International Journal on Recent and Innovation Trends in Computing and Communication
Volume: 3 Issue: 10

ISSN: 2321-8169
5909 - 5915

Micro-inverter with Fuzzy logic based MPPT of Partially shaded PV modules and energy recovery scheme

Anusha Talluri
Electrical and Electronics Department
JNTUK-UCEV
Vizianagaram,India
email: anushat52@gmail.com

G.Saraswathi
Electrical and Electronics Department
JNTUK-UCEV
Vizianagaram,India
email: bksaraswathi@yahoo.co.in

Abstract:- When there is occurrence of partial shading on PV modules there are two to three bypass diodes connected in junction box for 200W rated PV module. Due to this configuration the power-voltage characteristics of the PV module will have many peaks. So to extract maximum power even during the partial shading condition this paper proposes the use of micro-inverter based on flyback configuration with Fuzzy logic based maximum power point tracking technique. This can be achieved by implementing an equalization circuit across the PV module. This equalization circuit consists of series connection of diode and secondary winding of the flyback transformer of the micro-inverter. This equalization circuit is capable of energy recovery from the leakage inductance of the converter when the main switch is turned off. This proposed topology have the following features: fuzzy logic based mppt to extract maximum available power, energy recovery capability and conversion of dc to ac. The proposed technology's effectiveness is analyzed by comparing it with PV module having bypass diode configuration. The simulation results, control strategies and modes of operation and analysis of the proposed topology are presented in this paper.

Keywords:- *Photovoltaic module PV, PV sub-module micro-inverter, Fuzzy logic based maximum power point tracking (MPPT), partial shading, Flyback converter, Flyback transformer.*

*****

I. INTRODUCTION

To achieve desired voltage or current levels, depending on the application , PV modules are connected in series or parallel into a PV array configuration. To feed PV power into the Grid , generally centralized inverter or string inverter are used. However, due to PV array mismatch problems, module integrated converters (micro-inverters) are becoming increasingly popular for feeding PV power into the grid. Advantages of using micro-inverter are: (a) mismatch problems are eliminated; (b) Individual (distributed) MPPT operation (at the module level) and (c) Plug and play operation [1]. Many micro-inverter topologies have been proposed from time to time [2, 3]. PV module generally consists of typically 32, 54 or 72 cells connected in series. Current is limited to the weakest cells in the module when any of the cells in the module gets shaded or damaged. Due to this there is drastic reduction in PV module power. Also, there is occurrence of large negative voltage appears across the module increasing the possibility of hot spots. Solar manufactures configure a PV module into sub PV modules of 12 to 24 cells each with each sub-module having its own bypass diode, to overcome these issues.

When partial shading of the PV module occurs, there is occurrence of multiple peaks in the power-voltage characteristics of PV module configuration. It's not possible to operate the module at the global peak by using conventional MPPT.

Many searching algorithms have been proposed to track the global maximum power point for PV array configuration [4]. But these algorithms are able to extract the global peak power but unable to extract the partially shaded PV module power completely. A more efficient and desirable way is proposed by making each PV sub-module to operate at its maximum power point and extract maximum available power from both non-shaded and shaded PV sub-modules and by using fuzzy logic based mppt to track maximum power.

The rest of the paper organized as follows: In Section-II the proposed configuration is demonstrated and various operating modes and control scheme are discussed. In Section-III Matlab-Simulink results are presented. The major conclusions of the paper are summarized in section IV.

II. PROPOSED TOPOLOGY, MODES OF OPERATION AND CONTROL STRATEGY

A basic micro-inverter system is consists of extraction of MPP, DC to AC conversion and Active power decoupling, as shown Fig. 1.

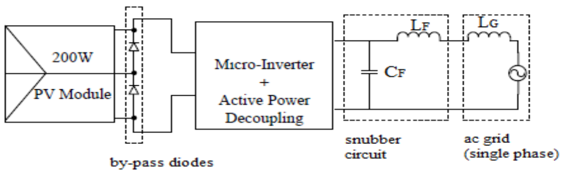


Fig1: Micro-inverter (flyback configuration type)

A. Circuit configuration (proposed)

In the proposed configuration as shown in Fig.2, PV module is used which consists of two sub-modules connected in series without bypass diode configuration and across this module micro-inverter is connected. Micro-inverter consists of voltage equalization circuit (secondary windings E_A & E_B of the flyback transformer), dc to ac conversion stage (S_A, S_B) and switching devices (S_{GA},S_{GB}) on the secondary side.

