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RESEARCH ARTICLE OPEN ACCESS

Soft-Switched Non-Isolated High Step-Up 3 Port Dc-Dc Converter for Hybrid Energy Systems

Karika Amulya, Navya Ananthula, M. Komali, B. Divya Sai, N. Sai Charan
Department of ECE, Vignan Institute of Technology and Science
Deshmukhi, Telangana.

Abstract:
A non-isolated high step-up three-port converter is proposed which provides two separate power flow paths from each input sources to the output load. In order to reduce the number of converter components, some components play multiple roles. Accordingly, the energy storage device is charged with the same components which are used in transferring power to the load. In this converter, coupled inductors technique is used to increase the voltage gain, and to mitigate the leakage inductance effect and to provide soft switching condition; two active clamp circuits are employed. Since the voltages across the switches are clamped, switches with low voltage stresses and consequently low conduction loss can be used. Various converter operating modes are discussed and design considerations are presented. A converter prototype to supply a 400v load is implemented and theoretical analysis validated by the experimental results.

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I. INTRODUCTION

Diversity in energy generation sources and simultaneous use of several energy sources in one system have made hybrid energy systems more attractive. Hybrid energy systems take advantage of different features of diverse energy sources in power electronic applications, such as increment in integration, reliability, durability, power handling capability and efficiency in comparison to single energy source systems. Hence the use of multiple energy generation sources with different *I-V* characteristics and converting the yielded energy into a regulated voltage to meet the load demand in the hybrid energy systems has led to appearance of the multi-input DC-DC converters [1, 2]. In such hybrid energy systems which use several energy sources, instead of using multiple single DC-DC converters to transfer power from each input source to the output load, a multi-input converter can be used. By integrating several converters in a multi-input converter the cost, size and complexity of the system can be reduced [1]. Another advantage of multi-input converters is using energy storage devices as the input source. In most hybrid energy systems, the existence of the energy storage system (ESS) is mandatory. Therefore, a category of the multi-input has been introduced which include an energy generation source and an energy storage device that provides a power flow path to send/receive energy to/from this energy storage device.

II. METHODOLOGY

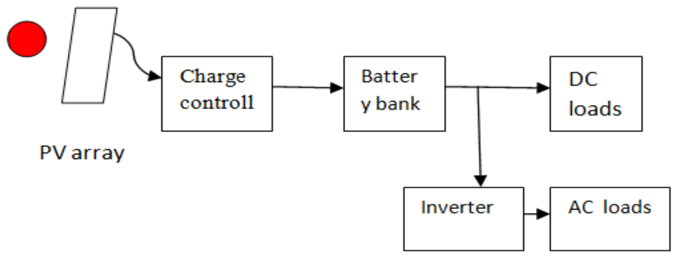
Ultra-capacitor and battery as an Energy Storage Systems and Fuel cell and renewable energy sources as the energy generation sources are among the sources that are widely used in hybrid energy system applications. Thus, the features of these sources must beconsideredintheconverterdesignconsiderations.Sincemostoftheseenergysourcesare inherently low voltage, so high step-up techniques are required to increase the voltage gain. To increase the voltage gain, many methods have been proposed [3] such as, coupled inductors, isolated transformers, series capacitors in the power flow path and switched-diode-capacitor structures. By using these methods, the problems associated with the extreme operating duty cycles in the conventional boost converter can be solved and the converter performance is enhanced. Recently, based on different applications, several isolated [4-9] and non-isolated [10-13] topologies on multi-input converters are proposed. The existence of transformers along with additional peripheral circuitry increases the volume, cost and design complexity of isolated converters. Thus, in some applications in which isolation is not required, non-isolated converters are more appropriate. In recent years, the use of non-isolated high step-up multi-input DC-DC converters in different applications has been increasing and some related issues from different aspects have been addressed in literature [14-16]. Some important ones are described as follows: reducing the number of components, flexibility to extend the number of input sources, providing power flow paths for ESS, increasing voltage gain and employing soft switching methods to enhance efficiency.

