



SIMULATION OF PV WITH MPPT ALGORITHM FOR LLC RESONANT DC-DC CONVERTER EMPLOYING BURST MODE CONTROL

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Abstract

In this paper burst mode control for LLC converter is discussed along with the modeling of PV array and Maximum Power Point Tracking (MPPT) algorithm are presented. LLC can regulate the output voltage even at no load condition through ZVS and ZCS. Hence LLC is used to step up the voltage of PV and MPPT is implemented to track maximum power at variable weather conditions. This paper focuses on Burst mode control compared to the conventional PWM technique to improve the efficiency of the proposed converter under light load conditions. Simulation results are presented to show the significance of the burst mode control scheme and the results are verified..

Introduction

LLC Resonant converters operate even with variation of narrow switching frequency over a wide range of load variations through ZVS and ZCS. This will reduce the switching losses. Burst mode is the control of pulse pattern given to the switching devices. Since the complete turn off time after a train of pulses given to the device, it will not take part in the conduction during the turn off time. It will refresh the device for the next conduction. Hence the efficiency will improve.

Photovoltaics (PV) is the conversion of solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation involves solar panels consists of a number of PV modules containing PV arrays. Due to the increased need for renewable energy sources, the design and manufacturing of photovoltaic arrays has improved significantly. But the disadvantage in sunlight energy is variation in its insolation at different time intervals. Hence to maintain the maximum power is essential here. Maximum Power Point Tracking involves variety of algorithms. Perturb and Observe method is widely used one. This paper concentrates on the modeling of PV array and MPPT. Burst mode control is implemented for LLC converter.

LLC Resonant Converter

LLC can regulate the output voltage with a relatively small variation of switching frequency over wide load variations. It can also achieve zero voltage switching over the entire operating range. When resonant frequency is lesser than switching frequency LLC functions exactly like SRC. The advantage of LLC over SRC is it has the capability to achieve ZVS even at no load conditions. For heavy load conditions resonant frequency should be maintained higher than the switching frequency.

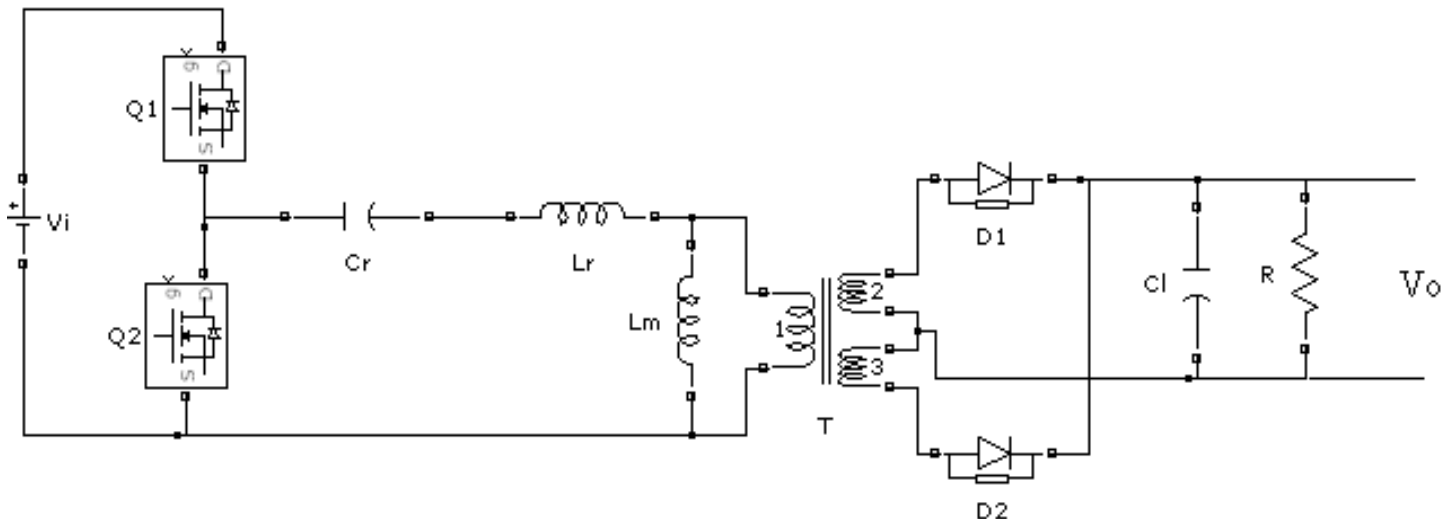


Fig.1.shows the circuit diagram of LLC Resonant DC-DC Converter

Operation of LLC

The operation of LLC resonant converter is explained with Zero Voltage Switching (ZVS) region and Zero Current Switching (ZCS) region.

In Zero Voltage Switching (ZVS) region, the converter functions exactly like SRC. In this region, magnetizing inductor L_m never resonates with the resonant capacitor C_r , it is clamped by output voltage and acts as the load for the series resonant tank. With this passive load of magnetizing inductor, LLC resonant converter can operate at no load condition without the penalty of very high switching frequency. Also, with passive load L_m , ZVS could be ensured for any load condition.

In Zero Current Switching (ZCS) region, the waveforms could be divided into two time intervals. In the first time interval, L_r resonates with C_r . L_m is clamped by output voltage. When L_r current resonates back to same level as L_m current, the resonance of L_r and C_r is stopped, instead, now L_m will participate into the resonant and the second time interval begins. During this time interval, the resonant components will change to C_r and L_m in series with L_r , which is shown in the waveforms as a flat region. In fact, that is a part of the resonant process between $(L_m + L_r)$ with C_r . From this aspect, LLC resonant converter is a multi resonant converter since the resonant frequency at various time interval is different. Because of the resonance between L_m and C_r , a peak on the gain appears at resonant frequency of $(L_m + L_r)$ and C_r . The operating of LLC resonant converter in region 2 is divided into three modes depends on time period.



