IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 12, Issue 3 Ver. IV (May – June 2017), PP 68-76
www.iosrjournals.org

Sepic Topology Based High Step-Up Step down Soft Switching Bidirectional DC-DC Converter for Energy Storage Applications

Deepadevi[1]. Bijo Merlin[2].M, Arunsankar.G[3]
[1] P, M.E (Power Electronics & Drives), Gojan school of Business and Technology, Chennai, Tamilnadu
[2] Asst.Prof / EEE Department school of Business and Technology, Chennai, Tamilnadu
[3] Asso.Prof / EEE Department, Gojan school of Business and Technology
Chennai, Tamilnadu

***Abstract**: SEPIC topology based bidirectional DC-DC Converter is proposed for interfacing energy storage elements such as batteries & super capacitors with various power systems. This proposed bidirectional DC-DC converter acts as a buck boost where it changes its output voltage according to its duty cycle. An important factor is used to increase the voltage conversion ratio as well as it achieves high efficiency. In the proposed SEPIC based BDC converter is used to increase the voltage proposal of this is low voltage at the input side is converted into a very high level at the output side to drive the HVDC smart grid. In this project PIC microcontro9 ller is used to give faster response than the existing system. The proposed scheme ensures that the voltage on the both sides of the converter is always matched thereby the conduction losses can be reduced to improve efficiency. MATLAB/Simulink software is utilized for simulation. The obtained experimental results show the functionality and feasibility of the proposed converter.*

I. Introduction

Energy storage systems have been widely used in numerous applications, such as renewable power systems, electric vehicles, uninterrupted power supplies and micro grids to compensate the power mismatch between the power generations and power consumptions. Bidirectional DC-DC converters which have bidirectional power converting and transferring capabilities are key components for interfacing energy storage elements one side of BDC is connected to a storage battery, whose voltage is 12V to 48V while the output side of the converter is connected to a high voltage bus up to 400V or higher. With this project is desired for energy storage systems to connect a HVDC bus. Generally AC-AC conversion can be easily done with a transformer, however dc-dc conversion is not as simple. Voltage regulators can be used to provide a reference voltage. Additionally, battery voltage decreases as batteries discharge which can cause many problems if there is no voltage control. The most efficient method of regulating voltage through a circuit is with a dc-dc converter. There are many types of dc-dc converters available, in which SEPIC converter produces non-inverted output. In SEPIC based DC converter ensures high voltage conversion ratio and improved efficiency.

1.2 OBJECTIVE OF THE PROJECT

For the high voltage conversion ratio and high gain, generally multilevel BDC's are used, it tends to increase the switches thereby it goes very severe switching and also conduction losses are there. Instead of this multilevel BDC's a Soft switching , bidirectional DC- DC converter with a coupled inductor and a voltage Doubler cell is proposed for high step up/ step down applications. A dual active half bridge converter is integrated into SEPIC converter to extend the voltage gain dramatically and decrease switch voltage stresses effectively. The output voltage of SEPIC is shared with the input of Dual active half bridge converter, so Pulse width modulation control can be adopted to SEPIC ,to ensure that the voltage on the two sides of the DAHB is matched. As a result, the circulating current and conduction losses can be lowered to improve efficiency. Zero voltage switching is achieved for all of the active switches to reduce the switching losses. The fluctuation nature of most renewable energy resources, like wind and solar, makes them unsuitable for standalone operation as the sole source of power. A common solution to overcome this problem is to use an energy storage device besides the renewable energy resource to compensate for these fluctuations and maintain a smooth and continuous power flow to the load. As the most common and economical energy storage devices in medium-power range are batteries and super-capacitors, a dc-dc converter is always required to allow energy exchange between storage device and the rest of system. Such a converter must have bidirectional power flow capability with flexible control in all operating modes.

1.3 Conventional Method

This system is having more no of switching devices, it tends to switching as well as conduction losses to a certain level. It leads to reduce the whole efficiency of the system. This soft-switching bidirectional DC-DC converter (BDC) with a coupled-inductor and a voltage doubler cell for high step-up/step-down voltage conversion applications.

