ISSN 2277–5528

Impact Factor- 4.015

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & MANAGEMENT

Design and Analysis of Dual Input DC-DC Converter for Integration of Multiple Energy Sources

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Abstract

The proposed dual input DC-DC converter topologies are introduced for two input energy sources. The converters have the capability to simultaneously deliver power to the load, from the input energy sources. The major advantages of the improved converter as compared to the basic topology are its capability to perform the buck, boost and buck-boost modes of operation using the same structure and the ability to deliver power to the load, even with the failure of any one of the input energy sources. Hence the detailed software simulation of the improved converter has been performed using MATLAB/Simulink platform. The state topology is individually presented from the buck, boost and buck boost operation of converter which indicates the integration of two renewable energy sources. The proposed converters have certain merits like less component count, compact structure and efficient energy utilization, compared to existing converter topologies which are already reported in the literature.

Key Word- Dual input Converter (DIC); multiple sources; Buck Boost operation; DC-DC converter.

1. Introduction

There has been a growing differential between the world energy needs and the amount of energy tapped into through various technologies. Today, Distributed Energy Resources (DER) has become quite promising in terms of meeting the world's energy needs of the future as against

Centralized Energy Resources (CER) of the past. More specifically the CER were the crude oil, natural gas and other forms of non-renewable sources of energy which are contributing aggressively to the climatic change and environmental adversities. Furthermore, the high cost of installing transmission lines and larger security concerns have made CER technologies uneconomical in especially the developing countries where there are pockets where grid is currently unavailable. Additionally, there has been technological advancement in terms of smaller generators, power electronics and storage systems which is paving the way for further development of DER. An added advantage of such development of DER is that the intended load is closer to the generation and hence transmission line loss is saved. It must also be appreciated that no CER energy resource presently exists that meets all the economic, social, and environmental requirements. Rather the renewable forms of energy are environmental friendly, are ubiquitous, are used as a source of income and industrial development. Consequently, there has been greater emphasis than ever on development of renewable sources of energy. And many governments globally are incentivizing use of renewable energy to cater to the energy gap, to stabilize the current grid, to create micro-grids where the grids are unavailable etc. This has led to a global-scale encouragement to development of DER.

While many commercial and industrial (C&I) enterprises are drawn to the sustainability and resilience advantages of energy storage, the technology is becoming increasingly valuable for its ability to create financial value by supporting multiple demand-side management strategies. One of the most important benefits of a well-designed and optimized energy storage system (ESS) is the opportunity for "stacking services," i.e. leveraging the same equipment, system, or process to deliver multiple benefits that maximize the financial impact. Some examples of these services include:

- **Demand response:** Businesses can leverage an ESS to create revenue by participating in demand response programs, while minimizing energy curtailment required at the site level.
- **Time-of-use charge management:** An ESS can enable businesses to avoid daily peak prices

by reducing grid demand in line with energy providers' time-of-use periods.

- **Demand charge management:** With an ESS, businesses can reduce costly demand charges that account for a significant amount of annual energy costs by reducing demand at the right time.

2. Objective:

As already discussed, the future of energy technology is greatly dependent on the evolution of improved techniques for hybridization of two or more different energy sources. In the earlier versions of hybridization, different categories of sources were combined through separate dc-dc converters and their outputs connected in series or parallel. Such arrangements of multiple input converter (MIC) topologies had limitations the remnants of which are of selection of voltage levels, limitation in the operating modes, switching scheme complexity, improper selection of switches, and inadequacy in analysis and component counts. Consequently, there has been an important role played by power electronics for better utilization of power through power conditioning. Quite apart from the reminisces of issues with MIC / DIC topologies, the inverters are required to maintain the voltage and frequency essentially constant at the consumer's terminal to ensure the system stability and satisfactory transient performance. There is various control methodologies reported in different literatures regarding the inverter control, operating in stand-alone mode. The repetitive control technique suffers from its incapability to deal with the disturbances which are periodic in nature, besides that it also claims large memory for its functionality. The robust control (H-infinity control) technique, although capable of providing a good balance between system performance and stability margin, the two desirable but incompatible features of the system, suffers the difficulty of not being implemented on digital processors also they possess complexity in their design specifications. Present work takes care of all the above-mentioned frailties in incremental stage first by implementing the solution through a DIC in which the energy storing units Battery and then connected to the PV source.

