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Optimizing the performance of Triple Input DC-DC converter in an Integrated System

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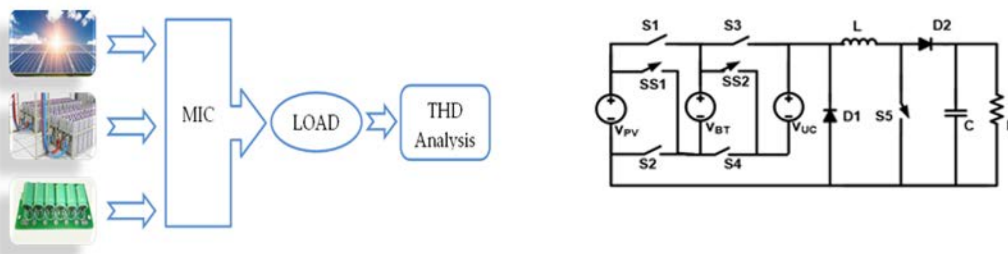
ABSTRACT



Power electronic converters are absolutely necessary for the notion of a hybrid energy system to integrate hybrid energy sources (HES). In this paper, a triple input DC-DC converter with buck-boost operating ability is presented. Multiple energy sources with various I-V characteristics can be integrated using the converter. Using the voltage-second concept, the output equation of the converter is determined from various operational conditions. The MATLAB / SIMULINK software was used to develop and simulate this converter topology. For the purpose of assessing the performance of the converter three different input sources with various voltage levels of 40 V, 30 V, and 16 V are used. Additionally, the adeptness profile of the proposed converter under different loading conditions has been examined, and this analysis demonstrates clearly that the converter under discussion has a high level of efficiency.

Keywords: Multi input Converter, DC - DC Converter, HES, MATLAB / Simulink

INTRODUCTION

The last twenty years have seen the uses of RESs (renewable energy sources) in the generation of energy. However, many RESs, particularly in rural regions, are used as standalone systems. Renewable energy sources are unlimited by nature, sustainable, environmentally benign, etc., but it is impossible to produce reliable electricity from stand-alone sources. An alternate solution to the aforementioned issue is to combine multiple renewable energy sources into a Hybrid Renewable Energy System (HES). In order to reliably power the load and extract the most energy from the sources, this effort attempts to create a three input DC-DC converter. The issues with power generation from various energy sources individually are addressed in large part by HES. Therefore, the HES is a very promising technology that can accept many non-conventional energy sources with similar or varied voltage-current characteristics to satisfy the varying needs of rural and urban areas for power. For the creation of HES, non-conventional sources and storages such as solar-PV, wind, battery, ultracapacitor, fuel cell, etc. are heavily exploited. [1–4]

For various energy source conversions, a new topology is provided. Sources different voltage-current characteristics to a single load while maintaining a low part count that topology is suggested. Analyzing the resulting operating modes, a fixed frequency switching method is examined. Experiments are used to confirm the analysis. The results indicate that the converter is a technology that makes power variation and optimization possible.[5] Additionally, a very effective dual-input interleaved DC/DC converter is suggested in paper.[6] The main obstacle to the bulk production of HEVs and EVs continues to be the need for a small, light, and efficient energy storage system. The charge controller circuit for the battery receives power from the rectifier's unregulated dc output, different energy storage system are discussed.[7,8]

Depending on whether it is charging or discharging, the system-connected battery bank can act as a load or a source of power.[9] A multiple input dc-dc power converter is given; the proposed configuration for the propulsion system includes an electric

