DEVELOPING A COMBINED SOFT-SWITCHING BIDIRECTIONAL DC/DC CONVERTER FOR SOLAR - POWERED LED STREET LIGHTS

Girija K G

Lecturer In Electronics Engineering,
Sree Rama Govt. Polytechnic College Thriprayar,
Valapad P O, Thrissur (Dt)
srpolyoffice@gmail.com

ABSTRACT

Soft switching increases efficiency and equipment lifespan by lowering voltage and current stress during transitions, smoothing and quieting processes, and lowering electromagnetic interference. Power electronics soft switching is influenced by circuit design, component choice, and switching frequency optimisation. A street lighting LED luminaire based on modular drivers is proposed in this work. A driver made up of two integrated DC-DC converters makes up each module. The first is a buck-boost converter that corrects power factor, while the second is a buck converter that regulates load current. The discontinuous conduction mode of current is used by both converters. Each driver provides a separate set of power LEDs to make the system resilient to failure. Therefore, the system is not totally affected in the event that one or more drivers fail. The electronic drivers' design is shown. Additionally, it uses pulse-width modulation (PWM) dimming to manage the LED-SLS's illumination. The suggested CI-BDC functions as a traditional BDC by turning off the auxiliary circuit in order to retain high efficiency even at light loads. Consequently, at light loads, the large conduction losses in it are avoided. To demonstrate the viability of the suggested solution, experimental results of a prototype with a rated power of 50 W (two modules of 25 W) are conducted.

Keywords: *LED driver; linked inductor; bidirectional; buck-boost; soft switching*

INTRODUCTION

Nowadays, solar photovoltaic (SPV) systems are important for using energy because they have many benefits. A lot of electricity is used for lighting, so using renewable energy can help reduce the load on the power grid. Energy-efficient LED lighting systems can also cut down power use. LEDs provide better light output, last longer, look more natural, and react quickly. To save energy, SPV-powered LED street lighting is becoming more common. In recent years, there's been a big rise in interest in renewable energy, which has led to a lot of research in power electronics, especially on high-gain non-isolated DC-DC converters [1, 2]. These converters help manage and transform energy in systems like solar, electric vehicles, and other renewable sources. The goal of making converters more efficient, with higher voltage gain and fewer parts, has led to new designs. Solar and wind energy are widely used around the world. But, solar panels produce low voltage, making them unsuitable for high-voltage applications [3]. To fix this, DC-DC converters are important. They help increase voltage levels for uses like LED street lighting microgrids, backup power, and medical devices. Different researchers have proposed ways to use coupled inductors (CI) in non-isolated DC-DC converters. One study [6] suggests a Boost-SEPIC design with soft switching to improve efficiency. Another study [7] introduces a converter using a diode-capacitor method and coupled inductors for a high step-up. A similar approach in [8] uses coupled inductors and switched capacitors to reduce current ripple through an interleaved setup. In [9], a high step-up converter with a modified super-lift structure and coupled inductors is introduced, offering better performance without extra components. Coupled inductors are also important in [10], where a converter using SC and coupled inductors increases voltage without more capacitors. Although these converters are successful in boosting voltage, they have some issues. They use a lot of active and passive parts, which causes parasitic resistance in capacitors and inductors, lowering efficiency and voltage gain. They also use low switching frequencies to get high voltage gain, but that requires larger capacitors and inductors. The use of silicon MOSFETs with high internal resistance affects efficiency, and silicon diodes with high reverse recovery currents also lower output voltage and efficiency. As mentioned in [7], changing the turn ratio of coupled inductors to boost voltage gain can increase internal resistance, affecting overall efficiency. In [4, 5], converters with coupled inductors face high voltage spikes on the power switch during off state due to inductance and parasitic capacitance in MOSFETs. A clamped circuit is used to address this [9, 10], but it can reduce efficiency and increase costs because of parasitic effects. With more energy being used in recent years, there has been a growing focus on distributed electric power sources like solar and wind energy, which are green and don’t release carbon dioxide. Compared to big power plants, these sources don't need to be placed in specific locations, making them easier to set up near where the energy is needed, and they can also be used in emergencies. Among these, solar cells are being considered here. However, solar cells have a problem: their power output changes depending on the season, weather, or time of day. To keep the power stable when used with electronic devices, switching power supplies are used because they are efficient and can handle different input voltages. Most switching power supplies use constant voltage control, but sometimes overcurrent or constant current control is needed too[9, 10].