In the conventional system, low voltage is converted into higher voltage to drive the dc voltage bus with the help of Bidirectional dc-dc converter system. Based on the PWM technique, MOSFET gate driver circuit gives pulses and also power from the 8051 Micro controller to the active devices in the converters. After that they are working under the ZVS soft switching principle in the conventional buck boost and BDC converter. It produces very high voltage to drive load it is nearly 400V in the experimental analysis. This output voltage is displayed in LCD display.

1.3.1 Drawbacks Of Conventional BUCK BOOST BDC System

- Hard switching
- limited voltage conversion ratio
- extreme duty cycle of switches
- Severe reverse-recovery of the diode of an active switch
- Switching losses are very high
- Conduction losses also high

1.4 Techniques To Reduce Switching Losses

- Bidirectional controlled switch network and an inductor into the Conventional buck-boost BDC
- Auxiliary circuits, such as LC series resonant circuit
- A coupled-inductor is employed to alleviate the reverse-recovery Problems of body diodes in the buck-boost BDC

1.5 Proposed Method

Thus, the proposed converter has higher step-up and step-down voltage gains than the conventional converter. Under same electric specifications for the proposed converter with SEPIC converter, the average value of the switch current in the proposed converter is less than the conventional method, because of its reduced switching devices.

1.5.1 Block Diagram Of Proposed Converter System

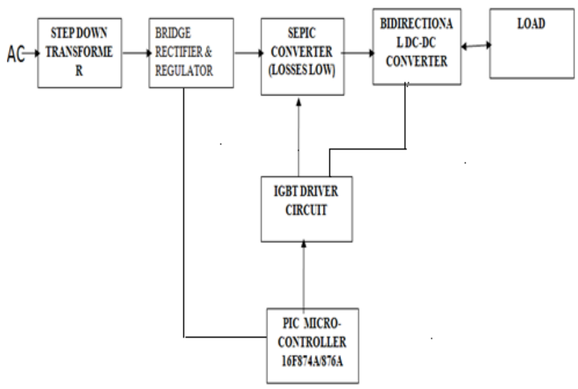


Fig.1. Block Diagram Of Proposed Converter System

1.5.2 Description

The proposal of this project comprises many blocks including SEPIC based Bidirectional DC-DC converter, Gate diver circuit for all active Switches like IGBT in the converter section, Liquid Crystal Display and PIC microcontroller IC. The main objective of this is, simple low voltage is converted into a very high voltage to drive smart grid. Input AC supply is step down to a low voltage with the help of Transformer, then it is rectified by dc voltage to a required level by using Bridge rectifier circuit, then it is regulated by a positive voltage regulator. This constant level voltage is used to give the PIC microcontroller IC, this handles the driver circuit then automatically it generates trigger pulses based on PWM principle.

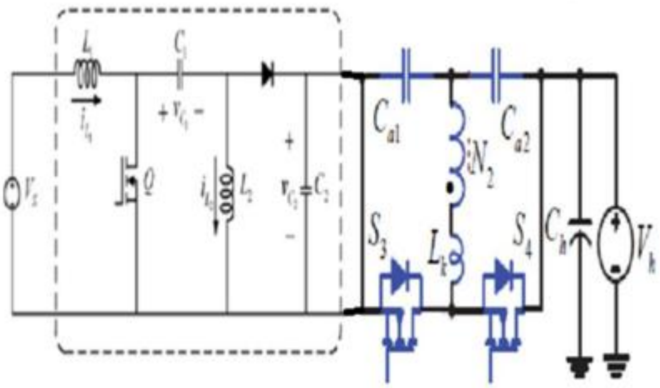
This initiates all the active devices with ZVS soft switching, minimum phase delay to the SEPIC and BDC converters. The SEPIC gives little boosted output voltage. In the same way, BDC generates higher multiplied output voltage depending on the SEPIC output to drive high voltage dc bus easily. Internally BDC acts like Dual active Half Bridge that is Voltage multiplier circuit. LCD displays how much outcome is received.

