Implementation of High step-up Three-port DC–DC Converter for Stand-alone PV-Battery Hybrid Power Systems

T. Hari Babu *M.TECH P.G. Scholar*, *KEC, Kuppam.*
Y.Damodharam *M.TECH Assoc. professor, Dept. of EEE, KEC, Kuppam.*
CH. Jayavardhana Rao *M.TECH Assoc. professor, Dept. of EEE, KEC, Kuppam.*
Velappagari Sekhar *M.E, LMISTE, LMSESI, AMIE, Asst.professor, Dept. of EEE, KEC, Kuppam*

ABSTRACT

Integrated multiport converters are becoming a big requirement now-a-days compared to conventional conversion topologies. In this paper, a three-port dc–dc converter combining photovoltaic (PV) and battery power for high step-up applications is proposed. The proposed converter consists of five power switches, two coupled inductors, and two active-clamp circuits. The coupled inductors are used to achieve high step-up voltage gain and to reduce the voltage stress of input side switches. Two sets of active-clamp circuits are used to recycle the energy stored in the leakage inductors and to improve the system efficiency. The proposed circuit is designed by usingMATLAB SIMULINK and the results are verified.

Index Terms- DC MicroGrid, Energy storage system, high step-up application, hybrid power system, renewable energy source, three port converter.

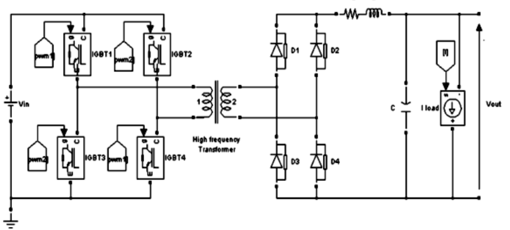
SECTION-1

INTRODUCTION

Integrated multiport converters for interfacing several power sources and storage devices are widely used in recent years. Instead of using individual power electronic converters for each of the energy sources, multiport converters have the advantages including less components, lower cost, more compact size, and better dynamic performance.

Many multiport converter topologies have been presented in the literature and can be roughly divided into two categories.

1. **Isolated type**:The isolated converters uses bridge topologies and multi winding transformers to match wide input voltage ranges.



2. **Non isolated type**:
The non isolated converters are usually derived from the typical buck, boost, or buck–boost topologies and are more compact in size. Resonant converters are also comes under non isolated type dc to dc converters.

Here in this paper we are considering non isolated resonant dc to dc conversion topologies.

In this paper, a high step-up three-port dc-dc converter for the hybrid PV/battery system is proposed with the following advantages: 1) high voltage conversion ratio is achieved by using coupled inductors; 2) simple converter topology which has reduced number of the switches and associate circuits; 3) simple control strategy which does not need to change the operation mode after a charging/discharging transition occurs unless the charging voltage is too high; and 4) output voltage is always regulated at 380 V under all operation modes. It is noted that for the MPP-tracking converters, operating range has to be limited to the voltage less than the MPP voltage when the output voltage or current control is active. This issue could be addressed by limiting the operating range of the converter in the voltages higher than MPP.

BASICS OF DC TO DC CONVERSION:

The purpose of a DC-DC converter is to supply a regulated DC output voltage to a variable-load resistance from a fluctuating DC input voltage.

Basically there are two types of conversions

1. Linear conversion.
2. Switched mode conversion.

1. LINEAR CONVERSION:

Linear conversion uses variable resistance to maintain the output voltage as required. Here the power will be dissipated in the form of heat. So this method is inefficient. As the heat dissipation increases there is a need for heat sinks to control the heat. To overcome these disadvantages we are going for switched mode conversion.

