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A Review Paper On Softswitched Non-Isolated High Step-Up Three-Port DC-DC Converter For Hybrid Energy Systems with Minimum Switches

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Abstract—In this paper, 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 stress 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 150W-400V load is implemented and the theoretical analysis is validated by the experimental.

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

I. INTRODUCTION

Nowadays, the 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 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 [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.

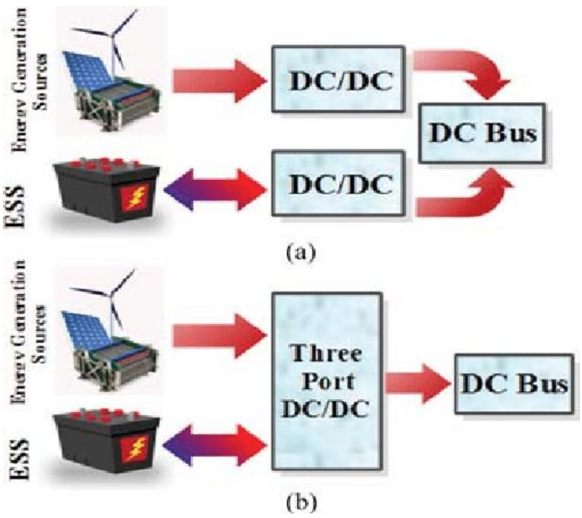


Fig.1. (a). Using typical multiple single DC-DC converters. (b) Three-port DC-DC converter configuration.

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.

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.

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.

III. ENERGY STORAGE

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. 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.

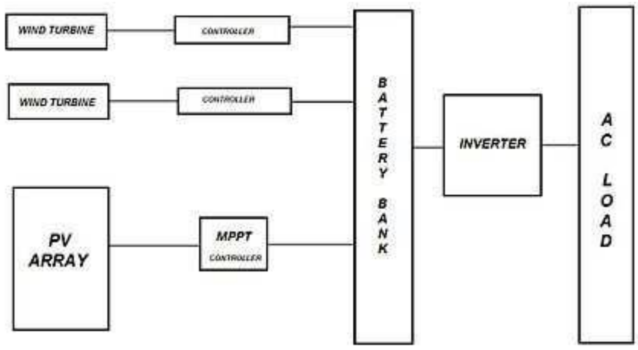
IV. HYBRID ENERGY SYSTEMS

4.1 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.

4.2 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.



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.

4.3 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

4.4 Drawbacks of Standalone Renewable Energy Sources

Most of us already know how a solar/wind/biomass power generating system works, but, all these generating systems have drawbacks of some kind. Solar panels, for example, are expensive to set up, and are peak output is not obtained during the night or cloudy days. Similarly, Wind turbines can't operate safely in high wind speeds, and low wind speeds produce little power. Biomass plants collapse at low temperatures.

How to Overcome?

So if all the three are combined into one hybrid power generating system the drawbacks can be avoided partially/completely, depending on the control units. As the one or more drawbacks can be overcome by the other, as in northern hemisphere it is generally seen that in windy days the solar power is limited and vice versa and in summer and rainy season the biomass plant can operate in a full flagged so the power generation can be maintained in the above stated condition. The cost of solar panel can be subsided by using glass lenses, mirrors to heat up a fluid, that can rotate the common turbine used by wind and other sources. Now the question arises what about the winter nights or cloudy winter days with very low wind speeds. Here comes the activity of the Hydrogen. As we know the process of electrolysis can produce hydrogen by breaking water into hydrogen and oxygen, it can be stored; hydrogen is also a good fuel and burns with oxygen to give water. Hydrogen can be used to maintain the temperature of the biomass reservoir in winter so that it can produce biogas in optimum amount for the power generation. As stated above biogas is a good source in summer; in this period the solar energy available is also at its peak, so if the demand and supply is properly checked and calculated the excess energy can be used in the production of hydrogen and can be stored. In sunny, windy &hot day, the turbine operates with full speed as the supply is maximum, and this excess power can be consumed for the process of manufacturing hydrogen. In winter, the power consumption is also low so the supply limit is low, and obtained with lesser consumption. Driving hybrid cars will disable this outcome.

4.5 DC-DC CONVERTER

A **DC-to-DC converter** is an electronic circuit or electromechanical device that converts a source of direct current (DC) from one voltage level to another. It is a type of electric power converter. Power levels range from very low (small batteries) to very high (high-voltage power transmission).

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Please note that there are are many more specific templates. Please use {{R from alternative spelling}} for spelling changes (including punctuation and spacing); see subcategories of Category:Redirects from modifications for other options (capitals, abbreviations, diacritics, plurals, stylizations, transliteration, ligatures, different parts of speech, etc.). If you are unsure which to use, this template is fine; someone will make it more specific later if necessary.

V. 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.

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 connected to the output high voltage side, thus it is always OFF. Also, at the converter start-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.

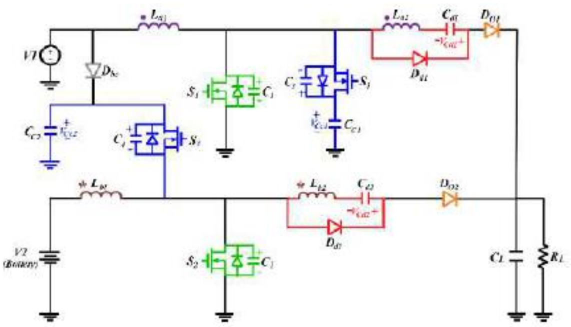


Fig. 2. Proposed non-isolated high step-up three-port DC-DC converter.

