A Topology for Equal Power Sharing In a Multiple Input DC-DC Converter for Hybrid Energy System

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Abstract:*Amany input DC/DC converter topology is proposed for hybrid energy diversification from renewable storage energy sources independently or simultaneously. It can be working in different modes of operation with the ability of unidirectional and bidirectional energy flow to haverequired voltage level on load side. The development of topology based on multiple-input state has beendiscussed. A power quality, voltage profile and extract equal powers from multiple input schemes for the proposed converter has been presented. The algorithm works on the principle of varying the duty ratios of switches (IGBT) to regulate the average power drawn from each input. Theproposed concept has been validating through simulation using the MATLAB/Simulink software method.*

Keywords:DC-DC converters,Hybrid Energy System (HES),Multiple input converters (MICs),High switching frequency (HSF),Bidirectional power,Power electronic converters,Power quality.

1. Introduction

DC-DC converters/regulators form the Backbone of different portable electronic devices like cellular phones, laptops, MP3 players which are using batteries as their power supply. Portable devices usually comprise of several sub-circuits that should be supplied with different voltage levels, which are not the same as battery's voltage level which is the main supply voltage.

Employing DC-DC converters can be offered as a method to generate multiple voltage levels from a single DC supply voltage to feed the different sub-circuits in the device. This method of generating multiple voltage levels from a single battery source can reduce the device area substantially [2, 6]. On the other hand DC voltage provided by battery or rectifier contains high voltage ripples and it is not constant enough, thus it is not applicable for most devices. DC-DC regulators are employed to attenuate the ripples regardless of change in the load current or input voltage [1].Every Electronic circuit is assumed to operate off some supply voltage which is usually assumed to be constant. A voltage regulator is a power electronic circuit that maintains a constant output voltage irrespective of change in load current or line voltage. Many different types of voltage regulators with a variety of control schemes are used. With the increase in circuit complexity and improved technology a more severe requirement for accurate and fast regulation is desired. This has led to need for newer and more reliable design of DC-DC converters.

The DC-DC converter inputs an unregulated dc voltage input and outputs a constant or regulated voltage. The regulators can be mainly classified into linear and switching regulators. All regulators have a power transfer stage and a control circuitry to sense the output voltage and adjust the power transfer stage to maintain the constant output voltage. Since a feedback loop is necessary to maintain regulation, some type of compensation is required to maintain loop stability. Compensation techniques vary for different control schemes and a small signal analysis of system is necessary to design a stable compensation circuit.

Hybrid energy system (HES) is an emerging technology that has the potential to meet future energy requirements. Hybridisation of energy systems is gaining more and more popularity in the field of electric power systems because of its reliable operation, durability,cleanliness and efficient operation as compared with single source energy systems [1, 2]. A well designed HES provides good power handling capability during steady-state operation and better dynamic response during transients [2]. The integration of more than one energy source to form HES heavily depends on power electronic interface which integrates several energy sources having different V-I characteristic [3]. Multiple-input DC-DC converters (MICs) are playing a significant role in interfacing and diversification of different energy sources. The energy sources like fuel cell, battery, ultra-capacitor and renewable energy sources of same or different category with distinct V-I characteristic are traditionally connected together through individual DC-DC converter and their outputs are connected to common dc bus either in series or parallel [2, 3, 4]. However, such configurations are costly, bulky and relatively complex in design and reduce overall efficiency as well as reliability of the system. Multiple single-input DC-DC converters can be successfully replaced by a single multiple-input DC-DC converter. MIC offers simple and more compact design and reduces the cost and complexity of the system. In addition, efficient dc power distribution at regulated output voltage enhances reliability [5, 6].

In the last decade, several isolated and non-isolated topologies on MIC have been proposed [6, 7, 10, 17]. The isolated topologies are based on magnetically connected circuit (MCC) and non-isolated topologies are based on electrically connected circuit (ECC). In MCC, flux addition along with time domain multiplexing is a commonly used technique for energy transformation from sources to load [8]. The mandatory requirement of transformer along with additional peripheral circuitry makes MCC complex, bulky, costly and increases dependency on circuit parameters [5, 9, 10]. In ECC, modular structure, low cost and absence of transformer make it attractive and minimises the issues associated with MCC to a large extent. The electrically connected MIC topologies combine various input energy sources either in parallel [6, 11, 12] or in series [13, 14, 15]. The major limitations of parallel connected source topologies are, input source voltage should be asymmetric and only one input source can supply power to the load at a time to avoid power coupling effect. In order to supply power simultaneously, input sources are connected in series. In series configuration, each source can bypass the other to form a parallel connection through an individual diode which increases component counts. In the literature most of the proposed MIC topologies are inspired from basic DC-DC converter topology and have not been explored and synthesised completely which leaves space for further improvement in topological structure. In addition bidirectional power processing and small signal modelling are ignored.

