# CLOSED LOOP CONTROL OF THREE PORT CONVERTER WITH HIGH VOLTAGE GAIN

Santhi Mary Antony A
Assistant Professor,
Department of Electrical and Electronics Engineering,
Sathyabama University, Chennai -119.
msanthimary@gmail.com

**ABSTRACT**

**Photovoltaic (PV) system is one of the best renewable energy sources for power generation system due to their pollution free and low cost properties. The PV cells has less efficiency compared to other source of power generation. The system efficiency is improved by reducing components count, which reduces the losses. In this paper a new three port converter (TPC) is proposed for stand-alone renewable power applications. The proposed converter has three switches to achieve the power flow control. Single inductor is used for common energy transfer element for two different sources. The coupled inductor is used to increase the voltage conversion ratio with reasonable duty cycle. Thus the proposed converter has high voltage gain with less components count. The output voltage is regulated through feedback network. The system performance is verified through simulation results.**

***Keywords:*** Three port converter (TPC), Photovoltaic source, MPPT, Zero voltage switching.

## I. INTRODUCTION

Renewable energy based power generation is more popular due to their low cost and continuous availability. Photovoltaic (PV) system is one of the best renewable energy sources for power generation system [A. I. Bratcu et al., 2011, M. Cacciato et al.,2010]. PV sources does not supply power to the load constantly. It requires storage elements for constant power delivery [Y. M. Chen et al., 2013, R. Y. Duan et al., 2012]. Fig.1(a) shows a conventional stand-alone solar system with a low dc input voltage source and a storage element [K. Sun et al., 2011, F. Locment et al., 2012]. Battery and the PV source are low-voltage sources, thus the converters have to boost the voltages to match the load [Y. P. Hsieh et al., 2011]. The system needs two converters at the front end. One is a unidirectional converter used to boost the input voltage and track maximum power point (MPP). The other is a bidirectional converter used to control the power flow between the battery and dc bus. This type of system with two conversion stages required more no of components and increases the volume. Fig.1(b) shows a stand-alone solar system with a TPC and a battery backup. Different topologies have been proposed for renewable energy power systems with the battery backup or hybrid energy source [D. Liu et al., 2006].

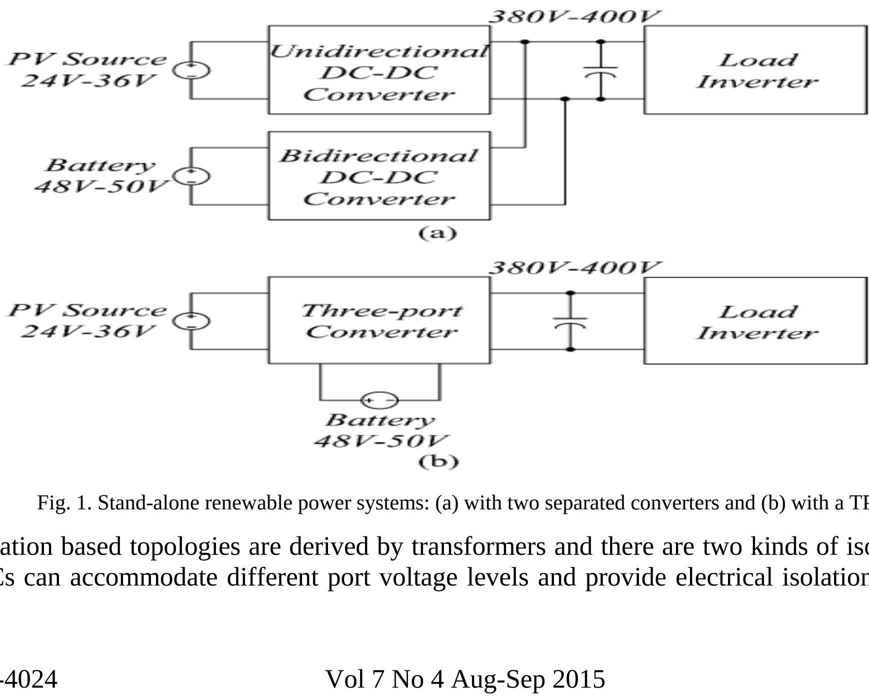



Fig. 1. Stand-alone renewable power systems: (a) with two separated converters and (b) with a TPC.

The isolation based topologies are derived by transformers and there are two kinds of isolated TPCs. Fully isolated TPCs can accommodate different port voltage levels and provide electrical isolation for each port [D.

Liu et al., 2006, K. Haribaran et al.,2009]. By using phase shift PWM control method, the converter can achieve zero voltage switching (ZVS) on all switches [D. Liu et al., 2006, H. Tao, 2008]. TPC with resonant also to increase the efficiency [K. Haribaran et al.,2009]. But this topology has more no of components due to full bridge converter. It increases the cost, more power loss and controlling also more complex. To solve this problem full bridge is replaced with half bridge converter [Z. Qian et al., 2010]. In this topology the battery supply is used for all operating condition as a result the life time of the battery is reduced. Converter voltage gain depends on the duty cycle and transformer turns ratio. More duty cycle increase the voltage stress and diode reverse recovery problem. More turns ratio increase the leakage inductance and power loss. To solve the above said problem non isolated topology is proposed. This topology has less conversion stages without transformer [Y. C. Liu et al., 2009]. But some multiport topology has more components and unidirectional power flow. In this paper, a new nonisolated TPC with high-voltage gain is proposed. By adjusting the turn's ratio of coupled inductor, the converter can provide a higher conversion ratio for both low input voltage ports under a reasonable duty ratio. Additionally it has only one inductor, the power flow between the PV source and battery can be controlled by a simple control method.

## II. PROPOSED THREE PORT CONVERTER

The proposed three port converter is shown in Fig. 2. This circuit has PV and battery input source, three power switches, five diodes, one coupled inductor, one inductor, and three capacitors. *PV cell* is primary input source. Battery is secondary input source connected to a bidirectional port. The coupled inductor is modeled as a magnetizing inductor *Lm*, leakage inductance $L_k$ , and an ideal transformer *Np* /*Ns* . The capacitor *C*1 can balance the magnetic energy of magnetizing inductor *Lm*. The diode *D*1 and capacitor *C*2 form a lossless snubber with leakage inductance energy recycle. The capacitor *C*3 and the secondary-side of coupled-inductor *Ns* form a step-up cell to provide extra voltage gain. The voltages *Vpv, VC*2, $V_{Ns}$, and *VC*3 are connected in series to build up a high output voltage. In order to simplify the circuit analysis, the converter is analyzed in continuous-conduction mode (CCM), and the following conditions are assumed:

1) Battery Voltage *Vbt* is higher than solar panel *Vpv* .

