

Fuzzy Logic Based MPPT Technique For a Single Phase Grid Connected PV System with Reactive Power Exchange Capability

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ABSTRACT: In the proposed paper power generation from photovoltaic array is used to connect the grid. DFCM Inverter control with PSPWM technique is used in order to control active and reactive power injected into grid. FLC MPPT technique is proposed for maximum power point tracking and is compared with Constant voltage MPPT technique. The simulation results of proposed system and Constant voltage MPPT technique are compared by using MATLAB/SIMULINK software.

KEYWORDS: PSPWM Technique; DFCM converter; FLC controller; MPPT.

I. INTRODUCTION

Now-a-days Renewable energy is one of the worlds challenging aspect. There is a growing effort to make renewable energy more feasible. Among renewable energy sources, photovoltaic energy is one of the most considerable sources.

A photovoltaic cell converts the energy of light directly into electricity. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are used as building blocks for photovoltaic modules. A PV module is an assembly of solar cells. Solar panels can be used to generate and supply electricity in commercial and residential applications. Solar modules use light energy (photons) from the sun to generate electricity through the photovoltaic effect. Electrical connections are made in series to achieve a desired output voltage and/or in parallel to provide a desired current capability [1], [2].

Power electronic converters carry out a prominent role to connect the PV array to the utility grid, injecting a sinusoidal current to the grid, and even power conditioning. In the proposed method DFCM converter is used for converting the DC voltage to sufficient ac voltage in order to connect the grid [6]. The inverter used in this paper is dual flying capacitor multi-cell (DFCM) converter [7].

The proposed system uses fuzzy MPPT technique for maximum power point tracking. Boost converter is used to boost the PV voltage to a sufficient level in order to connect to the grid [3], [5]. Active and Reactive power injection from proposed system to grid is achieved as a part of the work. In the simulation, the grid impedance is assumed as a resistive-inductive series branch.

II. PHOTOVOLTAIC MODEL

The equivalent circuit of a photovoltaic cell is described as shown in Fig.1.

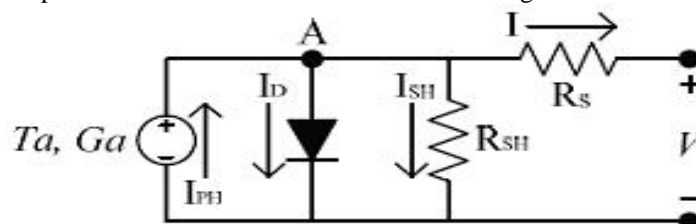


Fig.1 PV cell

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Equations derived for a photovoltaic cell [1], [2] are shown below

Module photo – current, I_{ph}

$$I_{ph} = (I_{scr} + k_i \times (T - 298)) \times (\lambda/1000)$$

... (1)

Module reverse saturation current, I_{rs}

$$I_{rs} = I_{scr} / [\exp((qV_{oc}) / (N_s KAT)) - 1]$$

... (2)

Module saturation current, I_o

$$I_o = I_{rs} (T/Tr)^3 \exp(q E_{go} / (Bk \{ (1/Tr) - (1/T) \}))$$

... (3)

Current output of PV module is, I_{pv}

$$I_{pv} = N_p I_{ph} - N_p I_o \exp((q(V_{pv} + I_{pv} R_s)) / (N_s KAT)) - 1$$

(4)

PV array parameters for each sub module are shown in below Table 1

Table 1. PV array (sub module) parameters

Parameters	Description	Unit
Ns	Number of series solar cells	48
N	Diode ideality factor	1.3
Isc STC	PV short circuit current	8.15A
Voc STC	PV open circuit voltage	29.4V

Where the description of parameters in the equations (1),(2),(3),(4) are as described in Table 2.