III. SYSTEM DESIGN

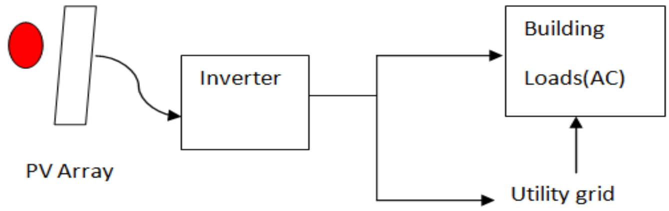
There are two main system configurations – stand-alone and grid-connected. As its name implies, the stand-alone PV system operates independently of any other power supply and it usually supplies electricity to a dedicated load or loads.It may include a storage facility (e.g.battery bank) to allow electricity to be provided during the night or at times of poor sunlight levels. Stand-alone systems are also often referred to as autonomous systems since their operation is independent of other power sources. By contrast, the grid-connected PV system operates in parallel with the conventional electricity distribution system. It can be used to feed electricity into the grid distribution system or to power loads which can alsobe fed from thegrid.

It is also possible to add one or more alternative power supplies (e.g. diesel generator, wind turbine) to the system to meet some of the load requirements. These systems are then known as 'hybrid'systems.

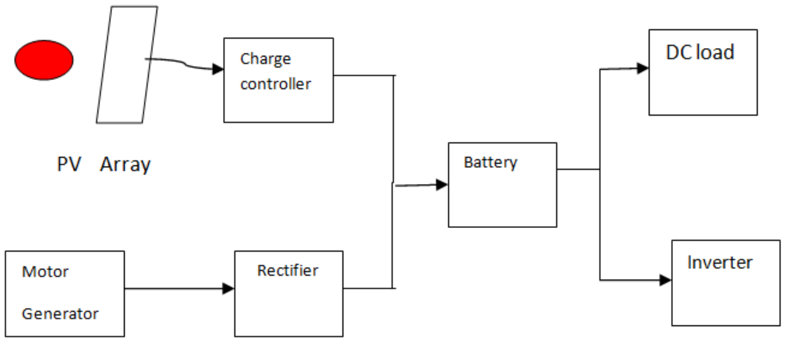
Hybrid systems can be used in both stand-alone and grid-connected applications but are more common in the former because, provided the power supplies have been chosen to be complementary, they allow reduction of the storage requirement without increased loss of load probability. Figures below illustrate the schematic diagrams of the three main system types.



Stand alone photovoltaic system



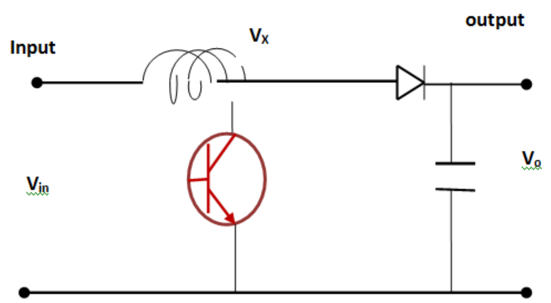
grid connected photovoltaic system



Hybrid system incorporating a photovoltaic array and a motor generator

DC-DC CONVERTER

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically, the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc. This is a summary of some of the popular DC-to-DC converter topologies.



Boost Converter Circuit

BOOST CONVERTER STEP-UP CONVERTER

The schematic in Fig shows the basic boost converter. This circuit is used when a higher output voltage than input is required.

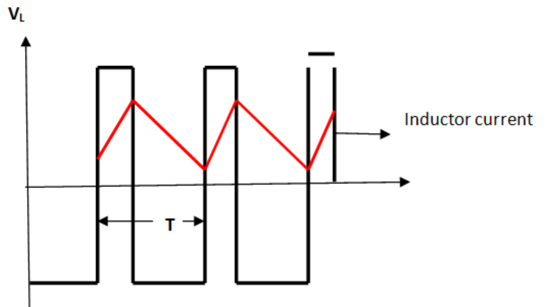
While the transistor is ON $V_x = V_{in}$,and the OFF state the inductor current flows through the diode giving $V_X = V_O$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor is shown in Fig and the average must be zero for the average current to remain in steady state

$$V_{in}t_{on}+(V_{in}-V_O)t_{off} = 0 \;....(1)$$

This can be rearr

And for a lossles $\frac{V_O}{V_{in}} = \frac{T}{t_{off}} = \frac{1}{(1-D)}$ ....(2)