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generator (EG), an ultra capacitor tank (UC), and battery systems.[10] It describes the design elements of a multiple input DC-DC converter. Furthermore, the selection of storage devices and their dimensions are described.[11] The findings of the simulation have been used to validate the frequency domain analysis of the proposed system. The method of creating a suitable control strategy for the MIC dedicated to HEV application is covered in paper.[12] Here, the MIDC converter effectively controls the power flow between the associated energy sources. An in-depth explanation of the efficiency analysis of multiport DC-DC converters used for EV applications is provided.[13] For power conditioning of alternative energy sources and applications, such as HEVs, novel power conversion architecture is presented.[14] Recently, some converters have been proposed as PV and renewable energy interfaces.[15–18] A multi-input converter (MIC) may deliver power to the load from many energy sources either simultaneously or separately.[19–21] It has been suggested to use a methodical process to create MICs.[22]

For HEV applications, proposes a dual input DC-DC converter with a single stage power conversion.[23] The simulation studies have been carried out using the mathematical model of the converter. A brand-new MIDC converter with the ability to transfer power both ways is suggested.[24] The suggested converter offers a wide fluctuation in input voltage range and is capable of handling active power sharing between the connected energy sources to the load. A high voltage gain three input boost type DC-DC converter is described.[25] The proposed converter has a complicated structure and a high part count, which makes the system bulky, raises the cost, and decreases efficiency. The examination of the proposed three input DC-DC converter is covered in the parts that follow. The suggested TIC topology is depicted in Figure 1, the load is fed by three sources, either sequentially or simultaneously, each with a different voltage current characteristic.

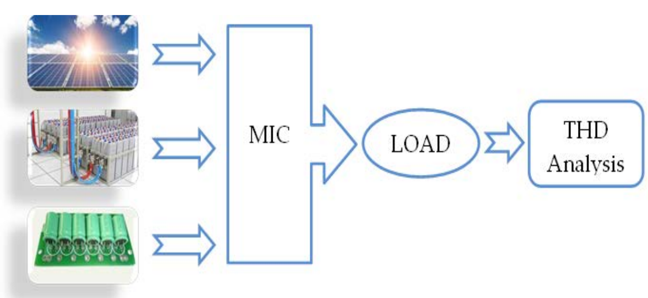

Figure 1. Block diagram of suggested TIC topology

OPERATION OF TIC IN BUCK-BOOST MODE

Three sources with different V-I characteristics are employed to feed the load either separately or concurrently in the proposed TIC topology as depicted in figure 2. The three input sources employed in TIC are an ultra-capacitor bank, a battery storage system, and a solar photovoltaic (PV) system. A single inductor (L), a sizable dc link capacitor (C), four bidirectional switches (S1 to S4), two unidirectional switches (SS1 and SS2), two diodes, a load resistor, and a load capacitor are all used in the converter section.

