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Peak Current Control Mode of a Symmetrical Half Bridge Push-Pull Converter Topology for Photovoltaic Array with P&O MPPT

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***Abstract*—In this paper a peak current mode control(PCMC) of a symmetrical half bridge push pull converter for good dynamics and performance, capable of boosting up the voltage by controlling the power of a photovoltaic system using Maximum Power Point tracking (MPPT) control mechanism is proposed. The MPPT extracts the maximum possible power from the photovoltaic system and via the push pull converter it is fed to the load, which steps up the voltage to the required magnitude. The P&O MPPT algorithm proposed identifies the DC-DC converter's suitable duty ratio which should be operated to obtain maximum power output and control converter's dc-link voltage. PCMC bring the half-bridge capacitor voltage back to balance. The simulation is done using Matlab and the results are presented.**

Keywords—DC-DC Converter, Half Bridge Push-Pull Converter, Peak Current Mode Control ,P&O MPPT, PV

I. INTRODUCTION

The present energy production has mainly been based on energy sources like oil, gas and coal, which until todaywas looked upon as close to inexhaustible. as the global energy consumption is growing with a drastically high rate and the fossil fuels reserves are shrinking, the urge for renewable energy resources has attained more focus [1]. Both renewable and non-renewable energy resources are mostly created by the sunrays hitting the surface of the earth. The sun is a non-polluting resource responsible for the sustained life on earth. among the renewable energy resources are hydro power, wind power and solar energy. While hydro power has been a well-known technology for a long time, there is a lot of research going on with wind and solar power today. Solar energy as a source of energy has a large theoretical potential, and can be utilized both directly and indirectly. In a grid connected Photovoltaic (PV) inverter system the PV system utilize the solar energy as the power source and transfer the power into the grid through power electronics conditioning. The demand for distributed generation (DG) [2] is increasing,single-phase grid-connected power conversion systems are been constantly studied to connect natural sources.

Photovoltaic system modeling and characterization based on Matlab-Simulink is done to estimate the parameters and the characteristic electrical behavior of a cell/array in regard to the changes in environmental parameter regarding irradiance, temperature, and surface conditions [3]-[5]. I-V and P-V characteristics curves are obtained for the selected module-PV UDI80MFS with the output power of 180W The objective is to find the parameters of the nonlinear I–V equation by adjusting the curve with respect to the three points: open circuit, maximum power, and short circuit.

The strategy behind Maximum Power Point Tracking(MPPT) results in appreciable increase in the efficiency of the Photovoltaic System. The MPPT algorithm thus proposed identifies the suitable duty ratio in which the DC/DC converter should be operated to obtain maximum power output. However the solar radiation never remains constant. It keeps on varying throughout the day. The main objective is to track the maximum power point (MPP) of the solar array by modulating the DC-DC converter's duty cycle, thereby, optimizing the power output of the panel. The Perturb and Observe (P&O) algorithm is utilized here which performed with a higher overall efficiency capable of tracking the MPP quickly. [6]-[7]

In Switch Mode Power Supplies (SMPS) both isolated/non isolated topologies are present. The transformation of unregulated to regulated dc voltage is accomplished by using dc-dc converter circuits. The push pull converter topology with high frequency switching transformer with continuous conduction mode (CCM) is proposed here, and usually preferred in high power switching transformer applications due to its less power dissipation with increased efficiency at higher switching speeds. The secondary output of the transformer is rectified and filtered to produce V_{out}[8]-[9]. DC-DC converters can generate or be affected by EMI. Common mode noise can be suppressed by the use of inductors within an EMI filter [10]-[11].The half-bridge topology concludes as a promising topology for low and mediumlevel power converters.