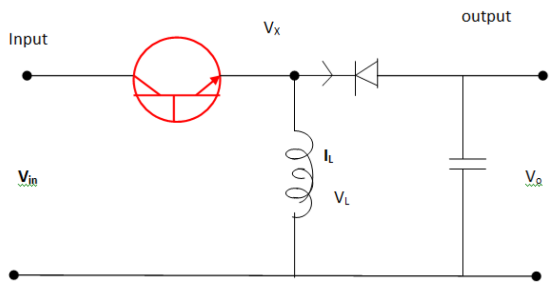
$$\frac{I_O}{I_{in}} = (1-D) \;.........(3)$$



Voltage & Current waveform

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the outputvoltage.

BUCK – BOOST CONVERTER



Schematic of Buck Boost Converter

WithcontinuousconductionfortheBuck-BoostconverterVx=VinwhenthetransistorisON andVx=VowhenthetransistorisOFF.Forzeronetcurrentchangeoveraperiodtheaverage voltage across the inductor iszero.

$$V_{in}t_{ON} + V_O t_{OFF} \;= 0 \;....(4)$$

This gives the voltage ratio

$$\frac{V_o}{V_{in}} = - \frac{D}{(1-D)} \quad ......(5)$$

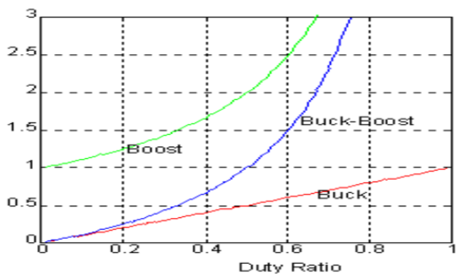
And the corresponding current

$$\frac{I_o}{I_{in}} = -\frac{(1-D)}{D} \quad .... (6)$$

Since the duty ratio "D" is between 0 and 1 the output voltage can vary between lower or higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

CONVERTER COMPARISON

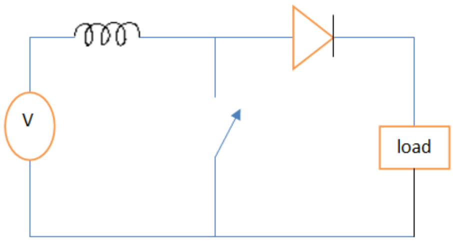
The voltage ratios achievable by the DC-DC converters are summarized in Fig. 7 Notice that only the buck converter shows a linear relationship between the control (duty ratio) and output voltage. The buck-boost can reduce or increase the voltage ratio with unit gain for a duty ratio50%.



Duty cycle Graph

BOOSTCONVERTER

A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply(SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.



Operating mode

Power can also come from DC sources such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it “steps up” the source voltage. Since power (P = VI) must be conserved, the output current is lower than the sourcecurrent.

A boost converter may also be referred to as a 'Joule thief'. This term is usually used only with very low power battery applications, and is aimed at the ability of a boost converter to 'steal' the remaining energy in a battery. This energy would otherwise be wasted since a normal load wouldn't be able to handle the battery's lowvoltage.

This energy would otherwise remain untapped because in most low-frequency applications, currents will not flow through a load without a significant difference of potential between the two poles of the source (voltage).

THREE PORT DC-DCCONVERTER

Hybrid energy systems take advantage of different features of diverse energy sources in power electronic applications, such as increment in integration, reliability, durability, power handling capability and efficiency in comparison to single energy source systems. Hence the use of multiple energy generation sources with different *I-V* characteristics and converting the yielded energy into a regulated voltage to meet the load demand in the hybrid energy systems has led to appearance of the multi-input DC-DC converters. In such hybrid energy systems which use several energy sources, instead of using multiple single DC-DC converters to transfer power from each input source to the output load, a multi-input converter can be used. By integrating several converters in a multi-input converter the cost, size and complexity of the system can be reduced. Another advantage of multi-input converters is using energy storage devices as the input source. In most hybrid energy systems, the existence of the energy storage system (ESS) is mandatory. Therefore, a category of the multi-input converters has been introduced which include an energy generation source and an energy storage device that provides a power flow path to send/receive energy to/from this energy storage device. Ultra-capacitor and battery as an ESSandFuelcellandrenewableenergysourcesastheenergygenerationsourcesareamong the sources that are widely used in hybrid energy system applications. Thus, the features of these sources must be considered in the converter designconsiderations.

