Soft switched Non-Isolated High Step-Up Three-Port DC-DC Converter for Hybrid Energy Systems with Minimum Switches

Pravindra Kumar[1], Vijay Anand Bharti[2]

[1]M.Tech, [2]Assistant Professor

Department of EE, Mittal Institute of Technology, Bhopal, India

Abstract— The application of renewable energy such as solar photovoltaic (PV), wind and fuel cells is becoming increasingly popular because of the environmental awareness and advances in technology coupled with decreasing manufacturing cost. Power electronic converters are usually used to convert the power from the renewable sources to match the load demand and grid requirement to improve the dynamic and steady-state characteristics of these green generation systems, to provide the maximum power point tracking (MPPT) control, and to integrate the energy storage system to solve the challenge of the intermittent nature of the renewable energy and the unpredictability of the load demand. In order to improve the efficiency and the power density of the overall circuit, the use of a three-port DC-DC converter, which includes a DC input port for the renewable source, a bidirectional.This paper proposes a non-isolated high step-up multi-input DC-DC converter for utilizing in hybrid applications. This converter provides the interfaces between input power sources, energy storage devices and load. The resonant auxiliary circuit used in the proposed converter provides soft switching condition for the main switches as well as charging the storage device which has caused considerable improvement in the converter efficiency.

Keywords—HESS, WS-CAES, SMES, PV, MPPT, BES, CAES.

I. INTRODUCTION

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 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. These types of converters are known as three-port converters [2] as shown in Fig.

Ultra-capacitor and battery as an ESS 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 be considered in the converter design considerations.

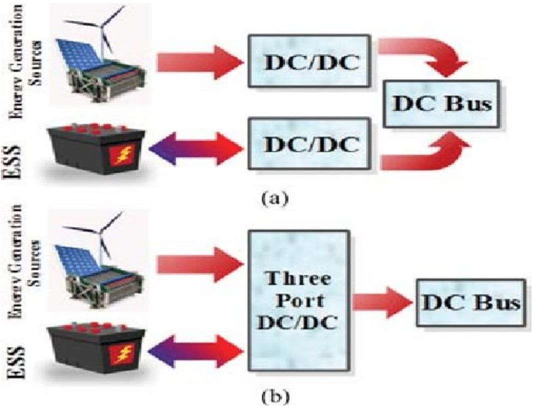


Fig.1. (a). Using typical multiple single DC-DC converters. (b) Three-port DC-DC converter configuration.

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. 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.

In [3], a 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.

In [4], another three-port converter is suggested which uses the coupled inductors with three windings to increases the voltage gain and to provide a power flow path from/to the energy storage device. In addition, the leakage inductance energy is recovered by a passive clamp circuit. In this converter, the boost converter is shared between inputs by a magnetic coupling. Also, a bidirectional path is used to charge/discharge the battery but it seems that by using the three windings coupled inductors for transferring power to/from input sources not only a complex control circuit is needed but the conduction loss is increased. Also, all switches operate under hard switching condition.

One of the factors that should be considered in design of the multi input converters is, reducing the number of the converter components and one solution to solve this challenge is, sharing the converter components. Accordingly, a new three-port DC-DC converter is proposed in this paper which has one separate phase for each input such that the task of the components is changed during each operating modes. Thus, some components are shared in different operating modes, leading to a reduced in component count.

II. LITERATURE REVIEW

Y. Zhao, W. Li, and X. He, have proposed in this paper, A single-phase improved active clamp coupled-inductor-based converter with extended voltage doubler cell is proposed for large voltage conversion ratio applications. The secondary winding of the coupled inductor is inserted into the half-wave voltage doubler cell to extend the voltage gain dramatically and decrease the switch voltage stress effectively. By combining the coupled inductor and voltage doubler cell structure, the disadvantage of the potential resonance between the leakage inductance and the diode stray capacitor is cancelled, and the unexpected high pulsed current in the voltage doubler cell is decreased due to the inherent leakage inductance of the coupled inductor. Meanwhile, the active clamp scheme is employed to recycle the leakage energy, suppress the switch turn-off voltage spikes, and implement zero-voltage-switching turn-on operation. In addition, there is only one magnetic component in the proposed converter and the coupled inductor operates not only as a filter inductor, but also as a transformer when the main switch is in the ON state, which reduces the volume of the magnetic core and improves the power density of the converter. A 500W prototype operating at 100 kHz with 48 V input and 380 V output is built to verify the analysis. The maximum efficiency of the prototype is nearly 97% and the efficiency is higher than 96% over a wide load range.

J. Zhang, J.-S. Lai, R.-Y. Kim, and W. Yu, have proposed A typical non-isolated bi-directional dc-dc converter technology is to combine a buck converter and a boost converter in a half-bridge configuration. In order to have high-power density, the converter can be designed to operate in discontinuous conducting mode (DCM) such that the passive inductor can be minimized. The DCM associated current ripple can be alleviated by multiphase interleaved operation. However DCM operation tends to increase turn-off loss because of a high peak current and its associated parasitic ringing due to the oscillation between the inductor and the device output capacitance.