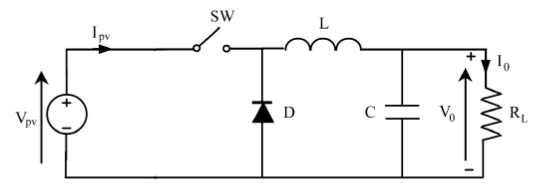
2. SWITCHED MODE CONVERSION:

In switched mode conversion process the energy will be stored in elements like inductor and capacitor when the switch is ON, after wards this energy will be supplied to the load. The output voltage in DC-DC converters is generally controlled using a switching concept. By varying the duty cycles of the switches the output voltage can be controlled as per the requirement. To vary the duty cycles we will use pwm technique in general. Modern DC-DCconverters classified as switch mode power supplies (SMPS) employ insulated gate bipolar transistors (IGBTs) and metal oxide silicon field effect transistors (MOSFETs).

In switched mode regulation basically we have two types i.e., isolated type and non isolated type.Here we are considering non isolated type dc to dc converters. Some of the non isolated type dc to dc conversion is as follows.

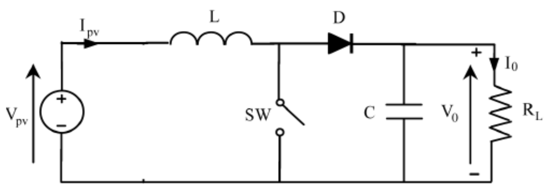
1. Buck converter.
2. Boost converter.
3. Buck boost converter.

1. Buck Converter:



A buckconverter is a voltage step down and current step up converter.. Beginning with the switch open (in the "off" position), the current in the circuit is 0. When the switch is first closed, the current will begin to increase, and the inductor will produce an opposing voltage across its terminals in response to the changing current. This voltage drop counteracts the voltage of the source and therefore reduces the net voltage across the load.

2. Boost converter:

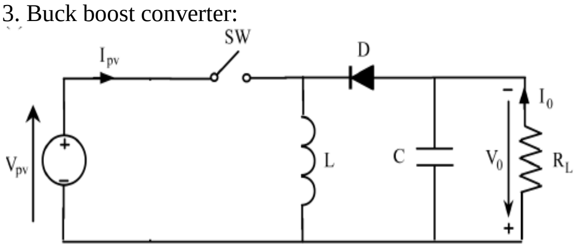


A boost converter (step-up converter) is a DC-to-DC power converter with an output voltage greater than its input voltage.

(a) When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

(b) When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current flow towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

3. Buck boost converter:



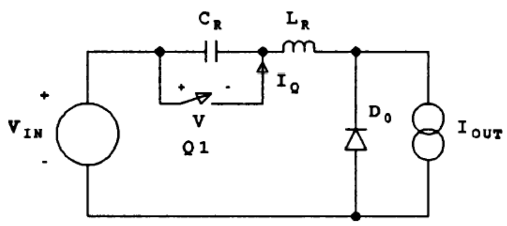
The **buck–boost converter** is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is equivalent to a fly back converter using a single inductor instead of a transformer.

Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, from an output voltage much larger (in absolute magnitude) than the input voltage, down to almost zero.

Increasing the frequency of operation of power converters is desirable, as it allows the size of circuit magnetic and capacitors to be reduced, leading to cheaper and more compact circuits. However, increasing the frequency of operation also increases switching losses and hence reduces system efficiency. One solution to this problem is to replace the "chopper" switch of a standard SMPS topology (Buck, Boost etc.) with a "resonant" switch, which uses the resonances of circuit capacitances and inductances to shape the waveform of either the current or the voltage across the switching element, such that when switching takes place, there is no current through or voltage across it, and hence no power dissipation. A circuit employing this technique is known as a resonant converter (or, more accurately, a quasi-resonant converter, as only part of the resonant sinusoid is utilized).
Basically we have two types of resonant converters.

Zero Current Switching (ZCS) circuit shapes the current waveform, while a Zero Voltage Switching (ZVS) circuit shapes the voltage waveform.An LC circuit shapes the voltage across the transistor and current through it so that the transistor switches when either the voltage or the current is zero.Here in this paper we are considering a non isolated ZVS resonant converter.