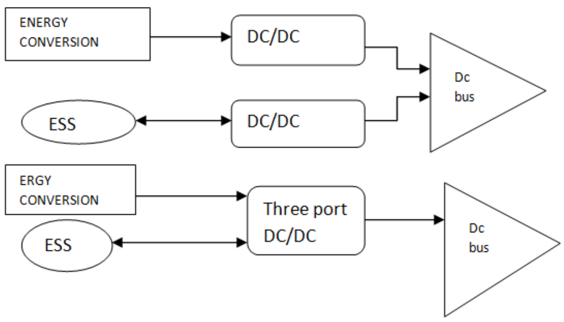


Fig Using typical multiple single DC-DC converters. And three-port DC-DC converter

ENERGY STORAGE

Photovoltaic cells are used to convert solar energy into electrical energy. Solar energy is only available during day time and its intensity is an effected by environmental condition such as cloudy weather etc. To overcome this issue, storage element is used to store solar energy whenever it is available in excess amount. Stored energy is utilized when solarpowerisnotsufficienttosupplyloaddemand.Batteryismostcommonlyusedstorage element as they store energy through an electrochemical process and thus have quick response in both charging and discharging processes. Also batteries have high power and energy density compared to other storage device like ultra-capacitors, compressed air systems, etc. The BSS can provide flexible energy management solutions, which improves the power quality of the PV power generation system.

BATTERYMODELING

Modeling of Battery has very important role for simulation of the standalone PV system where it is used to maintain power balance between generation and demand. Generally battery can be modeled in three ways, such as experimental model, electrochemical model and equivalent circuit model. But for dynamic simulation equivalent circuit model is most suitable, which assumes that the battery is composed of a controlled- voltage source in combination with a series.

Resistance as shown in Figure. In this work a generic battery model of lead-acid. Battery is used as it is more convenient for renewable systems because of its low cost and availability in large size. By using the charging and discharging equation the lead-acid batteryismodeledandthismodeliswellacceptedforuseinsimulationofrenewablesources like PV system and also can be used in electric vehicle applications. From the above equivalent circuit we can write;

$V_{bat} = E - R_b * i$,where

For discharging: $E = E_0 - K\frac{Q}{Q-it}(it) - K\frac{Q}{Q-it}(i^*) + Exp(t)$

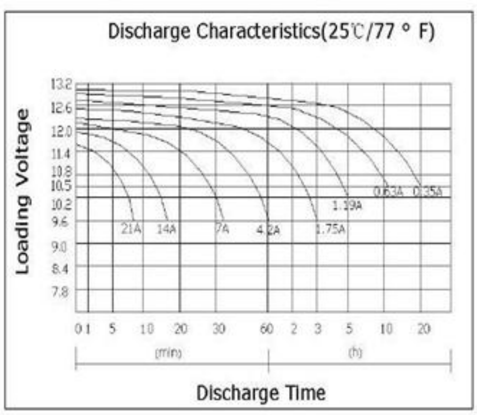
For charging: $E = E_0 - K\frac{Q}{Q-it}(it) - K\frac{Q}{it-0.1.Q}(i^*) + Exp(t)$

Where, V_{bat} is the actual battery voltage, E is the controlled voltage (V), iis the charging or discharging current of battery (*A*), Rb is the internal resistance of the battery (W), E0 is the constant open circuit potential (V), i is the filtered battery current (A) and actual battery charge, K is the polarization constant (V=Ah), Q is the battery capacity (Ah), Aistheexponentialzoneamplitude(V),andBistheexponentialzonetimeconstantinverse (Ah)^1. This exponential zone can be represented by a non-linear dynamicequation.

$$Exp(t) = B.|i(t)|.(-\exp(t) + A.u(t))$$

HYBRID ENERGY SYSTEMS

The increasing deployment of intermittent renewable energy sources (RESs) around the world has revealed concerns about the power grid stability. To solve this problem, a massive use of storage systems is needed. The main goal of this work is to develop ahybrid energy storage system (HESS) combining several storage devices with complementary performances. In this paper, lead-acid batteries and super capacitors (SCs) are associated in order to deliver a pulsed current. An innovative cascade control with anti-windup tracking manages the power sharing between a buck and a boost converter connected to the same DC bus. Analog control circuits and power converters have been designed to evaluate the performances of the HESS in realconditions.