Thus the efficiency is suffered with the conventional DCM operation. Although to reduce the turn-off loss, a lossless capacitor snubber can be added across the switch, the energy stored in the capacitor needs to be discharged before device is turned on in order to realize zero-voltage switching. This paper adopts a gate signal complimentary control scheme to turn on the non. active switch and divert the current into the anti-paralleled diode of the active switch so that the main switch can turn on under zero-voltage condition. Thus both soft switching turn-on and turnoff are achieved. This diverted current also eliminates the parasitic ringing in inductor current. For capacitor value selection, there is a trade-off between turn-on and turn-off losses. This paper suggests the optimization of capacitance selection through a series of hardware experiments to ensure the overall power loss minimization under complimentary DCM operating condition. A 100kW hardware prototype is constructed and tested. The experimental results are provided to verify the proposed design approach.

J.-B. Baek, W.-I. Choi, and B.-H. Cho, have proposed this paper introduces a digital adaptive control method for a bidirectional dc/dc charger/discharger, which is the core element for reliable and efficient energy storage systems. The proposed method achieves zero-voltage switching (ZVS) without the use of an auxiliary zero-crossing detection (ZCD) circuit. To satisfy ZVS conditions, proper switching frequency is determined through a digital calculation. It features soft switching over wide input and output ranges. Because this method does not require a ZCD circuit, it is easily implemented with bidirectional operation and reduces instability and noise susceptibility problems. To reduce conduction loss, a multiphase interleaving technique is applied. This interleaving method reduces the required capacitance by decreasing the current ripple. A phase shedding technique is also implemented to achieve higher efficiency over a wide load range. The operation of the proposed digital adaptive control method is analyzed. For experimental verification, a 200-W two-phase-interleaved bidirectional synchronous buck converter with 30-38-V bus voltage and 15-25-V battery voltage is implemented.

M. R. Mohammadi and H. Farzanehfard, have proposed in this paper, a new family of zerovoltage- transition (ZVT) bidirectional converters are introduced. In the proposed converters, soft-switching condition for all semiconductor elements is provided regardless of the power flow direction and without any extra voltage and current stress on the main switches. The auxiliary circuit is composed of a coupled inductor with the converter main inductor and two auxiliary switches. The auxiliary switches benefit from significantly reduced voltage stress and without requiring floating gate drive circuit. Also, by applying the synchronous rectification to the auxiliary switches body diodes, conduction losses of the auxiliary circuit are reduced. In the auxiliary circuit, the leakage inductor is used as the resonant inductor and all the magnetic components are implemented on a single core which has resulted in significant reduction of the converter volume. In the proposed converters, the reverse recovery losses of the converter rectifying diodes are completely eliminated and hence, using the low-speed body diode of the power switch as the converter-rectifying diode is feasible. The theoretical analysis for a bidirectional buck and boost converter is presented in detail and the validity of the theoretical analysis is justified using the experimental results of a 250-W prototype converter.

P.-H. Tseng, J.-F. Chen, T.-J. Liang, and H.-W. Liang have proposed A novel high step-up three-port converter is proposed in this paper. By utilizing coupled-inductor technique, voltage lift technique and multi-winding technique of coupled-inductor. However, main switch suffer from high voltage spike during the turned-off period. Hence, for suppressing and recycling the energy, the clamp circuit technique is applied. Finally, the prototype of the proposed converter with 250 W full-load, a low voltage input port (24 V), a bidirectional battery port (48 V), and a high voltage port (400 V) for output is implemented. The efficiency are above 94% at all load conditions of SISO mode.

L.-J. Chien, C.-C. Chen, J.-F. Chen, and Y.-P. Hsieh, have proposed in this paper, a novel threeport converter (TPC) with high-voltage gain for stand-alone renewable power system applications is proposed. This converter uses only three switches to achieve the power flow control. Two input sources share only one inductor. Thus, the volume can be reduced. Besides, the conversion ratio of the converter is higher than other TPCs. Thus, the degree of freedom of duty cycle is large. The converter can have a higher voltage gain for both low-voltage ports with a lower turns ratio and a reasonable duty ratio. The voltage stress of switches is low; thus, conduction loss can be further improved by adopting low R ds(on) switches. Therefore, the converter can achieve a high conversion ratio and high efficiency at the same time. The operation principles, steady-state analysis, and control method of the converter are presented and discussed. A prototype of the proposed converter with a low input voltage 24 V for photovoltaic source, a battery port voltage 48 V, and an output voltage 400 V is implemented to verify the theoretical analysis. The power flow control of the converter is also built and tested with a digital signal processor.

L. H. S. Barreto, P. P. Praca, D. S. Oliveira, and R. N. Silva have proposed this paper which presents a novel high-voltage gain boost converter topology based on the three-state commutation cell for battery charging using PV panels and a reduced number of conversion stages. The presented converter operates in zero-voltage switching (ZVS) mode for all switches. By using the new concept of single-stage approaches, the converter can generate a dc bus with a battery bank or a photovoltaic panel array, allowing the simultaneous charge of the batteries according to the radiation level. The operation principle, design specifications, and experimental results from a 500-W prototype are presented in order to validate the proposed structure.