For a highly reliable distributed power system efficiency is the first concern. Due to voltage imbalance peak current mode control (PCMC) cannot be applied directly on half-bridge. A compensation circuit enable peak current mode control to be applied to conventional symmetrical half-bridge. Peak current-mode control (PCMC) along with a slope compensation has advantages of automatic input line feed forward and current sharing capability for paralleled converters. Peak CMC behaves as a current loop inside the PI voltage control loop. The peak current loop senses the inductor current through a limiting resistor and generates a ramp signal which contributes to the pulse-width modulation (PWM) comparator. [12]- [14]

II. CHARECTERISTICS OF A PV ARRAY

Fig 1 shows the equivalent circuit of a PV cell which acts as a current source. An ideal cell is modeled by a current source kept as parallel with a diode. Shunt and series resistances are added to the model as shown in the PV cell. R_s is the intrinsic series resistance whose value is very small. R_p is the equivalent shunt resistance which has a very high value. The equation for the photovoltaic current is obtained as:

$$I = I_{Ph} - I_{Rp} - I_D \quad (1)$$

So we can conclude,

$$I = N_p I_{ph} - NpI_{rs}[\exp(\frac{q}{KTA} \times \frac{V}{N_s}) - 1] \quad (2)$$

The efficiency would be maximum if the maximum power from the PV system is tracked at different environmental condition such as solar irradiance and temperature by using P&O MPPT algorithm. The cell saturation current I_{rs}varies with temperature according to the following equation:

$$I_{rs} = I_{rr}[\frac{T}{T_r}]^3 \exp(\frac{qE_g}{kA}[\frac{1}{T_r} - \frac{1}{T}]) \quad (3)$$

The photo current I_{ph} depends on the solar radiation and cell temperature as follows:

$$I_{ph} = [I_{scr} + K_i(T - T_r)]\frac{S}{100} \quad (4)$$

Where,

I_{ph} : Insolation current
I : Cell current
I_d : Diode current
I_{rs}: Reverse saturation current
V : PV array output voltage
N_s, N_p : number of cells in series and parallel
q : charge of an electron($1.6*10^{-19}$ C)
k : Boltzmann's constant($1.38*10^{-23}$)
A : p-n junction ideality factor
T ,Tr : cell temperature (K), Reference Temperature(k)
E_G: band gap of the semiconductor used in the cell.
I_{scr} : cell short-circuit current at reference temperature
K_i : short circuit current temperature coefficient
S : solar radiation in mW/cm^2

The current to voltage characteristic of a solar array is non-linear, which makes it difficult to determine the MPP. Fig 2 shows the characteristic I-V and P-V curve for fixed level of solar irradiation and temperature.The IV and PV curves for various irradiance for a fixed temperature (25°C) are shown. Irradiance and temperature contributes an important role in calculating the I-V characteristic.

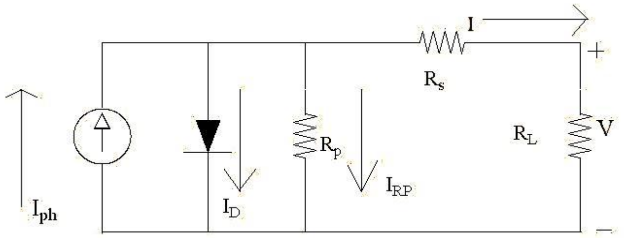

Fig. 1. Equivalent Circuit of a PV Cell

III. MAXIMUM POWER POINT TRACKING (MPPT): P&O ALGORITHM

The robust maximum power point (MPP) tracking (MPPT) is of vital importance in the operation of any photovoltaic (PV) system in order to harvest the maximum possible amount of energy. Converter's control is provided by an MPPT algorithm, which monitors the solar array output current and voltage from the array to track the highest power output of the array. The Perturb and Observe (P&O) MPPT algorithm will perturb the output setting and then observe by measuring the change in output power [15].