With solar cells, the best power output point varies based on the actual voltage needed by the device being charged, like a battery or a load.One key feature of solar cells is that they act as a constant current source, meaning the output current depends on the fluctuation of the maximum power point. Because of this, the output power is often lower than the maximum possible, and some energy is lost at the maximum power point (MPP). To fix this loss, a maximum power point tracking (MPPT) control is placed between the solar cell and the load. This helps the system run at the best power point all the time, leading to higher efficiency and better charging power [4].

But this method tries to get more power from the solar cells without considering the device being charged well. Controlling how batteries charge and discharge is very important because it directly affects their lifespan. In this paper, we propose a bidirectional DC-DC converter that uses digital control. This converter is designed to resist aging, makes it easy to change the control settings, and uses a common PWM control to provide a constant current in response to changes in input voltage and load[9, 10].The DC-DC converter in [1-7] uses a VM technique to achieve high gain in three modes. In [1-8], a transformer-free design is used that combines a dual boost converter with an SL structure to get high voltage gain without isolation. In [1-9], converters with active and passive SL, SC cells, and an auxiliary switch are suggested for high voltage gain in a non-isolated setup. In [2], (SL)/(SC) networks are used in a high step-up non-isolated DC-DC converter, helping to reduce voltage stress and allowing for even higher voltage gain. Even though these converters can produce high gains, they come with some challenges. A higher duty ratio increases both conduction and switching losses, which lowers power density and efficiency. It also puts more stress on the power switches and diodes, affecting reliability. The use of double inductors and low switching frequencies also introduces parasitic resistance, which harms overall performance.

In [2], a boost DC-DC converter is introduced that uses the voltage lift (VL) technique. It focuses on being simple, having low input current ripple, and providing high voltage gain. In [2], an SL double switch DC-DC converter is suggested for a more compact design and better performance with fewer parts. In [3], a transformer less single-switch high-gain DC-DC converter is presented, which uses a (SC)/(SL) cell and a voltage multiplier stage. In [3], an SL/VM cell is used to create a structure that can be expanded, though it has high current stress. To study high-gain non- isolated DC-DC converters, [2, 3] introduce four new topologies using four-terminal PWM high- gain switch cells with an inductor-switch network (LSN). Although these converters offer higher gain, they face challenges such as issues with different components, which affect the system's efficiency and performance. There is a lot of current stress on the power switches and high voltage stress on the power devices. Also, the complex gate control circuit needs a large amount of space [3-4].This paper introduces a new non-isolated DC-DC converter that aims to achieve ultra-high voltage gain and reduce current stress. It uses a modified double boost mode (MDBM) combined with a modified triple boost technique (MTBT) and a modified switched inductor- capacitor (MSLC). The goal is to get an exceptionally high voltage gain by combining MTBT with two main and one auxiliary MOSFETs, and MSLC. This setup effectively doubles the voltage transfer gain. Additionally, combining the MSLC with the auxiliary third and two main MOSFETs doubles the voltage gain while reducing the voltage stress on the auxiliary MOSFET and diodes in the converter.