1.6 ADVANTAGES OF THE PROJECT

- Switching losses are low because of switching devices are also reduced.
- Switching stress are reduced.
- High voltage conversion ratio. High output gain.

1.7 CIRCUIT DIAGRAM WITH DRIVER

Proposed converter of this project is having SEPIC converter as well as BDC circuit is shown in fig 3.4 .In which there are only three switching devices are used instead of six control devices in the conventional method.



For that IGBT driver circuit is utilized for this project is also shown in fig 3.5

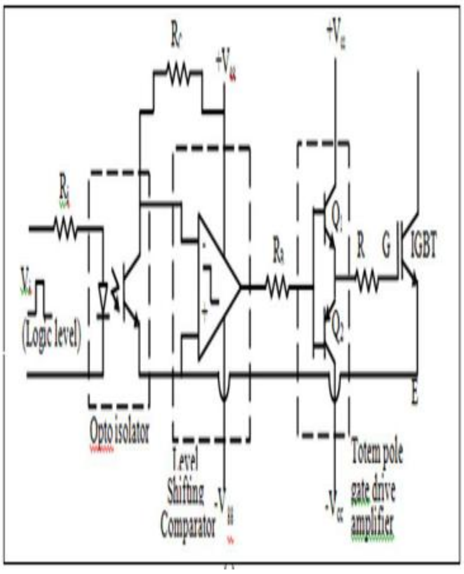
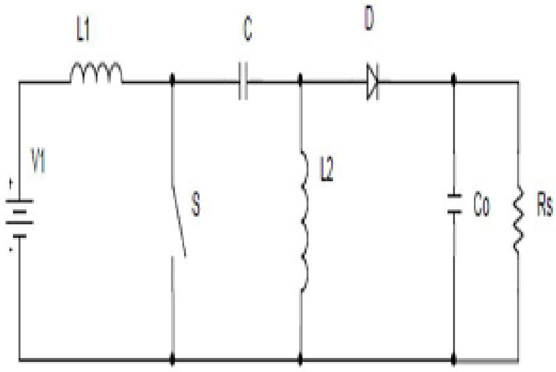


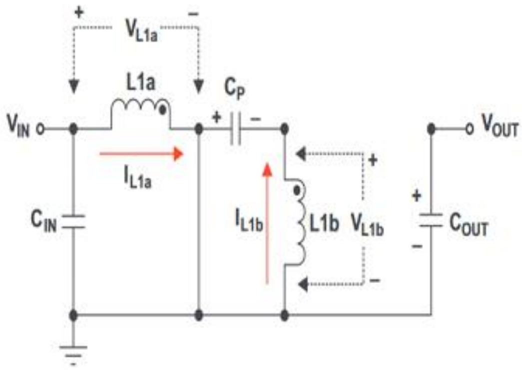
Fig 3. Driver Section

Many digital circuits can generate PWM signals (tputs). They normally use a counter that increments periodically (it is connected directly or indirectly to the clock of the circuit) and is reset at the end of every period of the PWM. When the counter value is more than the reference value, the PWM output changes state from high to low (or low to high). This technique is referred to as time proportioning, particularly as time-proportioning control – which proportion of a fixed cycle time is spent in the high state. A SEPIC is essentially a boost converter followed by a buck-boost converter, therefore it is similar to a traditional buck-boost converter, but has the advantages of having non-inverted output, using a series capacitor to couple energy from the input to the output.

Fig.4. Operation of SEPIC



4.3 MODES OF OPERATION OF SEPIC CONVERTER



4.3.1 Mode 1 Operation of SEPIC

A SEPIC is said to be in continuous – conduction mode, if the current through the inductor never falls to zero. During steady state operation, the average voltage across capacitor V_{c1} is equal to the input voltage. Because it blocks dc, the average current through it is zero, making inductor L_2 the only source of dc load current and hence independent of the input voltage.