Y.-M. Chen, A. Q. Huang, and X. Yu, have proposed A three-port dc-dc converter integrating photovoltaic (PV) and battery power for high step-up applications is proposed in this paper. The topology includes 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 operation mode does not need to be changed when a transition between charging and discharging occurs. Moreover, tracking maximum power point of the PV source and regulating the output voltage can be operated simultaneously during charging/discharging transitions. As long as the sun irradiation level is not too low, the maximum power point tracking (MPPT) algorithm will be disabled only when the battery charging voltage is too high. Therefore, the control scheme of the proposed converter provides maximum utilization of PV power most of the time. As a result, the proposed converter has merits of high boosting level, reduced number of devices, and simple control strategy. Experimental results of a 200-W laboratory prototype are presented to verify the performance of the proposed three-port converter.

T.-F. Wu, Y.-S. Lai, J.-C. Hung, and Y.-M. Chen, This paper proposes a boost converter with coupled inductors and a buck-boost type of active clamp. In the converter, the active-clamp circuit is used to eliminate the voltage spike that is induced by the trapped energy in the leakage inductor of the coupled inductors. The active switch in the converter can still sustain a proper duty ratio even under high step-up applications, reducing voltage and current stresses significantly. Moreover, since both main and auxiliary switches can be turned on with zero voltage switching, switching loss can be reduced, and conversion efficiency therefore can be improved significantly. A 200 W prototype of the proposed boost converter was built, from which experiment results have shown that efficiency can reach as high as 92% and surge can be suppressed effectively. It is relatively feasible for low-input-voltage applications, such as fuel cell and battery power conversion.

P. Das, B. Laan, S. A. Mousavi, and G. Moschopoulos, proposes a Power electronic converter systems for applications such as telecom, automotive, and space can have dc voltage buses that are backed up with batteries or supercapacitors. These batteries or supercapacitors are connected to the buses with bidirectional dc-dc converters that allow them to be discharged or charged, depending on the operating conditions. Bidirectional dc-dc converters may be isolated or nonisolated depending on the application. A new soft-switched bidirectional dc-dc converter will be proposed in this letter. The proposed converter can operate with soft switching, a continuous inductor current, fixed switching frequency, and the switch stresses of a conventional pulsewidth modulation converter regardless of the direction of power flow. These features are due to a very simple auxiliary active clamp circuit that is operational regardless of the direction of power flow. In the letter, the operation of the converter will be discussed and its feasibility will be confirmed with experimental results obtained from a prototype.

III. PROPOSED CONVERTER TOPOLOGY AND OPERATING MODES

The circuit of the proposed soft-switched TPC is shown in Fig. 2. In this converter, S1, S2 and S3 switches, D1, D2 and D5 diodes, LM inductor and CL capacitor are the same components of the TPC presented in [16]. D3 and D4 diodes, C1, C2 and C3 snubber capacitors, S4 switch and N2 winding are auxiliary elements that are added to provide previously mentioned benefits in the converter. In this converter, unidirectional sources like fuel cells, photovoltaic panels and wind turbines can be connected to the Vin1 port and bidirectional sources like battery or supercapacitor can be connected to the Vin2 port such that Vin2>Vin1. In this paper, the coupled inductor is modeled by a magnetizing inductance (LM), a leakage inductance (LLK) and the ideal transformer (N1 and N2) with the turns ratio of n= N2/N1. According to the generated power of Vin1, the charge status of Vin2 and the demand power of the output load, the TPC converter has three operating modes. When one of the inputs transfers power to the output individually, this operating mode is known as single-input-single-output (SISO). In the situations that both inputs provide power to the load simultaneously, this operating mode is called double-input-single-output (DISO). The third operating mode is defined as when the generated power source (Vin1) transfer power to both load and ESS. This mode is known as single-input-double-output (SIDO). In the following sections, the operating modes are discussed in detail.

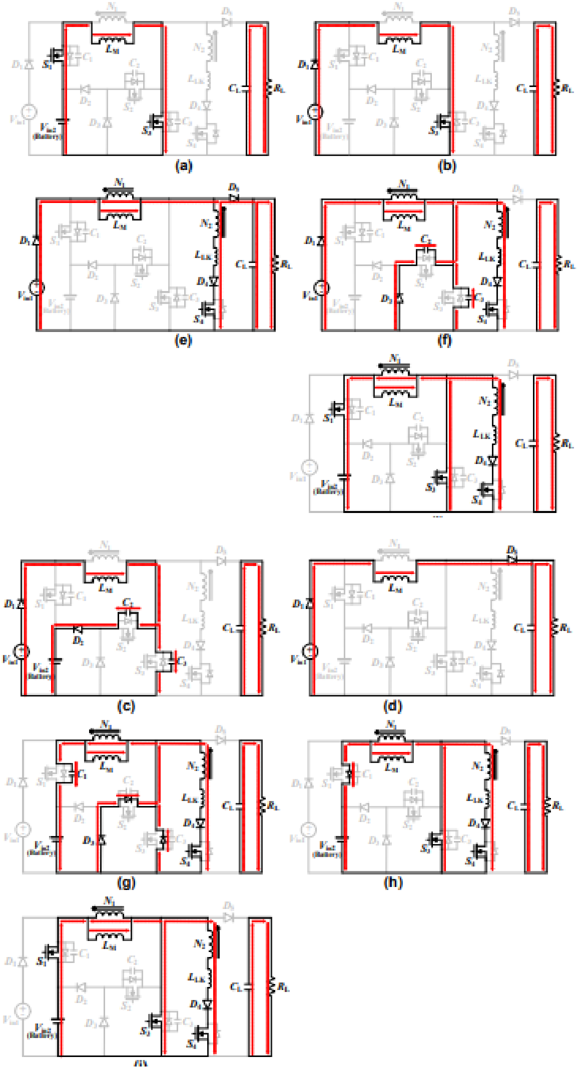


FIGURE 4. Proposed converter equivalent circuit in each interval for DISO mode: (a) interval I [t0, t1], (b) interval II [t1, t2], (c) interval III [t2, t3], (d) interval IV [t3, t4], (e) interval V [t4, t5], (f) interval VI [t5, t6], (g) interval VII [t6, t7], (h) interval VIII [t7, t8], (i) interval IX [t8, t9], and (j) interval X [t9, t10].