A bidirectional conducting and bidirectional blocking (BCBB) switch is used in designing the DIC, instead of bidirectional conducting and unidirectional blocking (BCUB) switch. The above-mentioned changes take care of defective operating state related to undesired conduction of the BCUB switches under the event of reverse bias being applied across them. The developed DIC is utilized to integrate a solar PV source with a storage battery source. The converter has the ability for power transfer from the sources discreetly or concurrently by connecting the sources in any mode: series or parallel. The converter also offers the effective control of flow of power between the sources and the load. Furthermore, the proposed converter is proficient in power flow in directions and buck, boost, buck-boost operation modes. Compact design, versatility in control of power and selection of voltage source with least part count are still the other features of the proposed converter.

3. Working States

The possible working states extracted from proposed converter of as shown in Figure. 1. The delineation of all working states are as follows;

State-I: In this state, the driving pulse is applied to switch T_1 while switches T_2, T_3 and T_4 are kept in the OFF state. The turning on of switch T_1 connects the source E_1 to the supply end of the inductor. The load is thus connected to the source E1 through inductor. As a result of switch T_1 conduction, the potential at the input terminal of the inductor is at the higher potential than that at the common terminal of the load which places a reverse bias across diode D_1. The inductor stores the energy in its electromagnetic field and the capacitor is charged at the same time the load is also supplied with the power through source E_1 acting alone.

State-II: In this state, the driving pulse is applied to switch T_2 while switches T_1, T_3 and T_4 are kept in the OFF state. The turning on of switch T_2 connects the source E_2 to the supply end of the inductor. The load is thus connected to the source E_2 through inductor. As a result of switch T_2 conduction, the potential at the input terminal of the inductor is at the higher potential than that at the common terminal of the load which places a reverse bias across diode D_1. The inductor stores the energy in its electromagnetic field and the capacitor is charged at the same time the load is also supplied with the power through source E_2 acting alone.

State-III: In this state, the driving pulses are applied to switch T_3 while switches T_1, T_2 and T_4 are kept in the OFF state. The turning on of switch T_3 brings the source E_1 in series with source E_2 and combination of both the sources are connected to the supply end of the inductor. The load is thus connected to the series combination of the sources E_1 and E_2 through inductor. As a result of switch T_3 conduction, the potential at the input terminal of the inductor is at the higher potential than that at the common terminal of the load which places a reverse bias across diode D_1. The inductor stores the energy in its electromagnetic field and the capacitor is charged at the same time the load is also supplied with the power through the combined sources E_1 and E_2 acting collectively in series.