2) Capacitors *C*1, *C*2, *C*3 , and *Co* are large enough that *VC*1, *VC*2, *VC*3 and *VCo* can be considered as constant voltages (CV);

3) The power MOSFETs and diodes are ideal, but the drain to- source parasitic capacitor of the MOSFET *Cds* is considered;

4) The turns ratio of the coupled-inductor *n* is equal to *Ns* /*Np* ;

5) The coupling coefficient of the coupled-inductor *k* is equal to *Lm*/(*Lm* + *Lk* ).

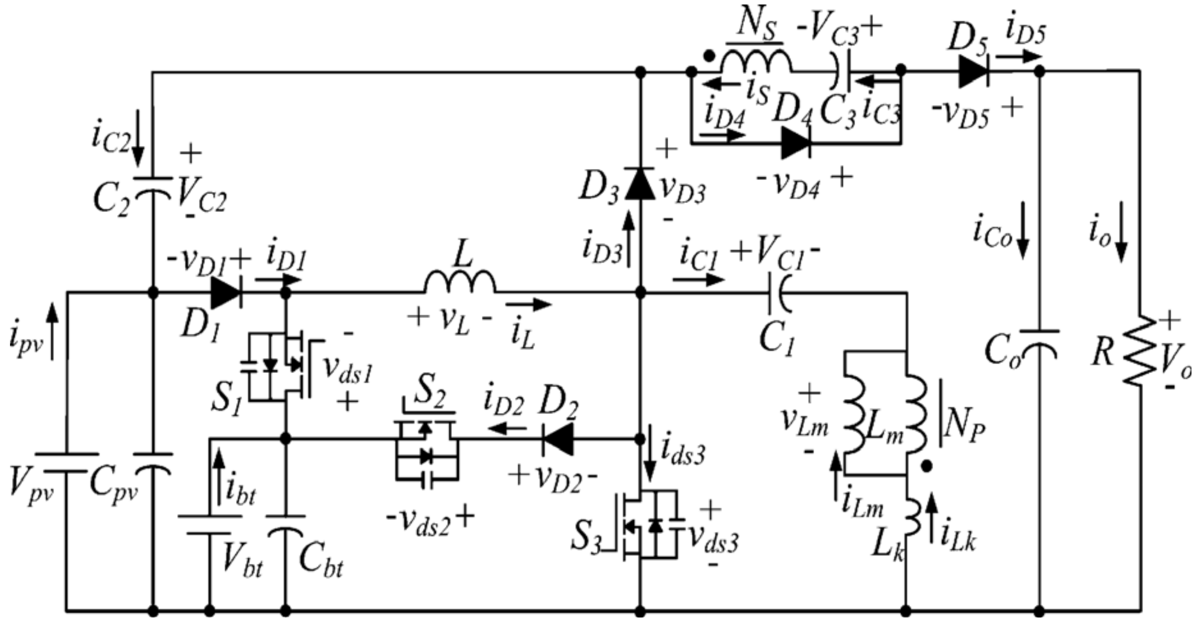



Fig. 2. Proposed Converter Topology.

1) Single input single output (SISO) mode: The battery provides energy to the load alone if there is no radiation received by the PV panel.

2) Double input single output (DISO) mode: PV source and battery provide energy to the load together.

3) Single input double output (SIDO) mode: PV source provides energy to the load and the battery stores unconsumed power from PV source.

*A. Operating Principle of DISO Mode*

Fig 3(b) shows the double input and single output (DISO) mode. Battery and PV source act as a source. In this mode the most of the modes are similar to those in SISO mode, the major difference is a two stage discharging of inductor *L* when *S*3 is turned OFF. *S*2 and *D*2 are always turned OFF. *S*3 is a MPPT switch and *S*1 is used to regulate the output voltage. The operating modes are described as follows:

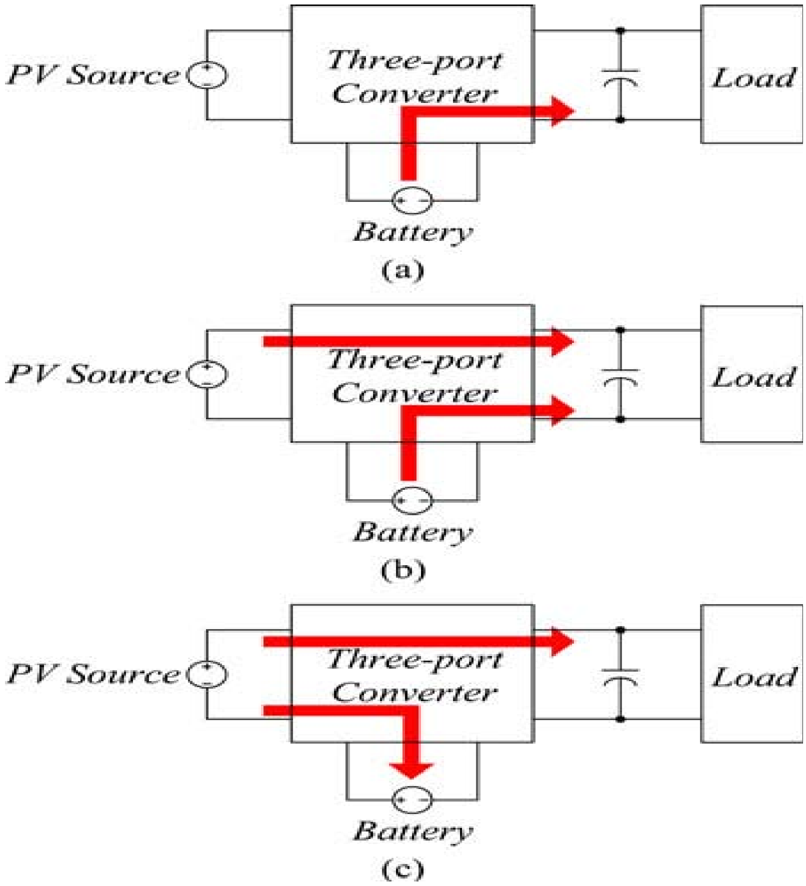
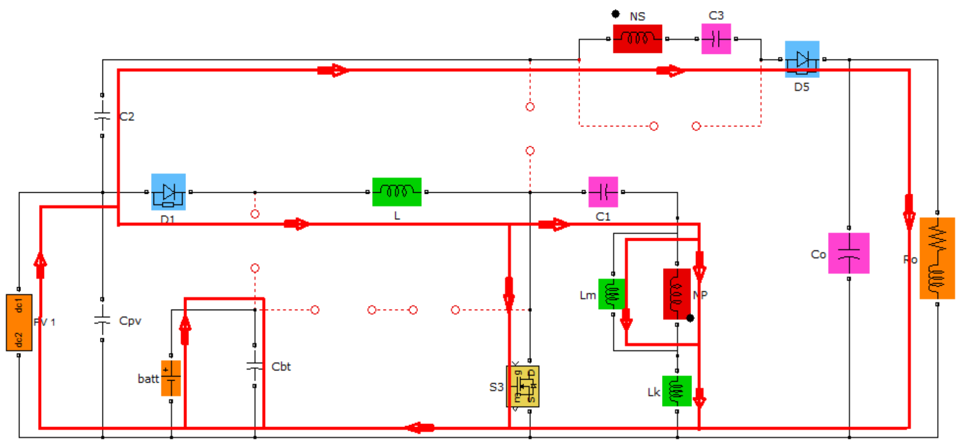