In both SISO and DISO modes, power is absorbed from the inputs and is delivered to the output. In SISO mode, each of the inputs can supply the load individually, but in DISO mode, the generated power by Vin1 is not enough for the output load and hence ESS provides the power shortage. Since the operation of DISO mode covers the operation of SISO modes, just the operating intervals of DISO mode are investigated in this section. To simplify the analysis, it is assumed that all semiconductor components are ideal, the converter is at the steady-state and Vin1, Vin2 and Vo have a constant voltage level during one switching cycle. With this assumption, the converter operation can be divided into ten distinct operating intervals in each switching cycle. The key waveforms and the equivalent circuit of each interval are shown in Figs. 3 and 4, respectively. Prior to the first interval, it is assumed that S1, S3 and S4 are ON and the current flows through S4 would reach zero. And, the iin is less than iLM.

Energy storage is the capture of energy produced at one time for use at a later time. A device that stores energy is generally called an accumulator or battery. Energy comes in multiple forms including radiation, chemical, gravitational potential, electrical potential, electricity, elevated temperature, latent heat and kinetic. Energy storage involves converting energy from forms that are difficult to store to more conveniently or economically storable forms.

Some technologies provide short-term energy storage, while others can endure for much longer. Bulk energy storage is currently dominated by hydroelectric dams, both conventional as well as pumped. Common examples of energy storage are the rechargeable battery, which stores chemical energy readily convertible to electricity to operate a mobile phone, the hydroelectric dam, which stores energy in a reservoir as gravitational potential energy, and ice storage tanks, which store ice frozen by cheaper energy at night to meet peak daytime demand for cooling. Fossil fuels such as coal and gasoline store ancient energy derived from sunlight by organisms that later died, became buried and over time were then converted into these fuels. Food (which is made by the same process as fossil fuels) is a form of energy stored in chemical form.

Recent history

In the twentieth century grid, electrical power was largely generated by burning fossil fuel. When less power was required, less fuel was burned. Concerns with air pollution, energy imports, and global warming have spawned the growth of renewable energy such as solar and wind power.[1] Wind power is uncontrolled and may be generating at a time when no additional power is needed. Solar power varies with cloud cover and at best is only available during daylight hours, while demand often peaks after sunset (*see* duck curve). Interest in storing power from these intermittent sources grows as the renewable energy industry begins to generate a larger fraction of overall energy consumption. Off grid electrical use was a niche market in the twentieth century, but in the twenty-first century, it has expanded. Portable devices are in use all over the world. Solar panels are now a common sight in the rural settings worldwide.[3] Access to electricity is now a question of economics and financial viability, and not solely on technical aspects.[4] Powering transportation without burning fuel, however, remains in development.

Mechanical storage

Energy can be stored in water pumped to a higher elevation using pumped storage methods or by moving solid matter to higher locations (gravity batteries). Other commercial mechanical methods include compressing air and flywheels that convert electric energy into kinetic energy nand then back again when electrical demand peaks.

Hydroelectricity

Hydroelectric dams with reservoirs can be operated to provide electricity at times of peak demand. Water is stored in the reservoir during periods of low demand and released when demand is high. The net effect is similar to pumped storage, but without the pumping loss. While a hydroelectric dam does not directly store energy from other generating units, it behaves equivalently by lowering output in periods of excess electricity from other sources. In this mode, dams are one of the most efficient forms of energy storage, because only the timing of its generation changes. Hydroelectric turbines have a start-up time on the order of a few minutes.

IV. HYBRID ENERGY SYSTEMS

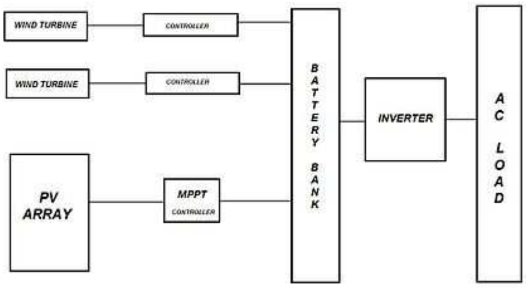
Hybrid renewable energy systems (HRES) are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

A **hybrid system** is a dynamical system that exhibits both continuous and discrete dynamic behavior – a system that can both *flow* (described by a differential equation) and *jump* (described by a state machine or automaton). Often, the term "hybrid dynamical system" is used, to distinguish over hybrid systems such as those that combine neural nets and fuzzy logic, or electrical and mechanical drivelines. A hybrid system has the benefit of encompassing a larger class of systems within its structure, allowing for more flexibility in modeling dynamic phenomena.