The P&O algorithm involves a stepwise perturbation in the operating voltage of the DC link between the PV array and the power converter [16]. Perturbing the duty cycle of the power converter modifies the voltage of the DC link between the PV array and the power converter. Here the sign of the last perturbation and the sign of the last increment in the power decide the next perturbation. As seen in Fig 3 on the left of the MPP incrementing the voltage increases the power, and on right decrementing the voltage increases the power. If there is an increment in the power, the perturbation is in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. The algorithm repeats until the MPP is reached and the operating point oscillates around the MPP. The algorithm simplifies as:

If dP/dV>0: PV panel has achieved an operating point closer to the MPP

If dP/dV<0: PV panel has achieved an operation point further away from the MPP

IV. SYMMETRICAL HALF BRIDGE PUSHPULL CONVERTER: PRINCIPLE OF OPERATION

Push-pull converter's transformer primary is supplied with current from the input line by pair of transistors/switches in a symmetrical manner.The switches are switched on and off alternatively, reversing the current in the transformerperiodically. Therefore current is drawn from the line during both halves of the switching cycle. Such converters have steadier input current; create less noise on the input line.In Fig. 4 we can see that the convertermostly refers to a two-switch topology with a split primary winding.Capacitors are often included at the output to filter the switching noise. The operation of the circuit means that both switches are actuallypushing, and the pulling is done by a low pass filter (coil) in general, and by a center tap of the transformer in the converter application. The dot convention is used to indicate relative polarity between the two windings.

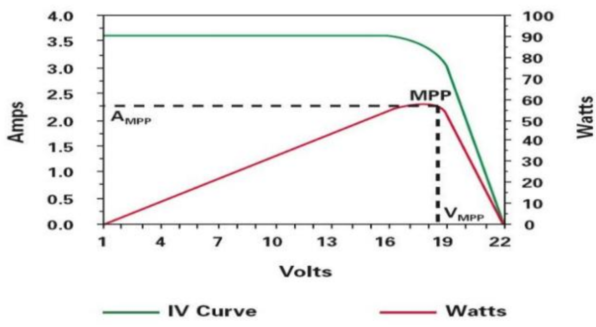

Fig.2. I-V and PV curve characteristics

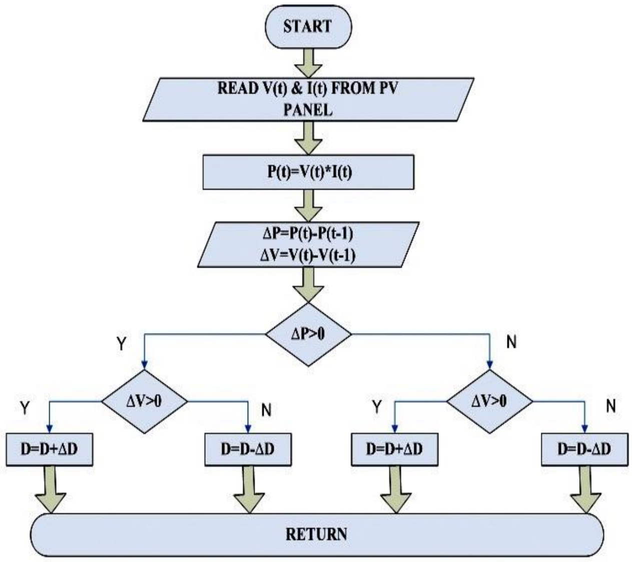

Fig. 3. Flowchart for P&O Algorithm

When the voltage at the dotted terminal on one winding is positive, the voltage at the dotted terminal on the other winding is also positive. When current enters the dotted terminal on one winding, current leaves the dotted terminal on the other winding. Switches S_{w1} and S_{w2} turn on and off with the switching sequence. Here the design parameter is the transformer magnetizing inductance, L_m.The converters output voltage is given as

$$V_{out} = 2V_s(\frac{N_s}{N_p})D \qquad (5)$$

The magnetizing Inductance of the transformer is given as,

$$L_m = \frac{(V_{DC}{}^{\min}.D_{\max})^2}{2P_{\text{in}}\, \text{f}_s\, K_{RF}} \quad (6)$$

Where,

P_{in}: Maximum input power
f_s : Switching frequency
$V_{DC}{}^{min}$: Minimum DC link voltage
D_{max}: Maximum duty cycle
K_{RF}: Ripple factor, For CCM operation KRF< 1.

