ISSN: 2581-3404 (Online)
International Journal of Innovative Research in Technology and Management, Vol-4, Issue-2, 2020.

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

Govind Kumar Maurya[1], Prof. Laxman Solankee[2]

[1]M. Tech Scholar, Department of Electrical and Electronics, TIT, Bhopal (India)

[2]Assistant Professor, Department of Electrical and Electronics, TIT, Bhopal (India)

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.

Keywords:- Three-port converter, Multi-input converter, DC-DC converter, High step-up, Soft switching, Hybrid power system.

INTRODUCTION

Nowadays, the diversity in energy generation sources and simultaneous use of several energy sources in one system has made hybrid energy systems more attractive. Hybrid energy systems take advantage of different features of diverse energy sources in power electronic applications, such as increment in integration, reliability, durability, power handling capability and efficiency in comparison to single energy source systems.

Hence the use of multiple energy generation sources with different I-V characteristics and converting the yielded energy into a regulated voltage to meet the load demand in the hybrid energy systems has led to appearance of the multi-input DC-DC converters.

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. 1.

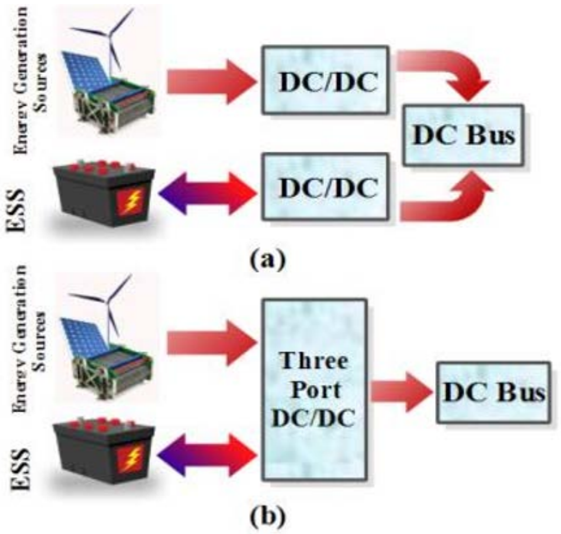


Fig.1.(a). Using typical multiple single DC-DC converters.
(b) Three-port DC-DC converter configuration.

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.

Since most of these energy sources are inherently low voltage, so high step-up techniques are required to increase the voltage gain. To increase the voltage gain, many methods have been proposed [3] such as, coupled inductors, isolated transformers, series capacitors in the power flow path and switched-diode-capacitor structures. By using these methods, the problems associated with the extreme operating duty cycles in the conventional boost converter can be solved and the converter performance is enhanced.

Recently, based on different applications, several isolated [4] and non-isolated [7] topologies on multi-input converters are proposed. The existence of transformers along with additional peripheral circuitry increases the volume, cost and design complexity of isolated converters. Thus, in some applications in which isolation is not required, non-isolated converters are more appropriate.

In recent years, the use of non-isolated high step-up multi-input DC-DC converters in different applications has been increasing and some related issues from different aspects have been addressed in literature. 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 ANALYSIS OF PROPOSED METHOD

2.1 Structure of the proposed converter and operating modes

In this paper, the structure introduction 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. 2.1

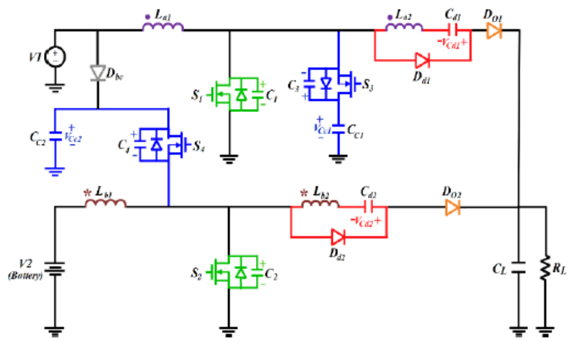


Fig. 2.1. Proposed non-isolated high step-up three-port DC-DC converter.

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.

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 Lk. Also, all semiconductor elements are considered ideal. The key waveforms and the converter equivalent circuits in various intervals are shown in Fig.2.2 respectively.