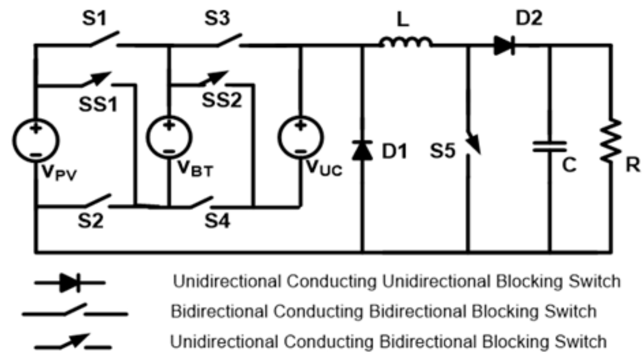

Figure 2. Equivalent Switch configuration of proposed TIC

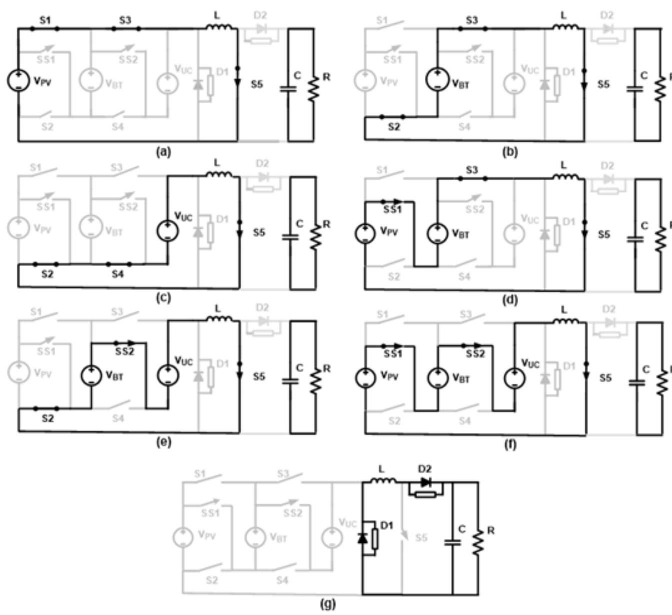

Figure 3. Working states of TIC operation in Buck-Boost mode

Table 1. Mode of operation for Buck-Boost operation

Working State	Conducting Switches	Active Source	Inductor Voltage	Inductor Status
1	S_1, S_3, S_5	V_{PV}	V_{PV}-0	Charging
2	S_2, S_3, S_5	V_{BT}	V_{BT}-0	Charging
3	S_2, S_4, S_5	V_{UC}	V_{UC}-0	Charging
4	SS_1, S_3, S_5	$V_{PV}+V_{BT}$	$V_{PV}+V_{BT}$ -0	Charging
5	SS_2, S_2, S_5	$V_{BT}+V_{UC}$	$V_{BT}+V_{UC}$-0	Charging
6	SS_1, SS_2, S_5	$V_{PV}+V_{BT}+V_{UC}$	$V_{PV}+V_{BT}+V_{UC}$-0	Charging
7	D_1, D_2	None	$-V_O$	Discharging

The possible working stages TIC operating in Buck-Boost mode for independent switching pulses is shown in Figure 3. In this mode combination of input voltage V_{PV}, V_{BT}, V_{UC} for time interval t_1, t_2, t_3, t_4, t_5 and t_6 are applied across the inductor and for time interval

t_7 negative voltage $-V_o$ appears across the inductor. Table 1 summarized the detailed analysis of Buck Boost mode of operation.

From the analytical waveforms as shown in figure 4, based on volt-second balance principle associated with energy storing elements, the average voltage across inductor can be obtained as;

$$V_o = \frac{V_{PV}D_{PV} + V_{BT}D_{BT} + V_{UC}D_{UC}}{(1 - D_{PV} - D_{BT} - D_{UC})} \quad (1)$$

Where,

Duty cycle of PV, $D_{PV} = \frac{\text{PV on time}(t_1 + t_4 + t_6)}{T_s}$

Duty cycle of BT, $D_{BT} = \frac{\text{BT on time}(t_2 + t_5 + t_6)}{T_s}$;

Duty cycle of UC, $D_{UC} = \frac{\text{UC on time}(t_3 + t_5 + t_6)}{T_s}$

In TIC operating in buck boost mode, it is of vital importance to evaluate the values of inductor forming the link between the load and the converter and the capacitor connected across the load. The values of these energy storing elements i.e. inductor and capacitor can be evaluated by identifying ripple content present in the current waveform of inductor Δi_L and ripple content present in the output voltage waveform of capacitor Δv_C respectively.

The value of inductance can be obtained as;