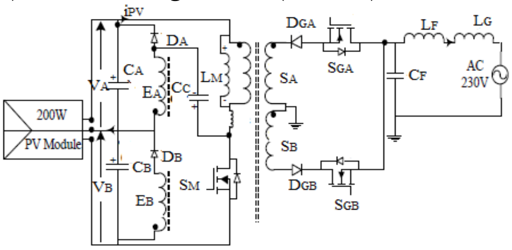


Fig.2. Proposed Micro-Inverter System.

To make the control simple the configuration is operated in Discontinuous Conduction Mode (DCM). The voltage across the two PV sub-modules is equalized by two windings E_A and E_B by injecting compensating current, (i_{cpn}) from the PV module. When S_M is turned OFF, the equalization circuit performs energy recovery also. To transfer energy stored in magnetizing inductor L_{mg} to AC grid, centre-tap of S_A-S_B are used by operating the switches on the secondary side. Secondary side switches S_{GA} and S_{GB} are synchronized with grid voltage by using Phase Locked Loop (PLL).

By using current/voltage equalization schemes with the PV sub-modules this can be achieved. To provide necessary power compensation to the shaded PV modules, the equalization schemes are usually implemented by using dc/dc converters [5-6].

The basic idea of voltage equalizing (in place of bypass diodes across PV sub-modules) is used to extract the maximum power available from the PV module in this paper. Voltage equalizing circuit, in the proposed scheme, consists of two secondary windings (of the main flyback transformer) which is connected across 2 PV sub modules. This circuit is able to recover the energy of leakage inductance present in the primary of the flyback transformer, when the primary side switch (S_M) is turned off apart from voltage equalization. Thus proposed topology improves the overall efficiency of flyback converter and also and the shaded PV modules. The results of the PV modules with flyback converter topology are compared with the results of PV modules with bypass diode configuration under partially shaded conditions.

B. OPERATION WITH DIFFERENT MODES AND ANALYSIS

The proposed circuit's operation can be divided into different modes which are described below:

Mode-1: During main switch S_M on-period interval ($d1T_{Sa}$) and at the first instant there is an increase in magnetizing current of the PV linearly and the peak value of this is obtained by the mppt algorithm. This current passes through flyback transformer's magnetizing inductor (L_{mg}) and the main switch S_M.

The operation of equivalent circuit of mode-1 is shown in Fig. 3. The magnetizing current's peak value is given by the equation below:

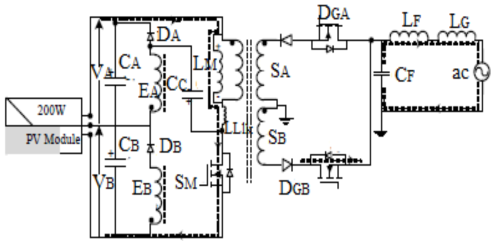


Fig.3. Mode-1 operation(d1Tsa)

$$v_{pv} = v_1 + v_2 ; \qquad v_{CF} = v_{LF} + v_G \qquad \{1\}$$

$$i_{pv} = I^*_{M(pk)} = \frac{d_1 v_{pv}}{L_M f_S} \qquad \{2\}$$

Mode-2: In this mode S_A is turned off and at this instant large voltage spikes occur across the main switch S_A which is because of the energy stored in the leakage inductance(L_{mg}) on the primary side. The energy stored in leakage inductance(L_{mg}) is transferred to clamping capacitor (C_c) through the diode, D_A as shown in Fig.4. The clamping capacitor's stored energy is given by the equation below:

$$E_{CS} \Rightarrow E_{Llk} = \frac{1}{2} L_{lk} I^2_{M(pk)} \qquad \{3\}$$

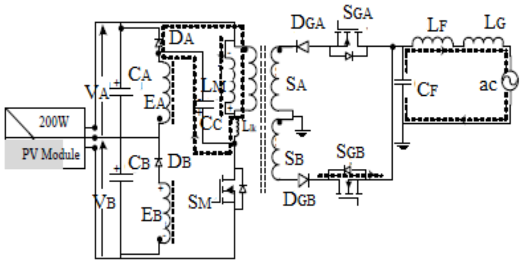


Fig.4. Mode-2 operation(d1aTsb)

Mode-3: This mode has energy of magnetizing inductance(L_{mg}) that is stored in mode-1and is transferred in two ways.