An MIC topology for integration of different energy sources is presented. The topology, pulsating source cells (PSCs) have been used for synthesis and generation of MIC which offers inherent bypass circuitry for other sources. The converter topology is proficient for energy diversification from different series connected energy sources and offers flexibility in source voltage magnitudes (they can be symmetric or asymmetric) and control algorithm. Moreover, all the connected energy sources can supply the load individually or simultaneously. Possibilities of bidirectional power flow with Buck, Boost and Buck–Boost modes of operation have been explored. It has a simple and compact structure and fault tolerant capability which enhances the reliability of the converter. In addition, all the sources are connected to the load through a single inductor. Therefore, a single sensor is required to monitor inductor current and hence power flow of each source can be controlled individually.

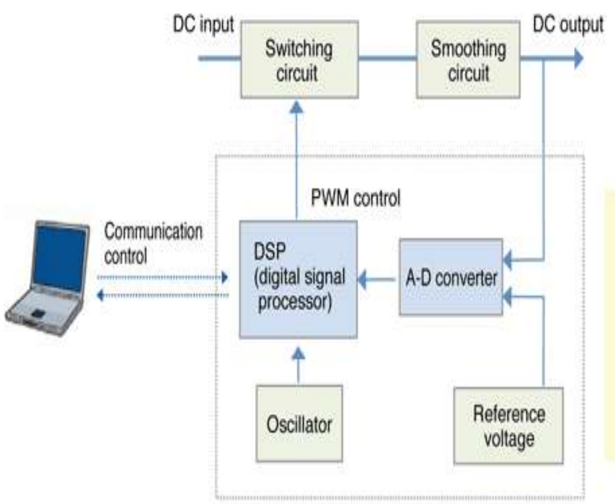

Fig.1: Block of a digital control DC-DC converter

In Fig.1 the monitored output voltage is converted into digital signals by the A-D converters, and the PWM control is performed through digital processing by the DSP, in order to stabilize fluctuating voltage. A power supply in which communication control is also digitally controlled is called a fully digital power supply.

Rest of the paper is organized as follows. The topology is described in section II. With the help of mathematical formulations, the proposed methodology is described in section III. In order to validate the proposed methodology, simulation studies and their results are presented in section IV. Concluding remarks are presented in section V.

2. Description of Topology

The working operation of MIC proposed in [10] is based on the basis dc-dc converter. The reactive elements of the converter are charged during a prefect period of time and then the stored energy of the reactive element is discharge through load during the residual period of time over a single switching cycle. In MICs, the inductor can be charged by several voltage sources instead of single source by adopt correct switching pattern that connect or disconnect several source to the inductor independently or concurrently. The topology is proposed in [10] is shown in Fig.1 with two input sources. It is categorize into two parts: part 1 and part 2. Part 1 is a multilevel dc-link part of voltage sources V_1 and V_2, switchS_1 and S_2, diodeD_1 and D_2. These parts synthesize a multilevel dc voltage. Part 2 consists of controlled switcherS_3 and S_4 and energy storage element$L$ and C. function of this part decide one of the working mode (buck, boost and bidirectional).

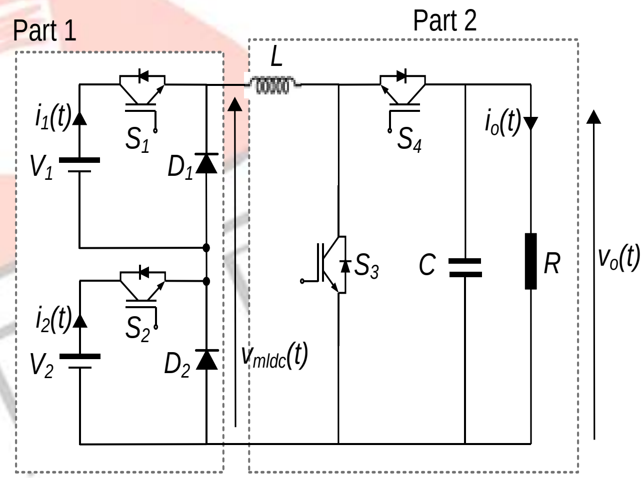

Fig. 2:Circuit diagram of proposed MIC topology

Complete function of the topology is described in [10] with different strategy such as : (a) intermediate synchronisation; (b) rising edge synchronisation; and (c) falling edge synchronisation of switching signal. In Figure 2, the source current of V_1 and V_2 are shown respectively as $i_1(t)$ and $i_2(t)$ while the dc voltage is shown as $v_{mldc}(t)$ and immediate load voltage and current are shown as $v_o(t)$ and $i_o(t)$.