Burst Mode Control

Nowadays higher efficiency is attained using *LLC* resonant converters. However, in the increasing demand, its light-load efficiency still cannot meet the requirements. Burst-mode control for the *LLC* resonant converter improves the light-load efficiency. Burst mode operation can be used for depleted batteries that require operation of the LLC converter. This method is used solely to revive neglected batteries.

In this mode of control instead of train of pulses, continuous pulse pattern will be given within a certain switching frequency. For the remaining time period the switching device will be turned off depends on the duty ratio. This will reduce the stress on the device in turn reduce the ripple. Hence the overall efficiency is improved.

To improve the efficiency further the Synchronous Rectification method is developed in which the conventional diodes of output rectifiers in LLC resonant converters are replaced by switching devices. Circuit Diagram for Burst Mode Control is shown in Fig.2.

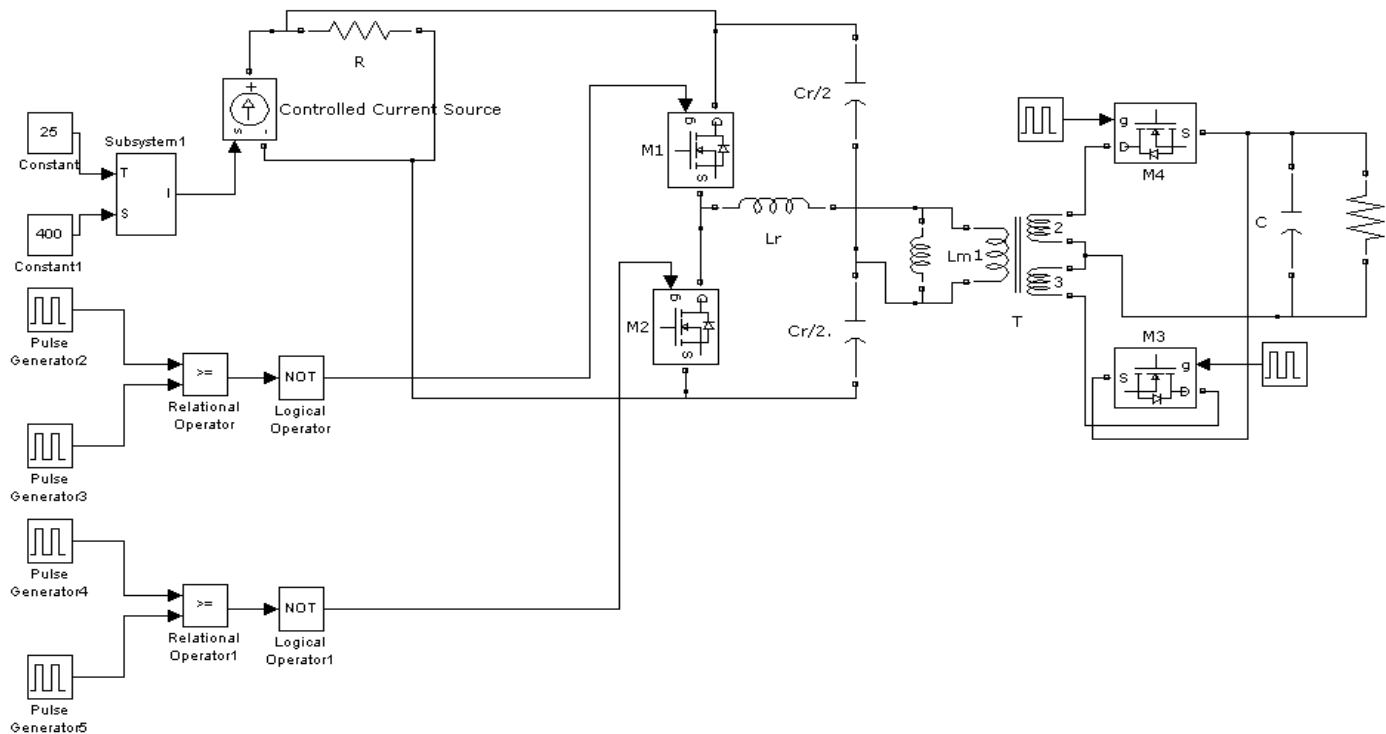


Fig.2.Circuit diagram of Burst Mode Control



Modeling of PV

To maximize the PV battery array efficiency and to protect it, it is important to build an accurate Photovoltaic array model and to analyze the characteristics of the PV array under different circumstances. A widely used method to model a PV array is to design mathematical equations for various insolation and temperature levels. Equivalent circuit for PV model is shown in Fig.3.

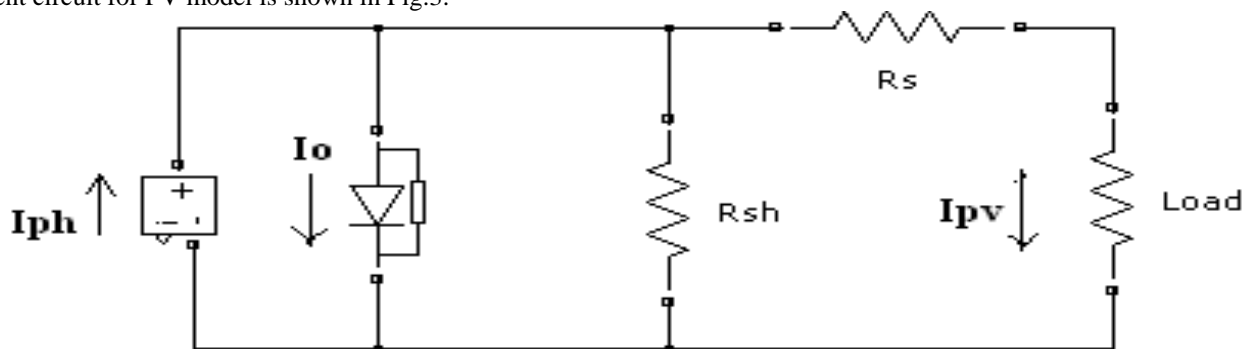


Fig.3. Equivalent circuit for PV model

Where

I_{ph} - cell photocurrent

R_{sh} - intrinsic shunt resistance

R_s - intrinsic series resistance

Equations

The photovoltaic panel can be modeled mathematically as given in equations:

