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Development of Multiport Converter for Hybrid Renewable Energy Systems

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Abstract: *This project presents a multiport converter with pulse width modulation (PWM) and phase shift control for renewable energy systems. The proposed converter works on the principle of an interleaved boost full bridge circuit. The advantages of zero voltage switching (ZVS) and zero current switching (ZCS) is applied in this work. By this method the voltage regulation is improved and powerflow can be regulated. Power flow between the inputs is controlled by duty cycle and voltage can be regulated via phase shift. Primary side MOSFETs achieve ZVS and secondary side diodes operate under ZCS. This converter can operates on various modes according to the availability of renewable energy source and load consumption. This topology has wide applications in hybrid energy systems. Solar energy is taken as the renewable energy source and maximum power point tracking (MPPT) algorithm is used to maximize the power delivered to the system. Simulation of the converter with two input ports and one output port is carried out and results are presented.*

Keywords: *Hybrid energy systems, interleaved boost full bridge, multiport converter, phase shift control, renewable energy.*

I. Introduction

Renewable energy sources such as solar, wind, tidal, hydrogen etc. has been widely used to overcome the current energy crisis. These sources are abundant in nature and can be used for supplying electricity effectively. It can eliminate the pollution and are dependable in future. The use of a single renewable source for powering the loads is not a accepted way. So for ensuring the proper energy transfer more number of renewable sources are connected to a single system called as hybrid systems. Hybrid energy conversion systems are applicable where average power demand is low and load dynamics are relatively high. Sometimes the power from sources are more than that of load demand and so extra energy has to be stored in some energy storage units. In contrast the load cannot be met by the sources in sometimes. Hence these energy storage devices need to be power the loads. Thus energy storage units are needed in order to balance the electricity generation and consumption within a power system. The variations in renewable energy results in power flow fluctuations. So that power flow has to be controlled effectively.

For galvanic isolation, multiple converter and multiple port conversions are used. In multiple converter conversion, power converters are connected in parallel or in series. In multiple port conversion, some components and circuits can be shared as a common part along the conversion path. It has high power density and low cost than that of multiple converter configurations. In general magnetic coupling method is used to obtain an isolated multiple port converter. The converter can be constructed from the basic high frequency switching cells including half bridge (HB), full bridge (FB), boost half bridge (BHB) and their combinations. A fully isolated three port converter in earlier stages includes large number of power switches. Hence it results in high components cost. In partially isolated multiport topologies, some of the input or output are fully isolated. But it requires only less number of components. So they can be easily controlled due to it's simple structure.

II. Scheme Of The Work

Proposed converter constitutes two input ports and a single output port. Thus it forms a three port converter (TPC) based on an interleaved boost full bridge converter topology. It has the advantage of interleaved boost converter and the overall circuitry is simple. One of the input port represents a renewable energy source. Here solar energy is taken as the renewable source. The other input generally represents an energy storage device like battery, fuel cells etc. This input port is termed as bidirectional port. For efficient input energy extraction, MPPT algorithm is implemented. This converter can operate in various operation modes such as, dual input (DI) mode, dual output (DO) mode and Single input single output (SISO) mode based on the availability of renewable energy and load consumption.

The proposed converter configuration is derived from a ZVS half bridge (HB) inductive dc-dc converter. The secondary rectifier diodes achieve ZCS and avoid reverse recovery losses. Voltage across the diodes is clamped by the output capacitor C_0. Secondary freewheeling current is also limited due to the absence of a dc inductor. Both phase shift and duty cycle of the primary side MOSFET switches are simultaneously controlled for obtaining power flow and voltage regulation.

III. Circuit Description And Operating Principles

This converter consists of four power MOSFETs, two input inductors L_1 and L_2, an ac inductor L_{ac} and a high frequency transformer with turns ratio 1:n. L_{ac} is used as the power interface element between primary and secondary sides of trans-former. V_1 and V_2 are the two input voltages. i_{L1} and i_{L2} represents the inductor currents. M_1 , M_2 , M_3 , M_4 are driven with complimentary gate signals with a dead band. v_{ab} is the voltage between midpoints of bidirectional interleaved boost converter and i_{Lac} is the secondary winding current. In order to decouple input volt-ages and regulate output voltage, both duty cycle and phase shift angle are adopted simultaneously. Primary side MOSFETs can achieve ZVS operation. Due to ac output inductor, the secondary side diodes can operate under ZCS. Duty cycle of power switches is used to adjust the power among independent sources. Phase shift angle between midpoints of full bridge is employed to regulate power flow to the output port.