The arrangement of the proposed multiple-input DC/DC converter topology is shown in Figure 2. There are two inputsources connected in series to the load shown in the dashed thin rectangle box, which require controlled switches and diodes. The series combination of switches is connected to the converter unit covered by a dashed thick line, which have a single inductor (L), switches S_3 and S_4 and a large dc capacitor (C). The drop or electrical loading is circle by a dotted line where output current andvoltage are characterize as i_o(t) andv_o(t)respectively.

3. Proposed Methodology

The proposed methodology improves the performance of the system network under study. The circuit diagram of the proposed methodology with two input sources for a givenasymmetric voltage ratio was shown in figure 1. The switch S_4 is always kept in on position. When the switch $S_1$is on,switch S_2 off and diode D_1 is OFF the input voltage V_1 gets connected with load. At this condition the voltage profile at the load end was studied and the result obtained shows the existence of transient condition (figure 2). Similar result was obtained with the voltage source V_2 connected. The transient condition obtained can be eliminated by properly controlling the operation of switch S_3. The switching function μ(t) for the switch S_3 can be define as:

$$\mu(t) = \begin{cases} 0\,, if\ \ power\ switch\ S\ is\ OFF \\ 1\,, if\ \ power\ switch\ S\ is\ ON \end{cases} \quad (1)$$

Thus, the multilevel dc link voltage can be expressed in terms of switching function and input sources as:

$$v_{mldc}(t) = V_1\mu_1(t) + V_2\mu_2(t) \quad (2)$$

The average power drawn for any given load current (and hence inductor current) can be controlled with the help of switching functionμ(t) and hence the duty ratios d_1 and d_2 for the switches S_1 and S_2must be chosen to satisfy the following relationship:

$$d_1V_1 = d_2V_2 \quad (3)$$

The input voltages V_1 and V_2 can be controlled by controlling the duty ratio from $d_1$to d_2 as seen from equation (3). Thus to obtain a desired voltage magnitude at the load, V_{mldc} has to be treated as an input to 'part 2' of the converter topology.

Designing inductor and capacitor of suitable value is very important in an MIC. The values of the inductor and the capacitor can be calculated from inductor current ripple (Δi) waveform and output voltage ripple (Δv) from capacitor current waveform, respectively.

$$\Delta i = V_o\ \{1 - (d_1 + d_2 - d_{12})\} L_{fs} \quad (4)$$

$$\Delta v = V_o\ (d_1 + d_2 - d_{12}) RC_{fs} \quad (5)$$

Similar analysis can be made for the buck-boost mode of operation of the proposed converter topology. A summary of brief study for boost, buck–boost andbuck mode of operation has been shown in Table 1.

For a two input converter in buck–boost mode of operation the output voltage is given by

$$V_O = V_1d_1 + V_2d_{21} - d_1 - d_2 + d_{12} \quad (6)$$

From equation (6), it can be concluded that when both the input voltages V_1 and V_2 are constant, multiple combinations of duty cycles d_1, d_2 and d_{12} are possible to regulate the output voltage at particular value. Thus, different arrangement ofd_1, d_{12} and d_2 generate same output voltage with a great difference in power drawn from each source. The amount of average power drawn from individual source can be obtained from the following equations:

$$P_1 = V_1I_1 = V_1 \times d_1I_L$$
$$P_2 = V_2I_2 = V_2 \times d_2I_L \quad (7)$$

$$P_o = P_1 + P_2$$

Addition and simplification of equation (6) and (7) yield the expression of output power as follows:

$$P_o = V_0^2/R \quad (8)$$

Thus, the output voltage and total power supplied to the load will remain constant and do not depend on specific value of duty cycles. Thus, by proper selection of duty cycles, the amount ofpower sharing among connected sources can be controlled. The performance of the system willbe further improved if the duty cycle is tuned based on source status which fulfills the requirement of power management controller and voltage was improved.