(IJIEST) 2019, Vol. No. 5, Jan-Dec e-ISSN: 2454-9584; p-ISSN: 2454-8111

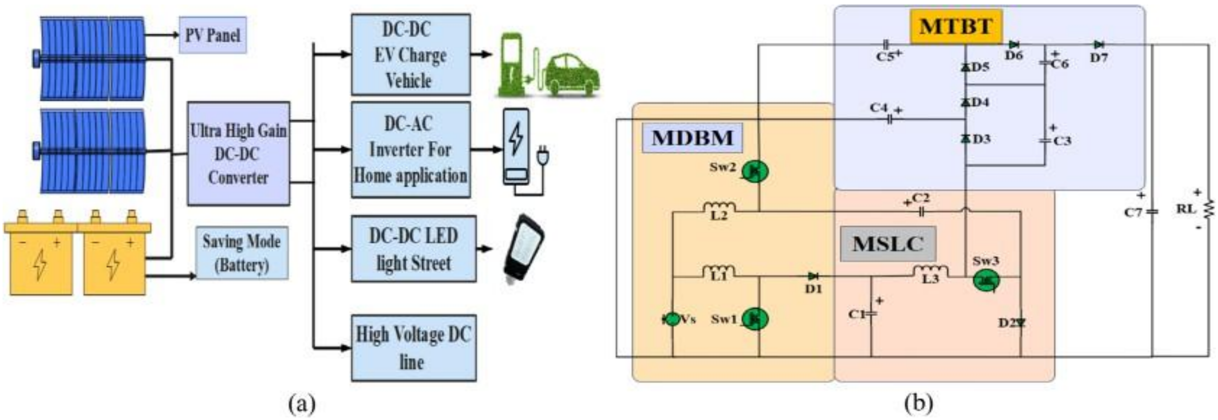

Figure 1: (a) The suggested converter is built for "Saving Mode" operation, allowing it to supply a variety of applications. It is integrated with solar panels (PV) and a battery. (b) The circuit diagram for the suggested converter.

AN EXPLANATION OF HOW A CIRCUIT WORKS

A bidirectional DC-DC converter circuit is shown in Figure 2. The mode charge and discharge of the circuit will be distinguished in the description of its activities that follows[9, 10].

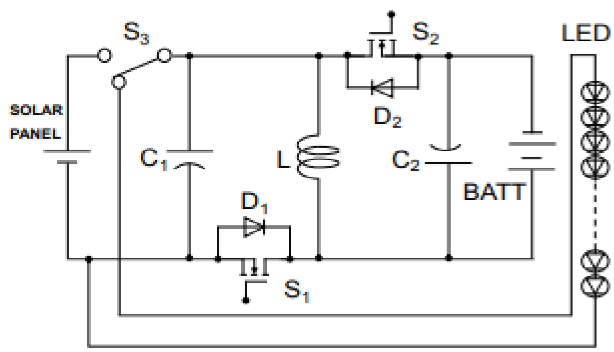

Figure 2: Proposed bidirectional DC-DC converter

A. Principles of operation during discharge mode

(1) In STATE 1, switch S_1 is turned on, switches S_2 and diode D_2 are turned off, and current flows from the input voltage Ei to the inductor L, where magnetic energy is stored[9, 10].

(2) In STATE 2, switches S_1 and S_2 are turned off, and the magnetic energy stored in the inductor L flows through diode D_2 and is released, creating the output voltage Eo.

(3) In STATE 3, switch S_1 is turned off and switch S_2 is turned on, and the magnetic energy that was flowing through diode D2 and released in STATE 2 instead flows through switch S_2 and is released.

(4) After STATE 3, switches S_1 and S_2 are turned off again, and the magnetic energy that was

flowing through switch S_2 now flows through diode D_2 and is released, making the operation similar to that of STATE 2. The system then returns to STATE 1[9, 10].

In Figure 1a, the integration of the photovoltaic converter (PC) with solar panels is shown, showing its potential use in energy saving mode[9, 10].

The converter also has a wide range of output voltages, making it suitable for various applications like charging electric vehicles (EV), powering electric home appliances, high- voltage DC lines, and LED lighting systems. In Figure 1b, the circuit diagram of the proposed converter is presented, which includes three small primary inductors, seven capacitors, and three power switches (with Sw1 as the first main switch, Sw2 as the second main switch, and Sw3 as the auxiliary third switch), along with seven diodes[9]. This circuit is designed to offer several notable advantages. One important benefit is that it doesn't require isolated coupled inductors and transformers, which are usually needed for voltage step-up. A S_iC MOSFET with low on- state resistance is used in the converter, helping achieve very high voltage gain while reducing conduction and switching losses [10]. Using SiC MOSFETs and diodes at a higher switching frequency helps improve efficiency and increase power density, while also reducing switching losses. Operating the converter at a high switching frequency can significantly boost efficiency because it allows for smaller inductors and capacitors[9, 10]. The proposed converter design is easy to implement, and all switches turn on and off at the same time. The design is more reliable, especially in photovoltaic applications, because the input current (Ii) at very low duty cycles has no pulsation. The system also addresses voltage stress on the double primary and third switches, as well as all diodes. The inductors face low voltage stress at high voltage gain, and the current stress on the double main and third auxiliary switches is reduced when the system delivers 440 W at 600 V output voltage with V_s equal to 30 V[6]. Compared to earlier DC-DC converters, the proposed converter aims to achieve a higher voltage gain using fewer capacitors and inductors. The control mechanism is made simpler by having all three power devices turn on and off at the same time, improving the overall efficiency and effectiveness of the suggested converter. Additionally, the gate control circuit is simple and compact in size[7].