According to the load power demand, generating power from V1 and the charge state of the ESS, the charging/discharging operating modes of the proposed converter are discussed as follows:

A.ESS discharging mode

In this operating mode, one of the phases or both of them are transferring power to the load and the diode Dbc is OFF which separates phases from each other. Since the operating modes of each phase are similar to each other and in order to simplify the analysis, the lower side phase operation is omitted and the upper side phase operation at different intervals is investigated. In this mode, the proposed converter has eight intervals in one switching period. Prior to the first interval, it is assumed that S1 and DO1 are ON, S3 is OFF. Due to large capacitance of the CC1 and Cd1, the voltage across these capacitors can be considered constant during all intervals. In the equivalent circuit of the proposed converter, the coupled inductors are considered as an ideal transformer with a parallel magnetizing inductance LM and series leakage inductance LLk. Also, all semiconductor elements are considered ideal. The key waveforms and the converter equivalent circuits in various intervals are shown in Fig.3 and Fig.4 respectively.

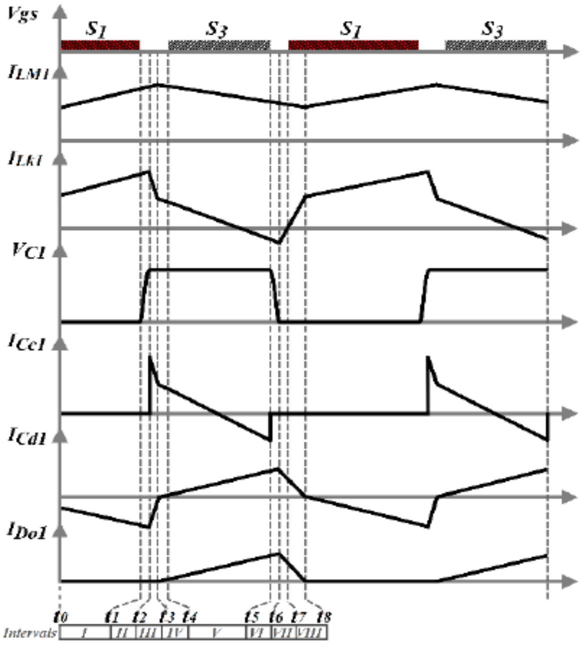


Fig. 3. Key waveforms of the proposed converter in ESS discharging mode.

V. SIMULATION RESULTS

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 the second 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 notesas 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.

This is not a Simulink manual. Sooner or later you will need to know more detail about something within Simulink. This document is intended to be used in conjunction to the documentation available with in the package. Mathworks provide extensive online documentation for Simulink that can be accessed using the MATLAB help system. There is so much online documentation that not many people have the time or inclination to read all of it. So an aim of the Seminar is to emphasize the things that you ought to know about Similink and to give you some idea about where you can find any other information that you require.

Circuit Modeling-

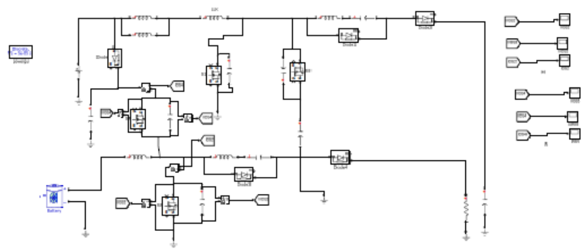


Fig. Simulation circuit charging mode

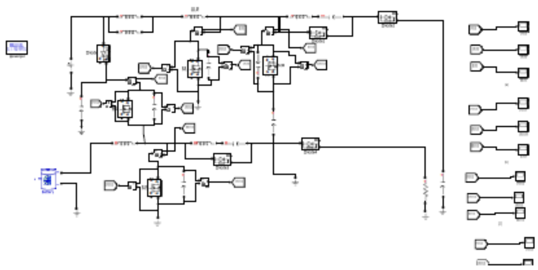
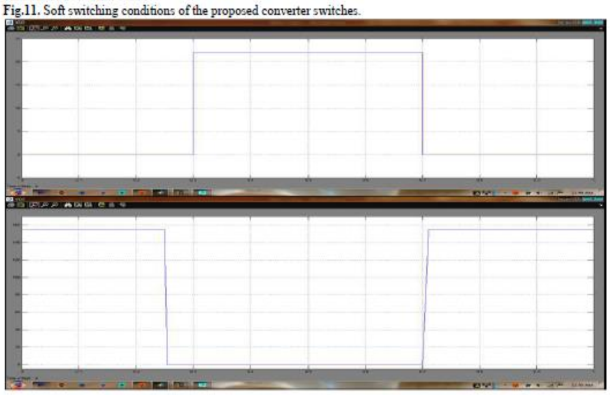
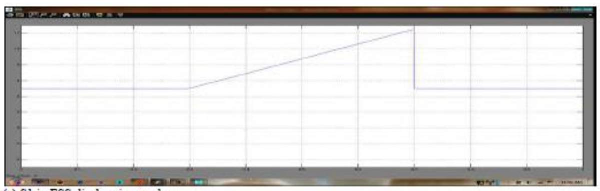


Fig –discharging mode simulation circuit

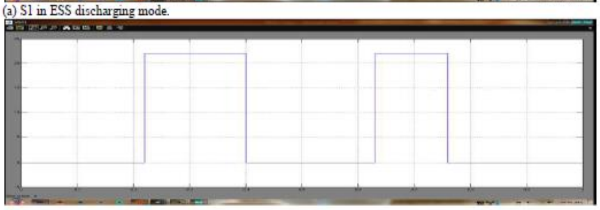
SIMULATION RESULTS

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





(a) S1 in ESS discharging mode.



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.

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.

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