Module photo-current is given by,

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

Module reverse saturation current is,

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

The module saturation current I_o varies with the cell temperature, which is given by

$$I_o = I_{rs} \left[\frac{T}{T_r} \right]^3 \exp \left[\frac{q * E_{g0}}{Bk} \left\{ \frac{1}{T_r} - \frac{1}{T} \right\} \right]$$

The current output of PV module is,



$$I_{PV} = N_p * I_{ph} - N_p * I_o [\exp\{\frac{q * (V_{PV} + I_{PV} R_s)}{N_s A k T}\} - 1]$$

Where

$$V_{PV} = V_{oc}, N_p = 1, N_s = 36, V_{oc} = 66V$$

Simulink Model of PV

The simulink diagram of PV is shown in Fig.4.

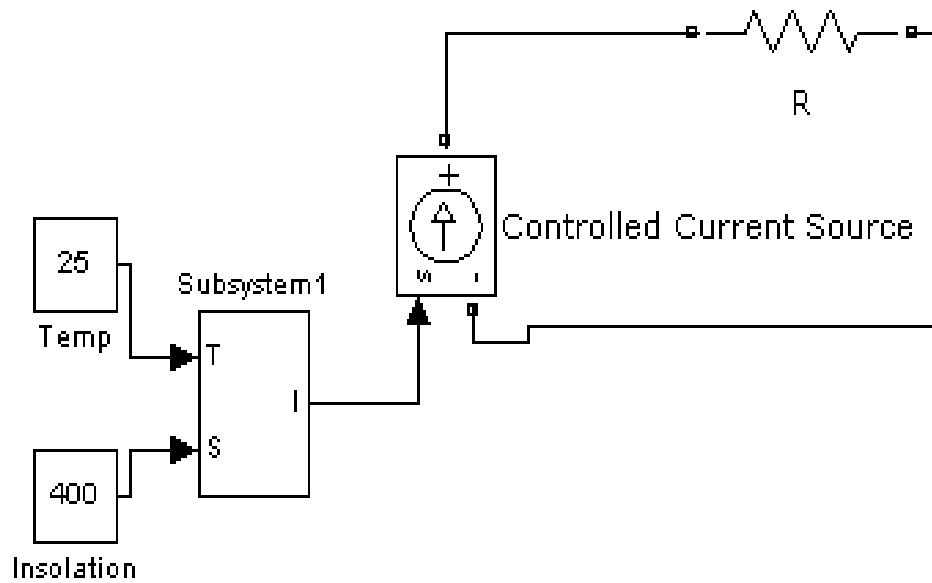


Fig.4. Simulink Model of PV

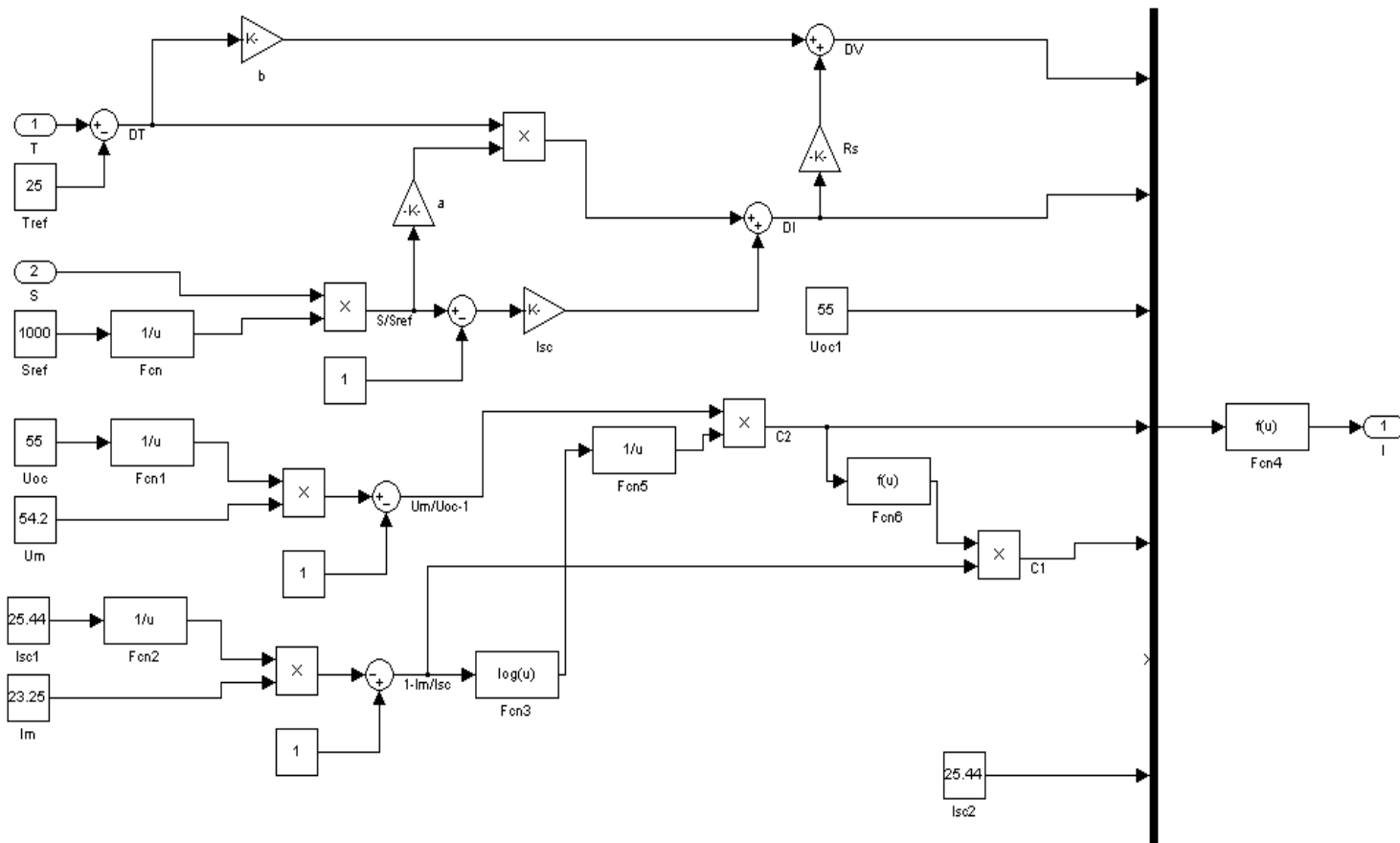


Fig.5.Circuit under subsystem 1

