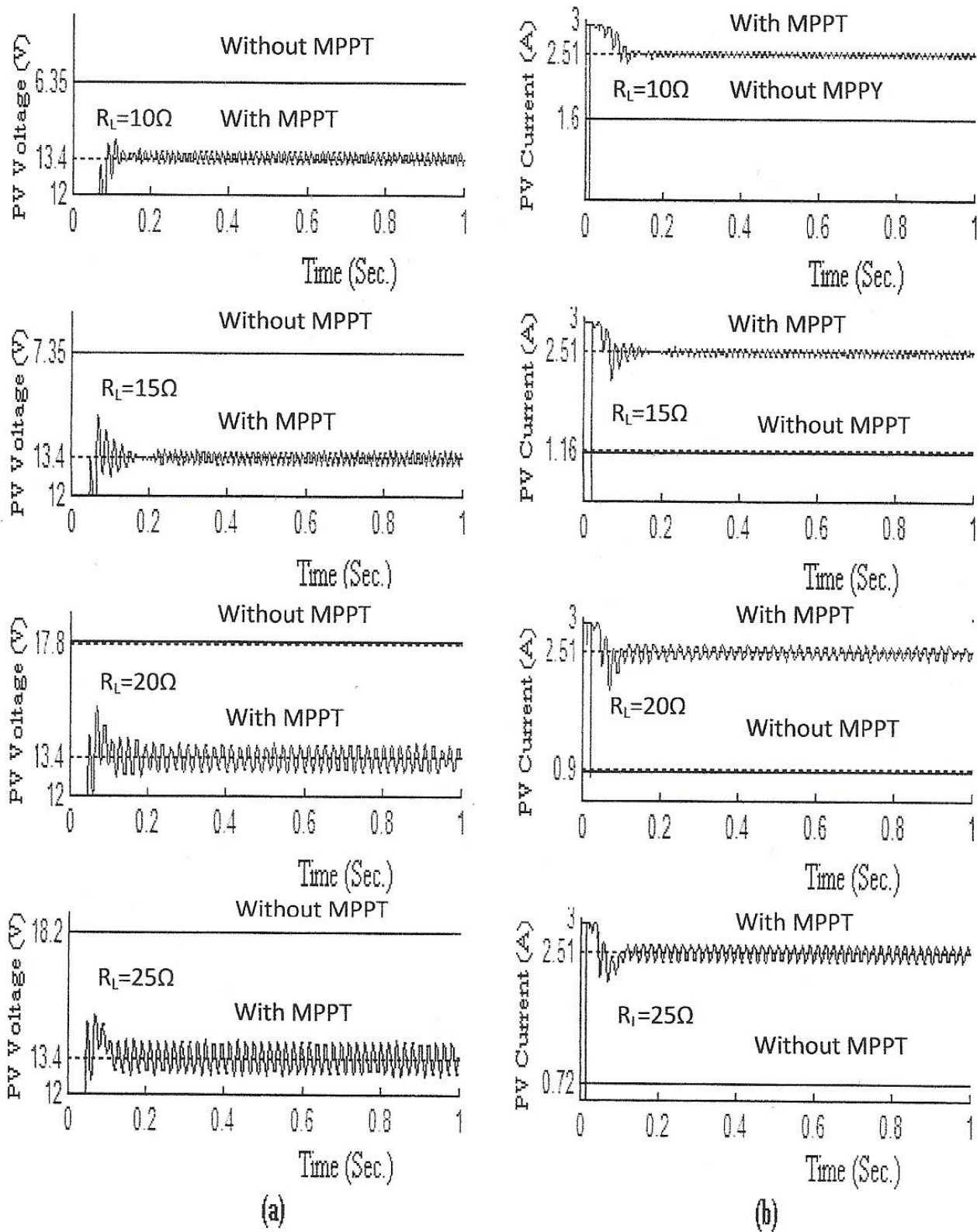


Fig.11: PV voltage and current responses under different loading and fixed irradiation with and without the proposed controller