Zero voltage switching resonant converter:



Zero voltage switching can best be defined as conventional square wave power conversion during the switch's on-time with "resonant" switching transitions. During the ZVS switch off-time, the L-C tank circuit resonates. This traverses the voltage across the switch from zero to its peak, and back down again to zero. At this point the switch can be reactivated, and lossless zero voltage switching facilitated. Since the output capacitance of the MOSFET switch (Co& has been discharged by the resonant tank, it does not contribute to power loss or dissipation in the switch. Therefore, the MOSFET transition losses go to zero - regardless of operating frequency and input voltage. This could represent a significant savings in power, and result in a substantial improvement in efficiency. Obviously, this attribute makes zero voltage switching a suitable candidate for high frequency, high voltage converter designs. Additionally, the gate drive requirements are somewhat reduced in a ZVS design due to the lack of the

gate todrain (Miller) charge, which is deleted when V and equals zero.
The technique of zero voltage switching is applicable to all switching topologies like buck, boost, buck-boost etc.

SECTION-2

BASIC BLOCK DIAGRAM

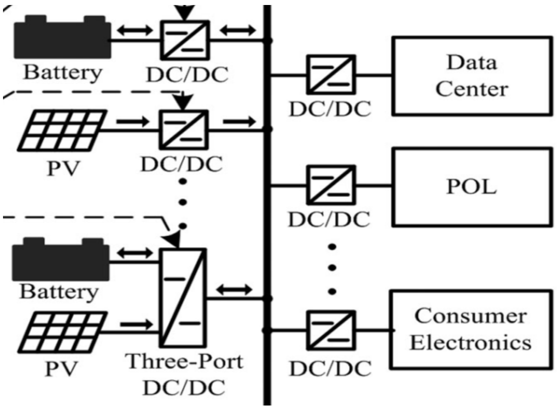


Fig.1 Block diagram of three port converter.

The basic block diagram consists of a hybrid system consisting of solar and battery power. Here a dc micro grid enabled by the solid state transformer is presented. In this block diagram we can observe that, if the solar is treated as the renewable energy source and battery as the storage device, the battery can either supply the load with solar energy or store the excess power from the panel for back up use. So a bidirectional power path has been provided for battery port .Here we can observe that multi port converter topology has considered hence for both PV as well as battery we will use one converter section instead of using two converters individually. Because of this multiport converter technique a single controller like microprocessor can be used for both battery as well as PV panels.

SECTION-3

PROPOSED THREE PORT DC TO DC ZVS RESONANT CONVERTER

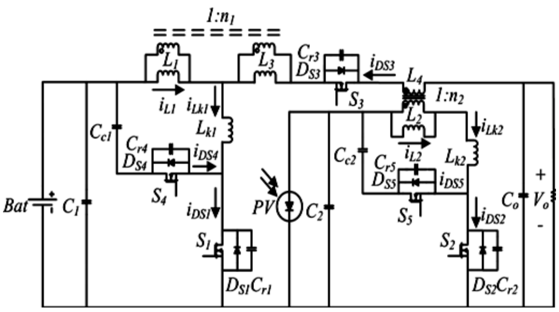


Fig2. Proposed three port dc to dc Converter.

The proposed three port dc to dc converter is shown in the above figure. The converter consists of two main switches S1 and S2 for the battery and PV port. Synchronous switch S3 is driven complementarily to S1 such that bidirectional power flow for the battery port can be achieved. Two coupled inductors with winding ratios n1 and n2 are used as voltage gain extension cells. S4, Lk1, Cc1 and S5, Lk2, Cc2 forms two active clamp circuits which are used to recycle the leakage energy. Lk1 and Lk2 representssmall leakage inductor from the coupled inductor and an External leakage inductor. Duty cycles d1 and d2 considered as two control variablesallow the control over two ports of the converter, while the third port is for the power balance. The fixed-frequency driving signals of the auxiliary switches S3 and S4 are complementary to primary switch S1. Again, S3 provides a bidirectional path for the battery port. Similarly, S5 is driven in a complementary manner to S2 .A 180◦ phase shift is applied between the driving signals of S1 and S2.