The converter is kept at a fixed duty ratio. For a periodic voltage and current, the flux has to be continuous and return to the starting point at the end of each switching period. Else flux will increase core saturation. Saturated core cannot support a voltage across a transformer winding. Therefore there should be a symmetry in the flux density.The main drawback of the conventional symmetric half-bridge is that both primary switches in the converter operate with hard switching.

Its chief disadvantages are that the transformer centre-tap connection, it complicates the transformer design and the primary windings are tightly coupled to avoid voltage spikes during transistor turn off.The push-pull drive automatically provides core reset on alternate half cycles, but these alternate half cycles must be quite symmetrical or the volt-seconds will not cancel, which results in core saturation.[17]. The converter is efficient as it doesn't require a step up transformer, due to the presence of galvanic isolation.

V. PEAK CURRENT MODE CONTROL(PCMC)

A perfect current-mode converter relies only on the dc/ average value of inductor current. Slope compensation is the best suited where an external ramp signal is added to the sensed inductor current to cancel out sub-harmonic oscillation.A turn-off command is released when the sensed inductor current peak plus slope compensation ramp reaches the comparator level and the PWM comparator resets the latch. Peak CMC places a fast current loop inside the voltage control loop. This loop senses the inductor current and uses this information as the ramp signal to the pulse-width modulation (PWM) comparator. The comparator compares the ramp signal and the Maximum Voltage at the maximum power by the MPPT algorithm to generate the PWM pulses for the two switches of the converter. A Peak current mode control modulator gain is used along with the sensed inductor current. Voltage Loop comprise of a PI controller along with the MPPT.From the Fig 5.we can see that peak current is given as

$$I_{ds}\, peak = I_{EDC} + \frac{\Delta I}{2} \qquad (7)$$

and

$$\Delta I = \frac{V_{DC} D_{\max}}{L_m\, f_s} \qquad (8)$$

Where,

fs : switching frequency of the converter
ΔI : Change in Magnetizing Peak Current

Fig.6 shows the complete block diagram of the PCMC of the push-pull converter with a symmetrical flux density to levitate the fluctuating voltage of the photovoltaic array by means of the MPPT algorithm to obtain the operating point to adjust with the duty cycle of the converter.

VI. SIMULATION RESULTS

MATLAB is used as the simulation platform tostimulate the soundness of the proposed results for a run time, t_s=1ms and the Simulink model of the PCMC of the selected converter topology is given in Fig 7.