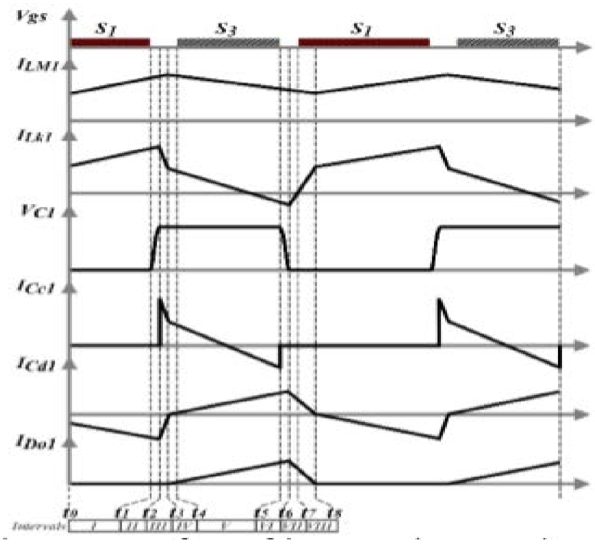


Fig. 2.2 Key waveforms of the proposed converter in ESS discharging mode.

Interval I (t0-t1)

This interval begins when Do1 turns OFF while S1 is still ON and S3 is OFF. During this interval, Lm1 is being charged by V1 and Cd1 is charged through Dd1 and La1-La2 coupled inductors. The LM1 and LLk1 current equations are described by (1) and (2) respectively.

$$i_{Lm}(t) = \frac{V_{Cd1}}{n.L_M}.(t-t_0) + i_{Lm}(t_0)$$
Eq. 1
$$i_{Lk}(t) = \left(\frac{V_1 - \frac{V_{Cd1}}{n}}{L_{Lk}}\right).(t-t_0) + i_{Lk}(t_0).$$
Eq.2

Interval II (t1-t2)

At the beginning of this interval, S1 is turned OFF under ZVS due to C1. Then leakage inductance starts a resonance with C1 and C3 and thus VC1 increases and VC3 decreases.

Proposed method:

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.

Advantages of proposed method:

1. Reducing the number of the converter components.
2. The sharing of the converter components is takes place in proposed method.
3. Due to the sharing of some components in different operating modes, leading to a reduced in component count

Improves the system stability

III SIMULATION RESULT AND DISCUSSION

The complete design related to the project is created in Matlab & Simulation using Sim Power System Toolbox and. This designing is conducted in two stages:

1. To Proposed non-isolated high step-up three-port DC-DC converter for charging modes
2. To Proposed non-isolated high step-up three-port DC-DC converter for discharging modes.

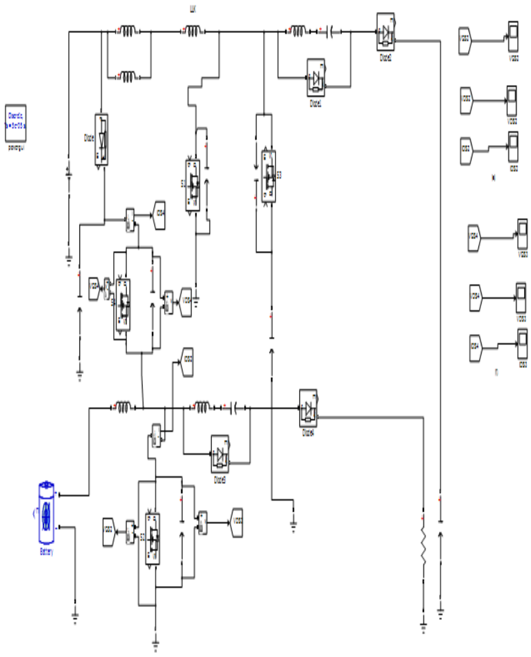


Fig.3.1. Proposed converter in charging modes.

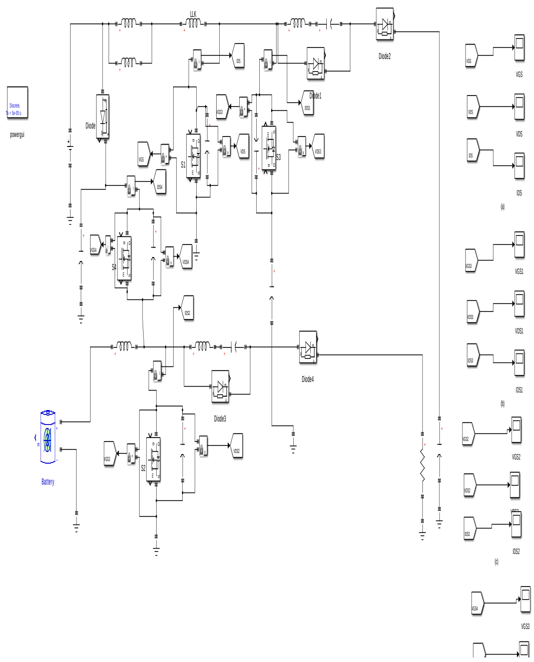


Fig. 3.2. Proposed converters in discharging modes.