Development of diversified energy sources is a world challenge in the struggle against pollution and energy costs reduction. Renewable energy sources (RESs) are more and more associated with Energy Storage Systems (ESSs) to mitigate their high variability and unpredictable nature. More reliable distributed sources of energy are obtained thanksto ESSs. Pumped hydro storage (PHS), Compressed Air Energy Storage (CAES), fuel cells, flywheels, batteries, super capacitors (SCs) can be used to balance intermittent energy sources with different time scales, specific energy and power densities, costs. All these characteristics enable to optimize the ESS design, in terms of reliability and costs, for any application.

HESS associating two storage elements that create a DC bus on which is connected a DC load. The HESS is delivering a periodic pulsed current to the load. Such systems could be part of a Micro grid (MG) as illustrated in Fig. In this example, a photovoltaic source is connected to storage devices through different power static stages to supply AC or DC loads. MG is said to be on "connected mode" when it has a connection with a main distribution grid and "islanded mode" if not.

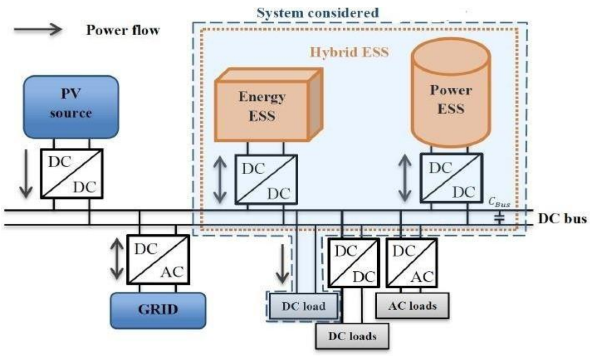


Fig Example for Micro grid with Hybrid Energy sources

CIRCUIT EXPLANATION Circuit Diagram:

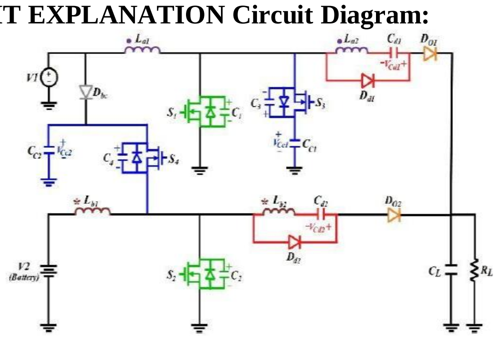
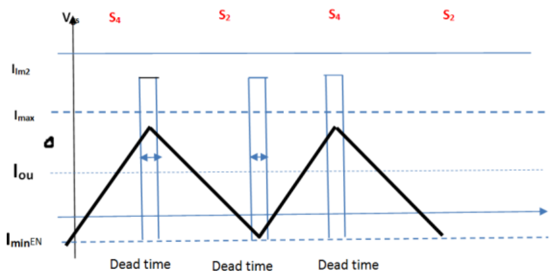