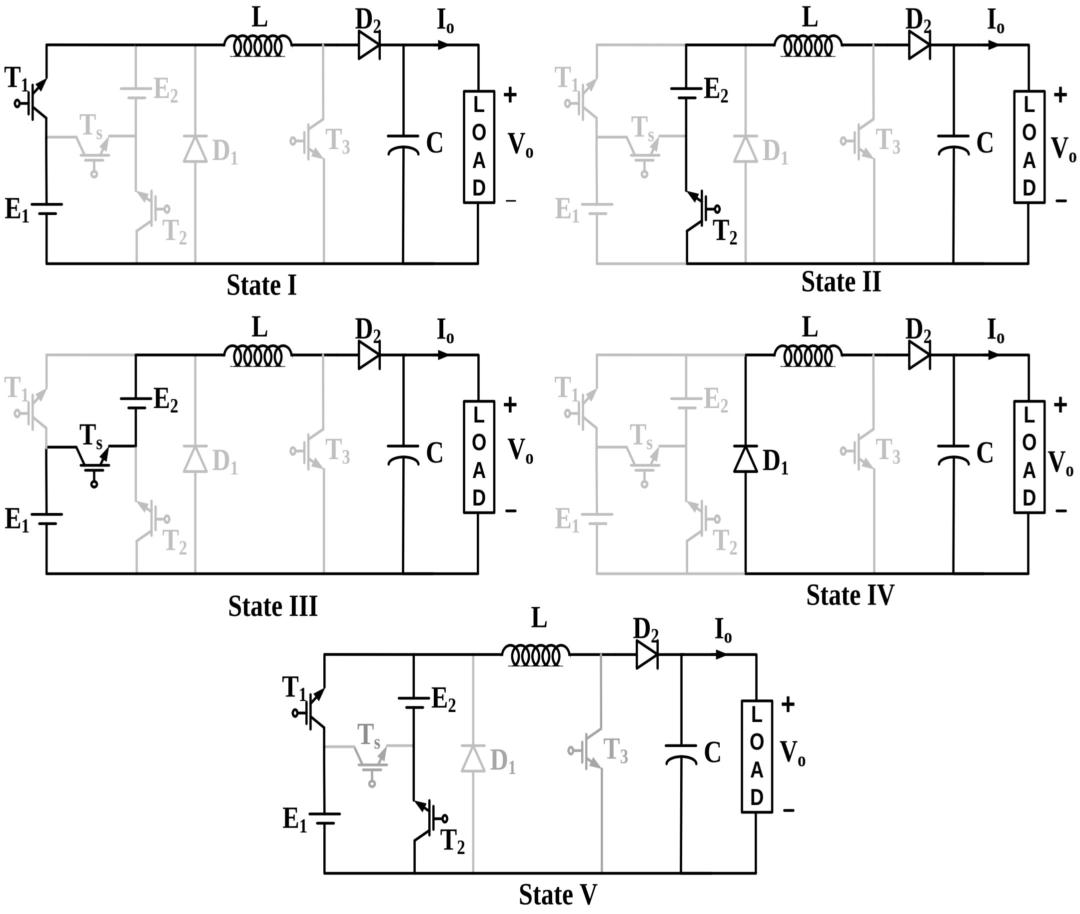

Figure 1: Different Working states of proposed converter

State-IV: This is freewheeling state where the stored energies in the energy storing elements are being freewheeled. The inductor current finds the path through diodes D_1 and D_2 however the capacitor being directly connected to the load supplies its energy directly to the load. All the other switches are in the relax state and not being provided with any switching signals. This time period is also termed as T_{OFF} period.

State-V: With the aim to bring both the sources operating in parallel, the driving pulses are applied to switches T_1 and T_2 simultaneously whereas switches T_3 and T_4 are kept in the OFF state. The turning on of switches T_1 and T_2 bring the source E_1 in parallel with source E_2 and combination of both the sources are connected to the supply end of the inductor. The load is thus connected to the parallel combination of the sources E_1 and E_2 through inductor. As a result of switches T_1 and T_2 conduction, the potential at the input terminal of the inductor is at the higher potential than that at the common terminal of the load which places a reverse bias across diode D_1. The inductor stores the energy in its electromagnetic field and the capacitor is charged at the same time the load is also supplied with the power through the combined sources E_1 and E_2 acting collectively in parallel. This state is brought into action whenever there is a demand of higher current from the load under such situation the sources are brought in parallel which increases the current supplying capability of the source and as far as voltage is concerned the higher voltage amongst the two sources E_1 and E_2 plays the dominant role and the state resembles the operation of either state I or state II depending upon the voltage magnitude. If the magnitudes of the voltage source are taken to be same then both the voltage source will deliver the energy together.

Table 1: Different working states of Proposed Converter (E2 > E1)

Working States	**ON State Switch**	**Active Energy Source**	**Inductor Voltage**	**Inductor status**
State- I	T_1, D_2	E_1	$E_1 - V_o$	Charging
State-II	T_2, D_2	E_2	$E_2 - V_o$	Charging
State-III	T_1,T_2,D_2	$E_1 + E_2$	$E_1 + E_2 - V_o$	Charging
State IV	T_1 & T_2	E_1 or E_2	(E_1 or E_2)- V_o	Charging

State-V	D_1,D_2	-	-V_o	Discharging

4. Simulation Results of Proposed DIC

The simulation study and experimental verification of the proposed dual input converter is accomplished utilizing two asymmetrical dc voltage sources. The study is first performed by making the simulated converter work in buck mode then boost mode and finally for the buck-boost mode. The proposed concept is validated through the results obtained from experimental work. The results obtained through the simulation and experimentation are evaluated for uninterrupted continuous mode of current conduction in both steady as well as transient states. The experimental results are obtained through performance of experimental work. The developed setup, to perform experiments, comprised of two dc sources with different working voltage ratings; dSPACE 1103 real time digital controller for generation of driving pulses for the IGBT switches and to establish real time system interfacing. Switches $T_1$to$T_4$are taken from STGW30NC120HD IGBT module and diodes D_1 and D_2 are 16KSR14. The switching strategy chosen for both simulation and experimental validation for the converter switches is the intermediate synchronization of switching pulse scheme. Table 2 summarizes the parameters and their values used in the simulation and experimentation. The values of inductance and capacitance are kept same for all modes of operation consequently deviation in percentage ripple content can be observed for different operating modes. However desired percentage of ripple content can be achieved with properly choosing the value of inductor and capacitor.