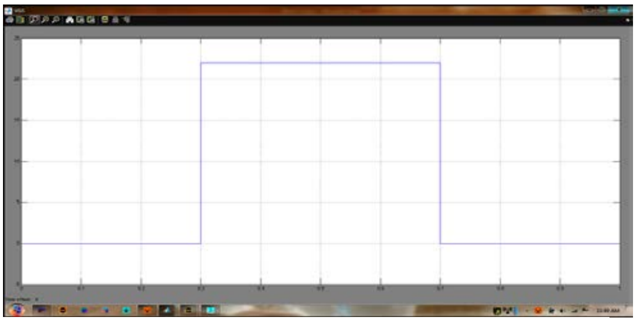


Fig. 3.3 Soft switching conditions of the proposed converter switches.

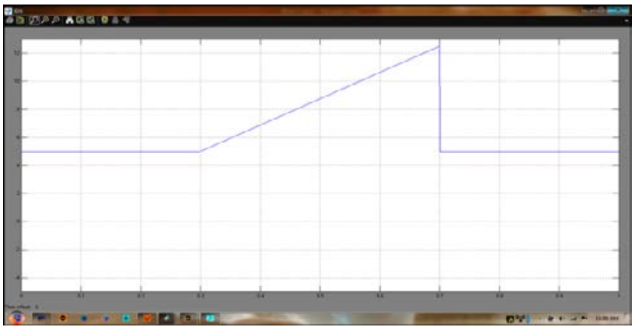
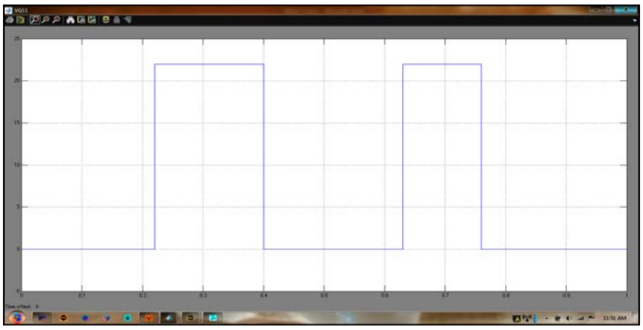
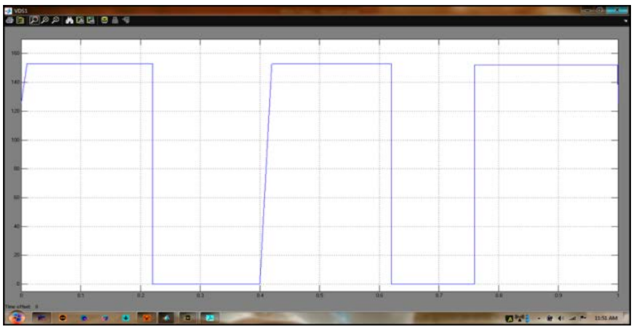


Fig. 3.4 (a) S1 in ESS discharging mode.