SECTION-4

OPERATION OF THE PROPOSED CONVERTER

Basically there are four operation periods based on the available solar power.

Period 1:
First, the sun is in the eclipse stage and the solar irradiation is either unavailable or very low. This operation period is considered as period 1, and here the battery will serve as the main power source.

Period 2:
As the sun starts to shine and the initial solar irradiation is enough for supplying part of the load demand, the operation period is changed to period 2. The load is supplied by both solar and battery power in this period.

Period 3:
For period 3, the increasing isolation makes the solar power larger than the load demand. The battery will preserve extra solar power for backup use.

Period 4:

During period 4, the charging voltage of the battery reaches the preset level and should be limited to prevent overcharging.
According to the solar irradiation and the load demand, the proposed three-port converter can be operated under two modes.

Mode1. Battery balance mode(solar voltage control).
Mode2.Battery voltage control mode.

In mode 1, maximum power point tracking (MPPT) is always operated. The battery port will maintain the power balance by storing the unconsumed solar power during light-load condition or providing the power deficit during heavy-load condition. The power sharing of the inputs can be represented as

P load = P pv SVC + P bat SVC

Where
Pload =load demand power,
Ppv SVC=PV power under solar voltage control (SVC), Pbat SVC=battery power under SVC.

When the battery charging voltage is higher than the maximum preset value, the converter will be switched into mode2. In mode 2, MPPT will be disabled; therefore, only part of the solar power is drawn. However, the battery voltage could be controlled to protect the battery from overcharging. The power sharing of the inputs can be represented as

Pload = Ppv BVC + Pbat BVC

Where

Ppv BVC= PV power under battery voltage control
Pbat BVC=battery charging power under SVC.

If the load is increased and the battery voltage is reduced, the converter will be switched to mode 1. The output voltage is always kept at 380 V in both modes.

SECTION-5

WORKING OF THE PROPOSED CONVERTER

Here we are considering a single cycle of the key wave form to explain the working of the proposed three port converter.

KEY WAVE FORMS OF THE PROPOSED CONVERTER

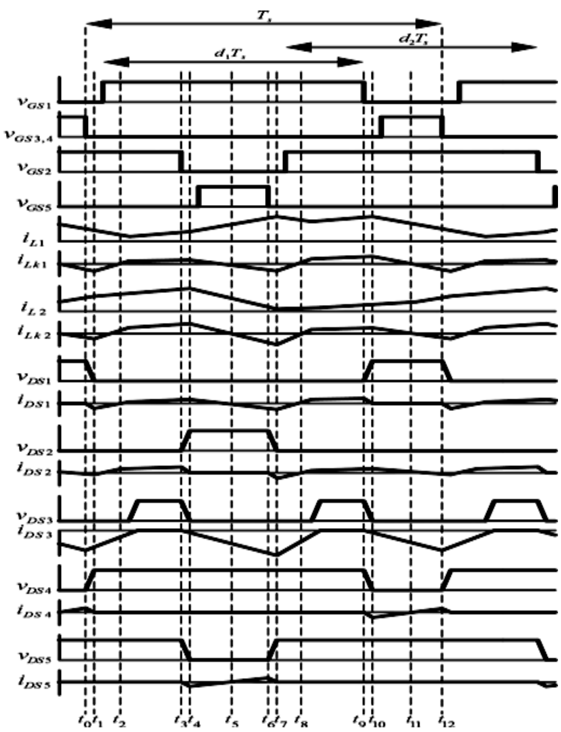
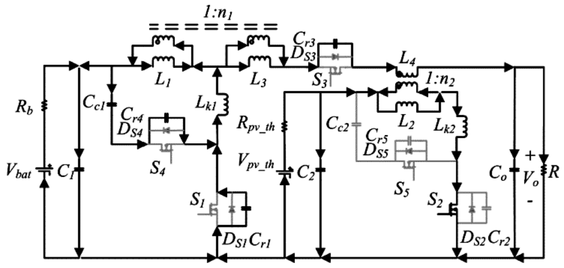


Fig3. Key wave forms of the proposed converter.