(a) Some of the energy which is stored is transferred to grid, as the magnetizing current(of the PV module) slowly decreased to zero and the switching devices S_{G1} and S_{G2} are operated based on negative and positive half cycles of the voltage of the grid . Secondary side's current and voltage of configuration is given by the equations below:

$$V_{Cf} = n_g v_{pv} \qquad \{4\}$$

$$\frac{i_m}{n_g} = i_c + i_g \qquad \{5\}$$

(b)The remaining energy compensates the (shaded) PV sub-module power. When there is occurrence of shading on the PV sub module - 2, the voltage (V_2) is lower than voltage across winding E_B and the compensating current (i_{cpn}) is injected into junction of the PV sub-modules connected in series which is shown in Fig.5. The compensating current(i_{cpn}) becomes zero when the voltages across the windings E_A and E_B becomes equal, since the diodes D_A and

D_B gets reverse biased . Compensating current (i_{cpn}) to the shaded PV sub module 2 is given as:

$$I_{cpn} = \frac{i_m}{n_g} \qquad \{6\}$$

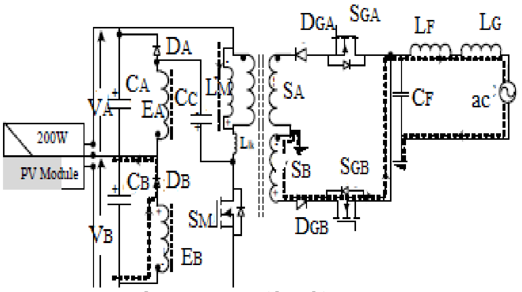


Fig.5. Mode-3 operation(d2Tsb)

Mode-4: Since the flyback converter is operated in Discontinuous Conduction Mode(DCM), all the switches will be in OFF state after the magnetizing current of the PV module becomes zero. The d_1V_{PV} energy stored in the filter capacitor(C_F) is supplied to the AC grid in this period, which is shown in Fig.6.

$$i_{SA} = i_{SB} = i_M = 0; i_{Cf} = i_G \qquad \{7\}$$

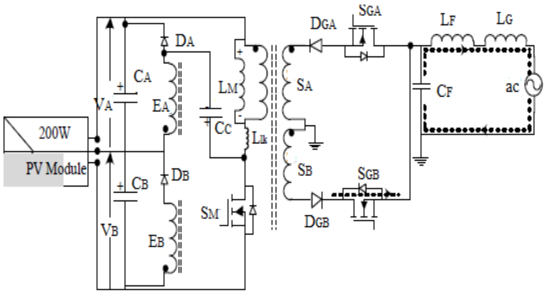


Fig.6. Mode-4 operation(d3Tsb)

Mode-5: Magnetizing current is zero in this mode. When main switch is turned ON, the energy which is stored in clamping capacitor(C_c) is used to magnetize inductor and also PV ,by recovering the energy of the equalizer winding(E_A & E_B), this is shown in Fig.7. The magnetizing current of the PV module is given by the following equation for this mode:

$$I_m = n_\varepsilon i_{Cc} + I^*_{M(pk)} \qquad \{8\}$$

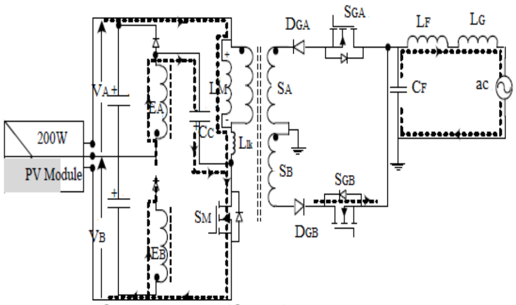


Fig.7. Mode-5 operation(d1Tsa)

C. Control circuit of the Configuration proposed:

The block diagram of the control circuit and the generation of gate pulses for the switching of the micro-inverter proposed as shown in the Fig.8. PV module's voltage (V_{PV}) and current (I_{PV}) are read and used as inputs to the fuzzy MPPT. The peak current(I^{**}) is generated from the MPPT. This value (i.e I^{**}) changes accordingly to the Fuzzy Logic Based MPPT commands [3]. The value generated (I^{**}) is multiplied with the "sin" component and the modulus of this value is compared with the carrier waveform(high frequency) to generate the pulses (to switch S1) with width varied in sinusoidal manner. The generated wave has high frequency. PLL (QSG-quadrature signal generator) is used to generate "sin" component[10] as represented in Fig.8, the output of PLL is used to compare with a constant value ' zero', so as to generate pulses of low frequencies to the switches (SGA, SGB).

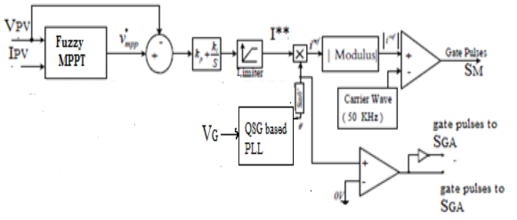


Fig.8. Control circuit and generation of gate pulses to the switching devices.