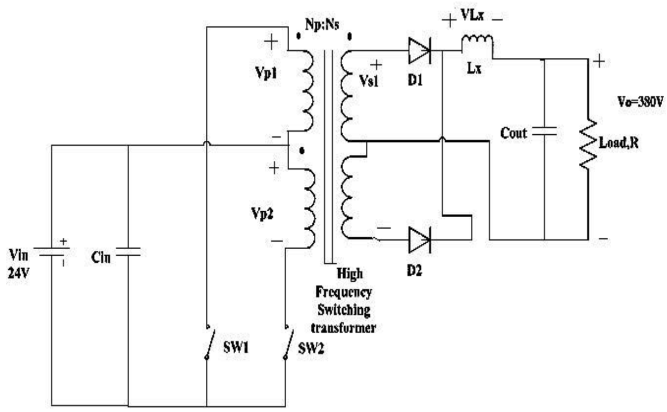

Fig.4. Push Pull Converter Half Bridge Topology

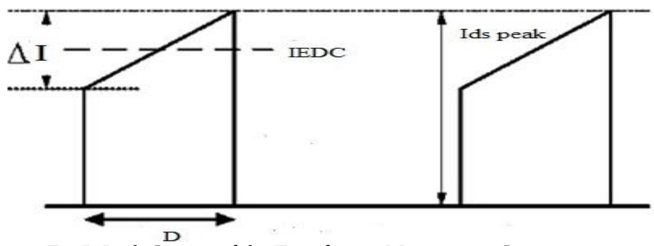

Fig.5. Peak Current of the Transformer Magnetizing Current

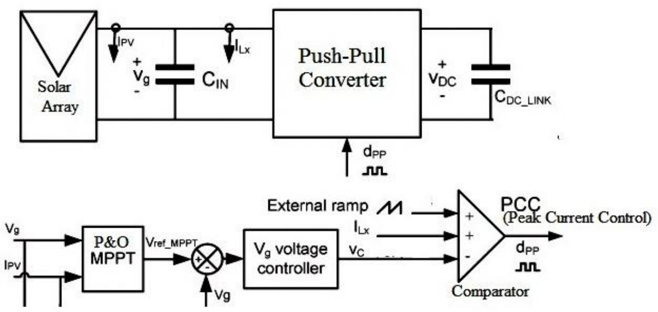

Fig.6. PCMC of DC-DC converter for PV array

The circuit is simulated for a controlled input voltage of 24V by the P&O algorithm to obtain a DC link Voltage 0f 380V. The PV array was modeled for 180W P_{max}. The Fig.8 and 9 depicts the IV and PV characteristics of the selected PV array with panel voltage variation of 22V-30V. The electrical parameters of solar array are shown in table 1.

TABLE I. Electrical Parameters of PV array

I_{sc}	8.03A
V_{oc}	30.4V
P_{max}	180W
Normal Operating cell temperature(NOCT)	47.5K
Temperature Coefficient	0.022

Fig.10 reveals the controlled input voltage of the converter ie, 22V.The PWM Pulses shown in Fig. 11for the converter switches for a switching frequency of 20kHz are generated by the PCMC control loop and the MPPT voltage control loop adjusting the duty ratio. A step change of Δd=0.05 was introduced to track the power. Fig 12 shows the MPP tracked at constant irradiance of 1000W/$m^2$and the corresponding V_{MPP} at 183W and controlled voltage = 22V. Fig 13 shows the panel output current I_{PV}=8.45A giving an output power of 136W in the converter. The P_{max} and V_{MPP} at step varying irradiance of 1000 and 600W/m2 is shown in Fig 14. The power increases as the irradiance level increases and decreases as irradiance level decreases. The current is the factor most affected by these variations. The stepwise increase/decrease of current depending on increase/decrease in the irradiation level is shown in Fig 15. Here as the irradiance is varied the panel output current and converter output power varies.