4. Simulation Results

With reference to figure 2, let the magnitudes of voltage sources be binary with values V1 = 24V and V2 = 12V. Accordingly, as per equation (20), d2 should be taken twice of d1. Hence d1 is taken to be 0.1 while d2 is taken as 0.2, with a switching frequency of 10 kHz. Thus, as per equation (16), the average value of multilevel dc link would be V1d1 +V2d2 i.e. 4.8V. Now, let us say that the average output voltage desired at load is 18 V, then it means that the multilevel dc link voltage is needed to be boosted and hence the switch S3 has to be operated with a duty ratio d3 , obtained by using the standard expression for boost conversion,

$$V_o = \frac{V_{mldc}}{(1-d_3)} \quad (9)$$

Hence, under the conditions described, d3 should be chosen to be 0.73.

In order to verify the concepts proposed herewith, a simulation study is performed using MATLAB/Simulink software along with SimPowerSystem toolbox. The parameters are source V_1 =24V, source V_2 =12V, inductance L=14.4 MHz, capacitance C=216 μF, frequency F=10 kHz, resistance R=10Ω, Duty ratio d_1=10%, Duty ratio d_2=20%, Duty ratio d_3=73% and output voltage V_o=18.

Simulation results of switching signal as proposed in paper is shown in figure 3. The instantaneous output voltage obtained from the simulation model as proposed in paper is simulated for 0.08 sec shown in figure 4. The ripple as simulated is to be within the range of 1-5% (acceptable) while the average output voltage is 16.73 V. The transit time is approximately 0.026 sec, overshoot time 20-25%, settling time is approximately 0.026 sec for output voltage obtained. The inductor voltage and currents as proposed in paper are shown respectively in figure 4.

The instantaneous output voltage obtained from the simulation model in this research work is simulated for 1 sec shown in figure 5. The ripples are seen in figure 6 to be within the range of 5-10% (acceptable) while the average output voltage is 17.25 V. The transit time is approximately 0.2 sec, no overshoot time; settling time is approximately 0.2 sec for output voltage obtained from the model simulated in this research work. The inductor voltage and currents are shown respectively in figure 7. In addition, the source currents from sources V1 and V2 are shown in figures 8 and 9. The load power and powers drawn from sources V1 and V2 are shown in Table I and it can be seen that both the sources impart equal power to the load, while the primary goal of voltage regulation is simultaneously achieved. Hence, it can be safely said that the proposed scheme works satisfactorily.