Table 2: Simulation and Experimental parameters for two input dc/dc converter

	E_1 [V]	**E_2 [V]**	**d_1 [%]**	**d_2 [%]**	**d_3 [%]**	**L [mH]**	**C (S/E) [μF]**	**f [kHz]**	**R(S/E)** [Ω]	**V_0 (S/E)**

										(V)
Buck	90	60	40	40	-	4	1.26/1100	10	10	62/58
Buck-Boost	90	60	40	40	60	2	60/1100	10	10	152/145
Boost	90	60	60	60	60	2	60/1100	10	10	185/203

4.1. Simulation and Experimental Results of Proposed DIC in Buck Mode

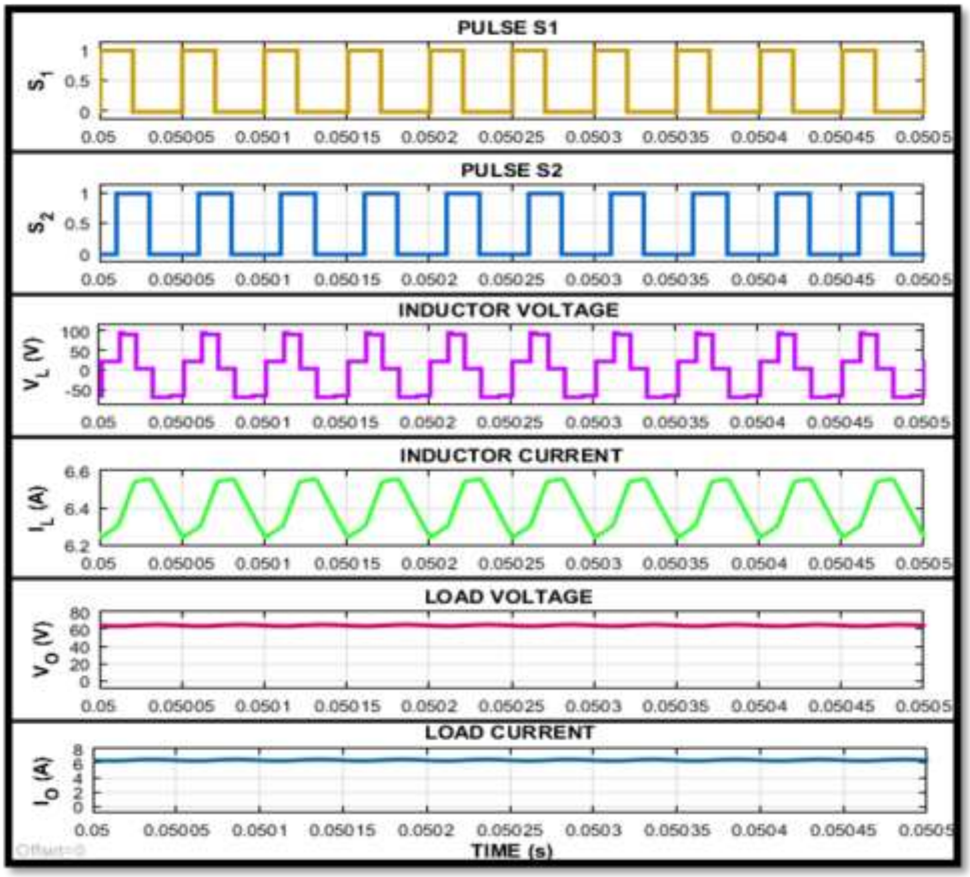

Figure 2: Switching signals S1 and S2; voltage across inductor and current through inductor; voltage across load and current through load for converter operation in Buck mode (Simulation)