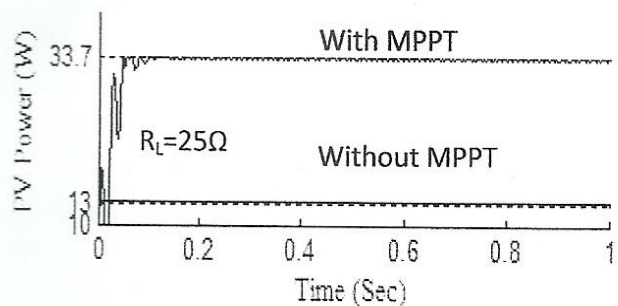
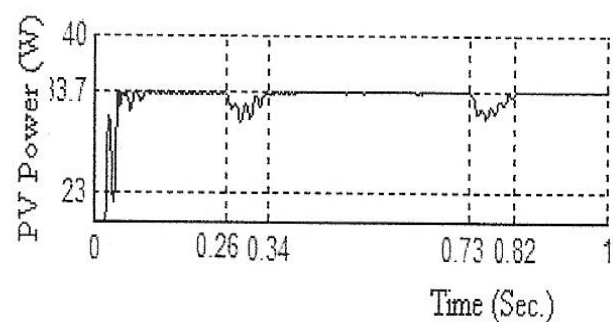
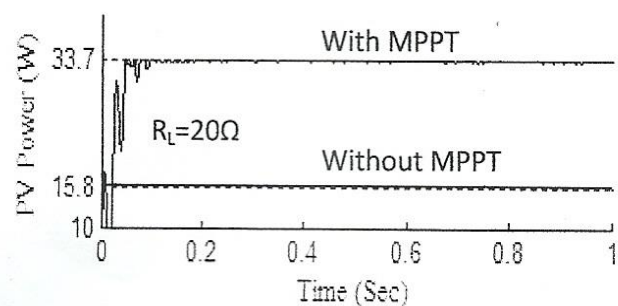
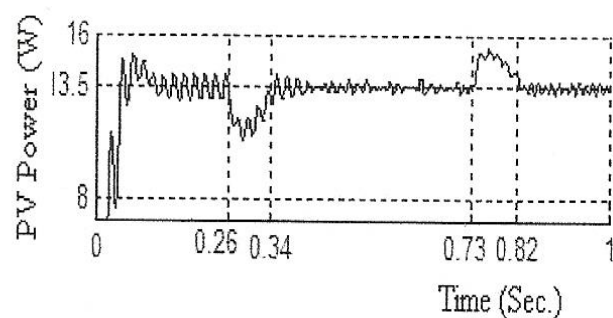
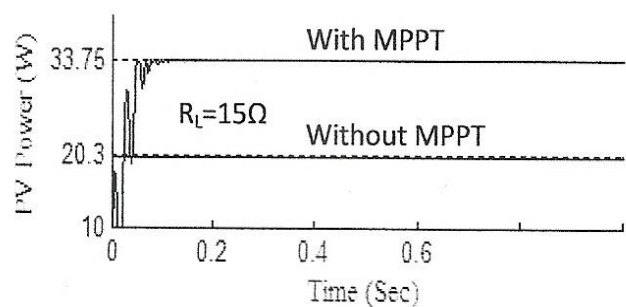
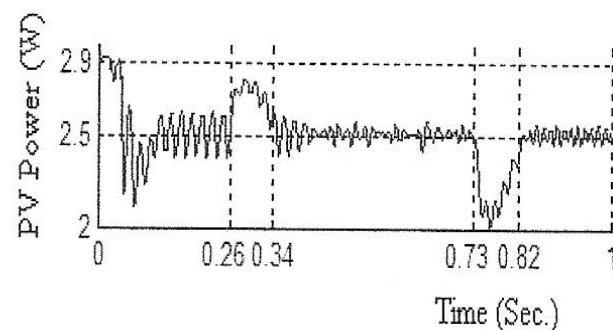
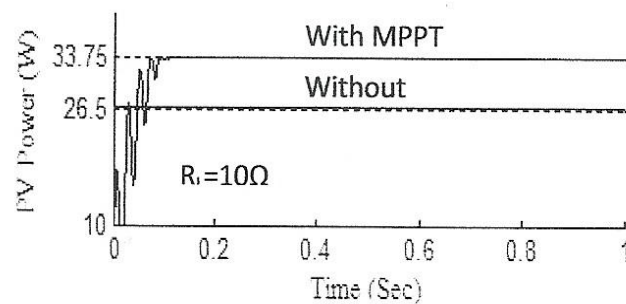


Fig.13: Dynamic response under step load changes ($25\Omega \rightarrow 10\Omega \rightarrow 25\Omega$)

Fig.12: PV power response under different loading with and without proposed controller

5. Conclusion

A simple and minimum rules fuzzy logic based maximum power point tracker has been proposed and simulated in Matlab software. The result obtained under different loading and step load resistance changes, proved the ability of this controller in matching the applied load resistance with that of the PV array and hence extracting the maximum power from the PV array.

6. References

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