In general, the state of a hybrid system is defined by the values of the continuous variables and a discrete mode. The state changes either continuously, according to a flow condition, or discretely according to a control graph. Continuous flow is permitted as long as so-called invariants hold, while discrete transitions can occur as soon as given jump conditions are satisfied. Discrete transitions may be associated with events

Biomass-wind-fuel cell

For example, consider a load of 100% power supply and there is no renewable system to fulfill this need, so two or more renewable energy system can be combined. For example, 60% from a biomass system, 20% from wind system and the remainder from fuel cells. Thus combining all these renewable energy systems may provide 100% of the power and energy requirements for the load, such as a home or business.



Photovoltaic and wind

Another example of a hybrid energy system is a photovoltaic array coupled with a wind turbine.[2] This would create more output from the wind turbine during the winter, whereas during the summer, the solar panels would produce their peak output. Hybrid energy systems often yield greater economic and environmental returns than wind, solar, geothermal or trigeneration stand-alone systems by themselves.

Completely Renewable Idea

Completely Renewable Hybrid Power Plant (solar, wind, biomass, hydrogen) A hybrid power plant consisting of these four renewable energy sources can be made into operation by proper utilization of these resources in a completely controlled manner. Hybrid Energy Europe-USA.

Caffese in Europe introduce hybridizing HVDC transmission with Marine hydro pumped Energy Storage via elpipes. The project of Caffese is 3 marine big lakes producing 1800 GW and transmission with elpipes. A part 1200 GW produce water fuels-wind fuels-solar fuels 210 billion liter year. (IEEE Power and Engineering Society-General Meeting Feb.9.2011,Arpa- E,Doe USA,MSE Italy,European Commission-Energy-Caffese plan and Consortium Hybrid renewable energy systems (HRES) are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

VI. ANALYSIS OF PROPOSED METHOD

Structure of the proposed converter and operating modes

In this paper, the structure introduced in [10] is used as the base of the proposed converter which includes a voltage extension cell based on the coupled inductors and an active clamp circuit. The proposed converter structure is shown in Fig. 2. 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.

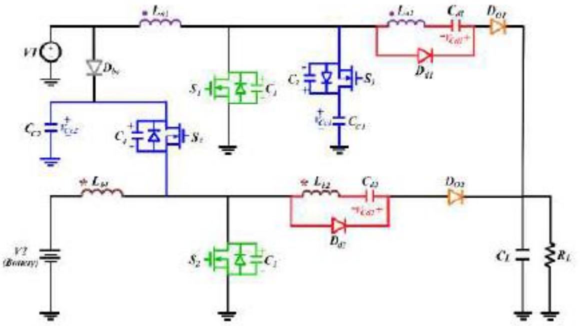


Fig. 2. Proposed non-isolated high step-up three-port DC-DC converter.

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.

VII. SIMULATION AND EXPLANATION

7.1. Introduction

This document is part of the Introduction to Using Similink seminar. This seminar is designed for people that have never used Simulink. There are two components to the seminar. There are exercises in a separate document that will take you step by step through the tasks required to build and use a Simulink model. Once you get started using Simulink, you will find a lot of the functionality is self intuitive. Inevitably, there are things that need a bit more explanation. So thesecond part of the Seminar is a talk and demonstration. This document contains the notes for the talk. It would be impossible to put everything about Simulink into such a short document, so I have concentrated on the parts of the package that I consider the most useful. I have also tried to highlight features that are not obvious to the casual user. The intention is that you use these notes as a reference when carrying out the exercises and when building your own models. Although these notes have there limits, I hope that they should be sufficient to get you started using the package and that they cover most of your modeling needs.