FUZZY LOGIC BASED MPPT:

Hence the fuzzy logic based MPPT is much capable to improve the performance of tracking. Fuzzy logic controller(FLC) can be classified into four categories they are: Fuzzification, Membership function, Inference and Defuzzification.

1. Fuzzification: In this process the crisp value(input) is converted into a Fuzzy value. Seven subsets(fuzzy) are used as the linguistic values which are assigned by the member function's values.
2. Membership Function: This is curvature which defines each and every point of the membership function's value of the input's space.

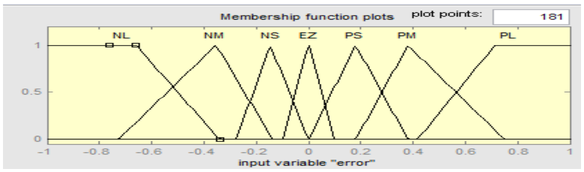
For this technique error(E) and change in error(CE) are the input variables taken and voltage reference is the output variable.

The fuzzy subsets are : negative large(NL),negative medium(NM), negative small(NS),zero(EZ),positive large(PL), positive medium(PM), positive small(PS)

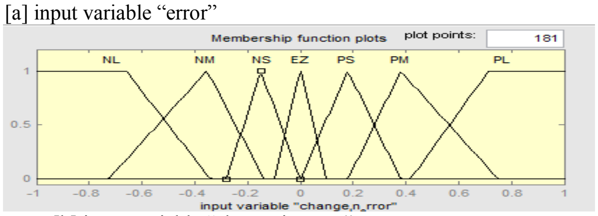
For N^{th} sample time the relation between these two are given as:

$$E(N) = \frac{dp}{dv} = \frac{P_N - P_{N-1}}{V_N - V_{N-1}} \qquad \{9\}$$

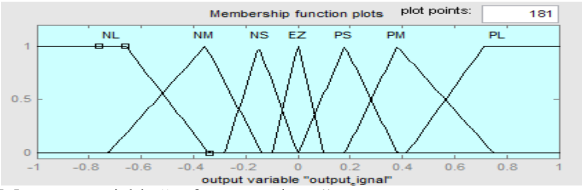
$$CE(N) = E(N) - E(N-1) \qquad \{10\}$$



[a] input variable "error"



[b] input variable "change in error"



[c] output variable " reference voltage"

Fig.9. membership functions of [a] error(E) [b] change in error(CE) [c] reference voltage

3. Inference:

Inference also known as rule base is used to collect all the then-if rules which contain all the required information for the control of parameters. The most common method which is used is the MIN-MAX method. These set of rules govern the behaviour of the surface controlled.

TABLE -1

Rule table

E / CE	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	EZ	PS	PM	PL	PL	PL	PL

4. Defuzzification:

This is the process where fuzzy values are converted into crisp values. The system needs a value which is not fuzzy to control hence this process is required.

III. SIMULATION RESULTS

The micro-inverter(flyback converter) and the peak current of the inverter(flyback) is controlled through S_M sinusoidally. Peak current(reference) is obtained by using the Fuzzy Logic based MPPT and then it is tracked by using ,duty ratio control of the switch, S_M. By using a PLL the switching devices S_{GA} & S_{GB} are synchronized with grid. The PV sub-modules have a rating of P_{MPP} =95.46W, V_{MPP}=17.61V, I_{SC} =5.75A, V_{OC} =22.5V and is operated at a radiation level of 1000W/m^2 and at a temperature of 25°C. The PV module consists of two PV sub-modules which are connected in series and have radiation levels of 1000W/m2 and 600W/m2 respectively. The electrical parameters of the proposed micro-inverter(flyback inverter) are: the turns ratio (ng) of secondary winding of S_A to primary winding of S_B is6, turns ratio (ne) of the secondary equalizing winding of E_A to primary winding of E_B is 5, Primary magnetizing inductance(LM) = 10μH, switching frequency (FS) = 50kHz, the maximum duty ratio (DM) = 0.65, snubber circuit's parameters filter inductance (L_F) = 8μH, filter capacitance (C_F) = 0.35μF and grid voltage (V_G)=230Vrms at 50Hz frequency.