Fig Circuit Diagram

The proposed converter structure is based on two distinct phases for each input. Since three-port converters have three operating modes including; transferring power from each input to the output independently, transferring power from both inputs to the output at the same time, and transferring power from the power generation source to the output and also charging the ESS simultaneously. So, by using two distinct phases, the received energy from each source can be controlled appropriately. In the proposed converter, to increase the voltage gain two voltage extension cells based on coupled inductors are employed and to eliminate the associated leakage inductance effect, two active clamp circuits are used. Another contribution of the proposed converter is sharing the converter components in various operating modes for different purposes to reduce the number of components. The proposed converter operation depends on charging/discharging states of the ESS. In ESS discharging mode, the Dbc diode is always OFF and both phases can operate independently from each other and transfer the energy from inputs to the output. In this mode, S1 and S2 switches act as the main switches of the converter (for each phase)and to recover the leakage inductances energy and also to provide soft switching condition two active clamp circuits which include S3 and CC1 components in the upper phase and S4 and CC2 components in the lower phase are considered. The Cd1, La2 and Dd1 elements in the upper phase and the Cd2, Lb2 and Dd2 elements in the lower phase are used for boosting the voltage gain. The La1-La2 and Lb1-Lb2 are the coupled inductors and C1, C2, C3 and C4 are snubber capacitors. In ESS charging, mode the operation of the upper phase is same as its operation in ESS discharging mode, but by changing the task of the components in lower phase, the ESS is charged by the buck converter composed of S4 as the main switch and S2 as the synchronous rectifier and also the magnetizing inductance of the Lb1-Lb2 coupled inductors acts as the inductor of the buck converter. In this mode, the cathode of Do2 is connectedtotheoutputhighvoltageside,thusitisalways OFF.Also,attheconverterstart- up moment, Cd2 is charged and remains at full charge, thus, it can be assumed that the Dd2 is always OFF and the current through Lb2 is zero. According to the load power demand, generating power from V1 and the charge state of the ESS, the charging/discharging operating modes.



Gating signals and inductor current waveform under buck mode operation

ANALYSIS OF THE PROPOSED CONVERTER

In this section, the analysis of the proposed converter is investigated and the voltage gain, semiconductor devices voltage and current stresses, converter design approach and soft switching conditions are discussed. To simplify the analysis, it is assumed that the voltages across Cd and CC are constant, all circuit elements are ideal and the converter operates at steady statecondition.

a.ESS Discharging Mode DesignConsiderations

Since in ESS discharging mode, the upper and lower phases have similar functionality. The parameter index names which are referred in the following change for each phase.

Static Voltage Gain

At steady state condition, in a switching period each phase operates in two main states namely the ON or OFF states of the main switch.When the main switch of each phase is ON, the LM and Cd charge through Vin:

$$\frac{V_{out}}{V_{in}} = \frac{1+n}{1-D}$$

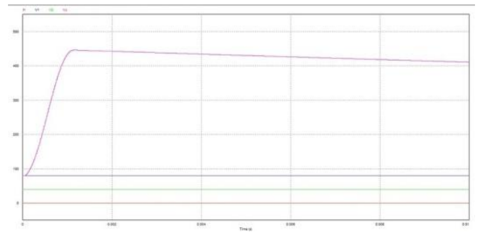
The voltage gain versus the duty cycle for various turns ratio. As illustrated, the converter has a high voltage gain which it is suitable for utilizing in high step-up applications.Due to the use of clamp circuit structure in the proposed converter, the voltage stress of the main and clamp switches in OFF state is equal to the clamp capacitors voltage. The highest current stress of the semiconductor elements in the proposed converter occurs when just one of the phases is transferring energy from one input source to the outputload.

IV. RESULTS

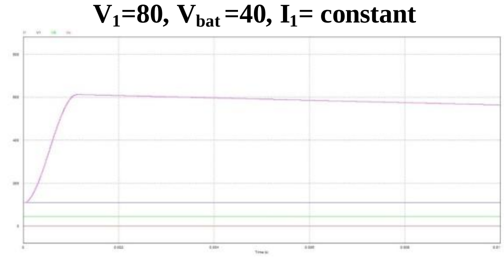
Hybrid Energy systems with different I-V characteristics are converting the yielded energy into a regulated voltage to meet the load demand. Source inputs i.e., solar battery super capacitors will be fed through the buck and boost converter, which converts the voltage into required measurements. The different sources are operated with toggle switch, the voltage that flows through the boost converter resultswith increase in voltage at the output. The variations in input and output are observed in PSIM software simulation.

(Note: V_1 voltage from main power supply, Vbat is the voltage from hybrid energy system, I_1 has maintained constant)