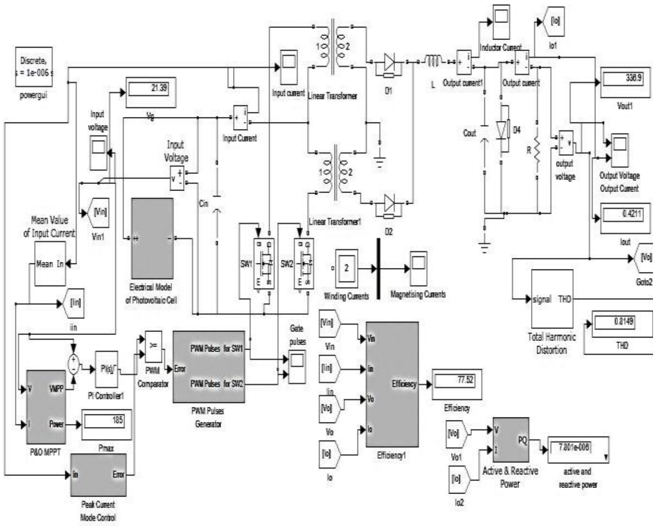

Fig.7. Simulink Model of the converter for PV with MPPT and PCMC

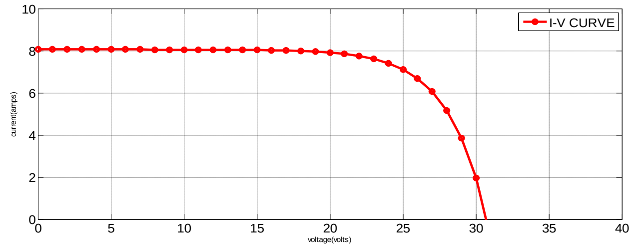

Fig.8. I-V curve of PV array

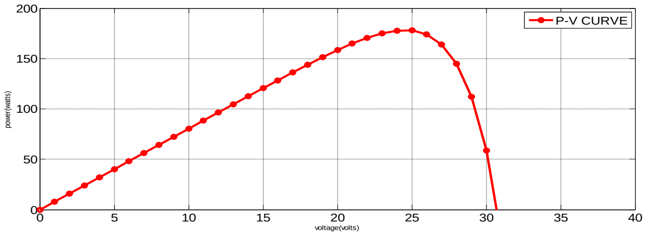

Fig.9. P-V curve of PV array

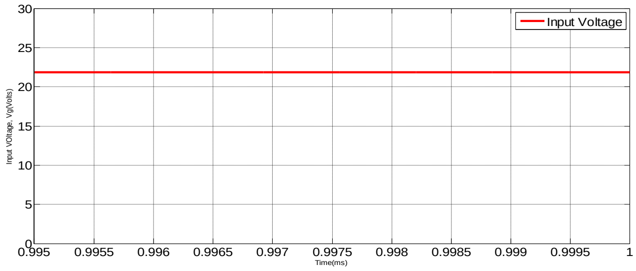

Fig.10. Input voltage to the converter, Vg

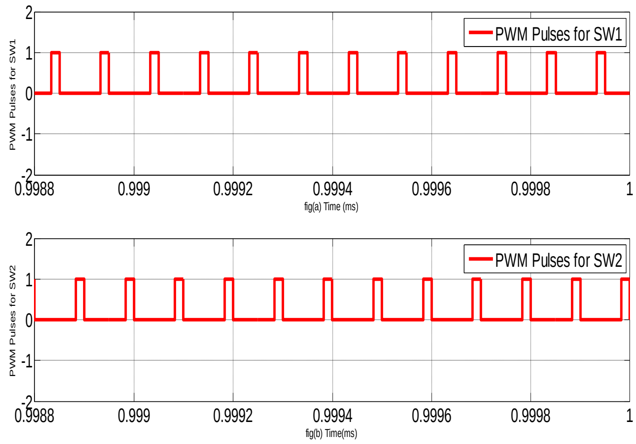

Fig. 11. PWM Pulses for SW1 and SW2

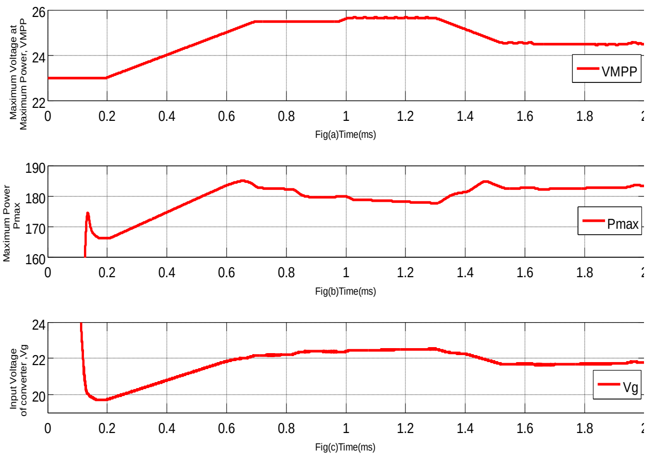

Fig. 12.(a) V_{MPP} at P_{max} (b)P_{max} by MPPT at 183W (c) V_g=22V ,input to the converter ; at constant irradiance 1000W/m^2