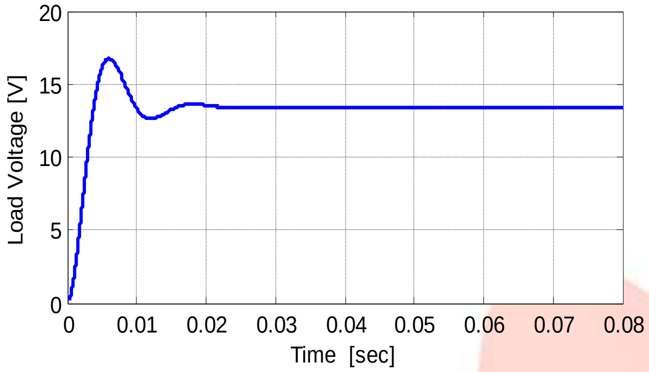

Fig.3: Simulated waveform for the load voltage proposed

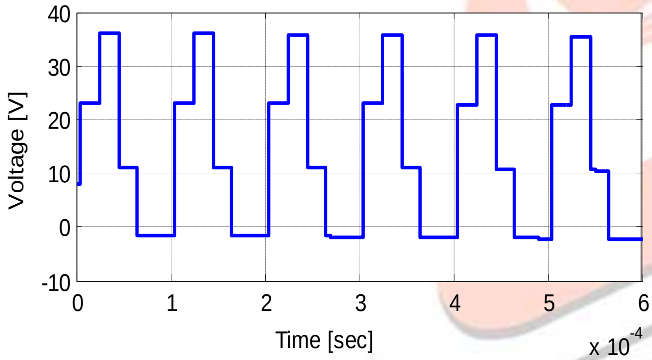

Fig.4: Simulated waveform for the inductor voltage proposed

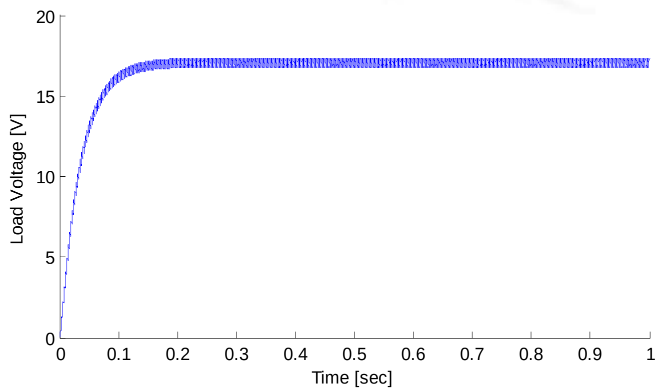

Fig.5: Simulated waveform for the load voltage

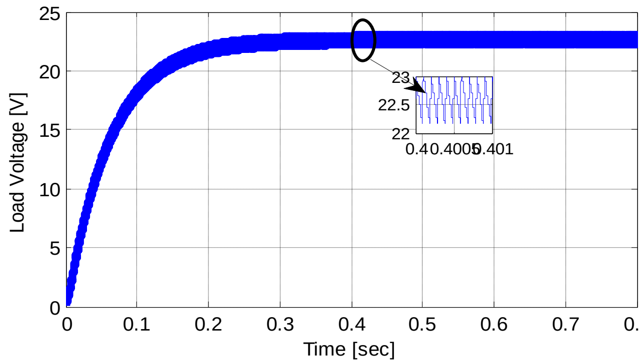

Fig.6: Simulated waveform for load voltage with ripple content

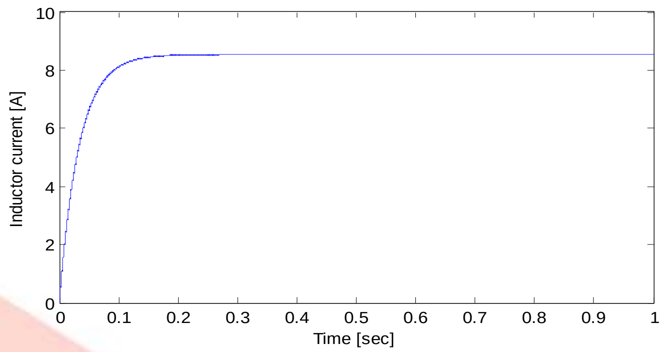

Fig.7: Simulated waveform for the inductor current

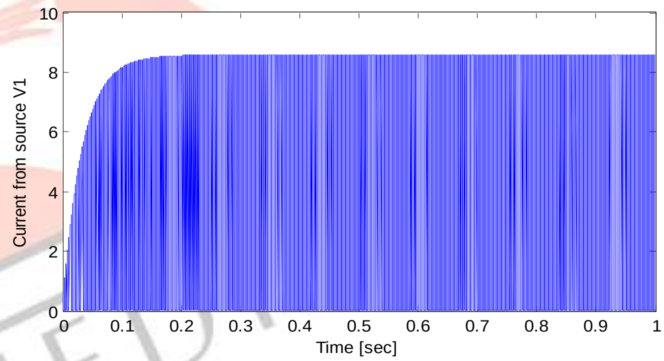

Fig.8: Simulated waveform for the current drawn from source V1

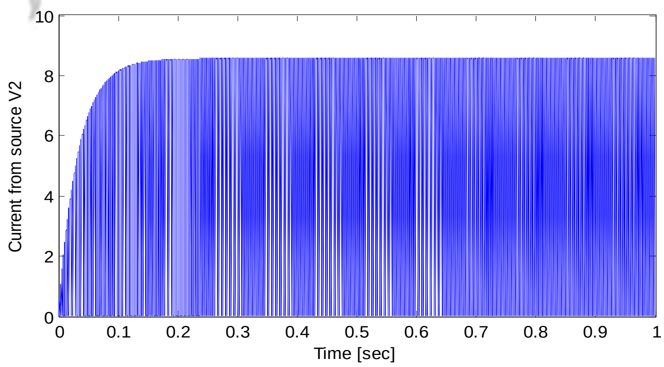

Fig.9: Simulated waveform for the current drawn from source V2

Table I Power Readings

Load	Source V1	Source V2
30 W	17W	17 W

5. Conclusion

In this research work, a methodology to extract equal average powers from multiple input dc sources in a dc-dc converter topology is presented. The sources voltages may be equal or unequal and accordingly the currents are drawn from the given sources such that the average powers drawn are equated and hence their lifetimes are enhanced. Because of the presence of multiple switching states, both the objectives are obtained: regulation of average output voltage, even power sharing among the input dc sources and power quality is improved.Proposed concepts are validated with the help of modelling and simulations carried out with MATLAB/Simulink software package. Obtained results are satisfactory.

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