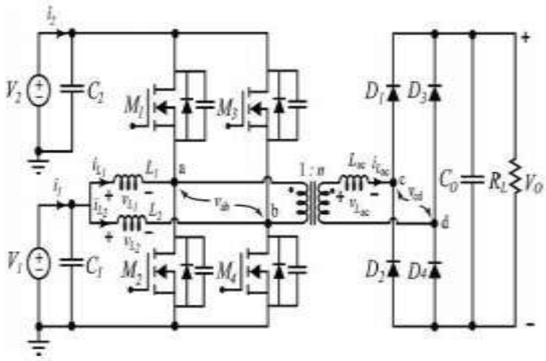


Fig1: Proposed TPC for hybrid renewable energy systems

The ac inductor current is chosen to be completely demagnetized for the analysis. Principle of operation of the proposed converter can be described based on the six time intervals. During interval [0- t_1], M_2 and M_3 are conducting. L_1 , L_2 are charged and discharged respectively. Voltage across midpoints a and b is given by V_{ab} = -V_2 and V_{cd} = -V_o. This interval is shown in fig.2. L_{ac} is charged with

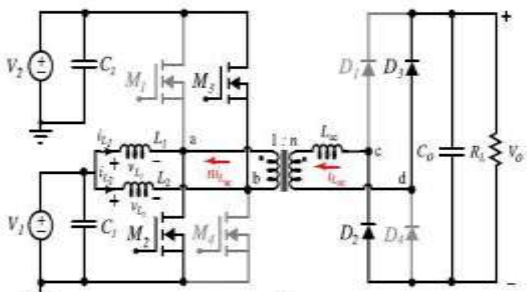
$nV_{ab} - V_{cd} = -nV_{2} + V_0$

$I_{Lacpk} = (-nV_2 + V_0)\phi T / L_{ac}$ (1)

Phase shift angle normalized to period

$\Phi = \Psi/2\pi$ (2)

Operating waveforms for the entire time intervals are shown in fig.3. During interval [t_1 - t_2] ,M_4 is triggered and L_1 , L_2 are charged.



(a)

Fig.2 Equivalent circuit for [0-t_1].

In this interval volte across the transformer v_{ab} is clamped to zero and L_{ac} is discharged with a slope by V_o. Therefore, $V_{ab} = 0$, $V_{Lac} = V_o$. This interval is normalized to period b which is given by,

$\beta = (nV_2 - V_0)\phi / V_0$ (3)

L_{ac} discharge interval,

$\Delta t = t_2 - t_1 = \beta T$ (4)

When i_{Lac} reaches zero, diodes stop conducting. The equivalent circuit is shown in fig.4.

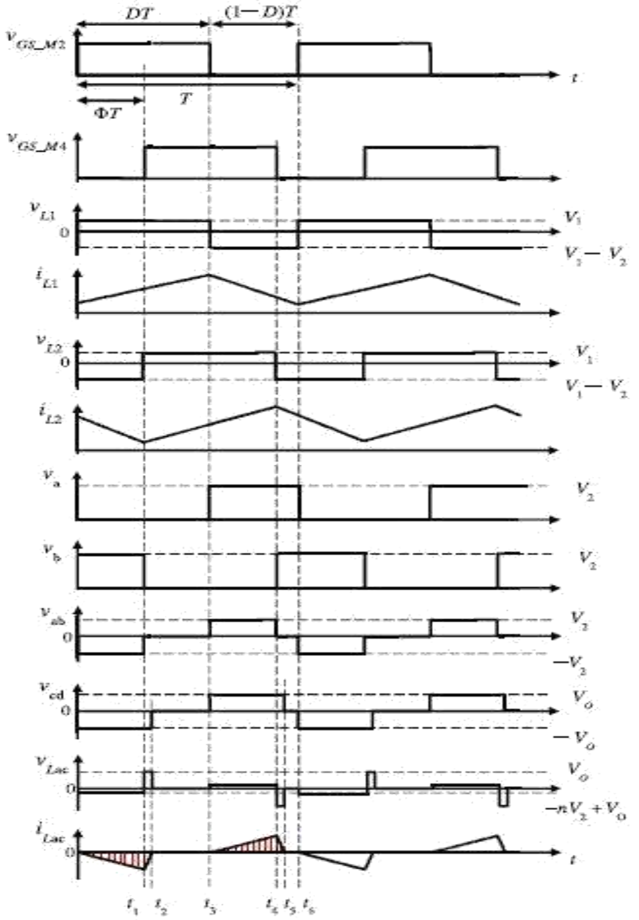


Fig.3 Operating waveforms for completely demagnetized ac inductor current

During interval [t_2 - t_3], L_1 and L_2 being charged until M_2 is turned off at t_3. L_{ac} is completely demagnetized in this interval. There is no power transfers from primary side to output port. Equivalent circuit corresponding to this interval is shown in fig.5.