The key wave form is divided in to twelve intervals for better understanding, and the working of the converter for twelve intervals is as follows.

Here the circuit is mentioned for first interval operation only and the remaining circuits will resemble same as interval one with changes like switches ON and OFF according to the description of each interval,

1. t0≤ t < t1:



At t0, S1,S4 and S5 are turned OFF, while switch S2 is turned ON. Although S1 is in the off state, resonant inductor Lk1 resonates with Cr1 and Cr4. In this period, Cr1 is discharged to zero and Cr4 is charged to Vbat + VCc1.For the PV port,S2 is turned ON and the current from the PV panels flows through Vpv-th− L2 − Lk2 − S2 loop. In order to achieve the ZVS feature for S1,the energy stored in resonant inductor Lk1 should satisfy the following inequality:

$$L_{k1} \geq \frac{(C_{r1} \parallel C_{r4})[v_{\mathrm{DS1}}(t_0)]^2}{[i_{\mathrm{Lk1}}(t_0)]^2}. \quad (1)$$

2. t1≤ t < t2:

This mode starts when vds1 is down to zero. The body diode of S1 is forward biased so that the ZVS condition for S1 is established. The resonant current iLk1 is increased toward zero. L2 is still linearly charged in this period.

3. t2≤ t < t3:

S1 begins to conduct current at t2 and the battery port current follows the path Vbat−L1−Lk1−S1. S2 is also turnedONin this interval. Therefore, both L1 and L2 are linearly charged and energy of both input ports is stored

in these magnetizing inductors. Auxiliary switches S3, S4, and S5 are all turned OFF.

4.t3≤t<t4:

In this interval, S2 starts to be turned OFF and the auxiliary switch S5 remains in the OFF state. However, a resonant circuit formed by Lk2, Cr2,and Cr5 releases the energy stored in Lk2. Resonant capacitor Cr2 is quickly charged to Vpvth + VCc2, while Cr5 is discharged to zero. In order to achieve the ZVS feature for S5, the energy stored in resonant inductor Lk2 should satisfy the following inequality:

$$L_{k2} \geq \frac{(C_{r2} \parallel C_{r5})[v_{\mathrm{DS5}}(t_3)]^2}{[i_{\mathrm{Lk2}}(t_3)]^2}. \quad (2)$$

5.t4≤ t < t5:

At t4, vDS5 reaches zero and the body diode across the auxiliary switch S5 is turned ON. Therefore, a ZVS condition for S5 is established. Given that the Cr5 is much smaller than Cc2, almost all the magnetizing currents are recycled to charge the clamp capacitor Cc2.Furthermore, VCc2 is considered as a constant value since the capacitance of Cc2 is large enough. This interval ends when inductor current iLk2 drops to zero.

6.t5≤ t < t6:

At t5, the current of Lk2 is reversed in direction and energy stored in t5 is released through the Cc2−S5−Lk2−L3 loop. This interval ends when S5 is turned OFF.