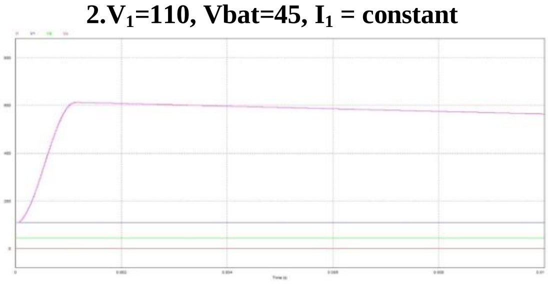
SOFTWARE RESULTS



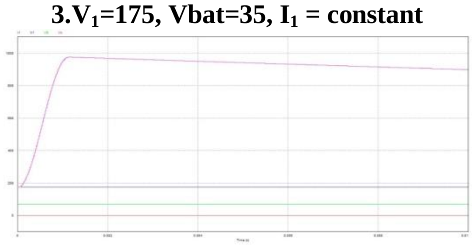
V_1=80, V_{bat}=40, I_1= constant



2.V_1=110, Vbat=45, I_1 = constant



3.V_1=175, Vbat=35, I_1 = constant



4.V_1=175, Vbat=35, I_1 = constant

HARDWARERESULT

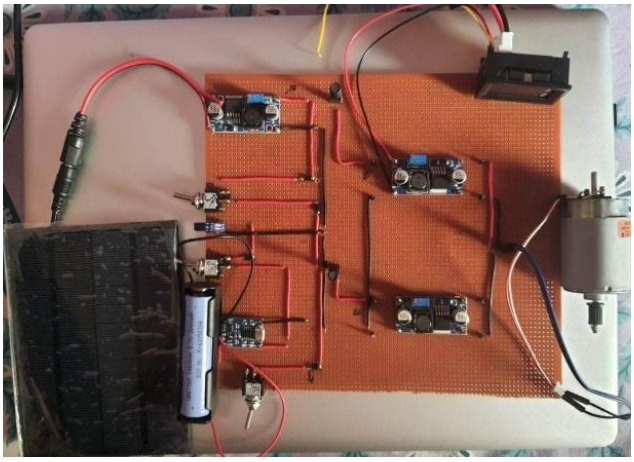


Fig . Hardware implemented circuit

Table HARDWARE OUTPUT

INPUT	Switch (1)	Switch (2)	Switch (3)	OUTPUT
Up to 5v	1	0	0	12v
Up to 5v	0	1	0	12v
Up to 5v	0	0	1	12v
Up to 5v	0	0	1	43v

Note: In case of switch (3) we also get an high sudden voltage because of an inductor discharge.

V. CONCLUSION:

A three-port converter for hybrid applications is proposed in this paper which has an input for power generation sources like fuel cell and renewable energy sources and has a port for energy storage devices like battery and ultra-capacitor. In this converter each input source has unique power flow path to supply the output load and also the energy storage device can be charged directly from power generation source regardless of the status of the load power. The number of converter components are reduced by sharing the converter components according to the operating modes. So, no extra components are used for providing power flow path to charge storage device. Also, the proposed topology has ability to apply to the other high step-up converters which consist of coupled inductor and active clamp structures and converts them to the multi-input converter. These features are achieved while providing soft switching condition and eliminating the leakage inductance effect. In addition, the proposed converter achieves high efficiency over a wide load range.

Future scope: Three-port converter based on the boost converter is introduced in which the boost inductor is shared between the input sources in order to reduce the volume of the converter. Also, the voltage gain is increased by using the coupled inductors along with series capacitors. And through a passive clamp circuit, the leakage inductance energy is recovered and used to further enhance the voltage gain. In this converter by using diode-switch structure, the number of inputs can be increased. In these kinds of converters, always a semiconductor element is placed in series with the input sources and in the power flow path, thus, in high step-up applications in which the current in the input side is very high, conduction losses are increased considerably. Also, a power balance management between two inputs must be established to harvest energy. Receiving energy from all inputs through a shared path, there is duty cycle limitation for input switch and the boost switch. On the other hand, in this converter soft-switching condition is not provided

REFERENCES

[1]. Z. Rehman, I. Al-Bahadly, and S. Mukhopadhyay, "Multi input DC–DC converters in renewable energy applications–An overview," Renewable and Sustainable Energy Reviews, vol. 41, pp. 521-539, 2015.

[2]. P. A. Harsha Vardhini, M. H. Vishnu Sai and B. Matta, "Human Footstep Power Harvesting Systems using Piezoelectric

Sensor Technology," 2022 International Mobile and Embedded Technology Conference (MECON), 2022, pp. 450-454, doi: 10.1109/MECON53876.2022.9752131.