$$L = \frac{V_o}{\Delta i_L f_s}(1 - (D_{PV} + D_{BT} + D_{UC})) \quad (2)$$

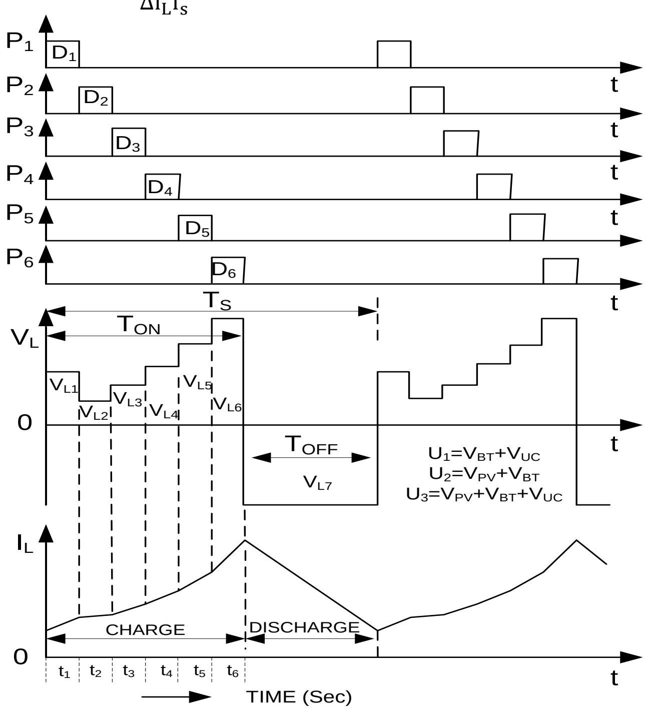

Figure 4. Analytical Waveform

Similarly, in figure 3 current waveform outline and voltage across capacitor are shown. Capacitor gets charged during the time intervals t1-t6 whereas it discharges during time interval t7. Thus, for time interval t1- t6 and t7 the capacitor current is given by

$$i_c = C\frac{dv_c}{dt} = I_o$$

The value of capacitor can be obtained according to the charge balance principle of capacitor

$$C = \frac{V_o}{R\Delta v_c f_s} \times (t_{PV} + t_{BT} + t_{UC}) \quad (3)$$

For a specific voltage ripple, the aforementioned equation is utilised to determine the capacitance value while designing a Buck-Boost converter.

Proposed TIC Simulation Results in Buck-Boost Mode

The proposed triple input converter topology is simulated in the MATLAB / Simulink environment to examine its performance. Three separate input sources are used for the simulation work: a solar photovoltaic source, a battery storage system, and a university central bank. The converter is run in buck-boost mode with continuous conduction, and the whole set of results is examined under steady state circumstances. The converter switches gate pulses are generated using an independent switching technique. Figures 5 to 10 show the simulation results for switching pulses, voltage appearing across the load and inductor, and current through inductor and the load for converter operation in buck-boost mode of operations with converter on time TON>0.5 (boost mode of voltage) and TON<0.5 (buck mode of voltage). According to the corresponding inductor current waveform, every level change in voltage is accompanied by an equivalent change in the slope of the current waveform. Positive voltage causes the slope of the current waveform to increase in proportion to the magnitude of the voltage pulse. The inductor current's slope turns negative with negative voltage. Additionally, it can be seen that the inductor current reaches the same level as at the beginning of the switching cycle. By making the necessary adjustments to the duty ratios D1 to D6, it is possible to change the voltage across the load and, consequently, the load current. Additionally, it can be utilised for applications that require bidirectional power flow. Conduction and switching losses, along with the accompanying drop in voltage, cause converter components to behave non-ideally, which results in negligible variations from idealistic conclusions. Table 2 provides specific information on the parameter values used for simulation.

Table 2. Parameters of Buck-Boost TIC for Simulation

Parameters	Mode Buck (b) / Boost (B)	
	$T_{ON} > 0.5T_S$ (B)	$T_{ON} < 0.5T_S$ (b)
V_{PV}	40V	40V
V_{BT}	30V	30V
V_{UC}	16V	16V
T_{ON}	$0.6T_S$	$0.4T_S$
T_{OFF}	$0.4T_S$	$0.6T_S$
L	7mH	7mH
C	470μF	470μF
f_S	20kHz	20kHz
V_O	77.5V	21V
R	10Ω	10Ω

For buck-boost mode of operation at TON > 0.5TS, the pulses delivered to various switches S1, S2, S3, S4, S5, SS1, and SS2 as depicted in figure 5. The pulse width, pulse duration, repetition frequency and off-duty period of the pulse are all dependent on the switching method and the output voltage used to match the load voltage. Figures 6 and 7 respectively illustrate the V-I characteristics through inductor and load.