Circuit Modeling-

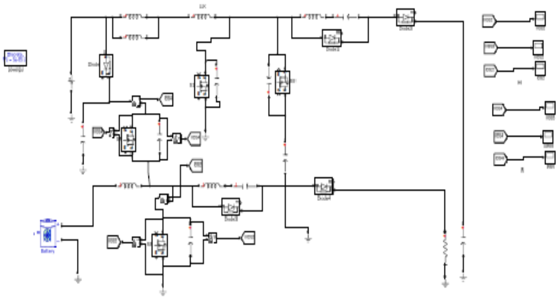


Fig. Simulation circuit charging mode

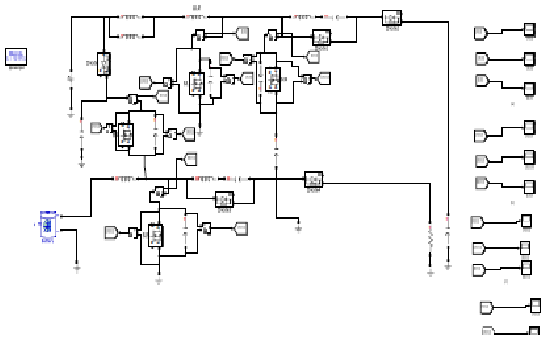
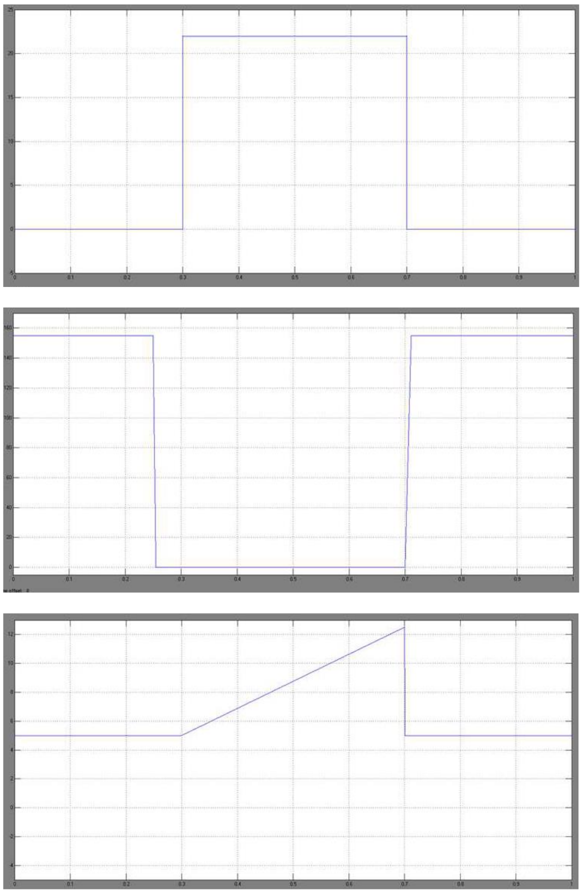


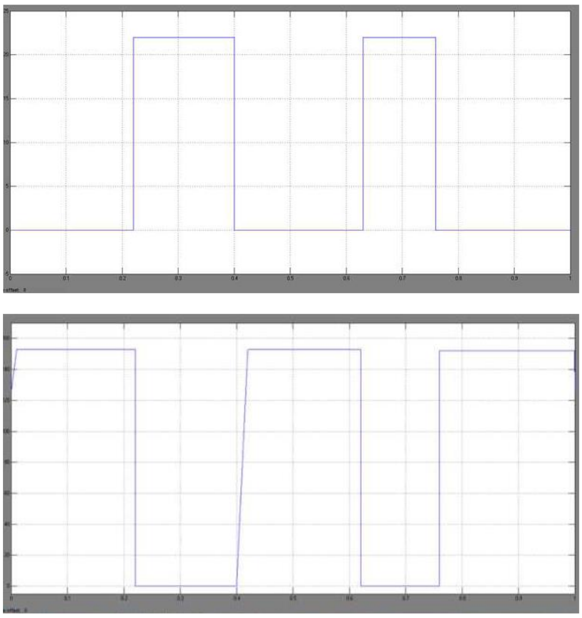
Fig –discharging mode simulation circuit

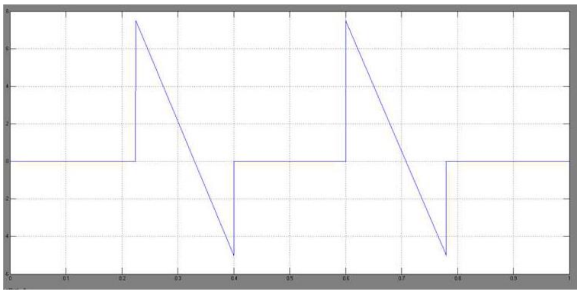
SIMULATION RESULTS

Fig.11. Soft switching conditions of the proposed converter switches.

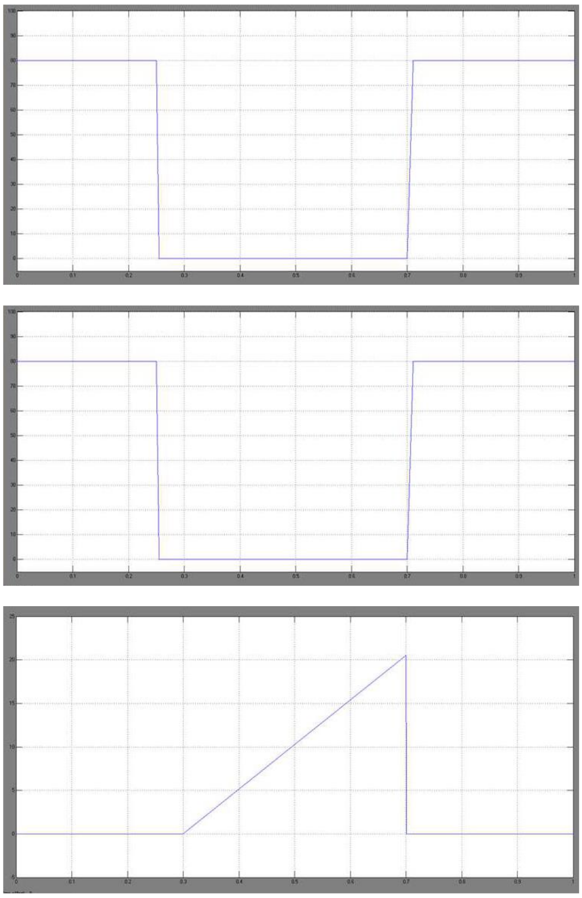


(a) S1 in ESS discharging mode.