The I-V characteristics of PV array are shown on Fig.6. It is clear from the figure that when the irradiation levels are increased the voltage as well as the current is maximum.



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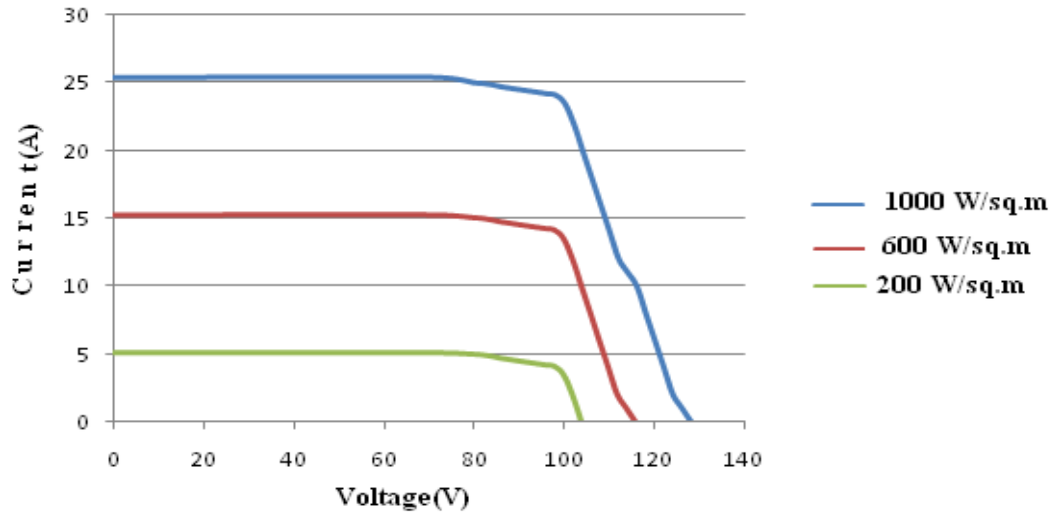


Fig.6. I-V characteristics of PV array

The P-V characteristics of PV array are shown on Fig.7. It is clear from the figure that after a particular point the maximum power is getting decreased

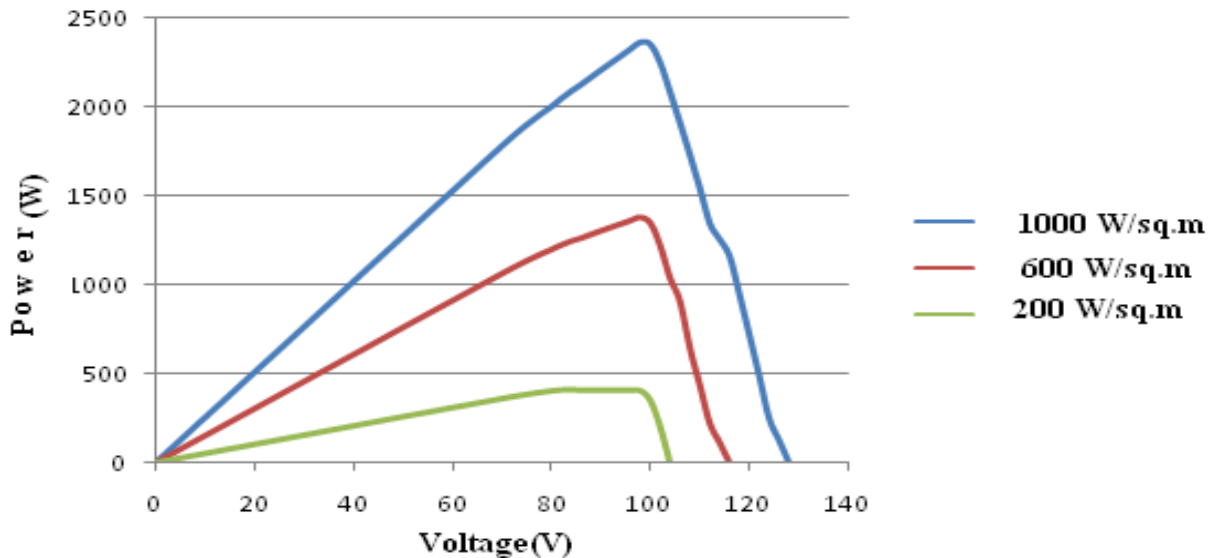


Fig.7. P-V characteristics of PV array



Maximum Power Point Tracking (MPPT)

Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions.

MPPT model is implemented by SIMULINK/MATLAB. MPPT algorithm has various methods. The Perturb and Observe method is used here. Based on the flowchart of P & O method the MATLAB code is implemented. It is shown in Fig.8.