Table 2. PV model parameters

T	Cell temperature in Celsius
K	Boltzmann's constant, 1.38×10^{-19} J/K
Q	Electron charge, 1.6×10^{-19} C
k_i	Short circuit current temperature coefficient at I_{scr}
λ	Solar irradiation in W/m^2
I_{scr}	Short circuit current at 25 degree Celsius
I_{lg}	Light-generated current
E_{go}	Band gap for silicon
R_{sk}	Shunt resistance
R_s	Series resistance

A single module consists of ten sub modules connected in series; each sub module consists of 48 photovoltaic cells connected in series making 480 cells in module. Twelve such modules are connected in parallel to make a PV array. Total PV array produces 20 kW of power. The Solar energy with irradiance levels of upto $1kW/m^2$ is abundant and photovoltaic Power is a prime candidate for electrical energy generation. Solar irradiance is not constant. It depends upon weather conditions. Input irradiance for PV array is shown in Fig.2.

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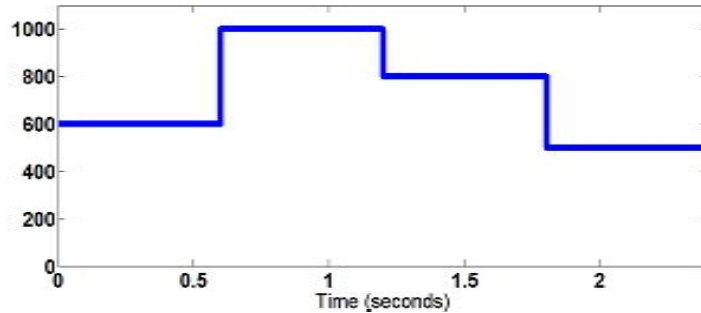


Fig.2 Input irradiance for PV array

Total PV array generate a Photo current which depends upon irradiance and vary with respect to time is shown in below Fig.3.

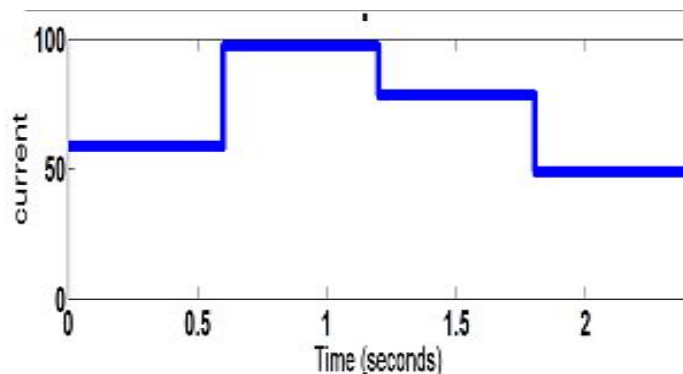


Fig.3 Current vs. Time graph for PV array

III. PROPOSED MPPT TECHNIQUE

Fuzzy MPPT technique is used in order to track maximum power point for the proposed system. In method error $E(k) = \Delta p / \Delta v$ and change of error $CE(k)$ are used as inputs. Output is the corresponding duty cycle [5].

The error $E(k)$ is given by

$$E(k) = (P_{pv}(k) - P_{pv}(k-1)) / (V_{pv}(k) - V_{pv}(k-1)) \quad \dots(5)$$

Change of error $CE(k)$ is

$$CE(k) = E(k) - E(k-1) \quad \dots (6)$$

Output $D(k)$ of the FLC is given by

$$D(k) = D(k-1) - D(k) \quad \dots$$

(7)

In this section we'll be building a simple MPPT technique using the graphical user interface (GUI) tools provided by the Fuzzy Logic Toolbox as shown in below Fig.4.

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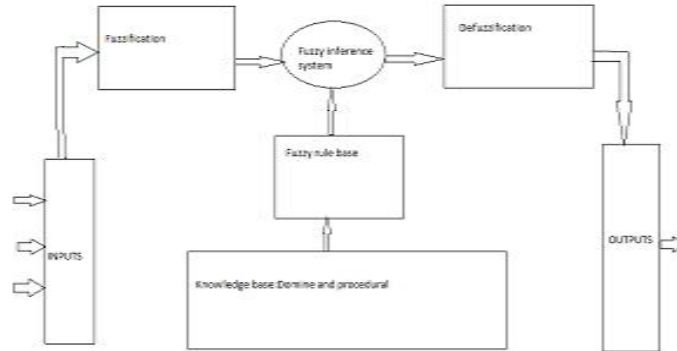


Fig.4 Internal structure of fuzzy logic system

Membership functions for inputs and output of FLC system are as shown Fig. 5. Fig.5(a) showing membership functions for error $E(k)$.