4.3.2 Mode 2 Operation Of SEPIC

A SEPIC is said to be in discontinuous – conduction mode, if the current through the inductor is allowed to zero

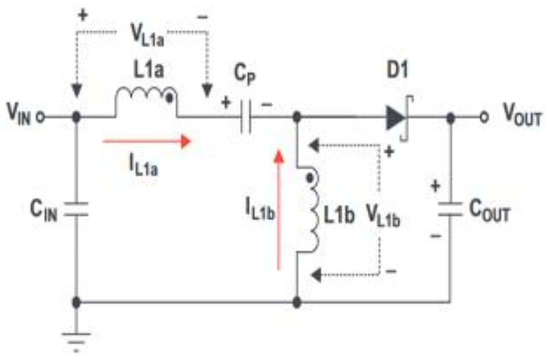


Fig. 5. Operation of SEPIC- Discharging mode

During Charging, when switch s1 is turned ON, current I_{L1} increases and the current I_{L2} goes to negative. The energy to increase the current I_{L1} comes from the input source. Since S1 is a while closed, and the instantaneous voltage V_{c1} is approximately V_{IN} , the voltage V_{L2} is approximately $-V_{IN.}$ Therefore the capacitor C1 supplies the energy to increase the magnitude of the current in I_{L2} and thus increase the energy stored in L2.

4.3.3 Duty-cycle calculation for SEPIC converter

Assuming 100% efficiency, the duty cycle, D, for a SEPIC converter operating in CCM is given by

$$D = \frac{V\,OUT + V\,FWD}{V\,IN + V\,OUT + V\,FWD} \qquad (4.1)$$

where V_{FWD} is the forward voltage drop of the Schottky diode. This can be rewritten as

$$\frac{D}{1-D} = \frac{V\,OUT + V\,FWD}{V\,IN} = \frac{I\,IN}{I\,OUT}$$

$D_{(max)}$ occurs at $V_{IN(min)}$, and $D_{(min)}$ occurs at $V_{IN(max)}$.operating modes.

As its name suggests, a Voltage Doubler is a voltage multiplier circuit which has a voltage multiplication factor of two. The circuit consists of only two diodes, two capacitors and an oscillating AC input voltage (a PWM waveform could also be used). This simple diode-capacitor pump circuit gives a DC output voltage equal to the peak-to-peak value of the sinusoidal input. In other words, double the peak voltage value because the diodes and the capacitors work together to effectively double the voltage.

The advantage of "Voltage Multiplier Circuits" is that it allows higher voltages to be created from a low voltage power source without a need for an expensive high voltage transformer as the voltage doubler circuit makes it possible to use a transformer with a lower step up ratio than would be need if an ordinary full wave supply were used. However, while voltage multipliers can boost the voltage, they can only supply low currents to a high-resistance (+100kΩ) load because the generated output voltage quickly drops-off as load current increases.Voltage Multipliers are simple circuits made from diodes and capacitors that can increase the input voltage by two, three, or four times and by cascading together individual half or full stage multipliers in series to apply the desired DC voltage to a given load without the need for a step-up transformer. However, the diodes and capacitors used in all multiplication circuits need to have a minimum reverse breakdown voltage rating of at least twice the peak voltage across them as multi-stage voltage multiplication circuits can produce very high voltages, so take care. Also, voltage multipliers usually supply low currents to a high-resistance load as the output voltage quickly drops away as the load current increases. Bidirectional dc-dc Converters (BDC) is one of the key elements in electrical energy storage systems. They provide a flexible power processing interface between a energy storage device that is battery and the rest of system. Bidirectional dc-dc converters (BDC) have recently received a lot of attention due to the increasing need to systems with the capability of bidirectional energy transfer between two dc buses. Apart from traditional application in dc motor drives, new applications of BDC include energy include energy storage in renewable energy systems, fuel cell energy systems, hybrid electric vehicles (HEV) and uninterruptible power supplies (UPS).