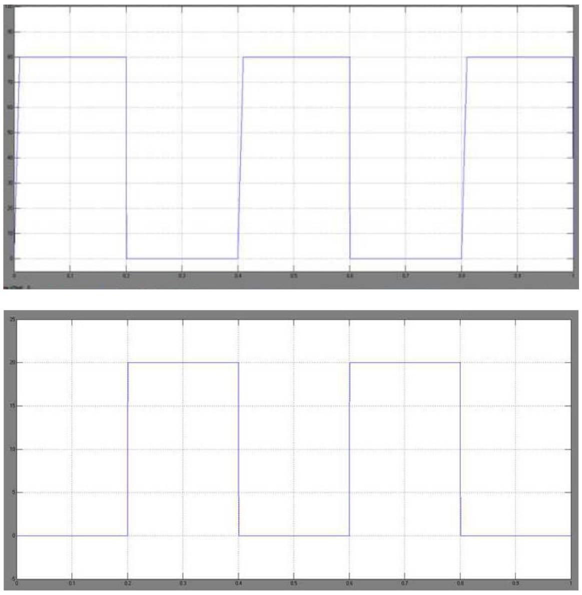


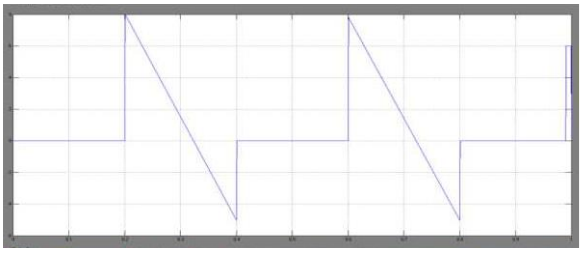


(b) S3 in ESS discharging mode.

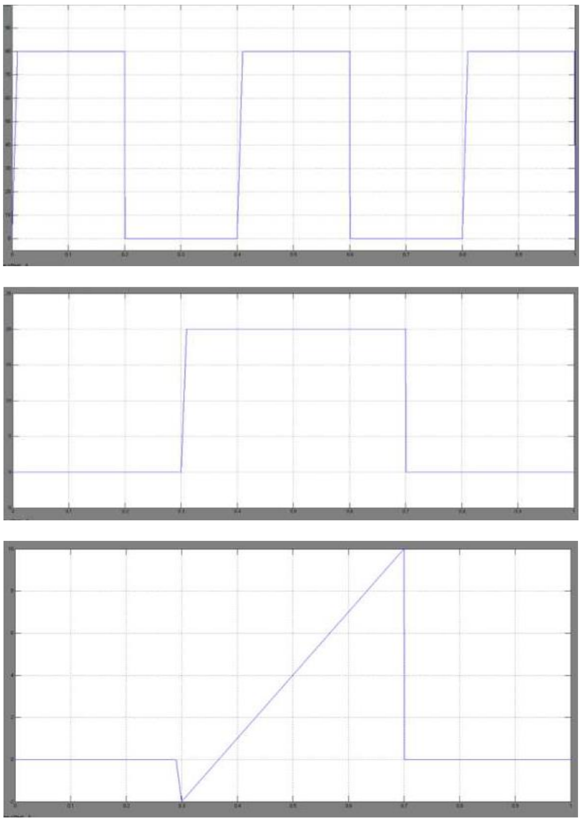


(c) S2 in ESS discharging mode.

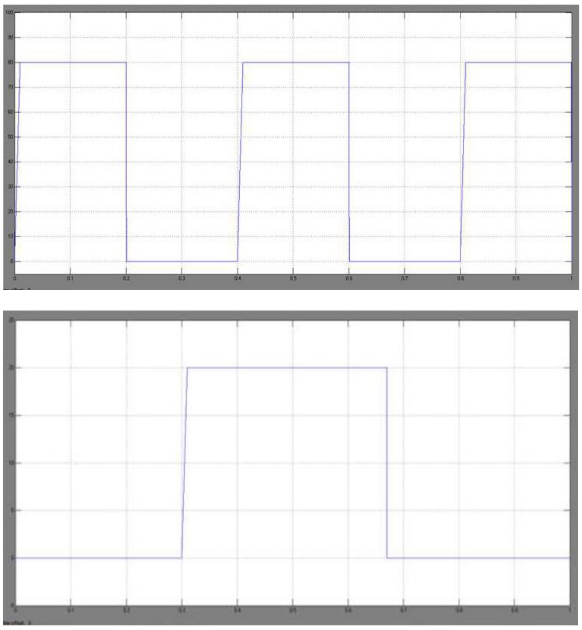


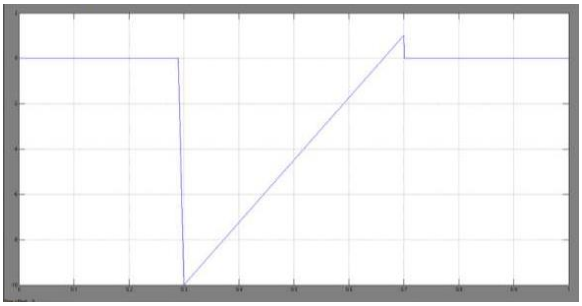


(d) S4 in ESS discharging mode.



e) S4 in ESS charging mode.





(f) S2 in ESS charging mode.

7.1.1. The Solver

Most of the time, you can just use the default settings to run your model. However you will find that sometimes you will want the model to use smaller steps, or fixed width steps. This is all configurable on the Solver page of the Configuration Parameters. From the menu bar on your model select Solver.

7.1.2. Simulation

Model Configuration Parameters

Then on the select menu on the left hand side, select **Solver**.