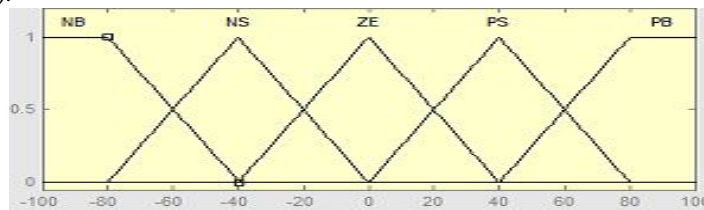


Fig.5 (a).Input $E(k)$

Membership functions for change of error $CE(k)$ are as shown in below Fig.5(b)

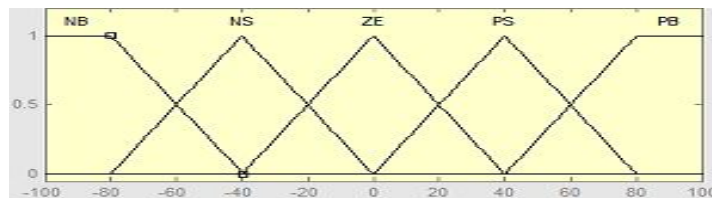


Fig.5 (b).Input $CE(k)$

Membership functions for Duty cycle $D(k)$ are as shown in below Fig.5(c)

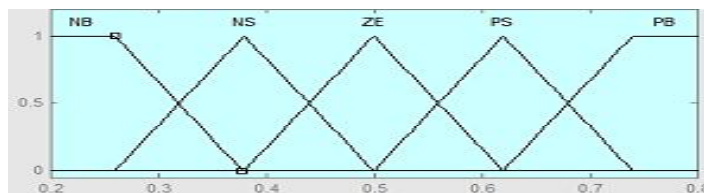


Fig.5 (c).Output duty cycle $D(k)$

In this process of fuzzification, converting the system actual input value E and CE into linguistic fuzzy labels using fuzzy membership function. These variables are expressed in different fuzzy levels: PB (positive big, PS (positive small), ZE (zero), NB (negative big), and NS (negative small), using basic fuzzy subset. Twenty five rules are used for building FLC system as shown in below Table 3.

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Table 3. Fuzzy rules

e/ce	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

IV. BOOST CONVERTER

The Circuit Diagram for the Boost converter is as shown in below Fig.6.

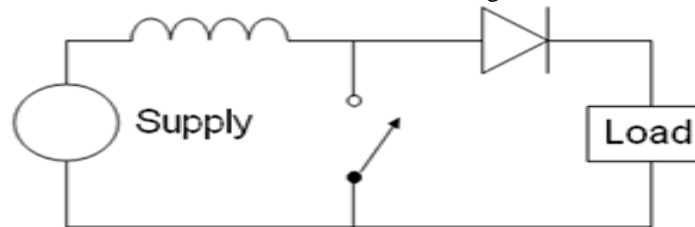


Fig.6 Boost converter

Output voltage of the boost converter

$$v_0 = v_s(1 - \alpha) \quad \dots$$

(8)

Where α is the Duty cycle. Boost converter is used to boost up the PV output voltage compatible with the grid voltage. Switching frequency for boost converter is 10 kHz [3].The parameters of Boost converter are as shown in below Table 4.

Table 4. Boost converter parameters

Parameters	Description	Unit
1	Inductor	50 μ H
2	Capacitors	8 mF
3	Switching frequency	10kHz

V. PSPWM TECHNIQUE

Four carrier waves phase shifted 90 degrees each are compared with the sine reference wave to generate switching pulses for DFCM converter [4] as shown in below Fig.8.



Fig.8 PSPWM Technique.

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VI. DFCM CONVERTER

With the use of DFCM converter transformerless operation is possible and it is more suitable for medium as well as high power applications. With comparison to other multilevel converters DFCM converter has less number of high frequency switches, flying capacitors and DC sources. DFCM converter is constructed by adding only two low frequency switches to the conventional configuration of FCM converter [3] and the Circuit model of DFCM Converter is as shown below Fig.9.