Fig. 3. Operation modes for TPCs: (a) SISO mode (b) DISO mode (c) SIDO mode.

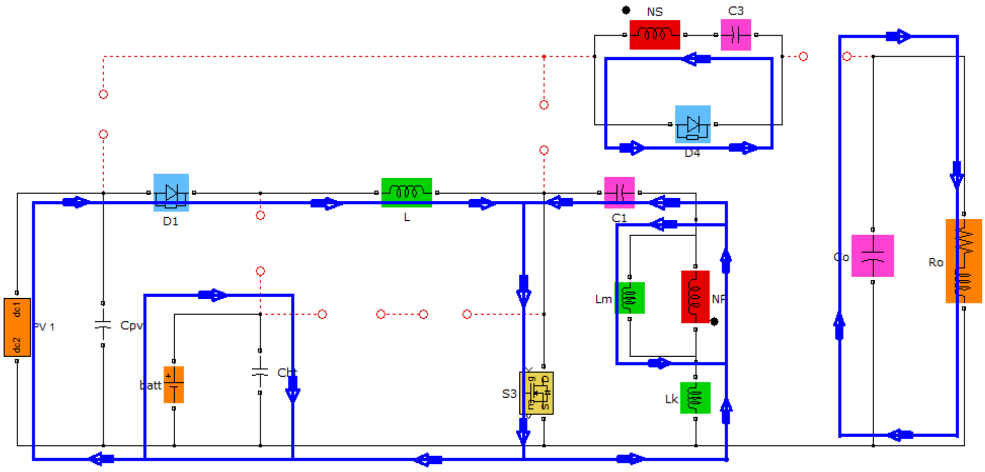
Mode: 1

During this mode switch S3, diode D1 and D5 are turned ON; switch S1, diode D3, and D4 are turned OFF. Thus inductor L is charged by Vpv. When Is = 0 at t = t1 , this mode ends.



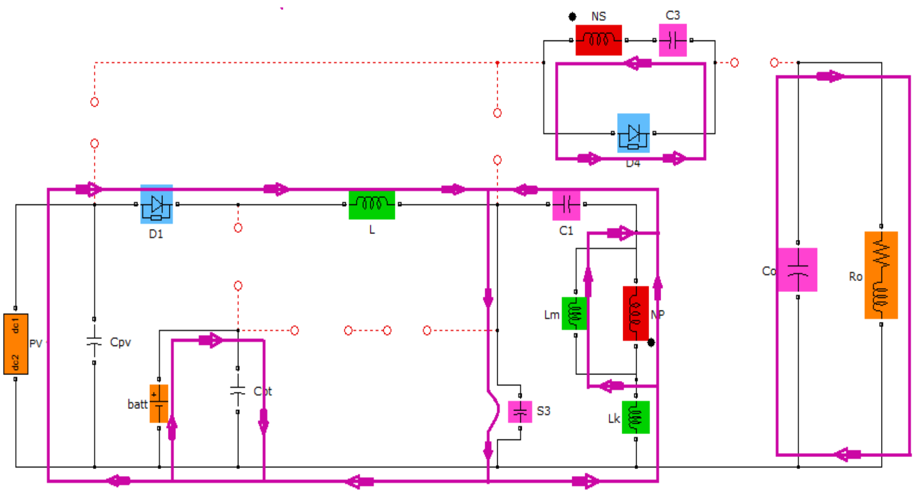
Mode:2

During this mode switch S3, diode D1 and D4 are turned ON. Switch S1, diode D3 and D5 are turned OFF. L is charged by Vpv . C1 charges Lm and Lk through S3. C3 is charged by C1 through Ns , and VC3 = nVC1 . This mode ends when S3 is turned OFF at t = t2 .



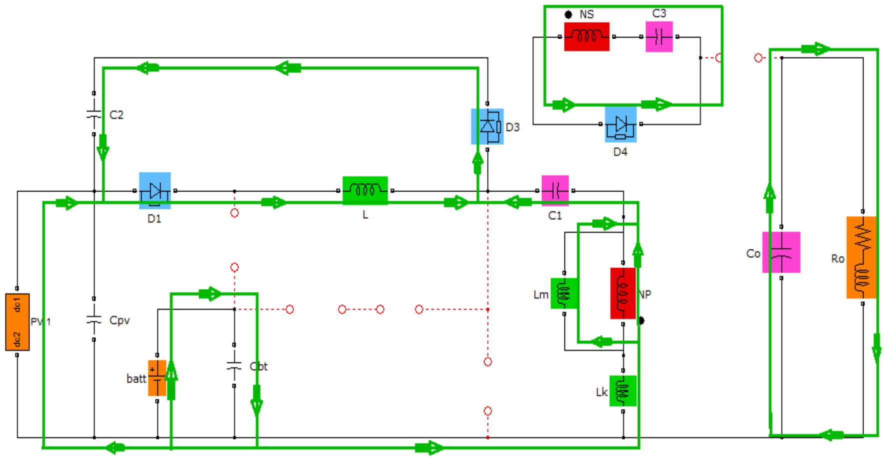

Mode: 3

During this mode after switch $S3$ is turned OFF, $Cds3$ is charged by $iL$ and $iLk$ . $C3$ is still charged by $C1$ through $Ns$ and diode $D4$. This mode ends when $vds3 = Vin + VL$ at $t = t3$.