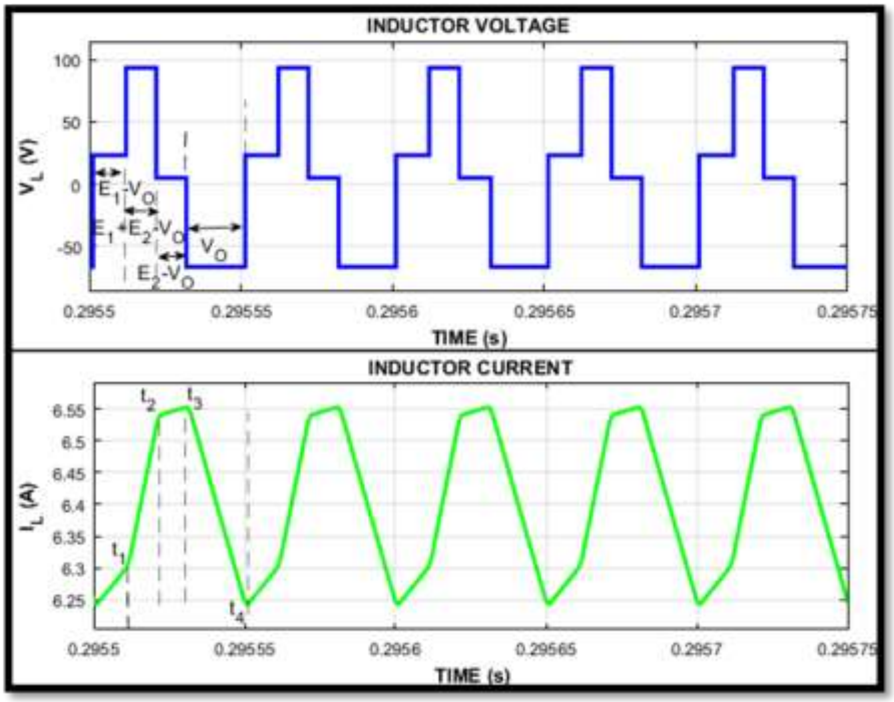

Figure 3: Inductor voltage and current for converter operation in Buck mode (Simulation)

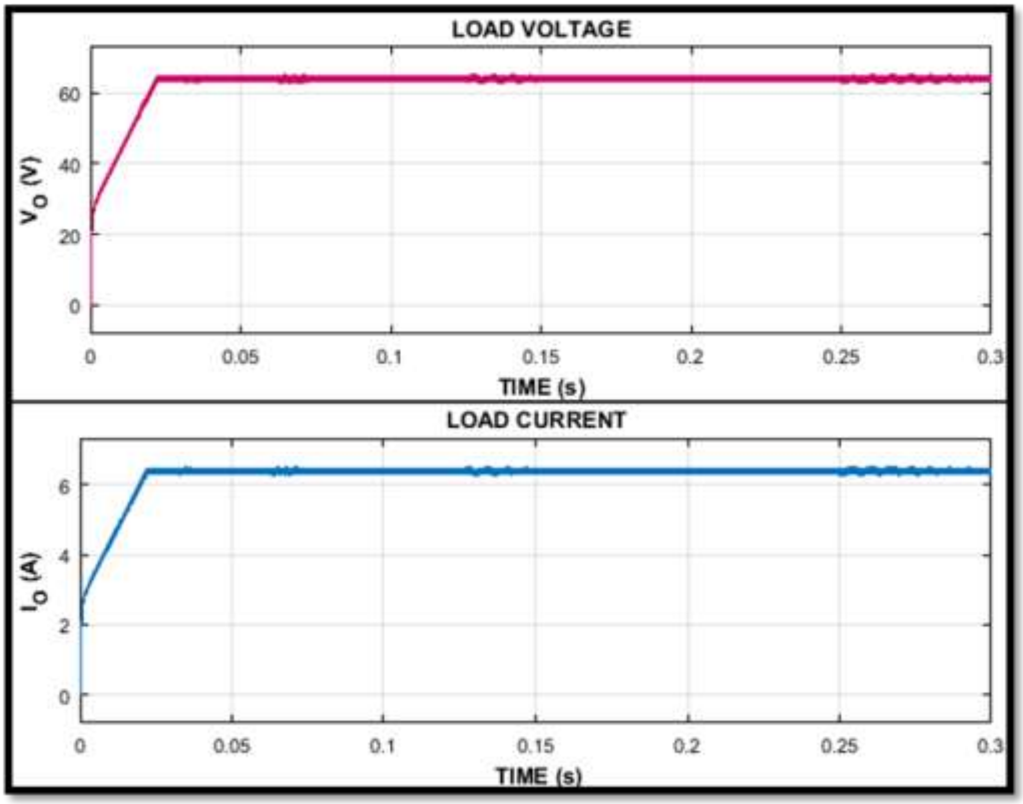

Figure *4*: Load voltage and current for converter operation in Buck mode(Simulation)