THE PC'S OPERATION

The PC operates in two modes: discontinues conduction mode (DCM) (low duty cycle, below 57%) for light load applications and continues conduction mode (CCM) (higher duty cycle, over 57%) for heavier load scenarios (Figure 3) [4-5].

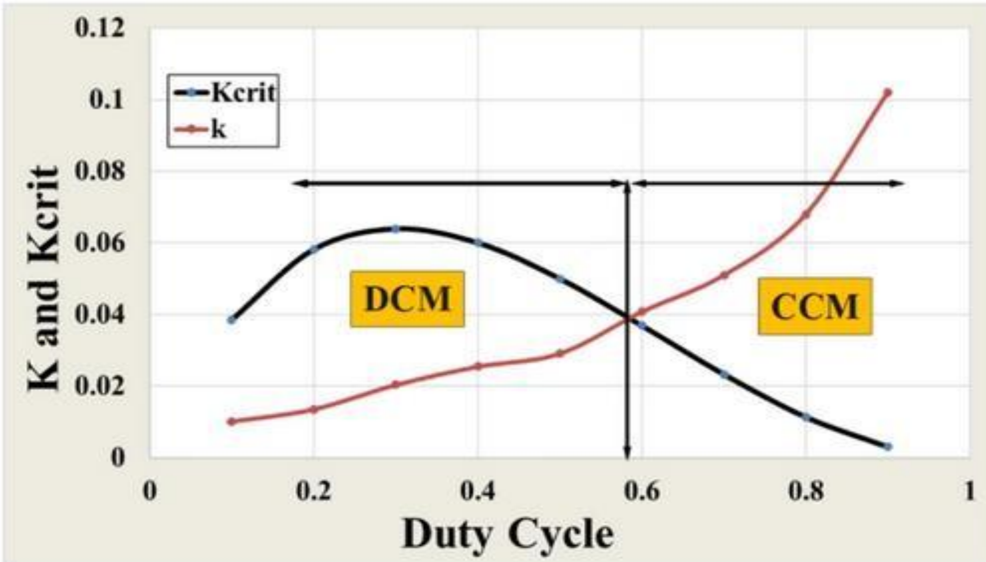

Figure 3: Dynamic performance of the PC Kcrit and K versus D.

Operation of the PC at DCM

In DCM, a CCM is maintained by the input current without pulsations, while L3 operates in DCM when the proposed converter supplies a 600 V output voltage at 440 W. The six operation modes for this scenario are shown in Figure 3a, and the corresponding current waveforms of the converter in DCM are presented[5].

Mode 1: [0 to t0].

Three MOSFETs, Sw_1, Sw_2, and Sw_3, are on. All diodes are off. During this phase, L_1 and L_2 start charging energy from the input source (V_s). At the same time, L_3 begins to store energy from C_1, which is connected in series with it. C_2 discharges current through Sw_2, and this current flows from both L_2 and C_2 during this mode[6].

D_4 and D_6 operate at Z_{CS} during the period m. C_7 discharges its energy to provide current to the load.

The equations during Mode 1 are as follows:

$$\left.\begin{aligned} VL_1 &= Vs \\ VL_2 &= Vs \\ VL_3 &= Vc_1 + Vc_2 \\ VL_2 &= Vc_1 + Vc_3 - Vc_4 \\ Vc_7 &= V_o \end{aligned}\right\} \quad (1)$$

$Ii = iL_1 + iL_2$

$I_{SW1} = iL_1$

$$\left.\begin{array}{l} Isw_2 = iL_2 - Ic_2 \end{array}\right\} \quad (2)$$

$$Isw_3 = Ic_1 = iL_3$$

$$iL_3 = Ic_1$$

$$Io = Ic_7$$

where Vs is the input voltage, VL is the inductor voltage, Vc is the capacitor voltage, V_o is the output voltage, Ii is the input current, iL is the current through the inductor, I_{sw} is the current through the power MOSFETs, Io is the output current, and Ic is the current through the capacitor[9, 10].