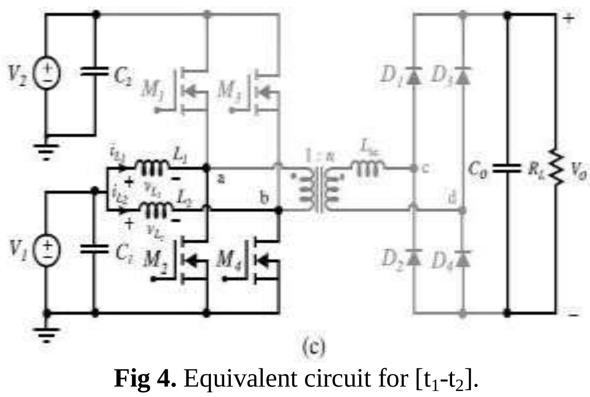


Fig 4. Equivalent circuit for [t_1-t_2].

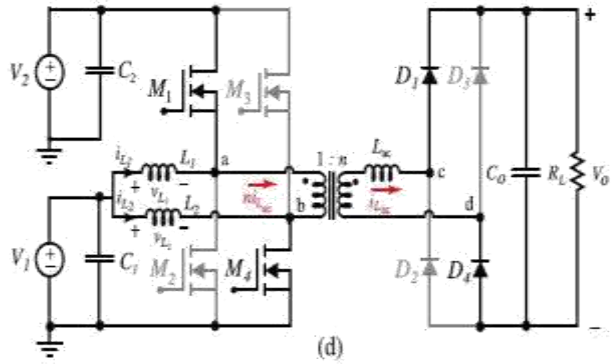


FIG.5: EQUIVALENT CIRCUIT FOR [T_2-T_3].

During interval [t_3 - t_4], M_1 and M_4 are conducting. This interval is symmetrical to case(a), ie,[0 - t_1].

$I_{Lac}(t_4) = - I_{Lac}(t_1)$ (5)

It is given as, $I_{Lac} = (nV_2 - V_o)\,\phi T / L_{ac}$ This interval is shown in fig.6.

During interval [t_4 - t_5], M_1 and M_3 are conducting. It is symmetrical to case(b) given in [t_1 - t_2]. Equivalent circuit for this interval is shown in fig.7.

$\Phi < \min[D,(1-D)]$ (6)

Using (1) – (4), output voltage of the converter can be derived as

$V_0 = nV_2\,\phi(-\phi + \sqrt{\phi^2 + 2k}) / k$ (7)

where k is dimensionless and is dependent on output load, inductance and switching frequency. It is given in (8)

$k = 2L_{ac} / R_L T$ (8)

Relation between V_1 and V_2 is obtained as,

$V_2 = V_1 / (1-D)$ (9)

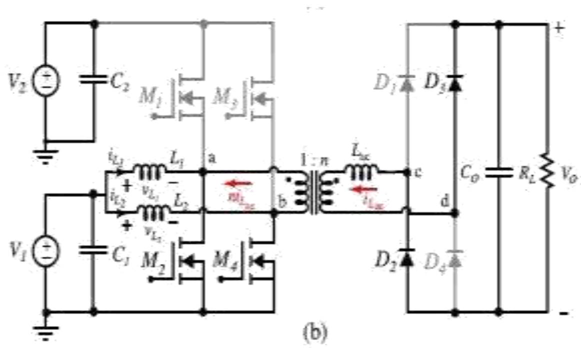


Fig. 6: Equivalent circuit for [t_3-t_4].

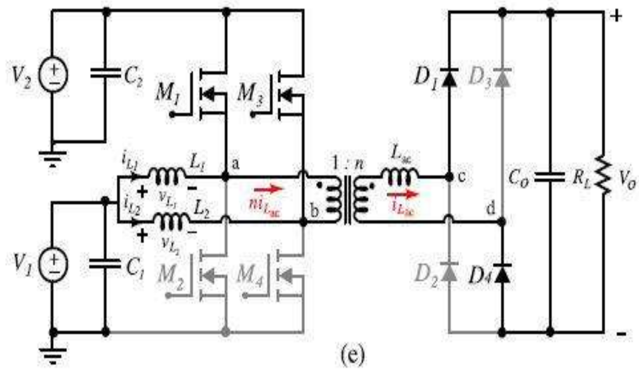


Fig.7: Equivalent circuit for [t_4-t_5].