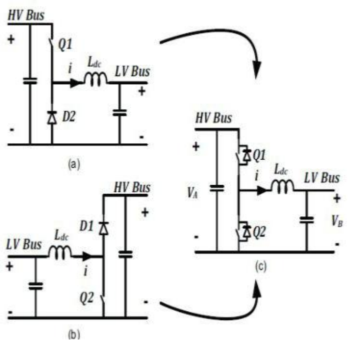


Fig 6. (A) Unidirectional Buck Converter (B) Unidirectional Boost Converter (C) Bidirectional From Unidirectional Converter

As the name bidirectional implies, there are basically two modes of operation in an IBDC in terms of power transfer. This notation " boost" or "step-up" and "buck" or "step-down" usually originates from the fact that the dc voltages at each side have usually different voltage amplitude and thus voltage boosting/bucking takes place along with energy transfer. Bidirectional operation requires both converters in a BDC to be equipped with controllable switches. Therefore, both converters can be actively controlled in both modes of operation. Basic dc-dc converters such as buck and boost converters and their derivatives do not have bidirectional power flow capability. In general, a unidirectional dc-dc converter can be turned into a bidirectional converter by replacing the diodes with a controllable switch in its structure. In the buck mode of operation, i.e. when the power is transferred from the high voltage HV to the low voltage LV side, one switch is the active switch while other is kept off. In the boost mode, when the power is transferred from LV to HV side, the second switch acts as a controlled switch and the previous one is kept off.

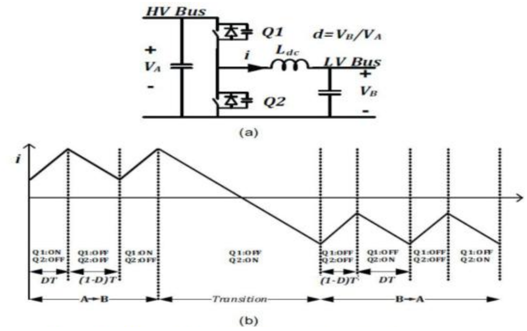


Fig.7 Bidirectional DC- DC Converter, (b) Operating Waveforms

The presence of inductor in the LV side results in lower ripple current which is advantageous in some applications. It is usually preferred to charge/discharge batteries with low ripple current in order to achieve higher efficiency and longer life time.

II. Simulink Model Of Sepic Topology Based Bdc For Energy Storage Applications

2. 1 Simulink Model for Step Up Mode

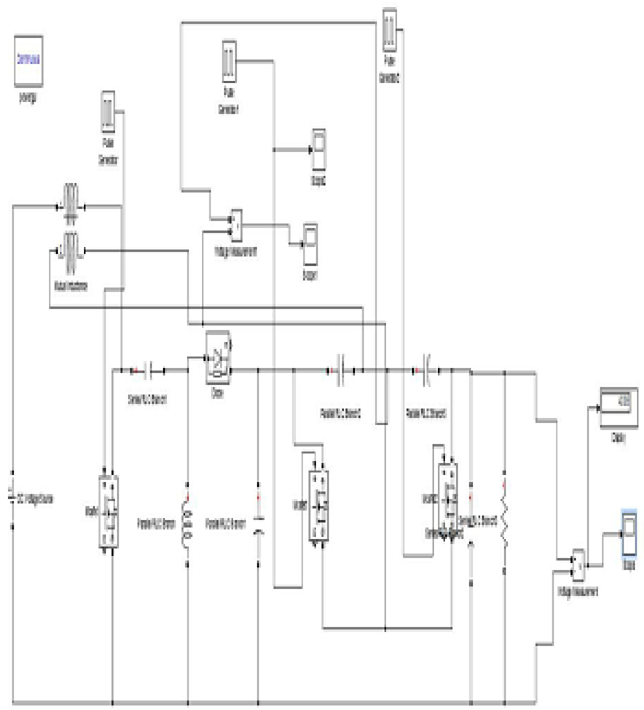


Fig 8 Simulink Model Of The Proposed System

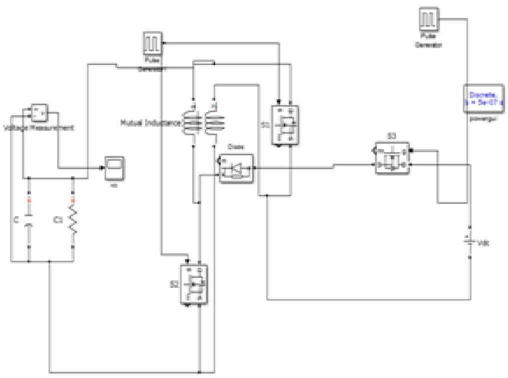
To implement three-phase voltage source with programmable time variation of amplitude, phase, frequency, and harmonics, and to implement three-phase source with internal R-L impedance.