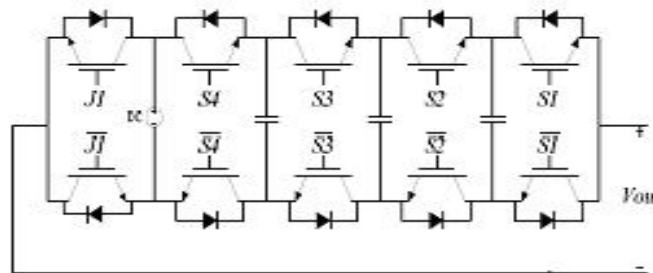


Fig.9 DFCM converter.

The parameters of DFCM converter are as shown in below Table 4.

Table 5. DFCM converter parameters

Parameters	Description	Unit
1	Switching frequency	1.5kHz
2	Flying capacitors	2mF
3	Output fundamental voltage frequency	50Hz

The Simulink block Diagram for the proposed system is as shown below Fig.10

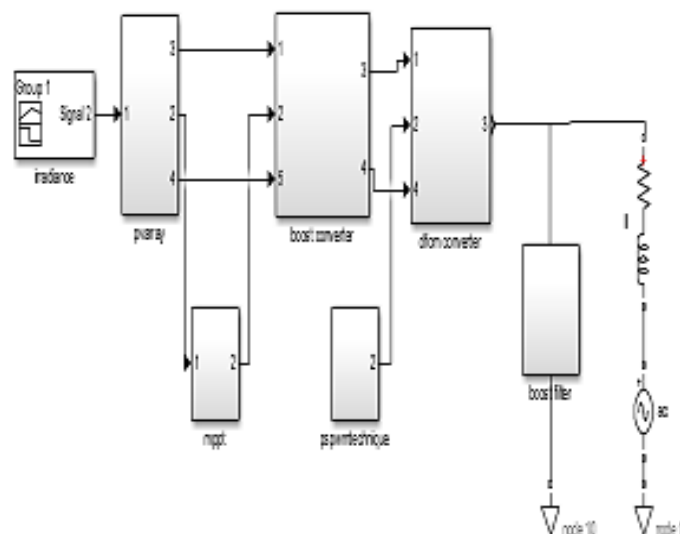


Fig.10 Block diagram of the PV system connected to Grid with Fuzzy MPPT technique and DFCM converter.

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VII. REACTIVE POWER EXCHANGE BETWEEN PV SYSTEM AND GRID

Grid voltage is taken as Peak voltage 300V. Grid impedance is taken as R-L series branch with R=0.5ohm, L=1mH. Active power injection into the grid is controlled by MPPT technique. Depending upon duty cycle the active power injected into Grid either increases or decreases. Active power flowing from port one to port two is given by

$$P = (V1 V2 \sin \delta) / X$$

... (6)

Reactive power flowing from port one to port two is given by

$$Q = (V1 V2 \cos \delta) / X - V2^2 / X$$

... (7)

The control method for the voltage output of the inverter and effectively the reactive power generated or absorbed is based on a simple reactive power flow equation (7) just as in the real power control method. Reactive power control is depending on phase angle between Grid voltage Vr, inverter voltage Vs. Depending upon phase angle and its direction Reactive power either injected into grid or consumed from the grid. In this way Reactive power exchange between PV system and Grid takes place.

Active Power exchange between proposed system and grid using ideal DC voltage source with 400V DC link voltage is as shown in below Fig.12

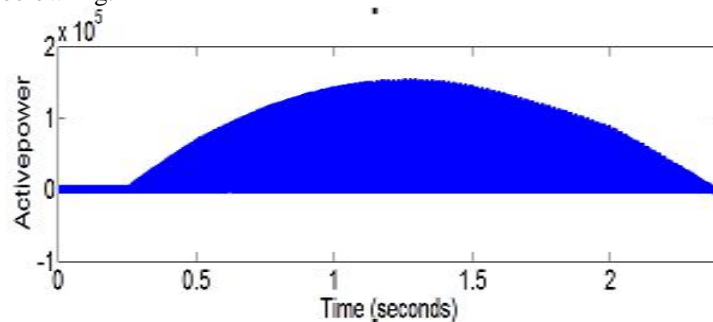


Fig.12 Active power injected into the Grid with 400V DC link voltage.