Fig.10 & 11 shows the PV module and sub-modules output voltages and current with bypass diode configuration when it is illuminated fully and at partially shaded condition respectively. By observing these waveforms it can be seen that with by-pass diode configuration the output voltage of the shaded sub-module is nearly zero; whereas by using the proposed circuit the output voltage of the shaded sub-module (shown in Fig.12) is improved which means that the shaded regions voltage is also utilized by injecting the compensating current into the shaded sub-module. The system results obtained by using fuzzy mppt is compared with the results obtained by using INC mppt in the control circuit. By observing the results it can be seen that there is reduction in compensating current(I_{cpn}), less ripple content in DC voltage and the system response is improved with Fuzzy mppt than with INC mppt; the results are shown in Fig.14 respectively. The DC side voltages with Fuzzy mppt and INC mppt are shown in Fig.15. The currents through the primary and secondary switches S_{GA} and S_{GB} with fuzzy mppt and INC mppt and the voltage, current of the grid is shown in the Figs.16, Fig 17 and Fig18 respectively.

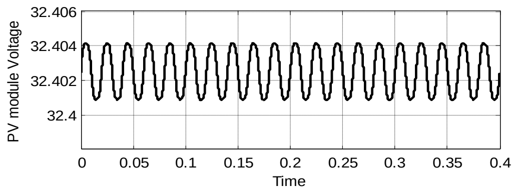


Fig. 10 (a)

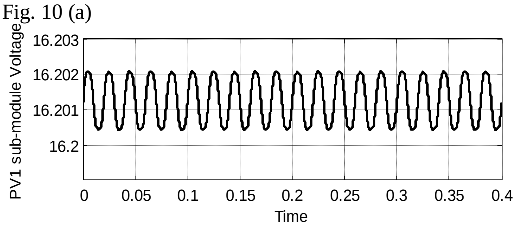


Fig. 10 (b)

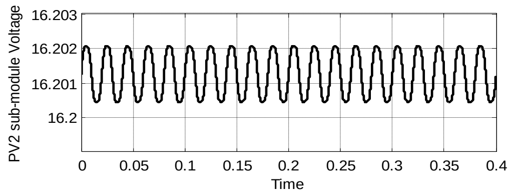


Fig. 10 (c)

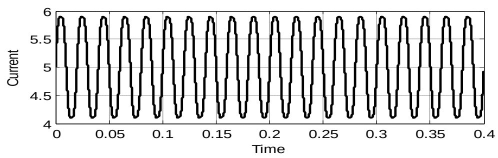
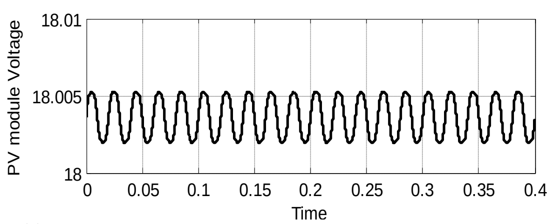
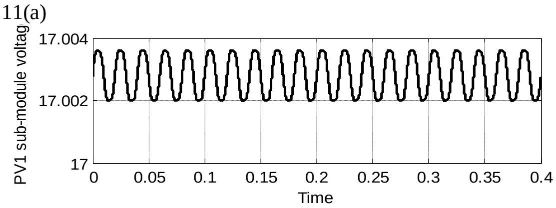


Fig. 10 (d)

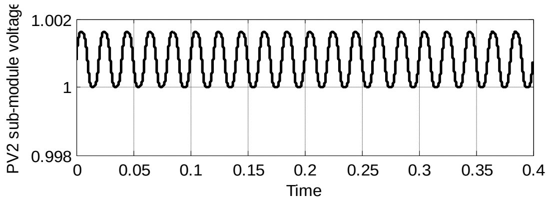
Fig.10 Fully illuminated (a) PV module voltage, (b)&(C) Voltages of PV sub-modules 1&2 and (d) PV module current with bypass diode configuration.



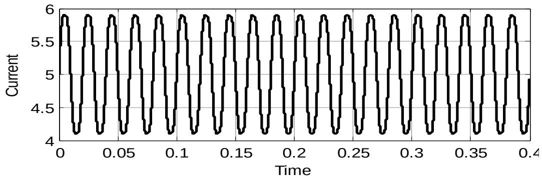
11(a)



11(b)

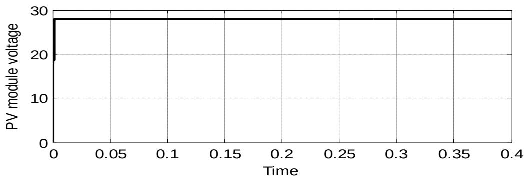


11(c)

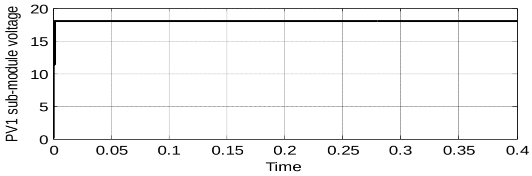


11(d)

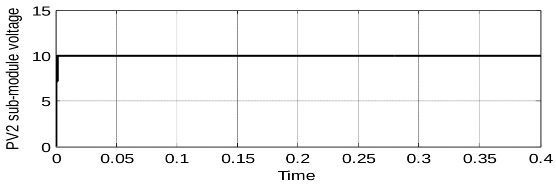
Fig.11 Partially shaded (a) PV module voltage, (b)&(C) Voltages of PV sub-modules 1&2 and (d) PV module current with bypass diode configuration.