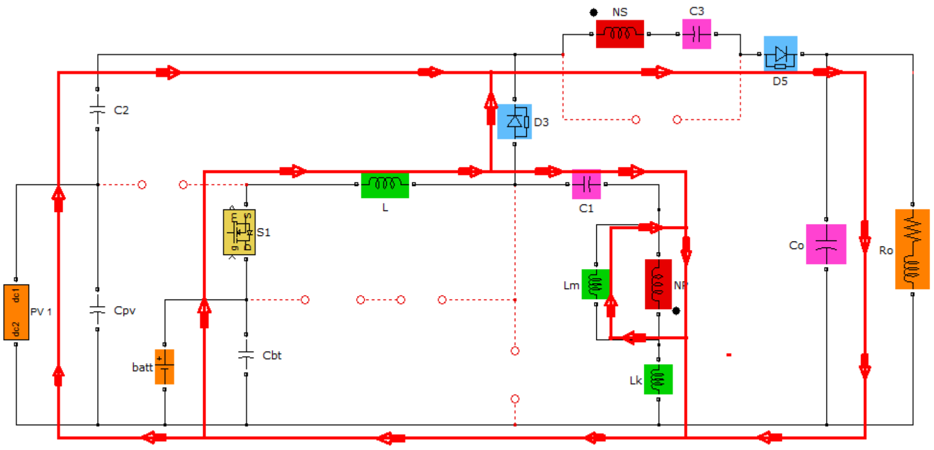

Mode:4

During this mode switch $S3$ is turned OFF. Diode $D3$ is turned ON to recycle energy from $Lk$ to $C2$ . The secondary-side current still charges $C3$ . When $S1$ is turned ON, this mode ends at $t = t4$ .



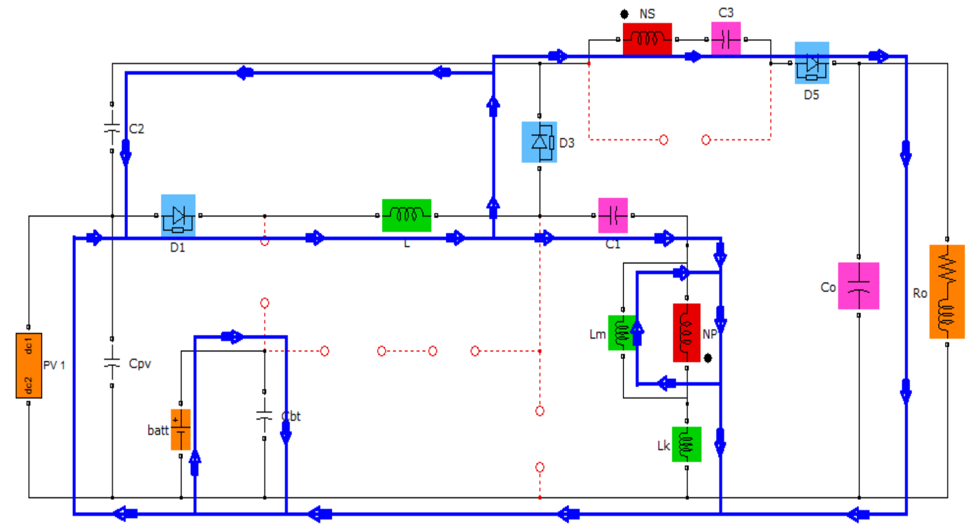

Mode:5

During this mode switch $S3$ and $D1$ are turned OFF. $S1$ and $D5$ are turned ON. The voltage variation of the input source causes a variation of different negative slope of the inductor current $iL$ . Battery port releases energy to the load through $L$. $C1$ is also charged by $Vbt$ and $L$. Voltages $Vpv$, $VC2$, $vNs$, and $VC3$ are connected in series to charge $Co$ and provide energy to the load. This mode ends when $S1$ is turned OFF at $t = t5$ .




Mode: 6

During this mode switch $S1$ and $S3$ are turned OFF. $D1$, $D3$ , and $D5$ are turned ON. The negative slope of $iL$ is changed again because of input voltage variation. $C1$ is charged by $Vpv$ and $L$. $C2$ is recharged by $L$ through $D1$ and $D3$. This mode ends when $S3$ is turned ON at $t = t6$ .




## III. SIMULATION RESULTS

### A. OPEN LOOP SYSTEM

Fig 4 shows the proposed circuit simulink model. It consists of PV cell, battery source, coupled inductor and load. Fig 5 and 6 shows the input voltage for PV cell and battery. PV cell has 24V and Battery has 48V output. Fig 7 and Fig 8 shows the gate pulse, drain current and Vds across switch S3 and S1.All power switches are operating in zero voltage switching condition, it is proven from Fig 7 and Fig 8. Fig 9 shows the gate pulse, current through inductor L, Lm and Lk. Fig 10 and 11 shows the output voltage and power of the converter. The converter input voltage 24 and output voltage 400V. The converter has 16.6 voltage gain. It is proven from simulation results.