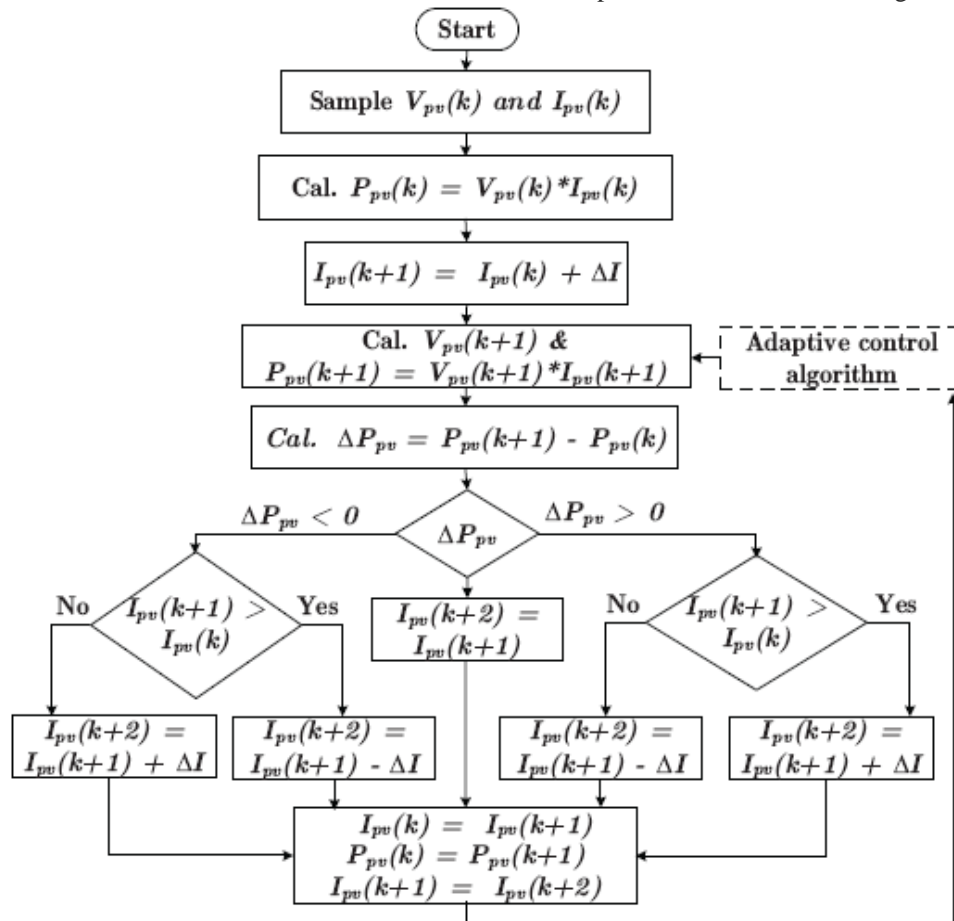


Fig.8. Flowchart for P & O algorithm for MPPT

Simulink model for MPPT is shown in Fig.9.

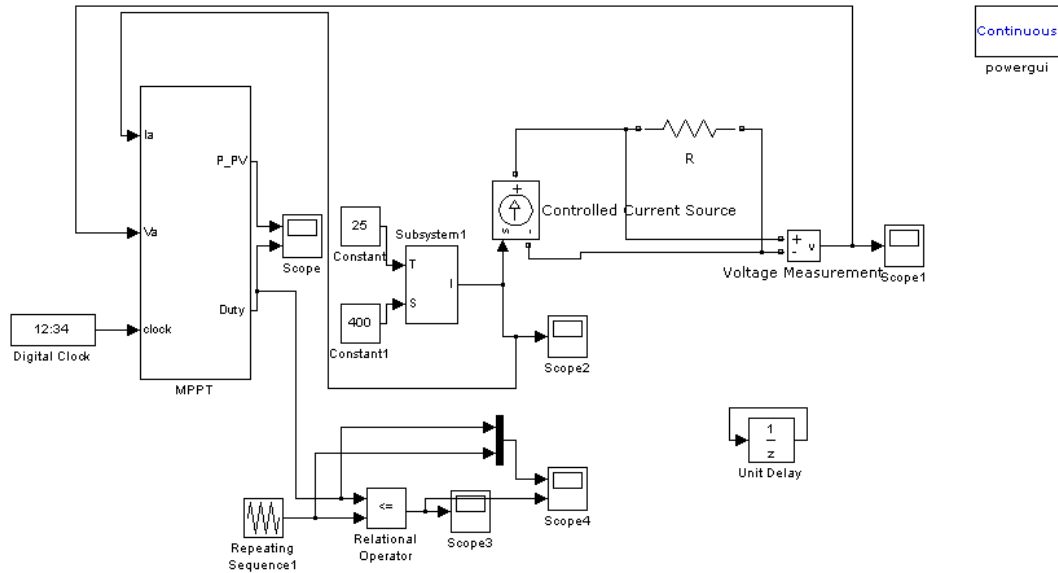


Fig.9. Simulink model for MPPT

Circuit under subsystem MPPT is shown in Fig.10.