In the completely demagnetized mode power flow from input to output port will be entirely controlled by f . If i_{Lac} does not decrease to zero before M_2 is triggered, then the resultant mode is partially magnetized.

Boundary condition between completely magnetized and partially magnetized inductor current is given by,

$$\Delta t + \phi T \leq (1-D)T \quad (10)$$

On substituting (4) into (10)

$$\Phi \leq (1-D) / M \quad (11)$$

Relation between input and output ports is defined as

$$M = nV_{ab} / V_{cd} = nV_1 / (1-D) V_0 = nV_2 / V_0 \quad (12)$$

If i_{Lac} does not decrease to zero before M_2 is turned off, then resultant mode will be fully magnetized. Both partial and fully magnetized modes allow high power transfer to output. This is due to increased charge per switching cycle delivered to output capacitor. But they results in higher current stress and higher losses than the completely demagnetized mode. When converter leaves completely demagnetized mode , output voltage no longer can be controlled by ϕ . Therefore the proposed converter works on completely demagnetized mode.

IV. Modelling Of Converter

The proposed converter can be dynamically modeled as two individual con-verters called as Bidirectional interleaved boost converter (BIBC) and Phase shift full bridge converter (PSFB). So it offers independent controllability by using duty cycle and phase shift as two control variables. BIBC balances power flow within the input sources whereas PSFB delivers power to the load through L_{ac}. High in-tegration of two structures results in a topology with lower component number and higher power density than multiple converter systems. Dynamic modeling is done as per the circuit shown in fig.8.

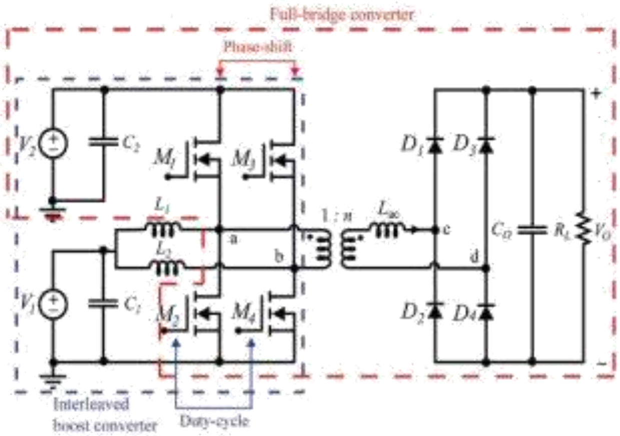


Fig.8: Integration of BIBC and PSFB as TPC.

V. Powerflow Regulation And Control

The system is always set to control renewable energy source. Here V_1 represents the renewable source and is taken as a solar photovoltaic (PV) cell. To maximize the power delivered to the system, MPPT algorithm can be implemented. At output port voltage regulation loop is employed to regulate load voltage by ϕ and it is shown in fig.9.Voltage or current of renewable energy port, V_1 is controlled by duty cycle, D. Bidirectional port V_2 is controlled by implementing either constant voltage (CV) or constant current (CI) control loop. Fuzzy logic can also be used for the same purpose.