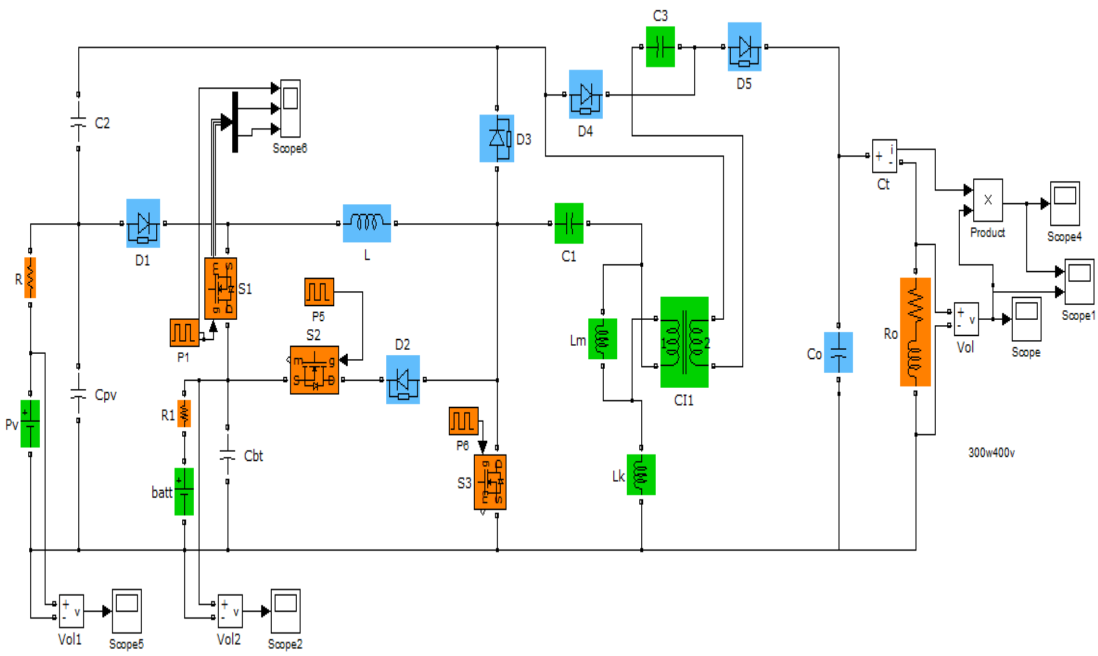



Fig.4 Proposed Circuit Diagram

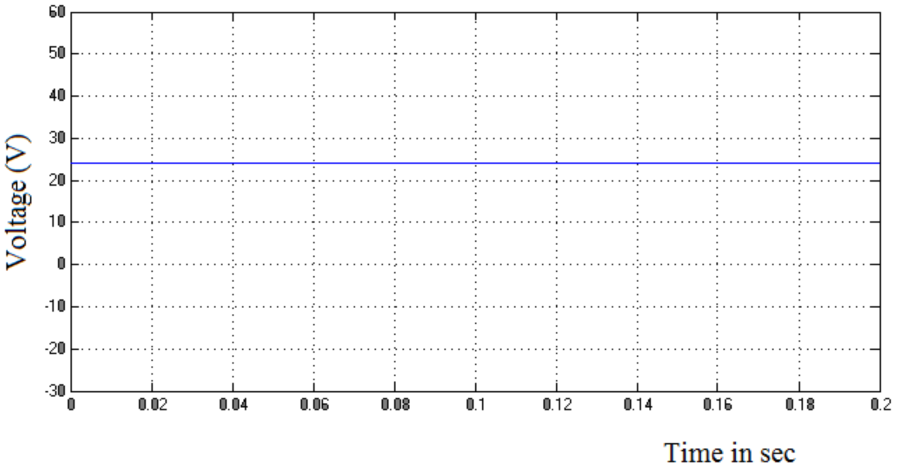



Fig.5 PV Input Voltage

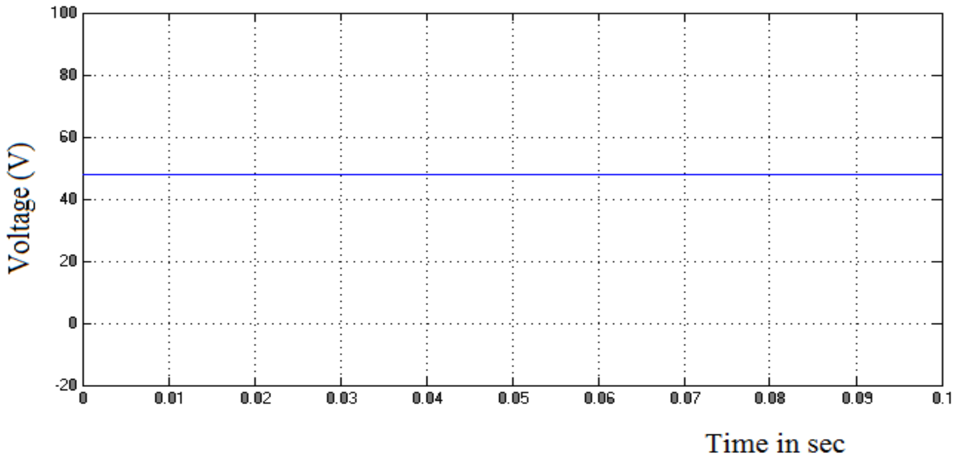



Fig .6 Battery Input Voltage

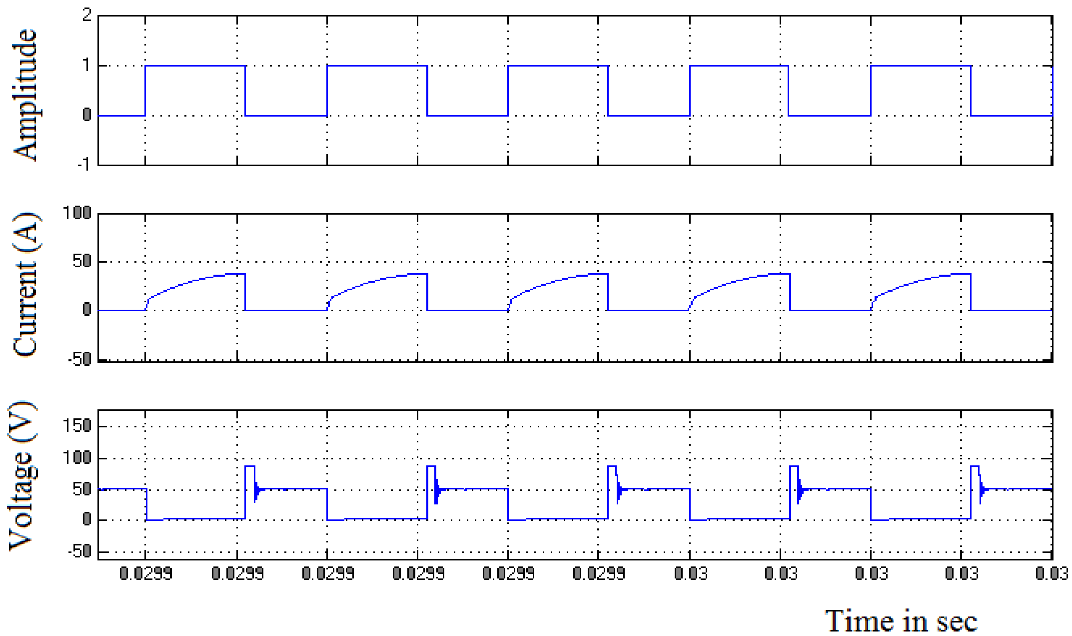



Fig .7 Gate Voltage, Drain Current and Vds across switch S3

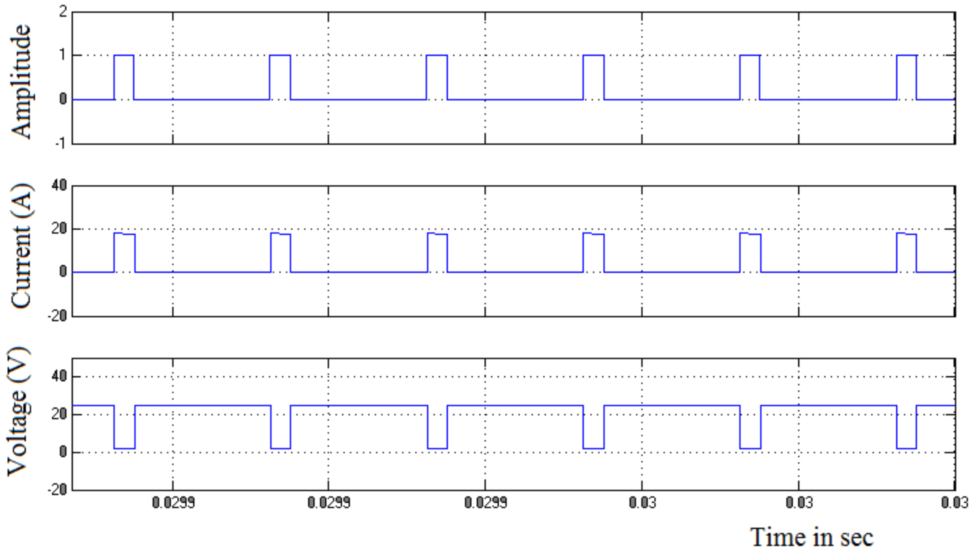



Fig .8 Gate Voltage, Drain Current and Vds across switch S1

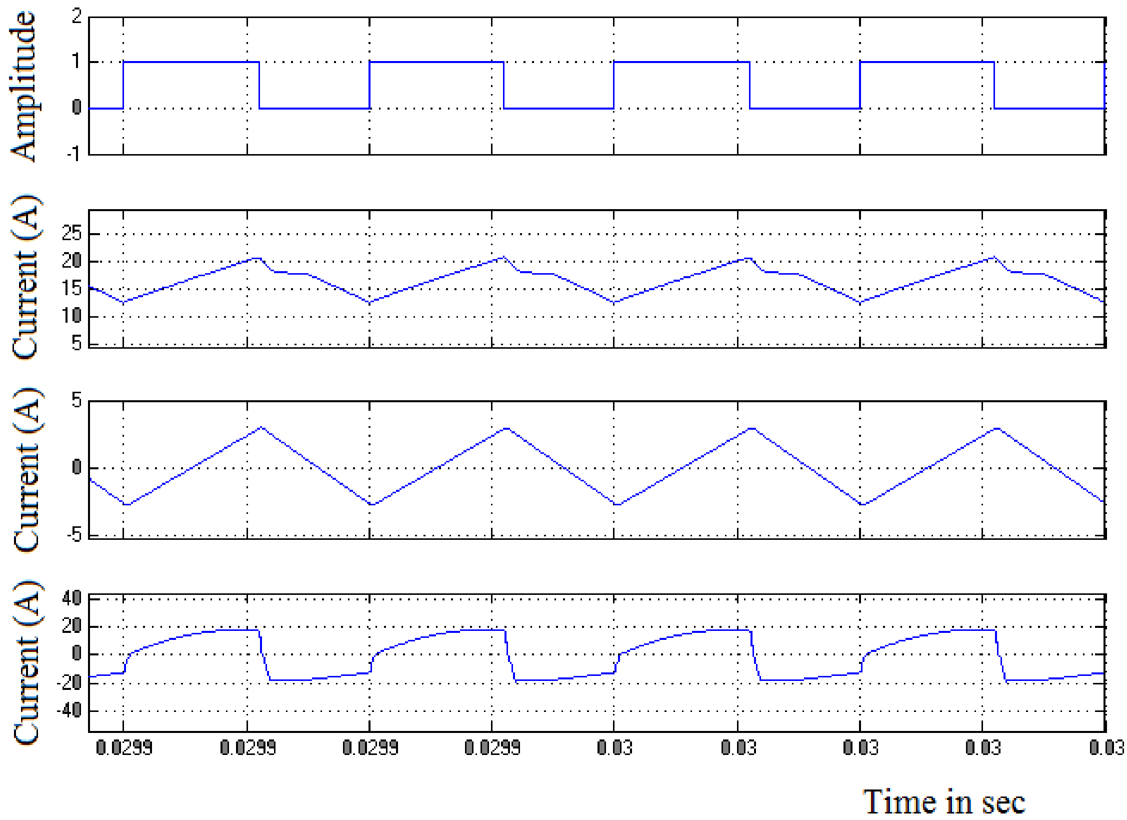



Fig .9 Gate Pulse, Current through inductor L, Lm and Lk

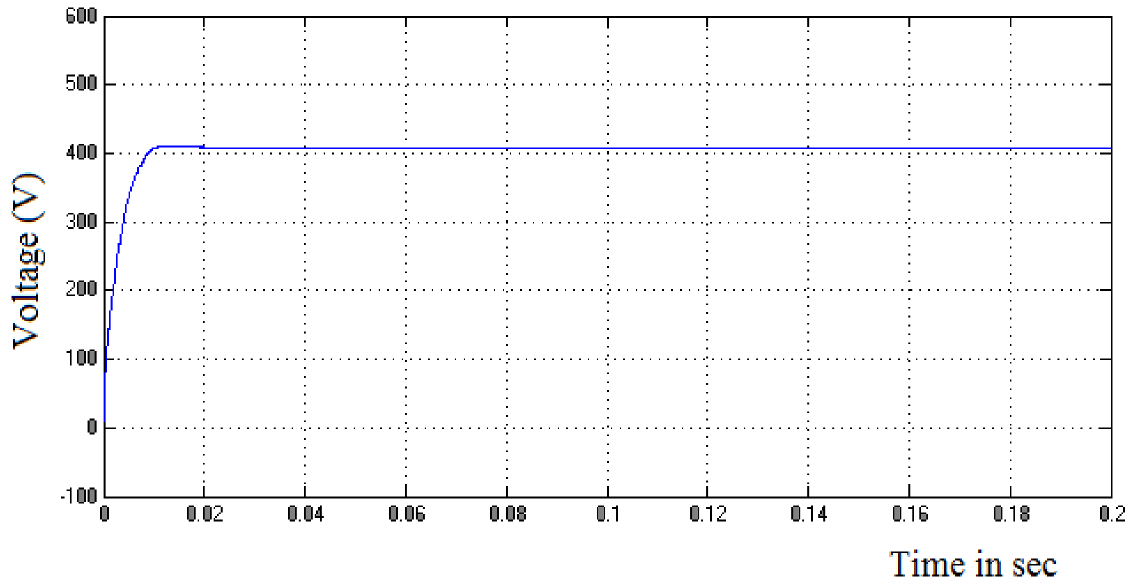



Fig .10 Output Voltage

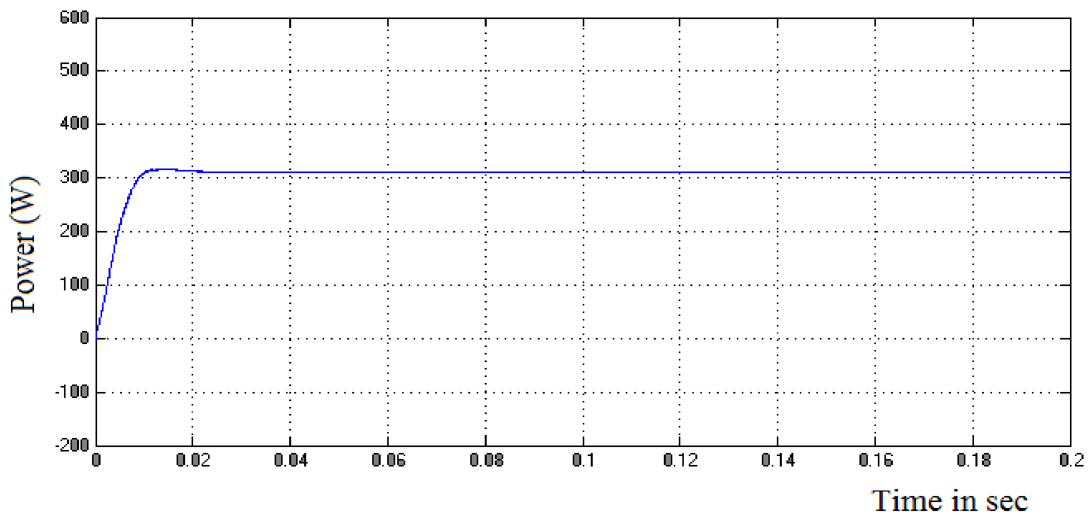