7.t6≤ t < t7:

Switches S2 and S5 are both in the OFF state at t6. A resonant circuit is formed byLk2, Cr2, and Cr5. During this interval, Cr2 is discharged tozero and Cr5 is charged to Vpvth + VCc2. To ensure the ZVSswitching of S2, the energy stored in Lk2 should be greater thanthe energy stored in parasitic capacitors Cr2 and Cr5.

$$L_{k2} \geq \frac{(C_{r2} \parallel C_{r5})[v_{\mathrm{DS2}}(t_6)]^2}{[i_{\mathrm{Lk2}}(t_6)]^2}. \qquad (3)$$

8.**t7 ≤t<t8:**

This interval starts when the voltage across Cr2 is zero and the body diode DS2 is turned ON. Leakage inductor current iLk2 is linearly increased and the secondary-side current of the coupled inductor is increased as well. The main switch S2 should be turned ON before iLk2 becomes positive to ensure ZVS operation.

9.t8≤ t < t9]

The circuit operation of interval 9 is identical to interval 3 since S1 and S2 are turned ON in both intervals.

10.t9≤ t < t10:

At t9, S1 is turned OFF, while S3 and S4 remain in OFF state. During this interval, Lk1 will resonant with Cr1 and Cr4 to release the energy trapped in it. Resonant capacitor Cr1 is charged to Vbat + VCc1, while Cr4 is discharged to zero. To achieve the ZVS feature for S4, the energy stored in resonant inductor Lk2 should satisfy the following inequality:

$$L_{k1} \geq \frac{(C_{r1} \parallel C_{r4})[v_{\mathrm{DS4}}(t_9)]^2}{[i_{\mathrm{Lk1}}(t_9)]^2}. \qquad (2)$$

11.t10≤ t < t11:

This interval begins when vDS4 drops to zero and the body diode across S4 is turned ON. The ZVS condition for S4 is then established. Almost all the magnetizing current is recycled to charge Cc1 since Cr4 is much smaller than Cc1 . Moreover, VCc1 is considered as a constant value since the capacitance of Cc1 is large enough. This interval ends when inductor current iLk1 reaches zero.

12.t11≤ t < t12:

The current flow through Lk1 is reversed in direction at t11, and the energy stored in Cc1 is released through the Cc1−S4−Lk1−L1 loop. This interval ends when S4 is turned OFF and the operation of the proposed converter over a switching cycle is complete.

SECTION-8

SIMULATION RESULTS OF THE IMPLEMENTED CIRCUIT

Here we are simulating the proposed Converter using Mat lab SimuLinksoftware. The results for different irradiation levels and load change have been verified throughsimulation diagram and the wave forms of the results are presented below.

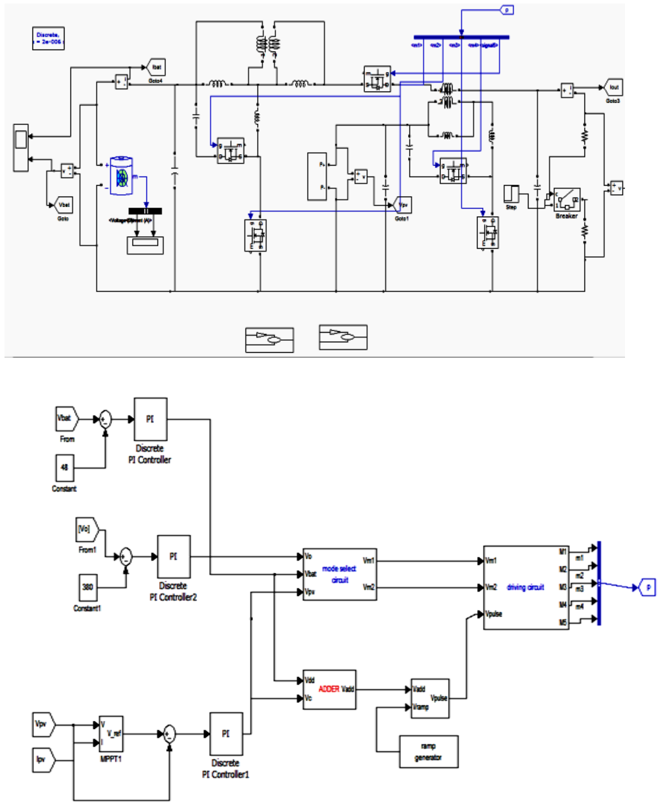


Fig 4. Simulation diagram of the proposed three port dc to dc converter.