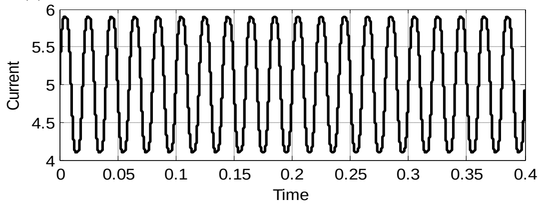
12 (a)



12 (b)

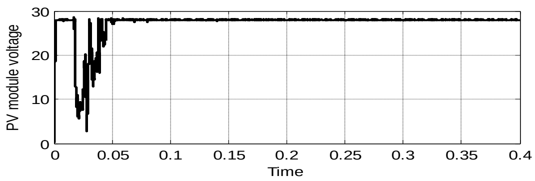


12 (c)

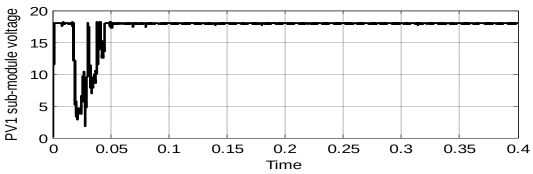


12 (d)

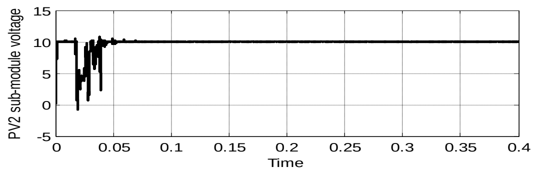
Fig.12 Partially shaded (a) PV module voltage, (b)&(C) Voltages of PV sub-modules 1&2 and (d) PV module current with the proposed Fuzzy configuration



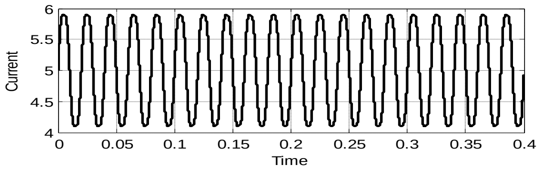
13(a)



13 (b)



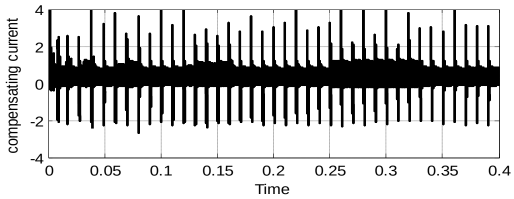
13(c)



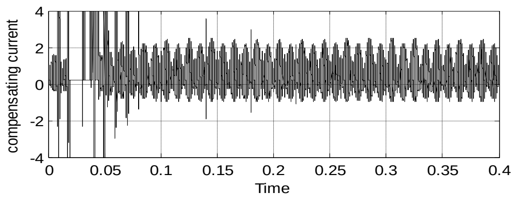
13(d)

Fig.13 Partially shaded (a) PV module voltage, (b)&(C) Voltages of PV sub-modules 1&2 and (d) PV module current with the proposed INC configuration.

Compensating current with INC mppt and fuzzy logic base mppt:



(a) With Fuzzy logic based mppt

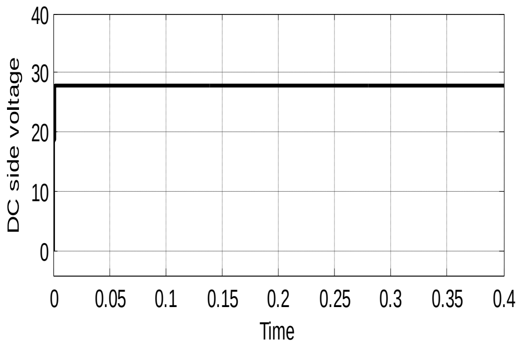


(b) With INC mppt

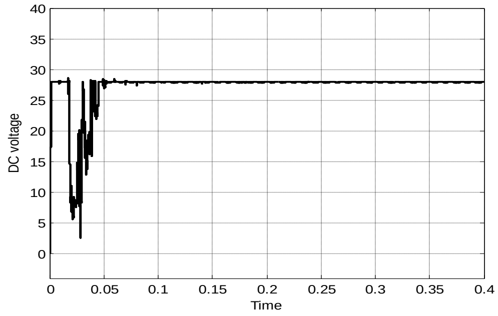
Fig.14. Compensating current(Icpn) injected into the junction of PV sub-module with (a) With Fuzzy logic mppt (b) with INC mppt.