Fig.11 Output Power

### *B. CLOSED LOOP SYSTEM*

Fig 12 shows the open loop circuit diagram with input voltage disturbance. Initially PV cell supply 22V to the converter after T= 0.2 sec. The input voltage vary from 22V to 25V, as a result the output voltage also vary from 400V to 440V. It is shown from fig 13. Here feedback circuit is not used to control the output voltage, so the output voltage gets varied according to input voltage variations.

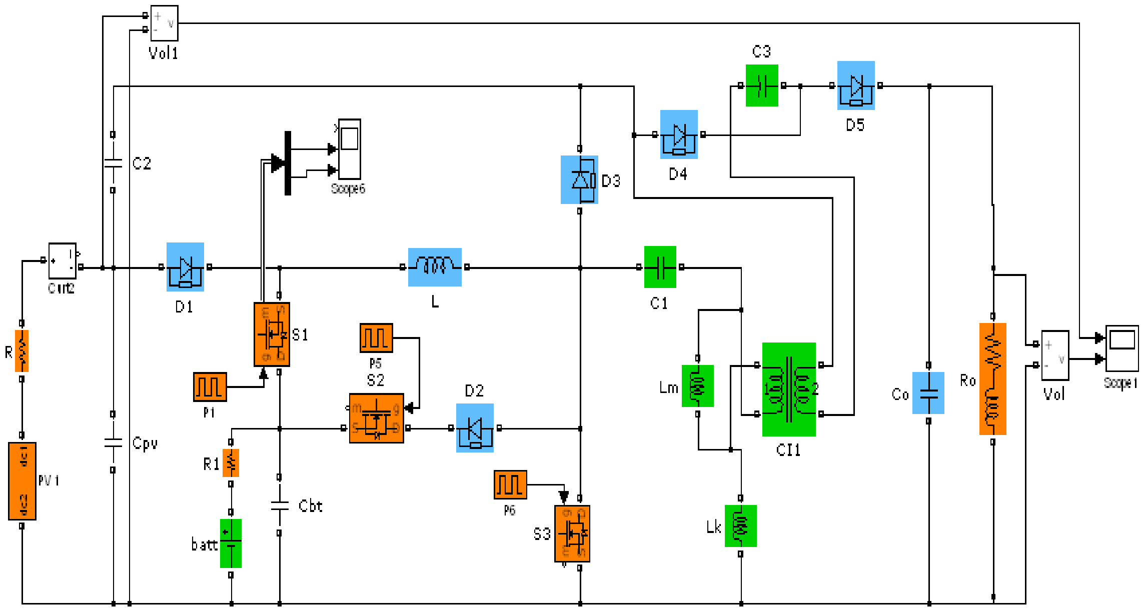



Fig .12 Open loop circuit diagram.

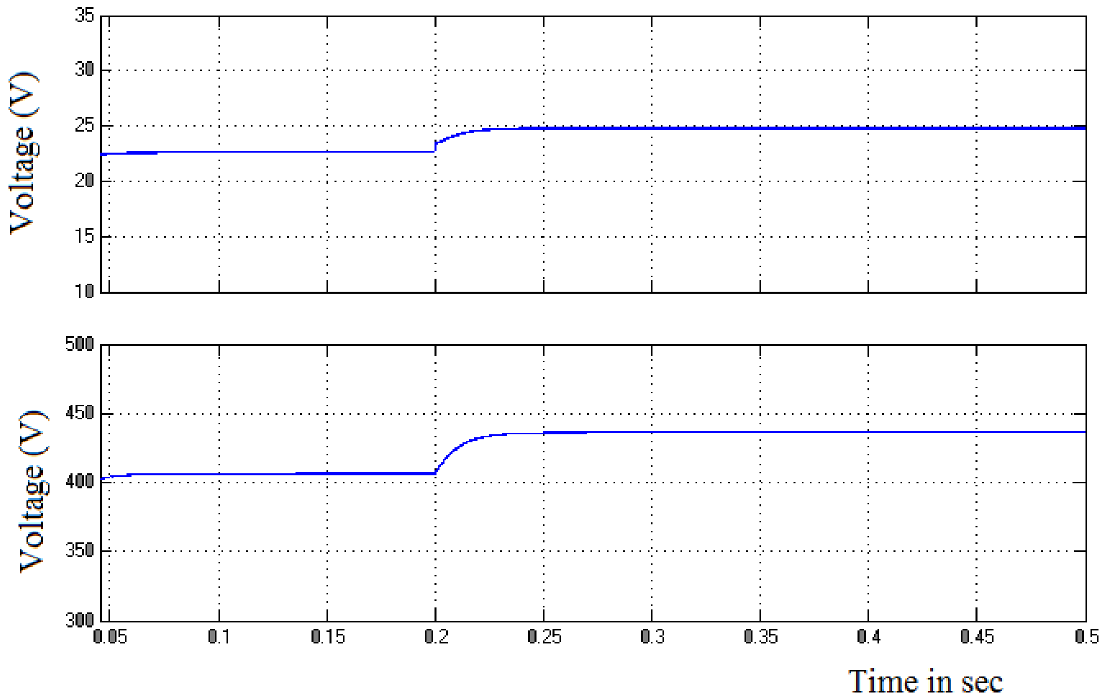



Fig .13 Input voltage and output voltage without regulation

Fig .14 shows the closed loop circuit diagram with input voltage disturbance and MPPT controller. Initially PV cell supply 22V to converter after T= 0.2 sec. The input voltage vary from 22V to 25V as a result the output voltage also varies from 400V to 440V. The output voltage starts its regulation after T=0.25 sec due to feedback circuit. It is shown from fig 15. Here feedback circuit is used to control the output voltage 400V so that output voltage gets regulation if any change occur in input supply also. Thus the proposed system has high voltage gain and output regulation. It is shown from fig .15