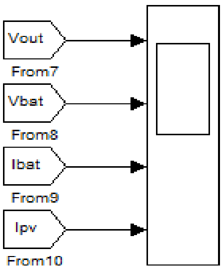


Fig 4.a. Scope connected to verify the out put results.

SIMULATION RESULTS FOR IRRADIATION LEVEL 200

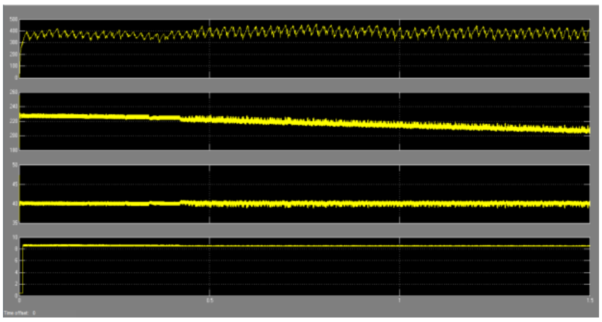


Fig 4.b.Output Voltage (V out), Battery Voltage (V bat), Battery Current (I bat) and PV Current (I pv).

SIMULATION RESULTS FOR IRRADIATION LEVEL 600

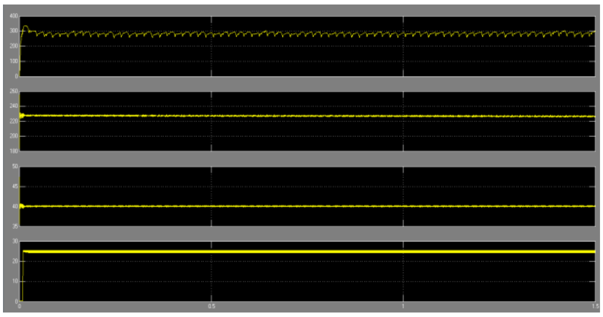


Fig 4.c.Output Voltage (V out), Battery Voltage (V bat), Battery Current (I bat) and PV Current (I pv).

SIMULATION RESULTS FOR IRRADIATION LEVEL 800

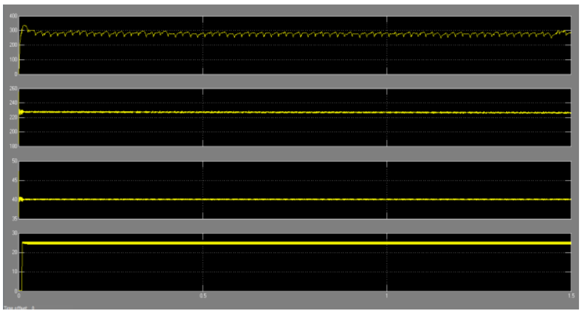


Fig 4.d.Output Voltage (V out), Battery Voltage (V bat), Battery Current (I bat) and PV Current (I pv).

SIMULATION RESULTS FOR A LOAD CHANGE

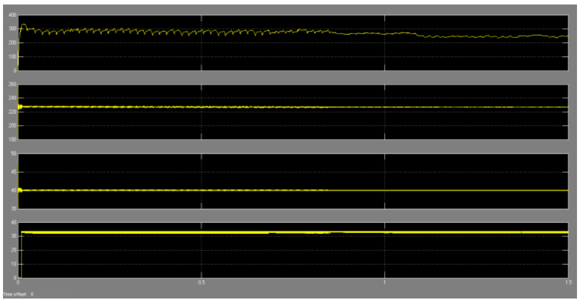


Fig 4.e.Output Voltage (V out), Battery Voltage (V bat), Battery Current (I bat) and PV Current (I pv).