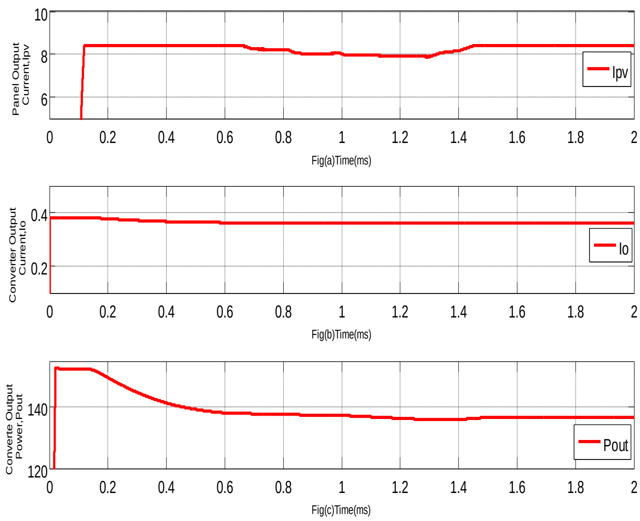

Fig. 13.(a) Panel Output Current (b) Converter output current (c) Converter output power; at constant irradiance of 1000W/m^2

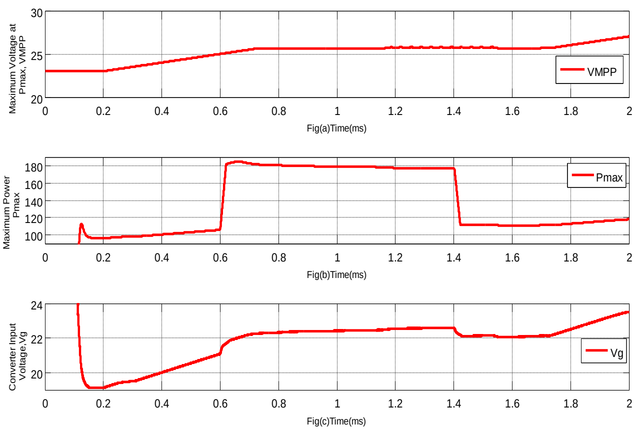

Fig.14. (a) V_{MPP} at P_{max} (b)P_{max} by MPPT (c) V_g,input to the converter ; at step varying irradiance of 1000 and 600 W/m^2

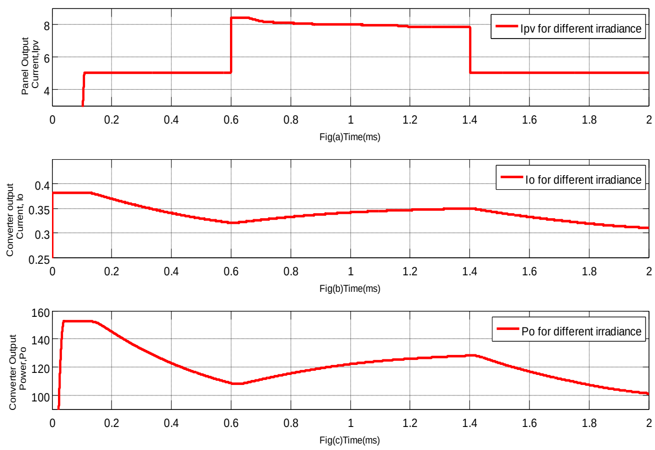

Fig.15. (a) Panel Output Current (b) Converter output current (c) Converter output power; at step varying irradiance of 1000 and 600W/m^2