Reactive Power exchange between proposed system and grid using ideal DC voltage source with 400V DC link voltage is as shown in below Fig.13.

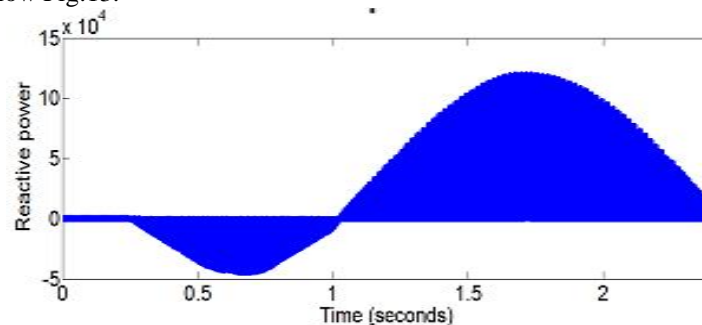


Fig.13 Reactive power injected into the Grid with 400V DC link voltage

Active Power exchange between proposed system and grid using ideal DC voltage source with 600V DC link voltage is as shown in below Fig.14.

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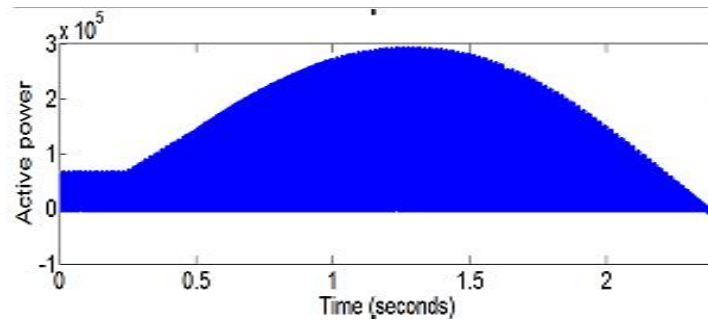


Fig.14 Active power injected into the Grid with 600V DC link voltage.

Reactive Power exchange between proposed system and grid using ideal DC voltage source with 600V DC link voltage is as shown in below Fig.15.

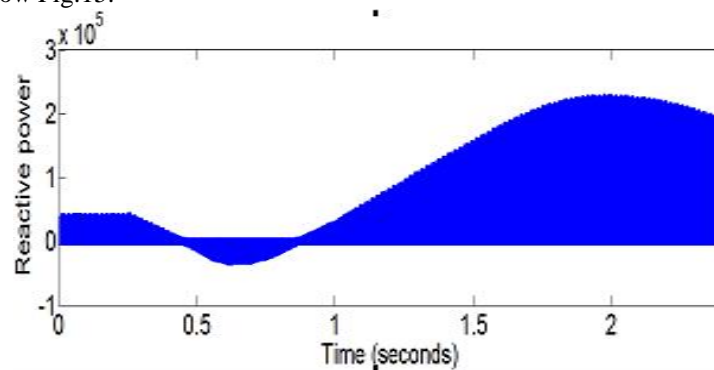


Fig.15 Reactive power injected into the Grid with 600V DC link voltage

VIII. OUTPUT WAVEFORMS WHEN PV SYSTEM CONNECTED TO GRID

Active power exchange between proposed system and grid when PV system is Connected to Grid and Constant voltage MPPT technique is used as shown in below Fig.20

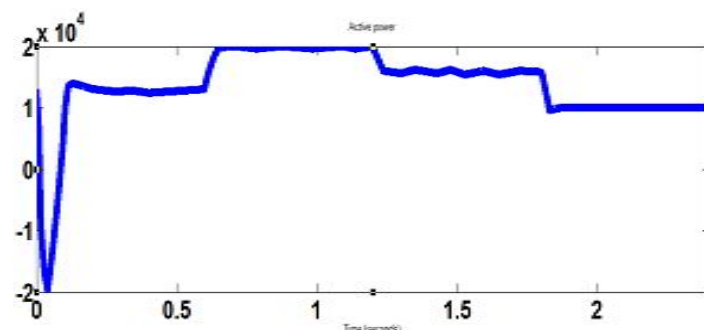


Fig.20. Active power injected into the grid and constant voltage MPPT is used.