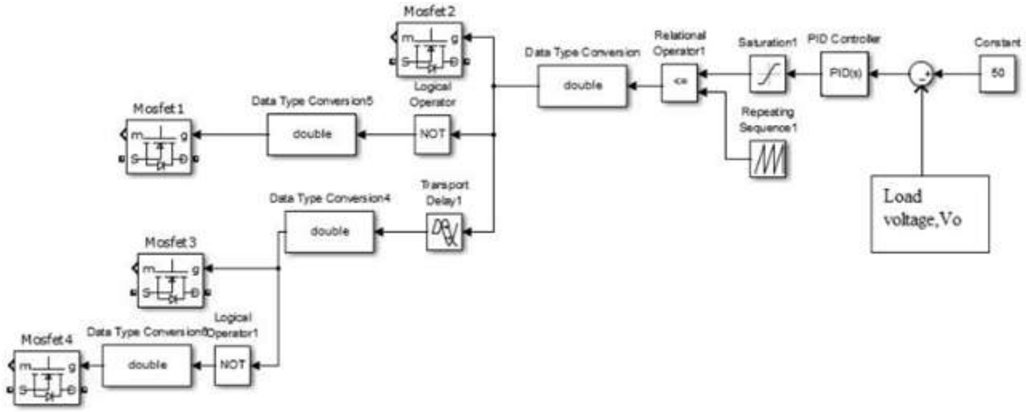


Fig.9: Closed loop control scheme for voltage regulation

VI. Simulation Results

Simulation diagram of the converter is shown in fig.10. Simulation was done in MATLAB/simulink by using the parameters given in the table. In the sim-ulation diagram the display shows the output voltage. Two inductor voltages V_{L1} and V_{L2} are measured with the help of voltage measurement. The ac inductor current is measured and is found to be completely demagnetized. Hence the simulation is conducted for completely demagnetized mode. Simulated waveforms are

Table I : Simulation parameters used

Parameters	Specification
Input voltage, V_1	12V
Input voltage, V_2	24V
Output voltage, V_o	50V
Maximum output power	25W
Transformer T	4:16
Inductors L_1 and L_2	155μH
Inductor L_{ac}	28μH
Capacitor C_1	20μF
Capacitor C_2	66μF
Capacitor C_o	200μF
Switching frequency	60 kHz

plotted. Proper gate pulses are given to the primary side switches by implementing suitable closed loop feedback control scheme. To obtain voltage regulation at output port and powerflow balance in the converter, both duty ratio and phase shift angle should be simultaneously adjusted. But it is a difficult task to be performed. So an accurate microcontroller based feedback loop has to be implemented. The switching pulses for the converter is developed by the closed loop control and waveforms are shown in fig.11.