DC voltage of converter with INC mppt and Fuzzy logic based mppt:

ISSN: 2321-8169
5909 - 5915

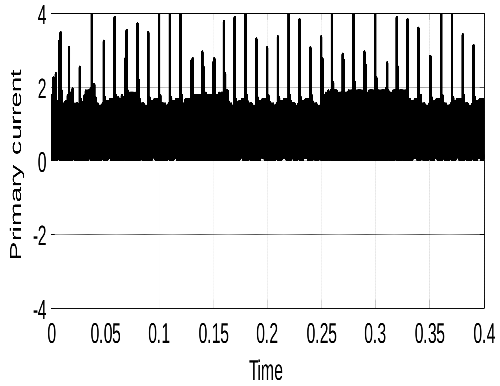


(a) Fuzzy logic based MPPT

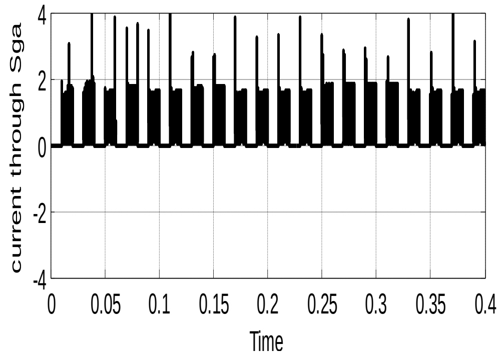


(b) With INC mppt

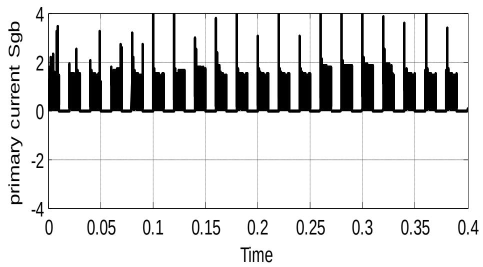
Fig.15. DC side voltage of flyback converter with(a) Fuzzy logic based MPPT (b) With INC MPPT



(a)

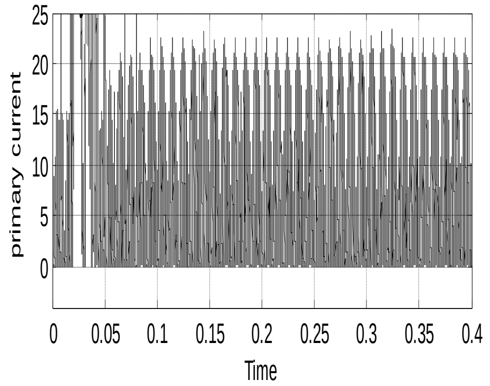


(b)

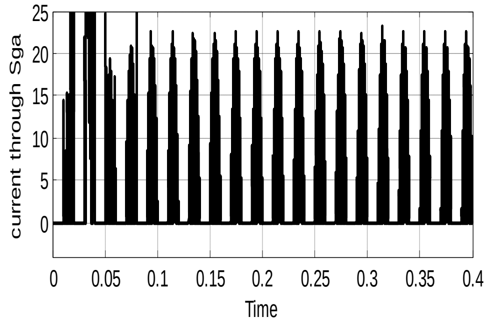


(c)

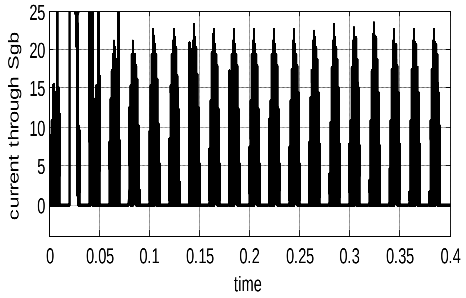
Fig.16. Currents through the primary (a), SGA(b) and SGB(c) of Flyback converter with Fuzzy Logic Based mppt.