Simulation and Experimental Results of Proposed DIC in Boost Mode

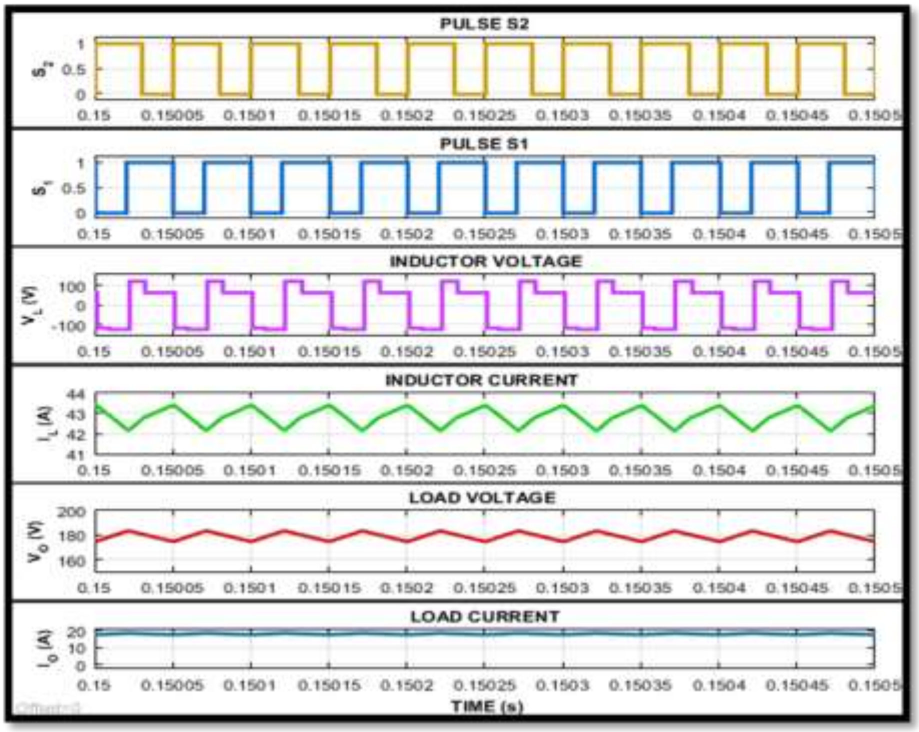

Figure 5: Switching signals S2 and S1; voltage across inductor and current through inductor; voltage across load and current through load in Boost mode

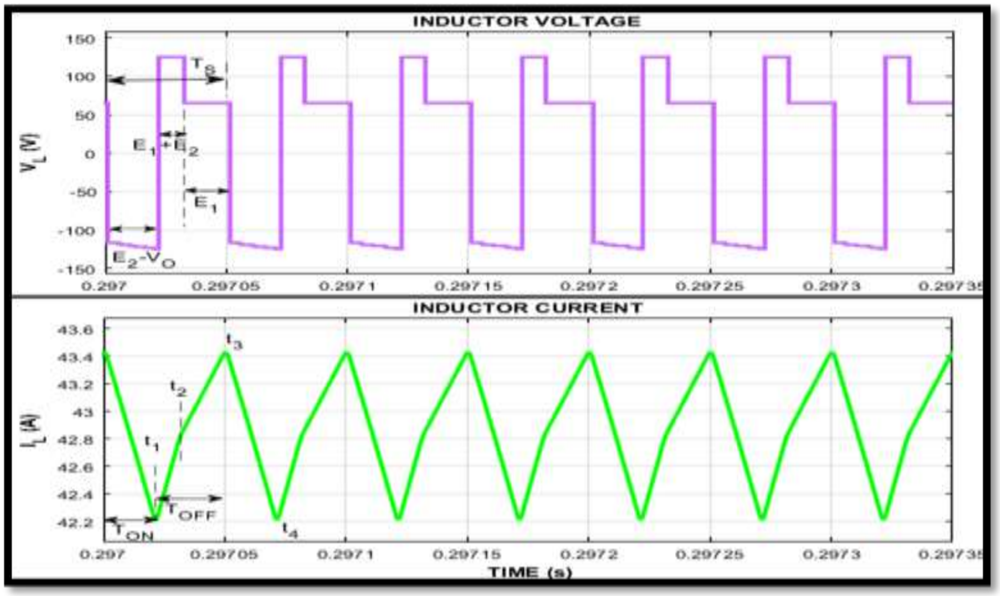

Figure 6: Voltage across Inductor and current through Inductor for converter operation in Boost mode (Simulation)