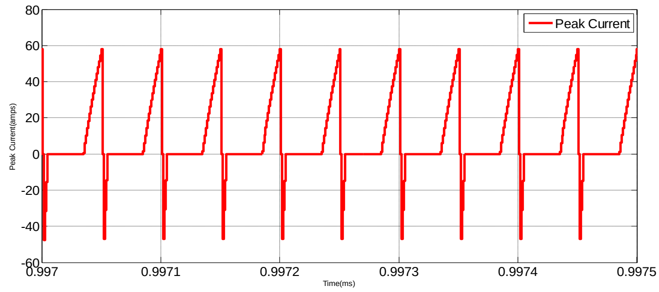

Fig. 16.Peak Current of converter without PCMC

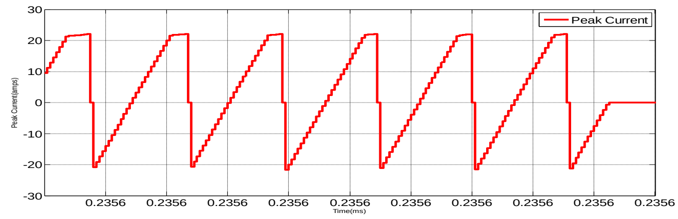

Fig. 17.Peak Current of converter with PCMC

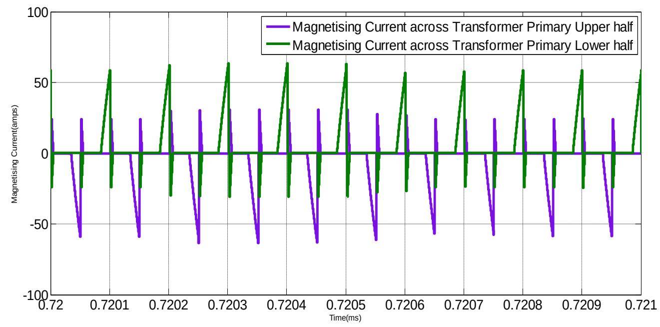

Fig. 18.Magnetizing Current of the transformer

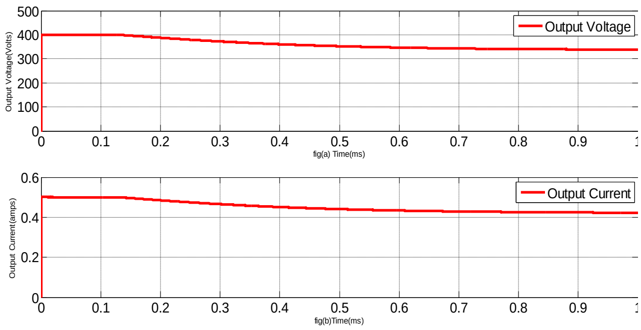

Fig. 19.: (a) Output Voltage of converter (b)Output Current of converter

The peak current obtained by PCMC was maintained at 21.2A4 as calculated by the peak modulator gain. Fig. 16 shows the peak current without PCMC obtained at 55A and Fig 17 shows the peak current with PCMC. The converters transformer magnetizing current across the upper and lower half of the primary split winding with L_m=0.05mH as design parameter with turns ration n=20, was obtained as shown in the Fig. 18. It shows the symmetrical flux distribution across the core of transformer. The final dc-dc converters dc-link output voltage after EMI filter is obtained at 345V and the output current obtained is .43A is observed in Fig 19. The selected converter’s efficiency was calculated as 77%.

VII. CONCLUSION

Peak Current mode control with slope compensation limited the peak current of the converter avoiding the transformer saturation. The converter was driven efficiently with 77% supplying the PV power to the load by means of the simplest P&O MPPT algorithm, which tracked the maximum power of the PV array adjusting the duty ratio of the converter for different irradiance level and thereby controlling the DC-link voltage. The converter was able to boost up the voltage by choosing the suitable turns ratio of the transformer. Compared to other DC-DC converter, the symmetrical half-bridge push-pull topology gave efficient results due to its symmetrical flux distribution and presence of galvanic isolation. The simulation results proved the application of PCMC to limit the input current fed to the converter.

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