2 .2 Simulink Model For Step Down Mode

This figure 9. shows the simulink model of SEPIC topology based BDC for energy storage applications in step down mode

III. Simulation Results

Fig. 9. Simulink Model For Step Down Mode



3.1 INPUT VOLTAGE

A low voltage battery is connected to the input side whose voltage is nearly 48 V, after that it fires the next blocks as well as its firing pulses for the given pulse generators in the simulink model. Based on the pulses form their Driver Circuit, Converter gives boosted output voltage, it drives BDC, The final Output from this Converter is used to Connect High Voltage DC Bus. X-axis represents the time period and Y axis represents the voltage magnitude.

OUTPUT VOLTAGE

This figure shows the final output of the project with high voltage nearly 430V in amplitude. X axis represents the time period and Y axis represents the voltage magnitude.

3.2 MODE1: Step up Mode peration Of BDC

Output voltage waveform for boost operation using SEPIC based BDC converter is shown in Fig 7.4.

Fig.10 Simulink Model for step down mode

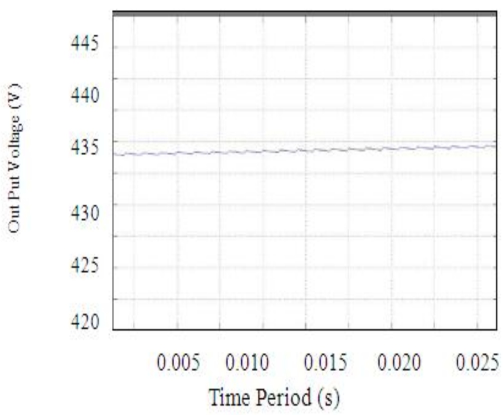
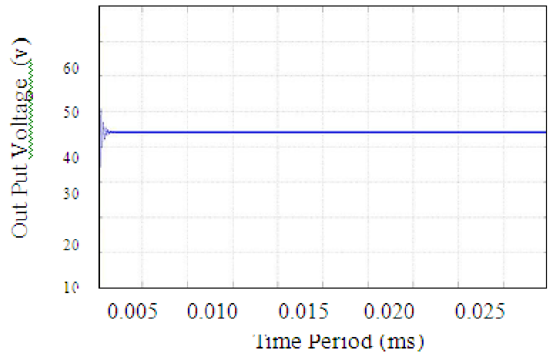


Fig.10 Simulink Model for step down mode

3.3 MODE 2: Output Voltage for Step Down Mode Operation
Output voltage waveform for BUCK operation using SEPIC based BDC converter is shown in Fig 7.6



IV DESIGN CALCULATION

Duty Cycle Calculation for SEPIC Converter of the Project is as follows

Input voltage of the Transformer = 12V

Input Transfomer Ratio is = 1 : 5

So output voltage of the Project is nearly 60 V

For Designing 100% efficiency, the duty cycle, D, for a SEPIC converter operating in CCM is given by

$$D = \frac{VOUT + VFWD}{VIN + VOUT + VFWD} \quad (1)$$

V_{in}= Input Voltage of the Transformer is 12 V

V_{out}= Output Voltage of the Transformer is 60 V

V_{fwd}= Forward Voltage drop of the diode is 0.6 V

$$D = \frac{60 + 0.6}{12 + 60 + 0.6}$$

Duty cycle D = 83.47%

For Hardware of this project switching frequency is 10 KHz

In Existing system of this project, 100 KHz switching frequency is used, but in the proposed system this is reduced to a half level, thereby reducing switching losses. That is increasing switching frequency tends to introduce a hissing noise in the inductance coil of the transformer. We have to avoid this problem we are going to design duty cycle above 70%.