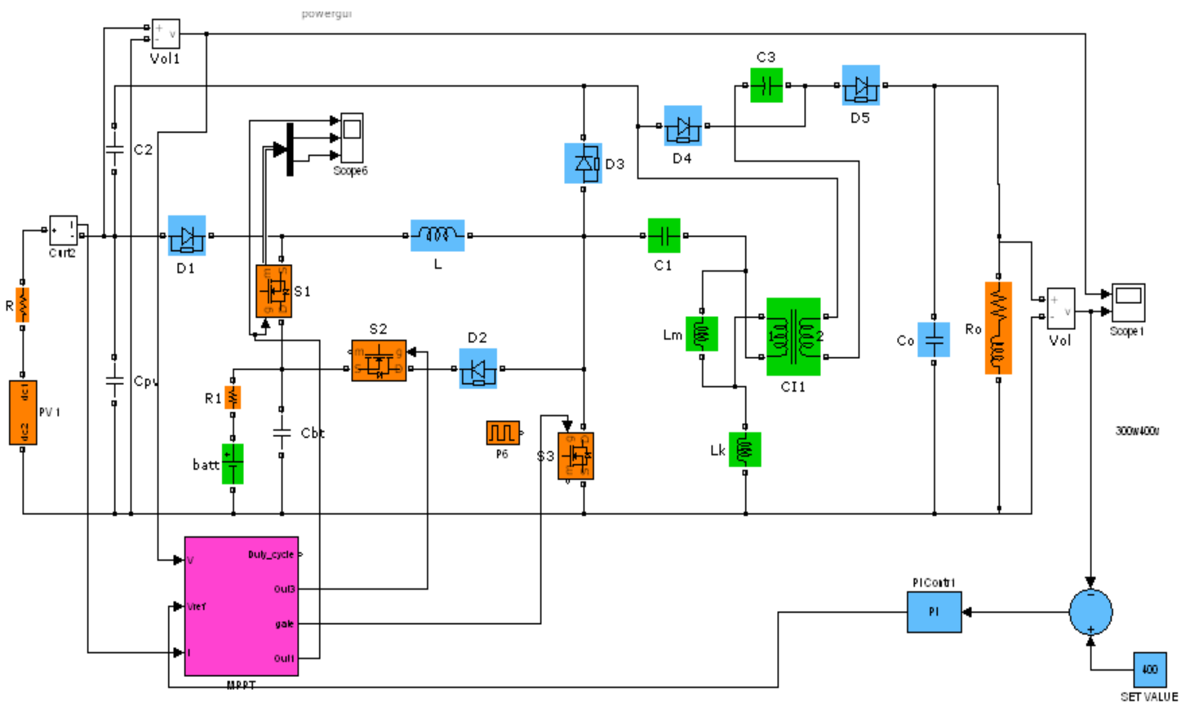


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Fig .14 Closed loop circuit with MPPT and voltage regulation.

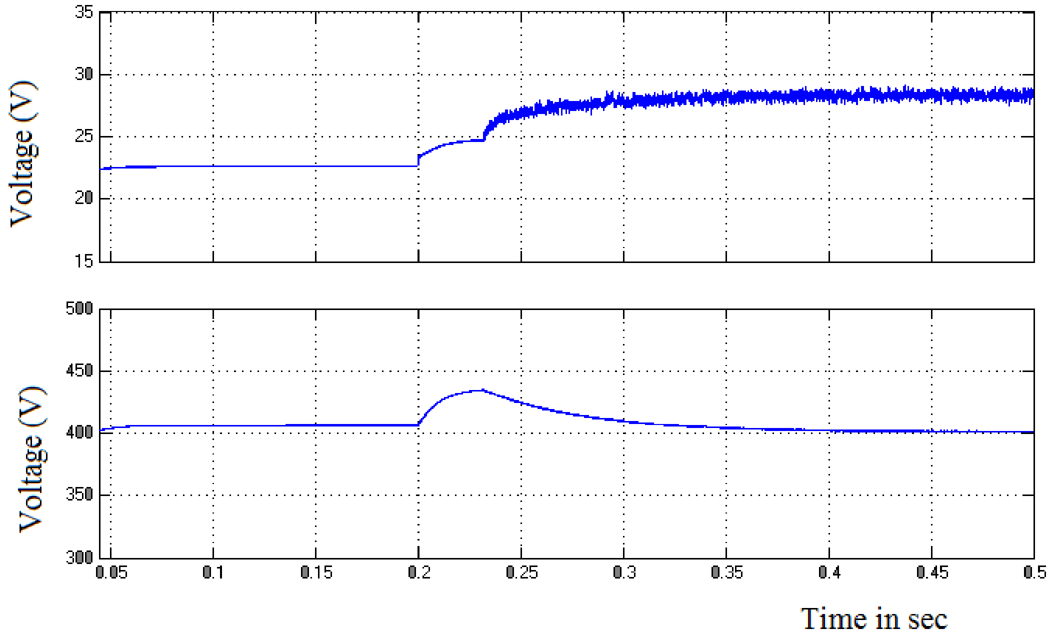


Fig .15 Input voltages and output voltage with regulation

## IV. CONCLUSION

A new three port converter for renewable energy applications is proposed. The proposed converter has bidirectional power flow between load and battery. The power transferred from low voltage source to high voltage load with help of coupled inductor and minimum switch combination. Thus the proposed converter has high voltage gain with minimum turn ratio and reasonable duty cycle, less no of power switches and simple control mechanism. The output voltage is regulated through PI controller. Maximum power is obtained through MPPT controller. The proposed circuit has high voltage gain compared with the conventional circuit. It is proven from simulation results.

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## Author’s details

Santhi Mary Antony A obtained her B.E. degree from University of Madras, Chennai in the year 2003, M.E. degree from Sathyabama University, Chennai in the year 2005. She has more than eight years of academic experience. She is currently working as Asst. Professor in the Department of EEE, Sathyabama University, Chennai.