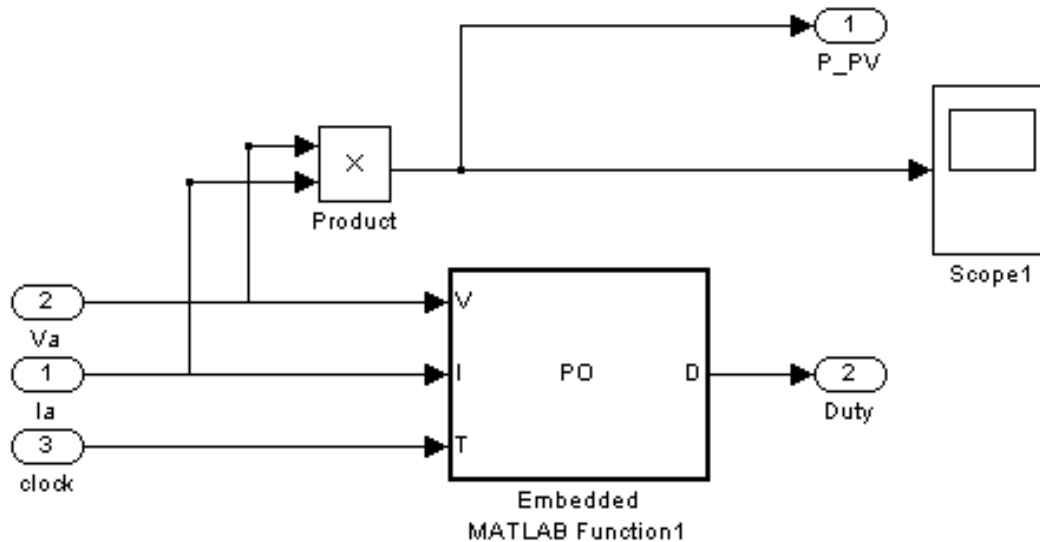


Fig.10. Circuit under subsystem MPPT



Fig.11 shows the diagram of LLC converter with burst mode control, contains PV array and MPPT model

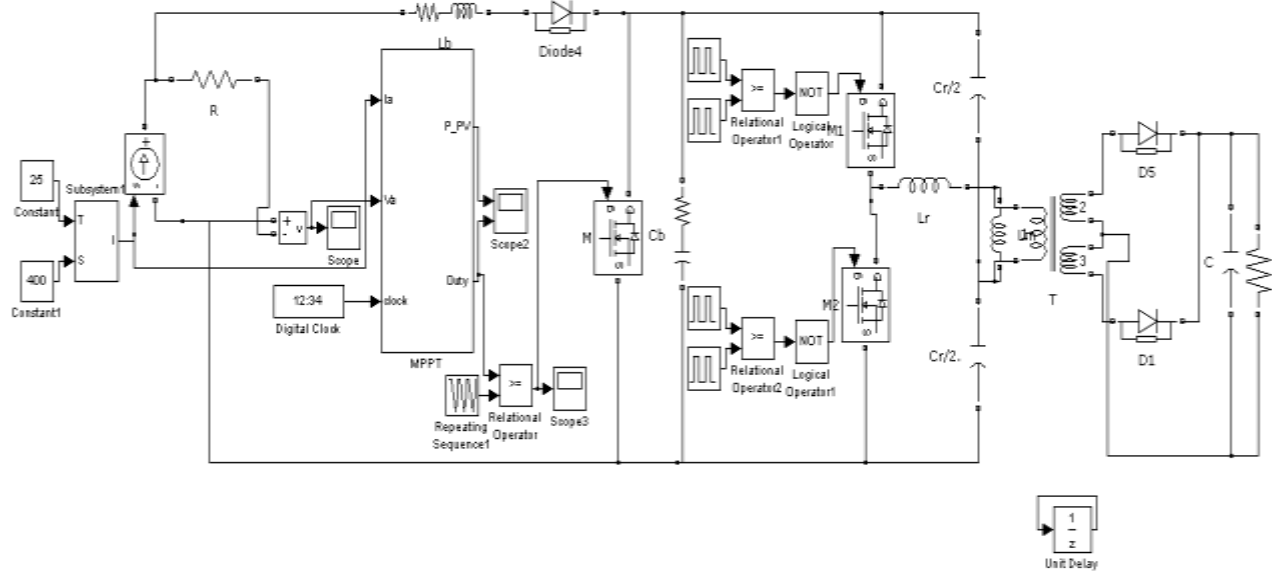


Fig.11. Final circuit diagram has PV array and MPPT models with burst mode controlled LLC Resonant Converter.

Simulation Results

Fig.12.shows the PV array output voltage. It is obtained as 101.7V.

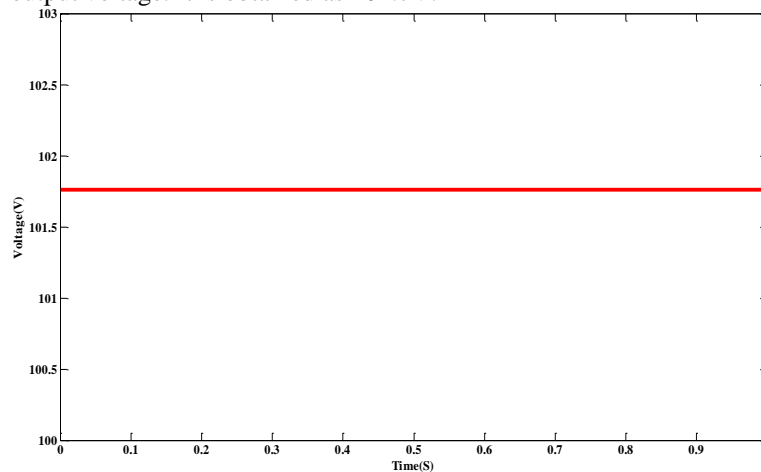


Fig.12.PV Array Output Voltage



Fig.13. shows the PV array output current. It is obtained as 10.2 A.