This can be rewritten as

$$\frac{D}{1-D} = \frac{V\,OUT + V\,FWD}{V\,IN} = \frac{I\,IN}{I\,OUT} \quad (8.3)$$

$D_{(max)}$ occurs at $V_{IN(min)}$, and $D_{(min)}$ occurs at $V_{IN(max)}$.operating modes.

$$\frac{0.83}{1-0.83} = \frac{60+0.6}{12} \quad (8.4)$$

This equations nearly matches ;Switching frequency= 10 Khz

For inductor selection, peak to peak ripple current to be approximately40% of the maximum input current at minimum input voltage.

$$\Delta Il = Iout\ X \frac{Vout}{Vin\ (min)}\ X\ 40\ \%$$

$$= 2.8\ X \frac{60}{12}\ X\ 40\ \% = 5.6\ A$$

$$L = L1 = L2 = \frac{Vin}{\Delta Il\ X\ F\ sw}\ X\ D\ max$$

$$= \frac{12}{5.6\ X\ 10\ X\ 1000}\ X\ 0.6 = 12\ \mu H$$

For Output capacitor , Assuming ripple is 2 % of the output voltage of the system

$$Cout = \frac{IoutX\ Dmax}{Vripple\ X\ 0.5\ X\ Fsw}$$

$$Cout = \frac{28\ X\ 0.6}{0.02\ X\ 60\ X\ 0.5\ X\ 10\ X1000}$$

Its nearly 28 µF for the capacitor value

V.Conclusion

High efficiency energy storage system applications with steep voltage gain and wide battery range is proposed by integrating a coupled inductor into the SEPIC converter. The voltage stresses of switches have been reduced and the voltage conversion ratio has been increased .Voltage matching control for BDC is achieved by regulating the switches duty cycles of the buck-boost BDC. To reduce the conduction losses and improve the soft-switching performance of the BDC. Power flow regulation is achieved by adopting phase shift control to the BDC. Furthermore, ZVS soft switching is realized for all of the switches to lower the switching losses. Finally, the effectiveness of the proposed SEPIC base BDC topology and control is verified using a 1.02 kW, 48V to 425V prototype.

References

[1]. M.R.Mohanmadi and H.Farzanfhafard, IEEE.Ind, Electron. "Analysis of diode reverse recovery effect on the improvement of soft switching range in zero voltage transition bidirectional converters", vol.62,no.3,pp.1471-1479,Mar.2015.

[2]. P. Das, B. Lann, S. A. Mousavi, G.Moschopoulos , "A non isolated bidirectional ZVS-PWM active clamped DC-DC converter" IEEE Trans. Power Electron., vol. 24, no. 2, pp. 553-558, Feb. 2009. [10]

[3]. J.-H. Lee, D.-H. Yu, J.-G. Kim, Y.-H. Kim, D.-Y. Jung, Y.-C. Jung, and C.-Y. Won, "Auxiliary switch control of a bidirectional soft-switching DC-DC converter" IEEE Trans. Power Electron., vol. 28, no. 12, pp. 5446-5457, Dec. 2013.

[4]. J.-W. Yang, H.-L. Do, "High-efficiency bidirectional DC-DC converter with low circulating current and ZVS characteristic throughout a full range of loads" IEEE Trans. Ind. Electron., vol. 61, no. 7, pp. 3248-3256, July 2014.

[5]. T.-J. Liang, J.-H. Lee, "Novel high-conversion-ratio high-efficiency isolated bidirectional DC-DC converter"IEEE Trans. Ind. Electron., vol. 62, no. 7, pp. 4492-4503, July 2015.

[6]. D.-Y. Jung, S.-H. Hwang, Y.-H. Ji, J.-H. Lee, Y.-C. Jung, and C.-Y. Won, "Soft-switching bidirectional DC/DC converter with a LC series resonant circuit" IEEE Trans. Power Electron., vol. 28, no. 4, pp. 1680-1690, Apr. 2013.

[7]. D. Debnath, K. Chatterjee, "Two-stage solar photovoltaic-based stand-alone scheme having battery as energy storage element for rural development" IEEE Trans. Ind. Electron., vol. 62, no. 7, pp. 4148-4157, July 2015