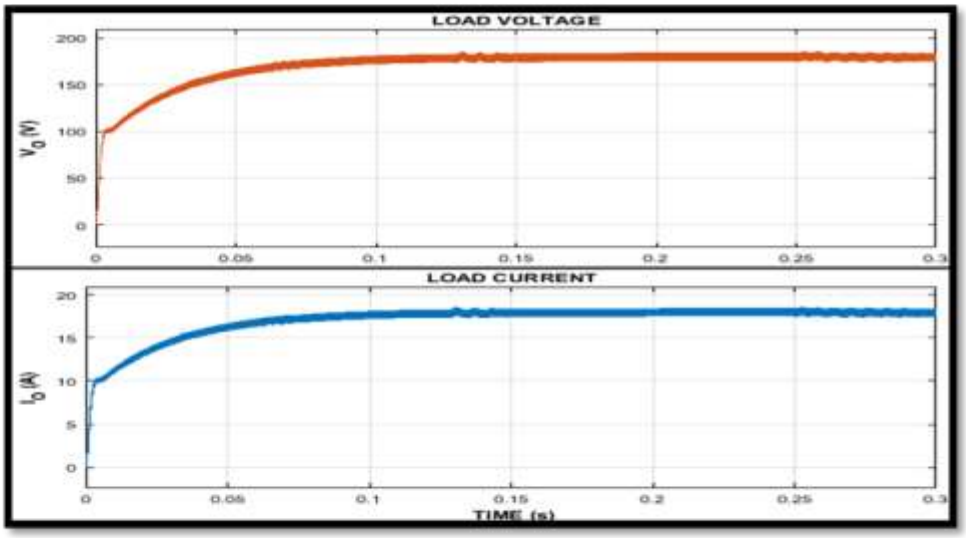

Figure 4.6: Voltage across load and current through load for converter operation in Boost mode (Simulation)

4.2. Simulation Results in Buck-Boost Mode

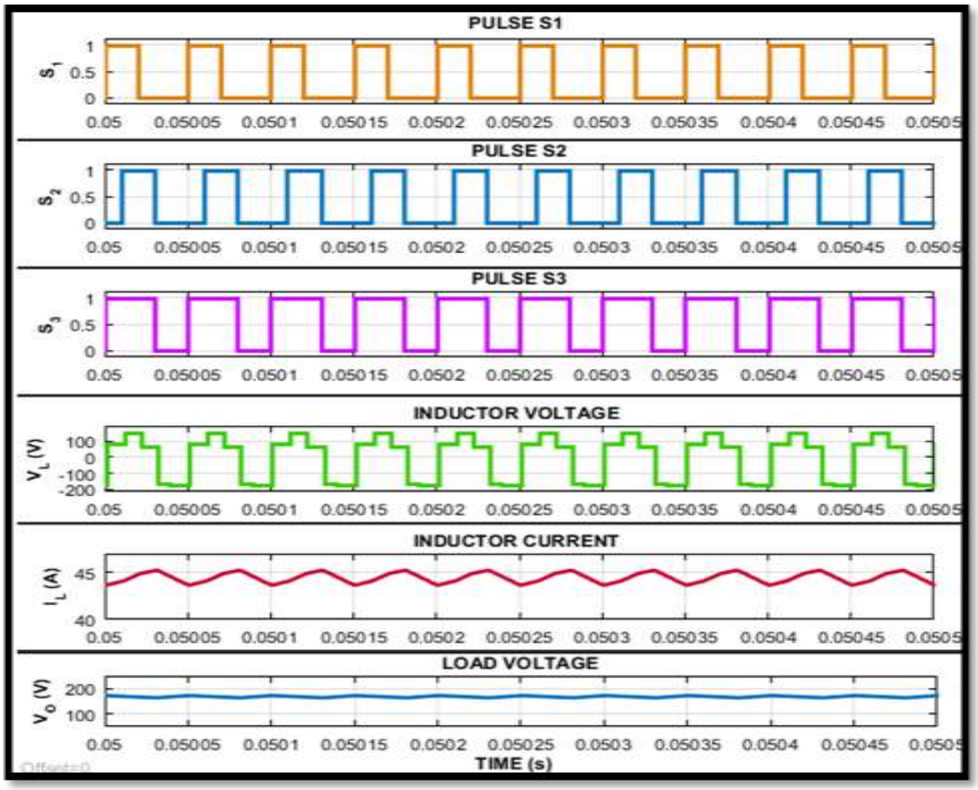

Figure 4.7: Switching signals S1 and S2; Voltage across Inductor, Current through Inductor; Voltage across load and current through load for operation in Buck Boost mode(Simulation).