CONCLUSION

An integrated high step up multi portdc to dc converter is implemented in this paper. Here a high step-up three port dc to dc converter consisting of PV and battery is implemented through simulation and the results have been checked for different irradiation levels and load changes.In the proposed topology, two coupled inductors are employed as voltage gain extension cells for high voltage output applications. Two sets of buck–boost type active-clamp circuits are used to recycle the energy stored in the leakage inductors and improve the efficiency. The proposed switching strategy only needs to control two duty ratios in different operation modes. The charging/discharging transitions of the battery could be achieved without changing the operation mode; therefore, the MPPT operation will not be interrupted.

References:

[1] A High Step-Up Three-Port DC–DC Converter for Stand-Alone PV/Battery Power Systems
Yen-Mo Chen, Student Member, IEEE, Alex Q. Huang, Fellow, IEEE, and Xunwei Yu, Student Member, IEEE
[2] S. H. Choung and A. Kwasinski, “Multiple-input DC-DC converter topologies comparison,” in Proc. 34th Annu. Conf. IEEE Ind. Electron., 2008, pp. 2359–2364.
[3] A.Huang, “FREEDM system—a vision for the future grid,” in Proc. IEEE Power Energy Soc. Gen. Meet., 2010, pp. 1–4.
[4] W. Li and X. He, “Review of non isolated high-step-up DC/DC converters in photovoltaic grid-connected applications,” IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1239–1250, Apr. 2011.
[5] T.-F. Wu Y.-S. Lai, J.-C.Hung, and Y-M Chen, “Boost converter with coupled inductors and buck–boost type of active clamp,” IEEE Trans. Ind.Electron., vol. 55, no. 1, pp. 154–162, Jan. 2008.
[6] W.G.Imes and F. D. Rodriguez, “A two-input tri-state converter for spacecraft power conditioning,” in Proc. AIAA Int. Energy Convers. Eng. Conf., 1994, pp. 163–168.
[7] F. D. Rodriguez and W. G. Imes, “Analysis and modeling of a two input DC/DC converter with two controlled variables and four switched networks,” in Proc. AIAA Int. Energy Conf., 1994, pp. 163–168.

T.HARI BABUhas received theB.Tech degree in EEE from Vemu Institute of Technology, P. Kothakota affiliated to JNTUA in the year of 2012. Present he is pursuing M.tech in Power Electronics in KuppamEngineering College, Kuppamaffiliated to JNTUA.

Y.DAMODHARAM has obtained hisB.Tech in EEE from Kuppam Engineering College affiliated to JNTUH in the year 2006. He completed M.tech in Power System emphasis on High Voltage Engineering from JNTU Kakinada in the year 2010. Currently working as Associate Professor in Kuppam Engineering College in the Department of EEE. His area of research is Renewable Energy Sources, High Voltage Engineering, and Power Systems Technology.

CH.JAYAVARDHANARAO has obtained his B.Tech Electrical Engineering from JNTUH, Hyderabad in the year 2002, and M.tech in power system emphasis on High voltage engineering from JNTUK, Kakinada in the year 2009. He has 5 years of industrial experience, 2experience and 5 years of teaching experience. Currently working as Associate Professor in Department of Electrical Engineering in Kuppam Engineering College Kuppam, Chittoor District, Andhra Pradesh, INDIA his area of research includes power systems, power electronics, high voltage engineering, renewable energy sources, industrial drives, HVDC & FACTS Technology.

VELAPPAGARI SEKHAR has obtained his B.Tech in Siddhartha Institute of Engineering and Technology, Puttur in the year 2008. He completed M.E in Power System Engineering from Velammal Engineering College, Chennai in the year 2010.since 2012. He is a member in LMISTE, LMSESI and in 2014, he got membership in AMIE. He is currently working as Assistant professor in Kuppam Engineering College with towards working as PhD at VIT,Vellore.His research includes the areas of interest in power system stability analysis & protection.