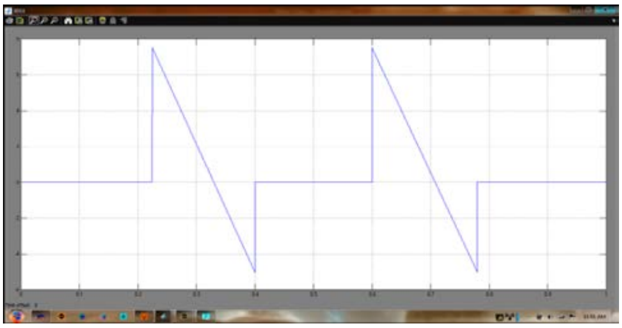
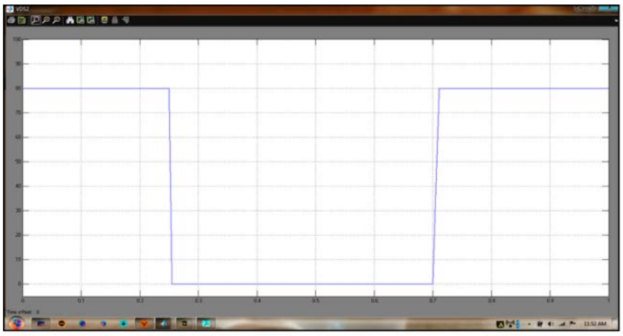
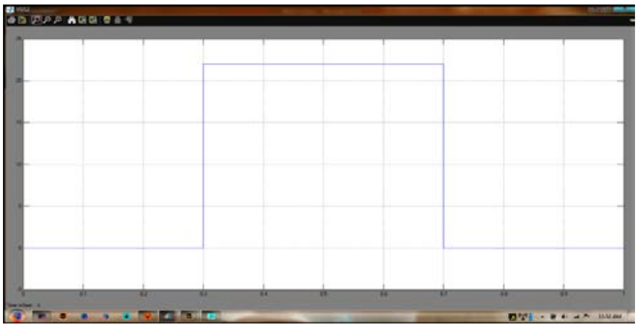


Fig.3.5 (b) S3 in ESS discharging mode.





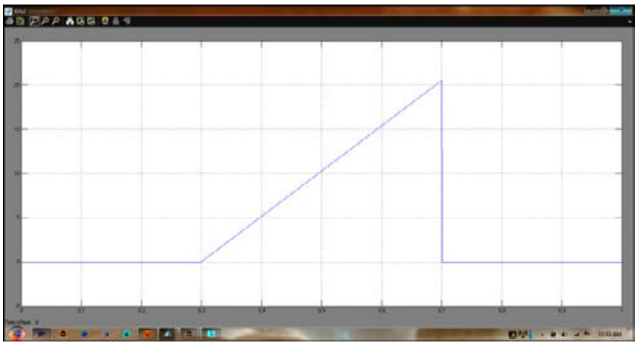
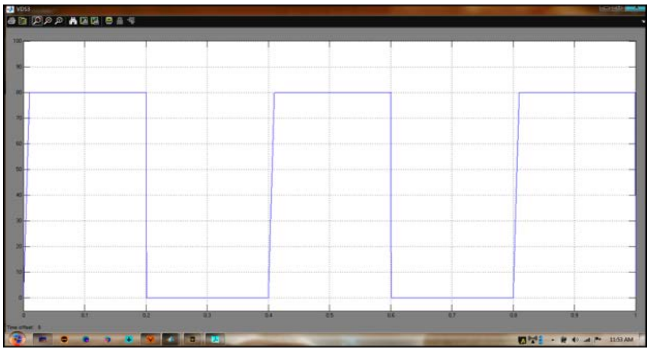
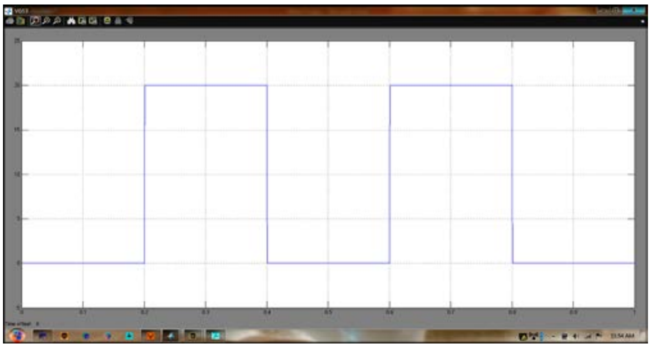


Fig. 3.5 (c) S2 in ESS discharging mode.