(a)



(b)



(c)

Fig.17. Currents through the primary (a), S_{GA}(b) and S_{GB}(c) of Flyback converter with INC mppt

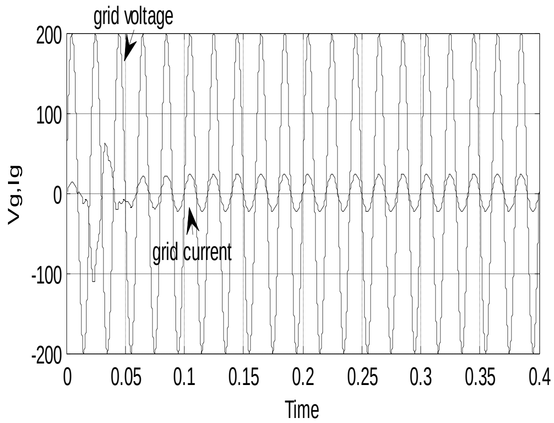


Fig18. Grid Voltage(VG) and Grid Current(IG)

CONCLUSIONS:

A new micro-inverter with Fuzzy Logic based mppt of partially shaded PV modules and energy recovery scheme is been used to extract maximum power available from un-shaded and shaded PV sub-modules. This circuit also performs energy recovery scheme. Since the inverter is operated in DCM this configuration is easy to implement. The voltage across the shaded PV sub-module is improved with the proposed circuit than with the use of by-pass diode configuration. Due to this the power-voltage characteristic has only one peak . The Incremental Conductance MPPT or Perturbation and observation MPPT do not quickly respond to the rapid changes in temperature and irradiance, hence Fuzzy logic mppt has been proposed to track maximum power. With fuzzy logic mppt the PV module and PV sub-modules have less ripple content, ripple in the dc voltage is reduced and compensating current is also reduced compared to INC mppt. Overall system response is improved with Fuzzy logic based MPPT than with INC mppt. Along with the operating modes the simulation results have also been presented in this paper.

REFERENCE:

[1] Z. Liang, R. Guo, J. Li, and A.Q. Huang, “A High-efficiency PV module-integrated DC/DC converter for PV energy harvest in FREEDM systems,” IEEE Transactions on Power Electronics, vol. 26, no. 3, pp.897-909, March 2011.

[2] Q. Li and P.Wolfs, “A review of the single phase photovoltaic module integrated converter topologies with three different DC link configurations,” IEEE Transactions on Power Electronics, vol. 23, no. 3, pp.1320-1333, March 2008.

[3] Y. Li and R. Oruganti, “A low cost flyback CCM inverter for ac module application,” IEEE Transactions on Power Electronics, vol. 27, no. 3, pp.1295-1303, March 2012.

[4] H. Patel and V.Agarwal, “Maximum power point tracking scheme for PV systems operating under partially shaded conditions, ”IEEE Transactions on Industrial Electronics, Vol. 55, no.4,pp. 1689-1698, Apr. 2008.

[5] S. Pooja, P.K. Peter, V. Agarwal, “Exact Maximum Power Point Tracking for Partially-Shaded PV Strings Based on Current Equalization Concept,” IEEE Photovoltaic Specialists Conference, 2012.

[6] T. Shimizu, O. Hashimoto, and G. Kimura, “A novel Utility Interactive Photovoltaic Inverter with Generation Control Circuit, “Proc. Of the 24th Annual Conference of the IEEE Industrial Electronics Society, IECON ’98, vol. 2, Sept. 1998, pp. 721-725.

[7] Toshihisa Shimizu, Keiji Wada, Naoki Nakamura, “Flyback-Type Single-Phase Utility Interactive Inverter With Power Pulsation Decoupling on the DC Input for an AC Photovoltaic Module System” IEEE Trans. Power Electron., Vol. 21, no. 5, Sept. 2006.

[8] H. Hu, Q. Zhang, X. Fang, Z.J. Shen, I. Batarseh, “A Single Stage Micro-inverter Based on a Three-port Flyback with Power Decoupling Capability” in Proc. Energy Conversion Congress and Exposition (ECCE), Vol., no., pp. 1411-1416, Sept. 2011.

[9] S.B. Kajer, F. Blaabjerg, “Design Optimization of Single Phase Inverter for Photovoltaic Applications” in Proc. IEEE PESC’ 03 Conf. 1, 1183-1190 (2003).

[10] S. Silva, B. Lopes, B. Filho, R. Campana, and W. Bosventura, “Performance evaluation of PLL algorithms for single-phase grid-connected systems,” in Proc. IEEE 39th Ind. Appl. Society Annu. Meeting, vol. 4, Oct. 2004, pp. 2259–2263.

[11] T.Bogaraj, J.Kanagaraj, E.Shalini, “Fuzzy Logic Based MPPT for Solar PV Applications”, INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING,Vol. 2, Issue 6, June 2014,pp 1566-1571 .

[12] Natraj Pragallapati, Vivek Agarwal “Flyback Configuration based Micro-inverter with Distributed MPPT of Partially shaded PV Module and Energy Recovery Scheme”,pp 2927-2931,IEEE-2013.