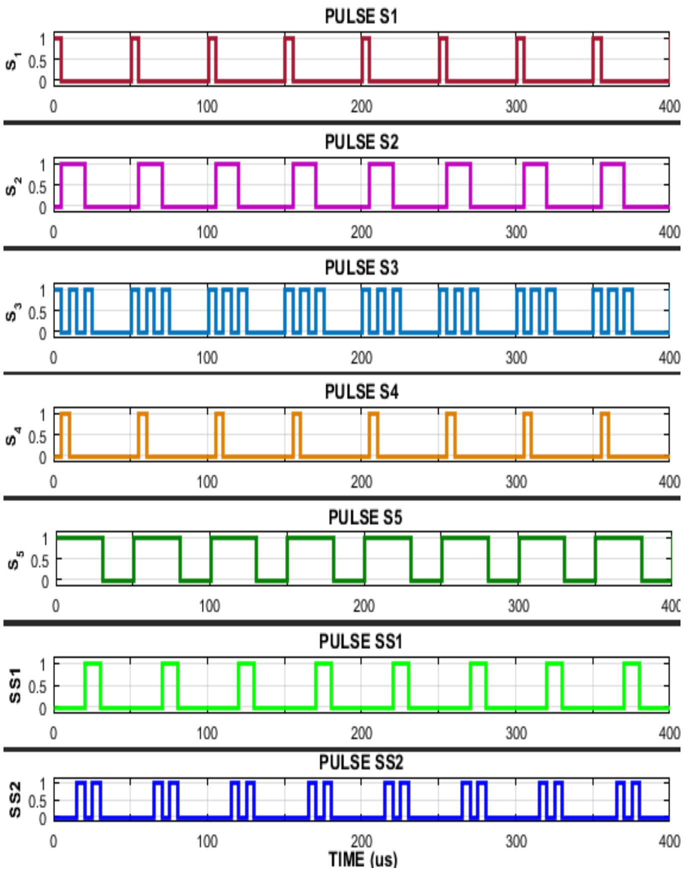

Figure 5. Applied Pulses at $T_{ON} > 0.5T_S$

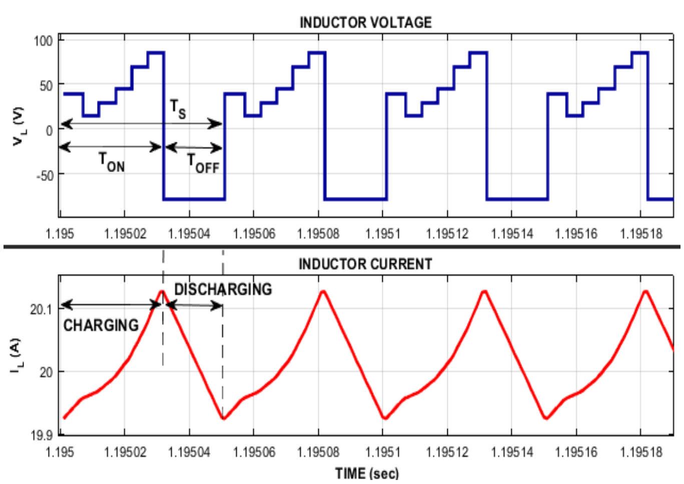

Figure 6. At (T_{ON}>0.5 T_S) V-I characteristics through inductor (L)