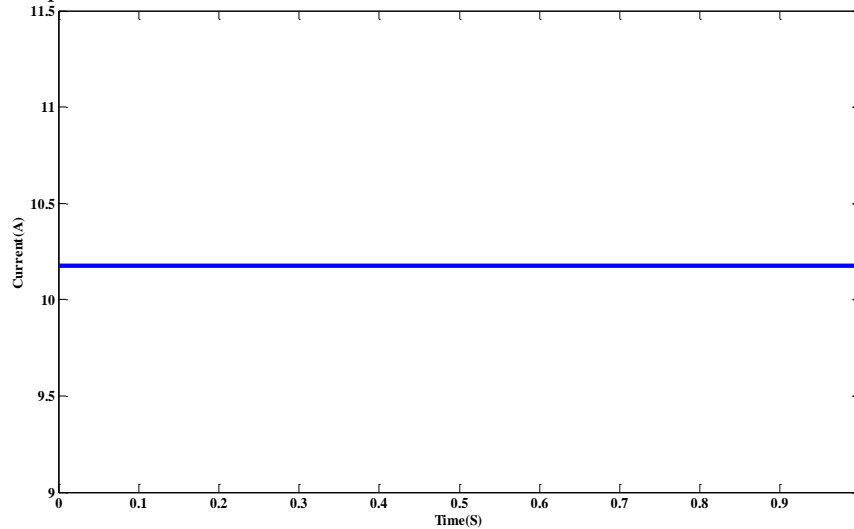


Fig.13.PV Array Output Current

Fig.14. shows the Maximum Power and Duty Ratio from MPPT Model. Maximum power is obtained as 1035.5 W and duty ratio is 0.5.

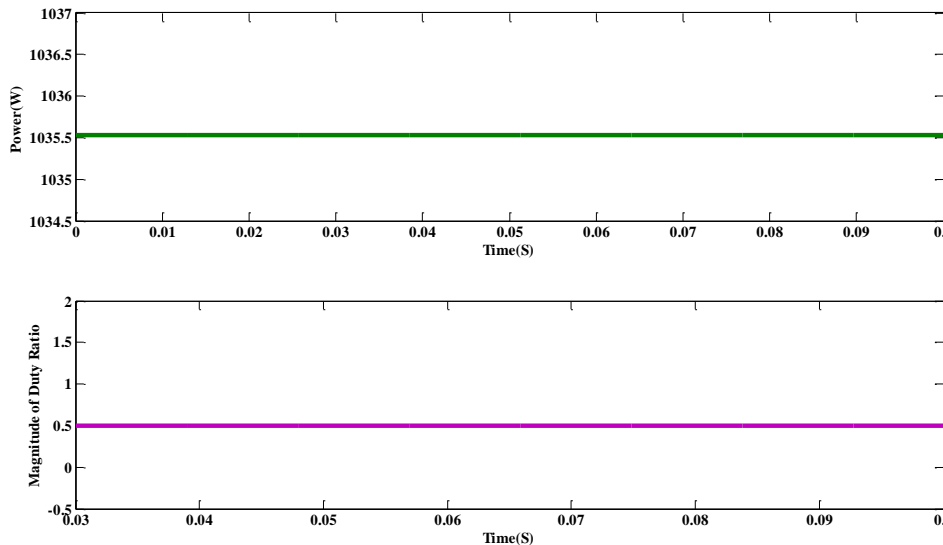


Fig.14.Maximum Power and Duty Ratio of MPPT Model



The DC output of duty ratio is converted into square waved pulses. It is shown in Fig.15.

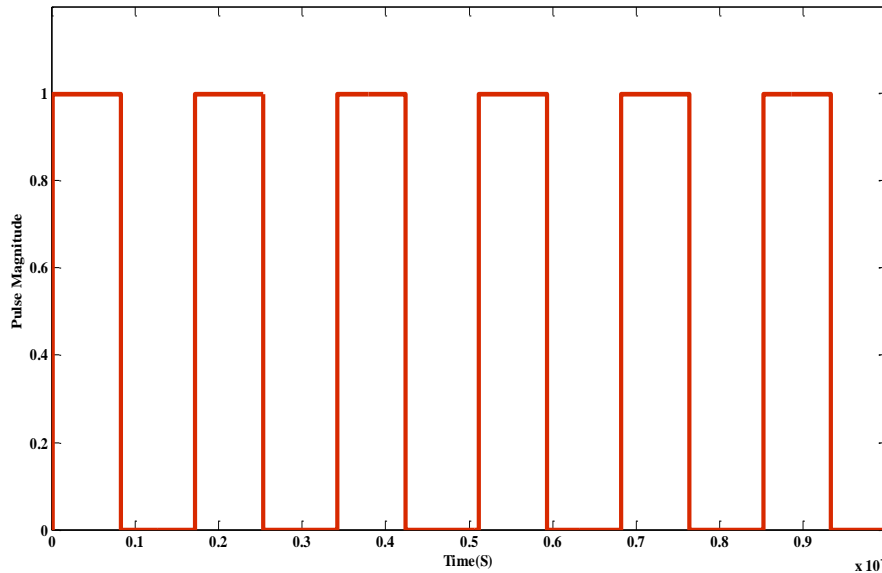


Fig.15.Pulse Width Modulated Duty Ratio

Fig.16 shows the boost converter output of 232V.

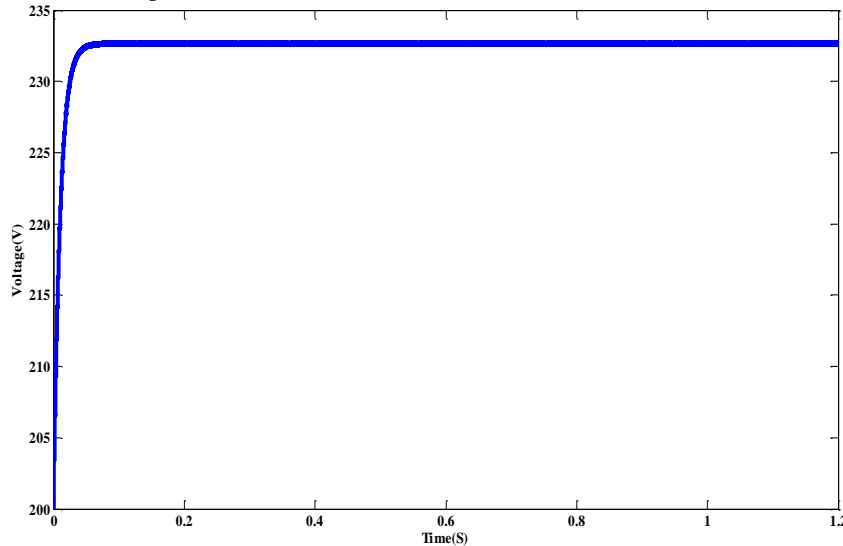


Fig.16.Boost Converter Output



The burst mode pulses is shown in Fig.17. It is clear from the figure that after a train of pulses turn off time is given.