Simulation time

To the right at the top you will find the Simulation time box. I suggest that you leave the start time as zero. The stop time is identical to the stop time on the icon bar at the top of your model.

7.1.3. Solver Options

There are two types of solver. By default, a variable step solver is used. This will automatically adjust the step size as the model runs. If you are using variable step I suggest that you keep the default solver (**ode45**). Set the **Max step size** to a fixed value to improve the smoothness of any graphs if required.Switching to a fixed width solver will be necessary for models with discrete components. If it also has no continuous components, change the solver to Discrete (no continuous states). I also suggest that you set the step size to a known value. The fixed solvers are numbered in order of simplicity. ode1 being the simplest.For more information about solvers, click on the **Help** button at the bottom of the configuration parameters window, while you are viewing the solver section. At the bottom of the page, select **Choosing a Solver**.

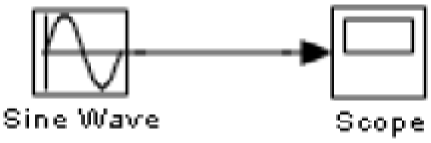
7.1.4. Zero-Crossing Options

At the bottom of the page you will find the Zero-crossing options box. You can disable zero crossing control if you think it will help.

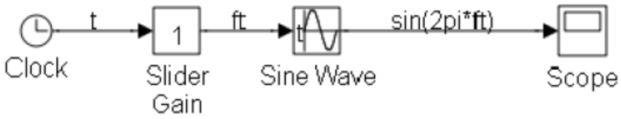
7.1.5. Sources Library

The Sine Wave Block

Most of the blocks in the source library are self expansionary. The basic sin wave block is easy to use. You just set the frequency and amplitude in the block parameters.



In the exercises we use the sine wave block to look at the frequency response of a system. However, repeatedly editing the block parameters to change the frequency of the sine wave is tedious. The alternative is to use an external time input to the block.



To do this, in the Sine Wave block parameters you set the **Time** parameter to **Use external signal** and set the **frequency** to 2*pi. You then connect a clock to the new input via a slider gain. The slider then sets the frequency of the sine wave.

From WorkSpace Block

This block is used for importing data into a Simulink model from the MATLAB workspace. A simple way of doing this is to place the data to be imported into a matrix, as shown below.

The variable name of the matrix is then entered into the block parameters of the block. Notice that the data in the above matrix is very course. Simulink will use interpolation to calculate values at any times between the given points. The block will also read in data from a structure. The MATLAB script below will generate a structure to read into Simulink.

VI. CONCLUSION & FUTURE WORK

6.1 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 is 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 multiinput 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. Finally, the experimental results obtained from the implementation of the prototype converter verify the theoretical analysis.

REFERENCES

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

[2] 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.

[3] 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.

[4] H. Wu, J. Zhang, X. Qin, T. Mu, and Y. Xing, "Secondary-sideregulated soft-switching fullbridge 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.

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

[6] 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.

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

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

[9] E. Babaei and O. Abbasi, "Structure for multi-input multi-output dc–dc boost converter," IET Power Electronics, vol. 9, pp. 9-19, .2016.

[10] 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.

[11] A. Pressman, Switching power supply design: McGraw-Hill, Inc., 1997.

[12] J. Zhang, J.-S. Lai, R.-Y. Kim, and W. Yu, "High-power density design of a soft-switching high-power bidirectional dc–dc converter," IEEE Transactions on Power Electronics, vol. 22, pp. 1145-1153, 2007.

[13] J.-B. Baek, W.-I. Choi, and B.-H. Cho, "Digital adaptive frequency modulation for bidirectional DC–DC converter," IEEE Transactions on Industrial Electronics, vol. 60, pp. 5167- 5176, 2013.

[14] M. R. Mohammadi and H. Farzanehfard, "A new family of zerovoltage-transition ,nonisolated bidirectional converters with simple auxiliary circuit," IEEE Transactions on Industrial Electronics, vol. 63, pp. 1519-1527, 2016.

[15] P.-H. Tseng, J.-F. Chen, T.-J. Liang, and H.-W. Liang, "A novel high step-up three-port converter, "in Power Electronics and Application Conference and Exposition (PEAC), 2014 International, 2014, pp. 21-25.

[16] L.-J. Chien, C.-C. Chen, J.-F. Chen, and Y.-P. Hsieh, "Novel threeport converter with highvoltage

[17] gain," IEEE Transactions on Power Electronics, vol. 29, pp. 4693-4703, 2014. 17- L. H. S. Barreto, P. P. Praca, D. S. Oliveira, and R. N. Silva, "High-voltage gain boost converter based on three-state commutation cell for battery charging using PV panels in a single conversion stage," IEEE Transactions on Power Electronics, vol. 29, pp. 150-158, 2014.

[18] Y.-M. Chen, A. Q. Huang, and X. Yu, "A high step-up three-port dc–dc converter for standalone PV/battery power systems," IEEE Transactions on Power Electronics, vol. 28, pp. 5049- 5062, 2013.

[19] 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 Transactions on Industrial Electronics, vol. 55, pp. 154-162, 2008.

[20] P. Das, B. Laan, S. A. Mousavi, and G. Moschopoulos, "A nonisolated bidirectional ZVSPWM active clamped DC–DC converter," IEEE Transactions on Power Electronics, vol. 24, pp. 553-558, 2009.