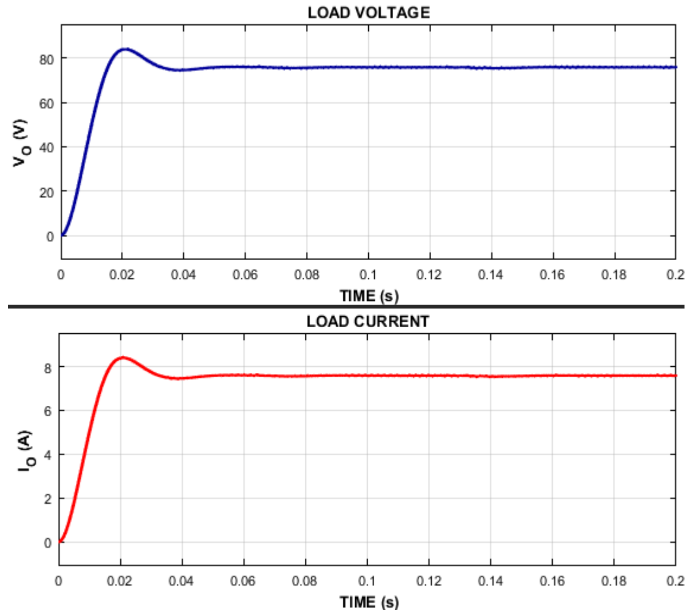

Figure 7. At (T_{ON} >0.5 T_S) V-I characteristics through load

For buck-boost mode of operation at TON < 0.5TS, the pulses delivered to various switches S1, S2, S3, S4, S5, SS1, and SS2 as depicted in figure 8. The pulse width, pulse duration, repetition frequency and off-duty period of the pulse are all dependent on the switching method and the output voltage used to match the load voltage. Figures 9 and 10 respectively illustrate the V-I characteristics through inductor and load, for buck-boost mode converter operation.

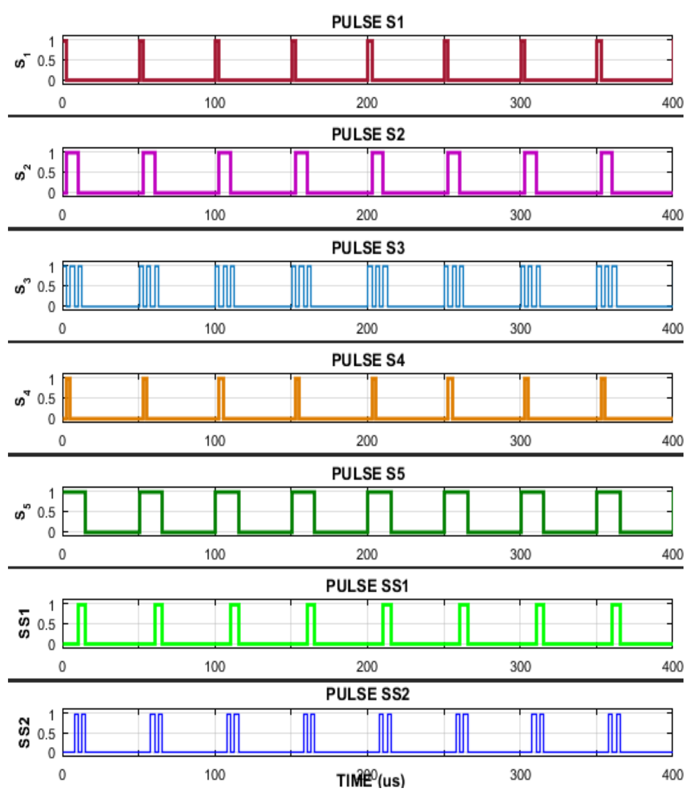

Figure 8. Applied Pulses at $T_{ON} < 0.5T_S$

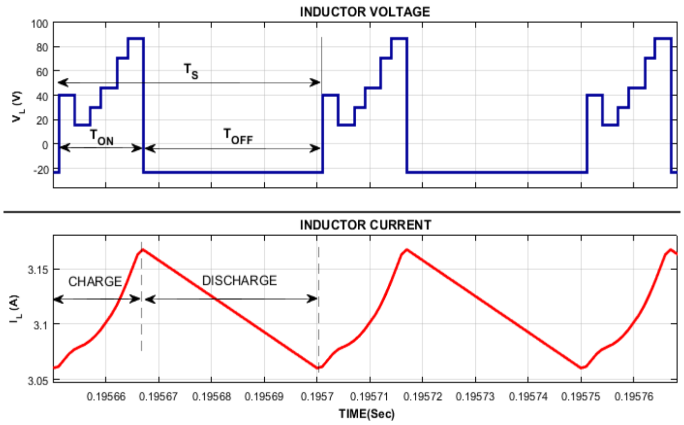

Figure 9. At ($T_{ON} < 0.5T_S$) V-I characteristics through inductor (L)