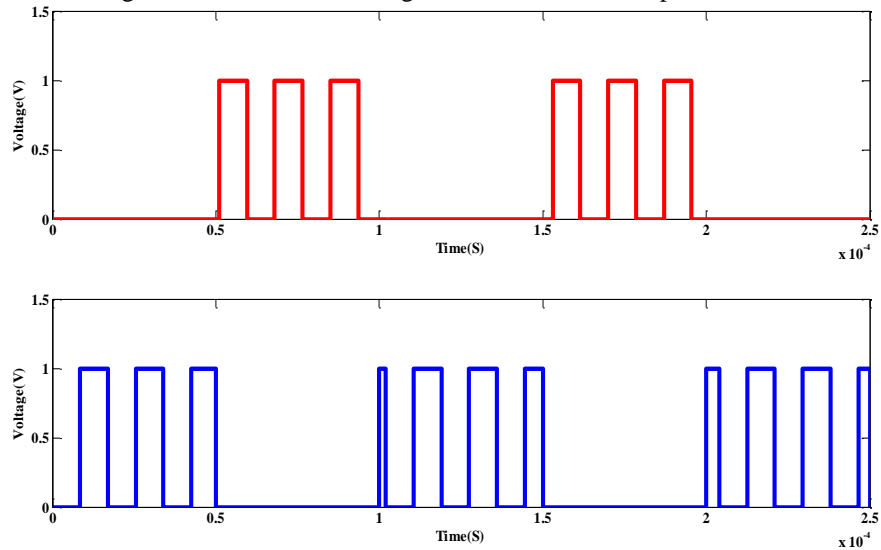


Fig.17. Burst Mode Pulses

The output voltage of 10.3 V is obtained from the burst mode controlled LLC converter is shown in Fig.18.

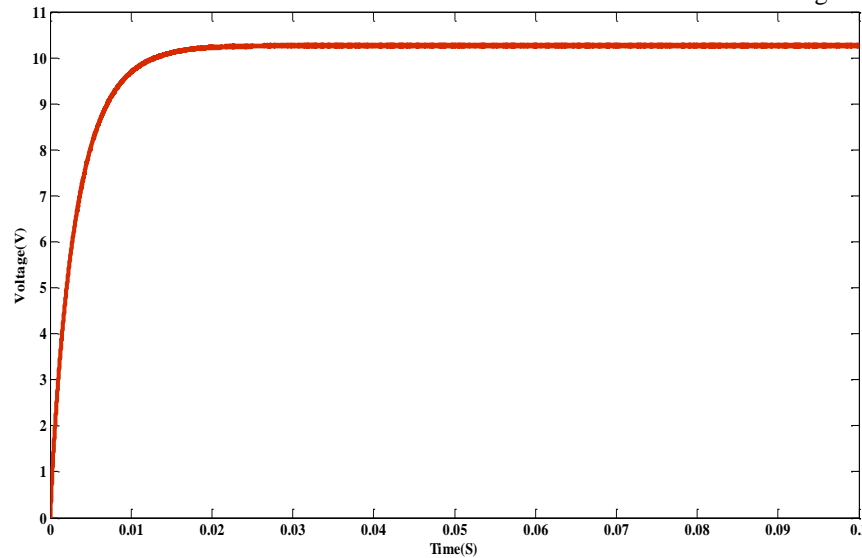


Fig.18. Output voltage of burst mode controlled LLC converter



Voltage ripple waveform of burst mode controlled LLC converter is shown in Fig.19. Voltage ripple is obtained as 0.00007 V which is lesser than uncontrolled LLC converter.

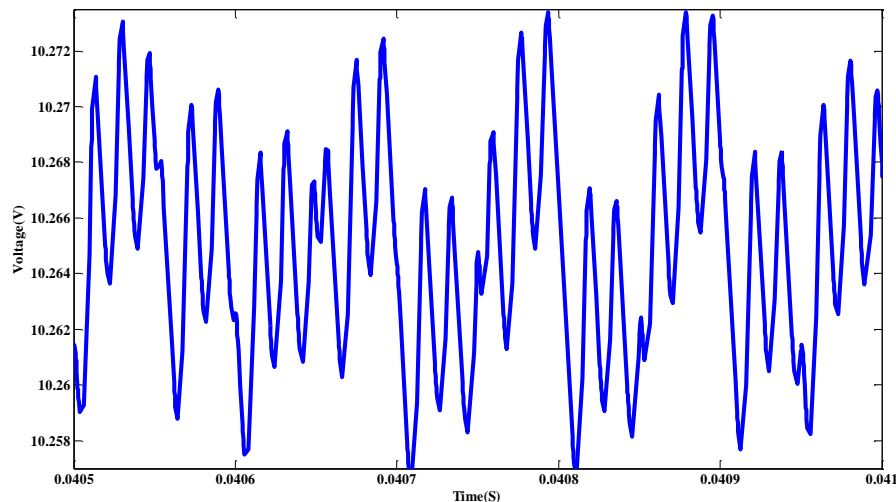


Fig.19. Ripple voltage waveform

Conclusion

In this paper simulation of burst mode control of LLC Resonant DC-DC converter for Photovoltaic Applications is discussed. By using mathematical equations the modeling of PV system is presented through building of PV array. The capability of LLC resonant converter even at light load conditions by operating at narrow switching frequency and its achievement of ZVS is suited for PV as it reduces the switching losses. Burst mode control for LLC converter is to improve the overall efficiency and to reduce the stress on the switching device in turn lessens the ripple.

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