Reactive power exchange between proposed system and grid when PV system is Connected to Grid and Constant voltage MPPT technique is used as shown in below Fig.21.

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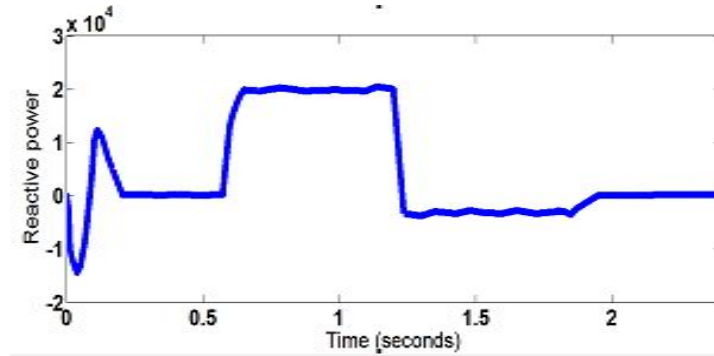


Fig.21 Reactive power injected into the grid and constant voltage MPPT is used.

Active power exchange between proposed system and grid when PV system is Connected to Grid and FLC MPPT technique is used as shown in below Fig.22.

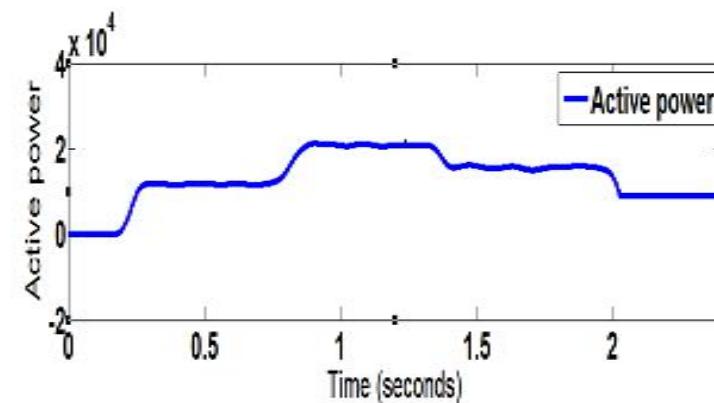


Fig.22 Active power injected into the Grid and fuzzy logic controller MPPT is used.

Reactive power exchange between proposed system and grid when PV system is Connected to Grid and FLC MPPT technique is used as shown in below Fig.23

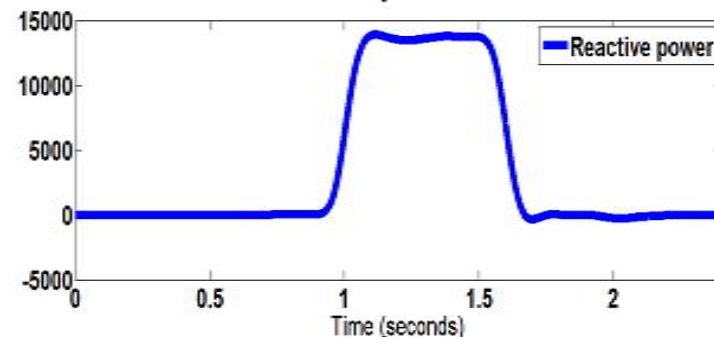


Fig.23 Reactive power injected into the Grid and fuzzy logic controller MPPT is used.



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Comparison results of PV system connected to Grid with Constant voltage MPPT technique and FLC MPPT technique are as shown in below Table 6.

Table6.Comparison of results

Constant voltage MPPT technique	FLC MPPT technique
In order to measure open circuit voltage current must be maintained at zero. So power interruptions takes place.	No current zero condition required. So no power interruptions.
Waveforms are less stable and efficient with constant voltage MPPT technique	Waveforms are more stable and efficient .

VIII. CONCLUSION

In this paper DFCM Converter with PSPWM technique is used in order to control active and reactive power injected into grid with FLC MPPT technique for maximum power point tracking. Results of proposed system are more stable and efficient and are compared with constant voltage MPPT technique using MATLAB/Simulink.

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