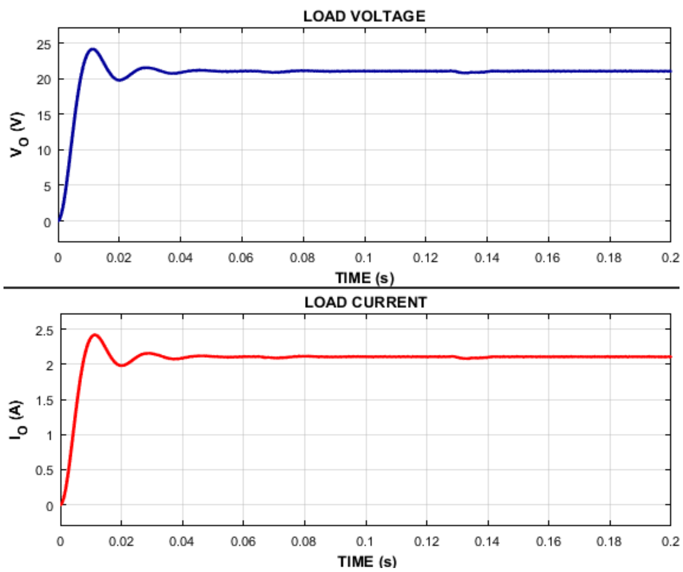

Figure 10. At ($T_{ON} < 0.5T_S$) V-I characteristics through load

Discussion

The topologies, presented in the paper have capability to integrate different energy sources with different ratings. The proposed topologies are capable of harvesting energy from three different energy sources (PV/Battery/UC) with different voltage current characteristics. It works well 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.

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, Battery and UC 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. The advantages of the proposed converter are its time saving feature, lower component count and the control methodology not involving complex mathematical procedure.

Future Applicability

The designed Triple Input Converter (TIC) have a wide range controllability of the output voltage in response to the control of the duty cycle and hence this feature of the converter provides a greater degree of the control freedom when applied to any circuit.

The controller operation can be extended by changing the duty cycle of the dc to dc converter along with the inverter to enhance the controllability attribute of the controller and make the system more stable under complex loading environment.

The goal of future research should therefore be to suggest novel multi-input topologies that are capable of effectively delivering both DC and AC output voltages. By displacing the original output inverter, such a converter will assist in lowering installation costs and dimensions. The control of many outputs also necessitates additional effort. Despite the wide input voltage ranges that many converters support, there is always opportunity for improvement, especially with regard to multi-input converters designed to capture energy from sources with very low RE. Future research on multi input converters might concentrate on circuitry simplicity, a reduction in the number of components, enhancements to voltage gain, and power scaling. Lower costs of converters will be achieved by circuit simplification and component reduction. Voltage gain enhancement will have a favourable effect on converter output.

Conclusion

A DC-DC converter with multiple input source for hybrid energy integration has been presented in this paper. A detailed explanation of each of the converter's operational states is included. It is extracted and demonstrated that there is a relationship between source voltages and output voltage. With the help of simulation results the performance of the converter is verified. In order to verify the triple input DC-DC converter's superior performance, the efficiency of the converter is examined using the results of simulations. According to the analysis, the presented converter is the best option for integrating hybrid energy because of its improved structure and reduced component count, which contribute to the converter's high efficiency.

Conflict of Interest

Authors declared no conflict of interest is there for publication of this work.

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