Mode 2: [t0–t1]. Three MOSFETs, Sw_1, Sw_2, and Sw_3, remain on. D_1, D_2, D_3, D_5, and D_7 are off. After a period called m, D_4 and D_6 turn on and both operate with zero current switching. During this time, L_1 and L_2 continue charging energy from V_s, and L_3 starts storing energy from C_1. C_7 keeps discharging to provide current to the load[7]. The current through Sw_3 comes from L_3 and is taken away by C_3, which lowers the current through Sw_3. As a result, the current through Sw_2 also decreases. The current through D_4 matches the current through C_4, and the current through D_6 matches the current through C_5. After the current in C_2 decreases, this setup helps reduce the stress on both Sw_3 and Sw_2, allowing the PC to work efficiently [8].It also lowers the conduction loss during this mode. Reducing current stress helps the PC produce very high voltage gain while using a smaller heat sink. This means the PC can be made much smaller. The current equations for the components during Mode 2 are given below. D_4 and D_6 operate at zero current switching during time m, and the value of m is calculated using Equation (5) [9].

$$\left.\begin{array}{l} Ic_5 = Id_6 = Ic_6 \\ Ic_4 = Id_4 \end{array}\right\} \text{from}(0 < t < m) \quad (3)$$

$$-Ic_3 = Ic_6 - Ic_4$$

$$\left.\begin{array}{l} \mathrm{I}sw_3 = iL_3 = Ic_1 - Ic_3 \\ \mathrm{I}sw_2 = iL_2 - Ic_2 \end{array}\right\} \quad (4)$$

$$Where, m = \frac{DTs}{0.69\sqrt{\left(\frac{1}{(C_1+C_2)}\right)(L_2+L_3)}} \quad (5)$$

COMPARISON OF THE PC WITH PREVIOUS HIGH-GAIN CONVERTERS

A comparison was done between the proposed converter and earlier high-gain converters among DC-DC converters. Previous high-gain converters were tested in PLECS and MATLAB software under the same conditions. Also, simulations of the converters shown in Figure 4 were run in both DCM and CCM to check the voltage and current stress on the power devices under different conditions[4]. From Figure 4a, it's clear that the proposed converter has better voltage gain than previous boosting converters. This higher gain at a low-duty cycle means less conduction and switching loss, which improves efficiency. As seen in Figure 4a, the proposed converter can produce a high output voltage by increasing a low input voltage, which is 31 V. This means the duty cycle (Mdc) is 20[9, 10]. Also, the proposed converter can give a higher voltage gain when the duty cycle is around 0.3, as shown in Figure 4a. Looking at Figure 4b, it's clear that the power switches in the proposed converter have lower voltage stress than those in the earlier converters. Lower voltage stress on the power switches also means less switching loss, which increases the efficiency of the proposed converter[8].