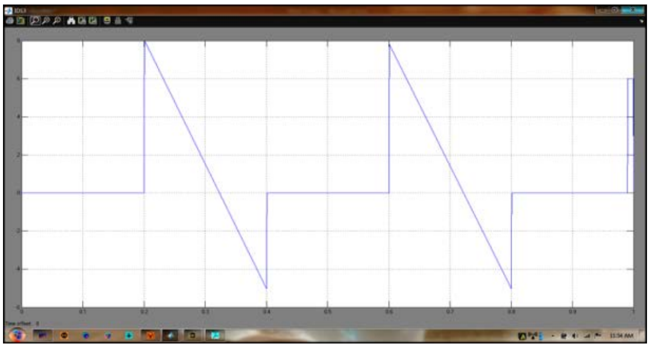
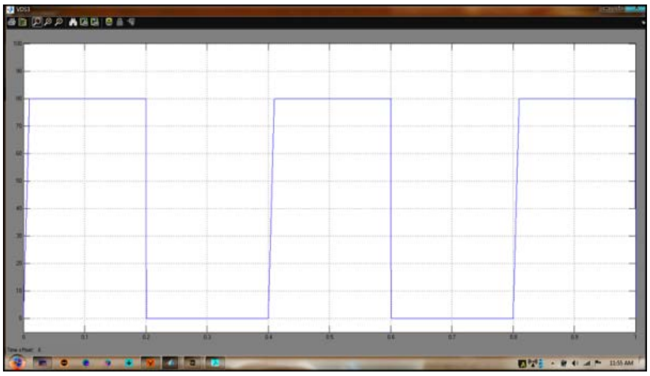
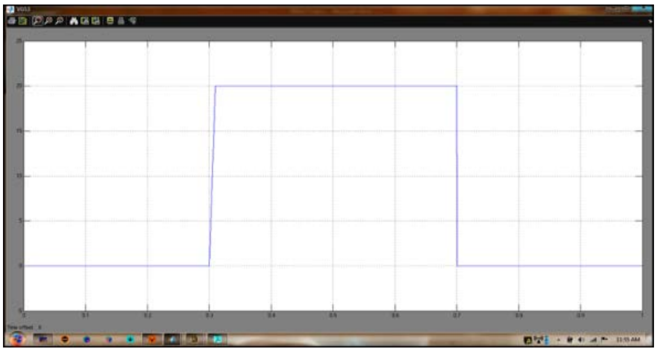


Fig.3.6 (d) S4 in ESS discharging mode.





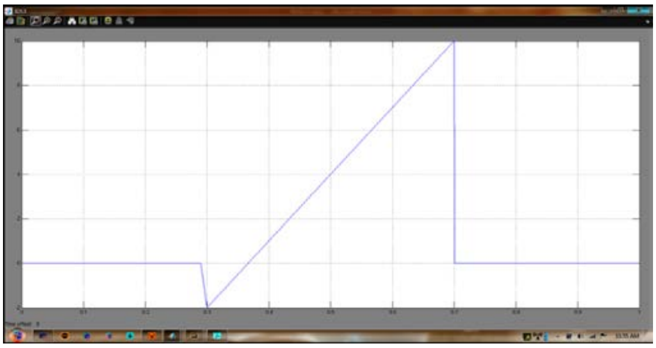
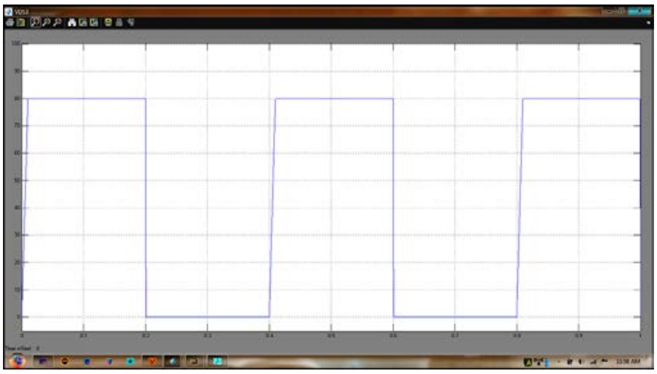
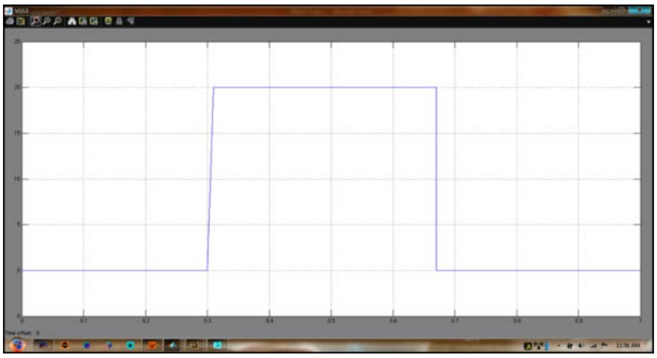


Fig. 3.7 (e) S4 in ESS charging mode.