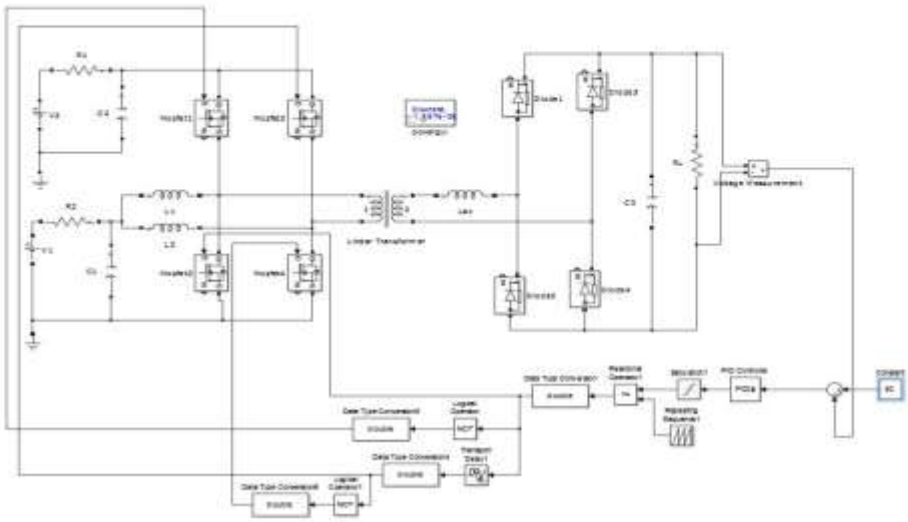


Fig.10: Simulation diagram of the converter

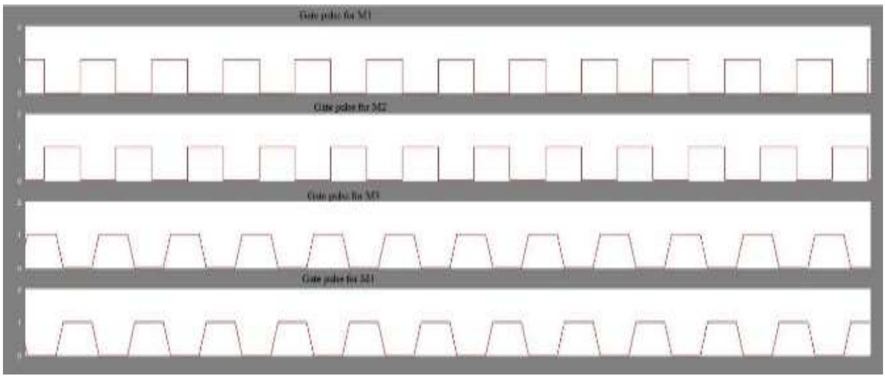


Fig.11: Switching pulses for MOSFET switches

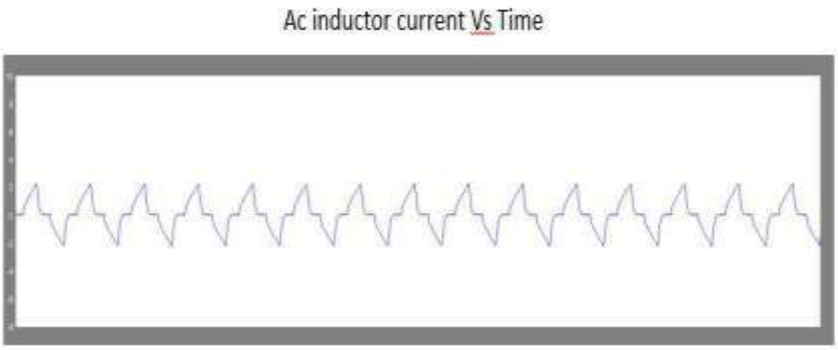


Fig.12: completely demagnetized ac inductor current

All switches are conducting for a duty cycle of 0.5 and phase shift angle is chosen to be 90^{o}. The converter works in completely demagnetized mode and the waveform that shows this ac inductor current is plotted in fig.12. The ac inductor current is in a range of 1.25A and is symmetrical in nature. Output voltage of the converter is found to be constant and the magnitude is given as 50V. Output current and power of the converter are found to be 0.5A, 25W respectively. They are shown in fig. 13.

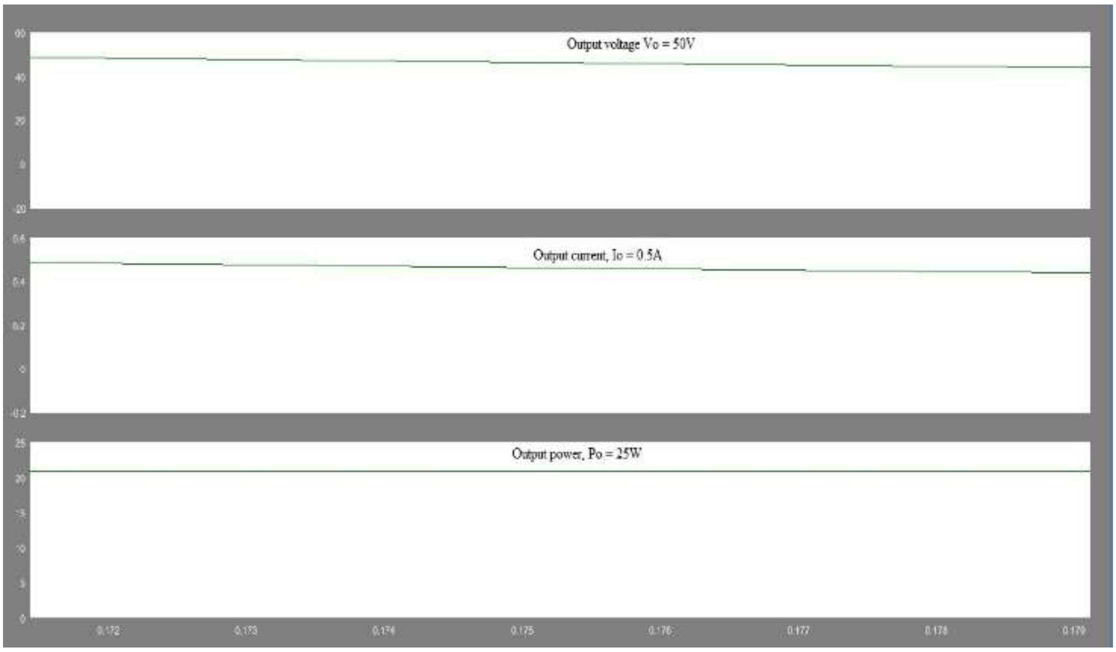


Fig.13: Output voltage, current and power VS time

VII. Conclusion

A TPC was designed and modelled as per the requirement. Simulation of the proposed converter was done and results are shown. Design of feedback loop is on progress. The concept will help to extract renewable energy from wind and solar with maximum efficiency even for low power applications. This converter is applicable for hybrid renewable energy systems so that power flow fluctuations can be eliminated and balance the power between different energy sources. It maximize the power delivered to the system through a maximum power point tracking algorithm (MPPT). The overall energy utilization can be improved.

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