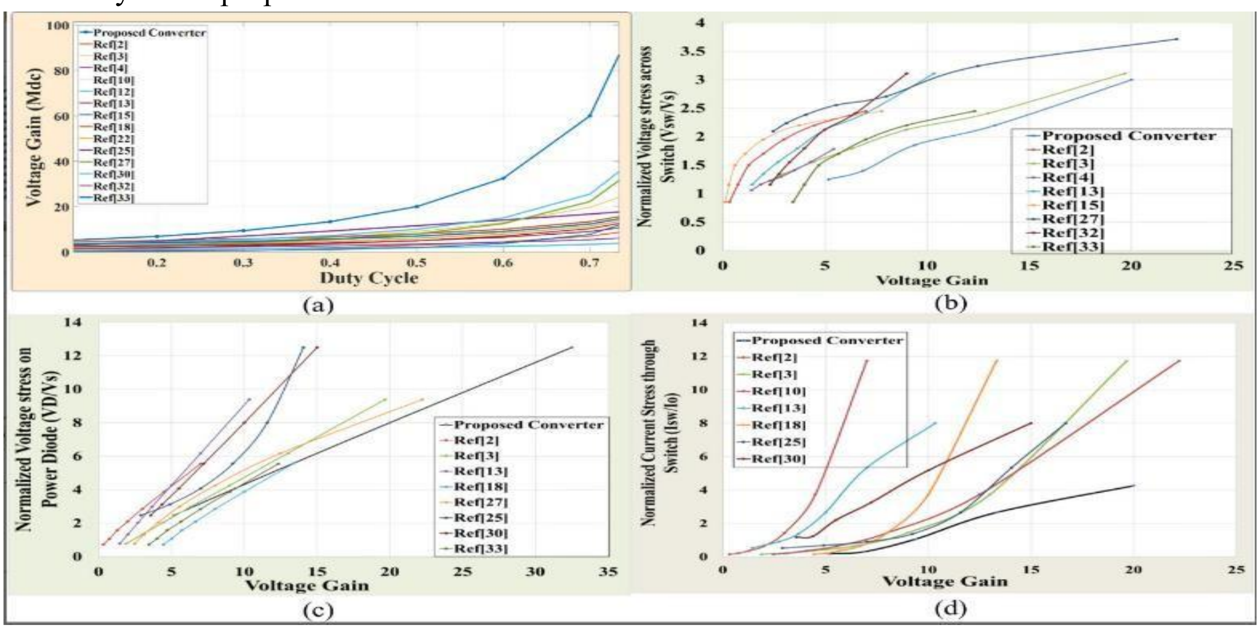

Figure 4: (a) Comparisons voltage gain (Mdc) versus duty ratio. (b) Vsw/Vs versus Mdc; (c) V_D/Vs versus Mdc; (d) Isw/Io versus Mdc.

CONCLUSION

In this paper, a bidirectional DC-DC converter with a digital constant-current control feature was introduced. Experiments were conducted using solar cells, batteries, and LEDs. This setup effectively doubles the voltage transfer gain. Also, the MSLC is combined with extra third and double main MOSFETs, which further increases the voltage gain while reducing the voltage across the auxiliary MOSFETs and diodes in the converter. The key findings are as follows. During discharge, when series-connected LEDs are lit by a battery, brightness changes were removed by using constant current control. During charging, when a battery is charged from a solar cell, current control was used to prevent overcurrent. Overcharging was avoided by using digital control to limit current based on the charging voltage. Based on these results, experiments using solar cells, batteries, and LEDs with the proposed bidirectional DC-DC converter and digital control showed that constant current control can be applied in both charging and discharging modes. Additionally, all diodes in the MTBT operate with zero current switching, ensuring that both the double main and auxiliary third MOSFETs face very low current stress at very high voltage gains. This efficiency is clear when the converter provides 600 V at 440 W with an efficiency of 96.1% at a very low duty cycle. The input current of the converter stays steady and without pulses at a low duty ratio, making the system more suitable for photovoltaic systems.

REFERENCES

Blinov, A., Kosenko, R., Chub, A., & Vinnikov, D. (2018). Bidirectional soft-switching dc–dc converter for battery energy storage systems. IET Power Electronics, 11(12), 2000-2009. https://doi.org/10.1049/iet-pel.2018.5054

Molavi, N., Adib, E., & Farzanehfard, H. (2018). Soft-switching bidirectional DC–DC converter with high voltage conversion ratio. IET Power Electronics, 11(1), 33-42. https://doi.org/10.1049/iet-pel.2016.0771

Moradisizkoohi, H., Elsayad, N., & Mohammed, O. (2018). A soft-switched DC/DC converter using integrated dual half-bridge with high voltage gain and low voltage stress for DC microgrid applications. Inventions, 3(3), 63. https://doi.org/10.3390/inventions3030063

Nayak, P., Rajashekara, K., & Pramanick, S. K. (2018). Soft-switched modulation technique for a single-stage matrix-type isolated DC–AC converter. IEEE Transactions on Industry Applications, 55(6), 7642-7656. https://doi.org/10.1109/TIA.2018.2874527

Varajão, D. A. C. P. B. (2018). Single-stage, bidirectional AC-DC matrix converter for energy storage systems (Doctoral dissertation, Universidade do Porto (Portugal)). https://www.proquest.com/openview/d63f3d831601177b93c91742663c8b4f/1?pq-origsite=gscholar&cbl=2026366&diss=y

Wu, Y. E., & Chiu, P. N. (2017). A high-efficiency isolated-type three-port bidirectional DC/DC converter for photovoltaic systems. Energies, 10(4), 434. https://doi.org/10.3390/en10040434

Wu, Y. E., Huang, K. C., & Li, M. X. (2016). A bidirectional DC/DC converter charge/discharge controller for solar energy illumination system integrating synchronous rectification SEPIC converter and active clamp flyback converter. International Journal of Circuit Theory and Applications, 44(2), 305-327. https://doi.org/10.1002/cta.2079

Yaqoob, M. (2018). Advanced topologies and modulation schemes for high-efficiency operation of dual-active-bridge series-resonant DC-DC converter. https://theses.lib.polyu.edu.hk/handle/200/9798

Zhang, C., Gao, Z., & Liao, X. (2018). Bidirectional DC–DC converter with series-connected resonant tanks to realise soft switching. IET Power Electronics, 11(12), 2029-2043. https://doi.org/10.1049/iet-pel.2018.5269