[3]. N. Zhang, D. Sutanto, and K. M. Muttaqi, "A review of topologies of three-port DC– DC converters for the integration of renewable energy and energy storage system," Renewable and Sustainable Energy Reviews, vol. 56, pp. 388-401, 2016.

[4]. P. A. H. Vardhini, R. Pavan Kumar, T. Singh, H. V. R. Puliyala and S. Chamarthy, "Efficient IoT based Smart Home Assistance System with Electrical Control Unit," 2022 International Mobile and Embedded Technology Conference (MECON), 2022, pp. 475-479, doi: 10.1109/MECON53876.2022.9752276.

[5]. Vardhini, P. H., & Hanku, V. Energy Efficient Implementation of IoT based Home Irrigation System Using Raspberry Pi. In 1st International Conference on Advanced Technologies in Engineering Management & Sciences" (pp. 218-223).

[6]. Vardhini, P. H. (2017). Efficient Irrigation System powered by Solar Panel Setup with Tracking Mechanism. International Journal of Emerging Technologies and Innovative Research, 4(3), 238-241.

[7]. M. Forouzesh, Y. P. Siwakoti, S. A. Gorji, F. Blaabjerg, and B. Lehman, " Step-Up DC–DC Converters: A Comprehensive Review of Voltage-Boosting Techniques, Topologies, and Applications," IEEE Transactions on Power Electronics, vol. 32, pp. 9143- 9178, 2017.

[8]. H. Wu, J. Zhang, X. Qin, T. Mu, and Y. Xing, "Secondary-side-regulated soft-switching full-bridge three-port converter based on bridgeless boost rectifier and bidirectional converter for multiple energy interface," IEEE Transactions on Power Electronics, vol. 31, pp. 4847-4860, 2016.

[9]. J. Zhang, H. Wu, X. Qin, and Y. Xing, "PWM plus secondary-side phase-shift controlled soft-switching full-bridge three-port converter for renewable power systems," IEEE Transactions on Industrial Electronics, vol. 62, pp. 7061-7072, 2015.

[10]. X. Sun, Y. Shen, W. Li, and H. Wu, "A PWM and PFM Hybrid Modulated Three-Port Converter for a Standalone PV/Battery Power System," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 3, pp. 984-1000, 2015.

[11]. P. A. Harsha Vardhini and G. Janardhana Raju, "Design of Internet of Things Based Smart and Efficient Water Distribution System for Urban and Agriculture Areas", Journal of Computational and Theoretical Nanoscience, vol. 17, no. 9–10, pp. 4688-4691, September/October 2020.

[12]. S. Khosrogorji, M. Ahmadian, H. Torkaman, and S. Soori, "Multi-input DC/DC converters in connection with distributed generation units–A review," Renewable and Sustainable Energy Reviews, vol. 66, pp. 360-379, 2016.

[13]. Ankaiah, B., Oommen, S., Harsha Vardhini, P.A. (2022). Microgrid Architecture with Hybrid Storage Elements and Its Control Strategies. In: Marriwala, N., Tripathi, C., Jain, S., Kumar, D. (eds) Mobile Radio Communications and 5G Networks. Lecture Notes in Networks and Systems, vol 339. Springer, Singapore. https://doi.org/10.1007/978-981-16-7018-3_49

[14]. H. Zhu, D. Zhang, B. Zhang, and Z. Zhou, "A nonisolated three-Port DC–DC converter and three-domain control method for PV-battery power systems," IEEE Transactions on Industrial Electronics, vol. 62, pp. 4937-4947, 2015.

[15]. A Sai Krishna, P. Alekya, M. Satya Anuradha, P. A. Harsha Vardhini and S.R Pankaj Kumar, "Design & Development of Embedded Application Software for Interface Processing Unit (IPU)", International Journal of Research in Engineering and Technology (IJRET), vol. 3, no. 9, pp. 212-216, Sept. 2014.

[16]. E. Babaei and O. Abbasi, "Structure for multi-input multi-output dc–dc boost converter," IET Power Electronics, vol. 9, pp. 9-19, 2016] Y. Zhao, W. Li, and X. He, "Single-phase improved active clamp coupled-inductor-based converter with extended voltage doubler cell," IEEE Transactions on Power Electronics, vol. 27, pp. 2869-2878, 2012.