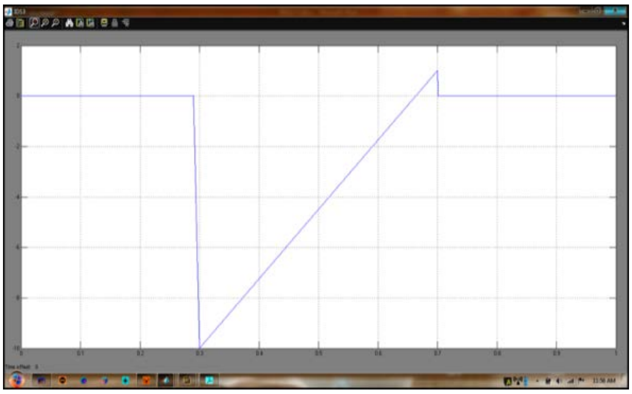


Fig. 3.8 (f) S2 in ESS charging mode.

IV 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 multi-input converter. These features are achieved while providing soft switching condition and eliminating the leakage inductance effect. In addition, the proposed converter achieves high efficiency over a wide load range.

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 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-side-regulated soft-switching full-bridge three-port converter based on bridgeless boost rectifier and bidirectional converter for multiple energy interface," IEEE Transactions on Power Electronics, vol. 31, pp. 4847-4860, 2016.

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

[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, "Multi-input DC/DC converters in connection with distributed generation units–A review," Renewable and Sustainable Energy Reviews, vol. 66, pp. 360-379, 201

[8] Mangu B, Akshatha S, Suryanarayana D, Fernandes BG. Grid-connected PV-windbattery-based multi-input transformer-coupled bidirectional DC-DC converter for household applications. IEEE J EmergSel Top Power Electron 2016;4:1086–95.

[9] Sun X, Shen Y, Li W, Wu H. A PWM and PFM hybrid modulated three-port converter for a standalone PV/battery power system. IEEE J EmergSel Top Power Electron 2015;3:984–1000.

[10] Hu Y, Xiao W, Cao W, Ji B, Morrow DJ. Three-port DC–DC converter for stand-alone photovoltaic systems. IEEE Trans Power Electron 2015;30:3068–76.

[11] Piris-Botalla L, Oggier GG, Airabella AM, García GO. Power losses evaluation of a bidirectional three-port DC–DC converter for hybrid electric system. Int J Electr Power Energy Syst 2014;58:1–8.

[12] Li W, He X. Review of nonisolated high-step-up DC/DC converters in photovoltaic grid-connected applications. IEEE Trans Ind Electron 2011; 58:1239–50.

[13] Tofoli FL, de Castro Pereira D, de Paula WJ, JúniorDdSO. Survey on non-isolated high-voltage step-up dc–dc topologies based on the boost converter. IET Power Electron 2015; 8:2044–57.

[14] Meneses D, Blaabjerg F, Garcia O, Cobos JA. Review and comparison of step-up transformerless topologies for photovoltaic AC-module application. IEEE Trans Power Electron 2013;28:2649–63.

[15] Molavi N, Adib E, Farzanehfard H. Soft-switched non-isolated high step-up DC–DC converter with reduced voltage stress. IET Power Electron 2016.

[16] Adib E, Farzanehfard H. Zero-voltage transition current-fed full-bridge PWM converter. IEEE Trans Power Electron 2009;24:1041–7.

[17] Lin BR. Hybrid soft switching converter for DC grid applications. Electr Power Syst Res 2017;150:84–95. [20] Hu Y, Cao W, Finney SJ, Xiao W, Zhang F, McLoone SF. New modular structure DC–DC converter without electrolytic capacitors for renewable energy applications. IEEE Trans Sustain Energy 2014;5:1184–92.

[18] Arshadi SA, Poorali B, Adib E, Farzanehfard H. High step-up DC–AC inverter suitable for AC module applications. IEEE Trans Ind Electron 2016;63:832–9.

[19] Poorali B, Torkan A, Adib E. High step-up Z-source DC–DC converter with coupled inductors and switched capacitor cell. IET Power Electron 2015;8:1394–402.

[20] Tseng K, Liang T-J. Novel high-efficiency step-up converter. IEE Proc-Electr Power Appl 2004; 151:182–90.