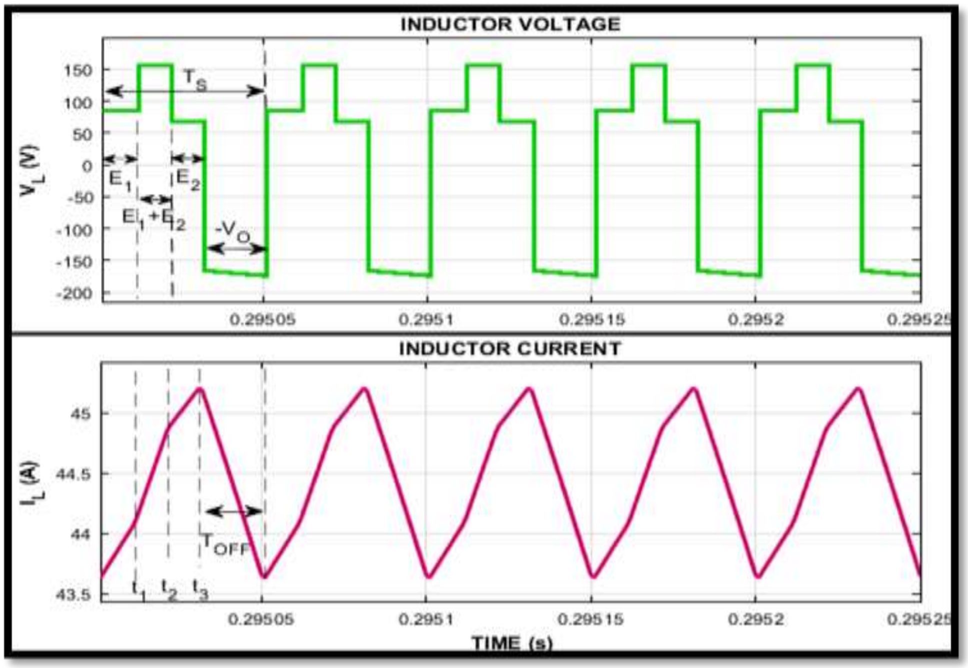

Figure 4.8: Voltage across Inductor, current through Inductor, for converter operation in Buck Boost mode (Simulation)

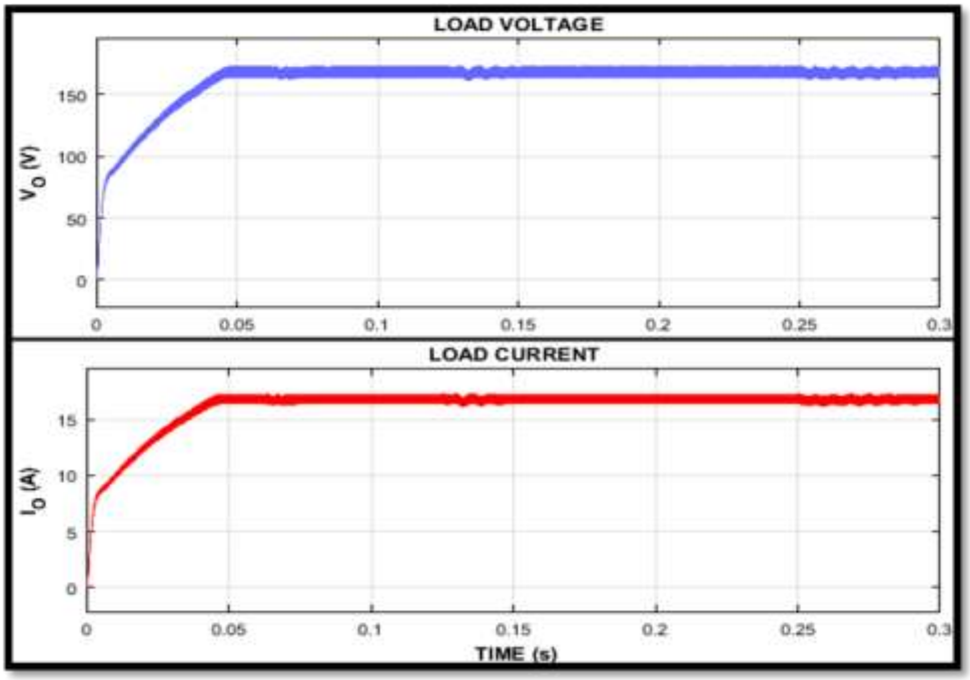

Figure 4.9: Voltage across load and current through load for converter operation in Buck Boost (Simulation)

5. Conclusion

Double Input Converter (DIC) and works equally well as a buck converter, as a boost converter and as a buck-boost converter along with a facility of connecting the load individually or collectively in series (or parallel) as per requirement of the load. The formulation of mathematical equations followed by theoretical analysis is done separately for both the converters with source side and load side voltages and currents under steady state, continuous conduction mode of operation. The successful operation of the presented DIC is due to the extensive simulation and mathematical study of converter functioning in as a buck converter, as boost converter and as a buck-boost converter. From the results obtained through simulation work it could be concluded that the proposed converters are proficient in not only collecting energy from the different sources with different characteristics (PV and Battery in present case), but it also offers higher degree of source electability, flexibility and availability. Amongst these, the other attributes of the converter include hassle free integration of the renewable energy sources and enhance the power sharing capability of the hybrid energy system.

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