A Methodology for Even Power Sharing among Input Sources in a Multiple-Input DC-DC Converter Topology

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Abstract: Among the power electronic converters, dc-dc converters find applications in key areas such as dc drives, battery charging, electric traction, renewable power generation and so on. While many topologies of dc-dc converters are popular, multiple input converters (MICs) have been emerging as practical and efficient means especially for hybrid energy systems. In this paper, a methodology is presented to extract equal powers from multiple (either symmetric or asymmetric) input dc sources of an MIC. The algorithm works on the principle of varying the duty ratios of switches to regulate the average current drawn from each source. Mathematical formulations are presented to describe the scheme. In addition, software based simulation results are presented to validate the proposed methodology.

Keywords: Hybrid Energy System (HES), DC/DC converters, Multiple input converters (MICs), Bidirectional power, Power electronic converters.

1. Introduction

Power electronics has become an enabling technology for many applications [1]. In principle, it deals with control and conversion of electric power and accordingly these converters are classified as dc-dc, dc-ac, ac-ac and ac-dc converters. Among these, a dc-dc converter has found many applications especially in dc drives, battery charging applications, electric traction, renewable power generation etc. [2]. An emerging application of dc-dc converters is in hybridization of energy. A Hybrid Energy System (HES) comprises of multiple dc sources contributing towards a single/multiple dc load(s). A HES is an emerging technology that can help in meeting future energy requirements. As compared to single source energy systems, HES offers several advantages such as: reliable operation, durability, cleanliness and efficient operation [3, 4]. In terms of practicality, a HES has to address the challenge of integrating multiple sources having different V-I characteristics [5]. In this regard, a class of Multiple-input DC/DC converters (MICs) has emerged and MICs are playing a significant role in interfacing and diversification of different energy sources [6].

In the past few years, several isolated and non-isolated topologies on MIC have been proposed [6–10]. Most of these topologies are inspired from basic dc-dc converters. A topology for MIC has been recently proposed in [11] by Sahu and Jain, claimed by the authors to be proficient for the energy diversification from renewable and storage energy sources individually or simultaneously. In [11], the authors have demonstrated the topology being operated in buck, boost and buck–boost modes of operation with the capability of bidirectional power flow to achieve the desired voltage level on either side. In addition, a power management control scheme for the proposed converter is also presented in [11]. In [11], however, no study is made so as to equalize the power drawn from the input dc sources. It is important to administer a control algorithm which leads to even power sharing among the input sources which otherwise would result in unequal lifetimes of the sources and hence increased maintenance [12]. Unequal load sharing may also lead to destabilisation of input dc levels [13, 14], thereby causing large ripples and fluctuations. Therefore, in this work, a methodology is proposed to implement power balancing among the multiple input sources which maintaining the desired output voltage.

Rest of the paper is organised as follows. The topology is described in section 2. With the help of mathematical formulations, the proposed methodology is described in section 3. In order to validate the proposed methodology, simulation studies and their results are presented in section 4. Concluding remarks are presented in section 5.

2. Description of Topology

The working principle and operation of MIC proposed in [11] is based on the basic dc-dc converter. The passive elements of the converter are charged during a particular period of time and then the stored energy of the passive element is discharged through load during the remaining period of time over a single switching cycle. In MICs, the inductor can be charged by multiple voltage sources instead of single source by adopting an appropriate switching pattern that connects or disconnects multiple sources to the inductor.
Part 1 Part 2

![Diagram of proposed MIC topology](image)

The average multilevel dc link voltage over a switching period 'T' can be accordingly expressed as:

$$V_{mldc} = \frac{1}{T} \int_{0}^{T} \{V_1 \mu_1(t) + V_2 \mu_2(t)\} dt$$  \hspace{1cm} (3)$$

Similarly, the source currents $i_1(t)$ and $i_2(t)$ can be expressed in terms of switching function and inductor current 'i_d(t)' as:

$$i_1(t) = i_L(t) \mu_1(t)$$  \hspace{1cm} (4)$$

$$i_2(t) = i_L(t) \mu_2(t)$$  \hspace{1cm} (5)$$

Thus, for any two given sources (and, for that matter)

$$V_1 \times \frac{1}{T} \int_{0}^{T} [i_1(t) \mu_1(t)] dt = V_2 \times \frac{1}{T} \int_{0}^{T} [i_2(t) \mu_2(t)] dt$$

Equation (6) indicates that, for any given load current (and hence inductor current), with the help of appropriate control of the switching functions, average power drawn from input dc sources can be equalized within one switching cycle. This means that appropriate duty ratios $d_1$ and $d_2$ for $S_1$ and $S_2$ have to be chosen which would satisfy the relationship:

$$d_1V_1 = d_2V_2$$  \hspace{1cm} (7)$$

Under this condition, however, as per equation (2), the average multilevel dc link voltage will be regulated depending on the ratio of $d_1$ to $d_2$. Accordingly, to obtain a desired voltage at the load, $V_{mldc}$ has to be treated as the input to 'part 2' of the converter topology.

### 4. Simulation Results

With reference to figure 1, let the magnitudes of voltage sources be binary with values $V_1 = 24$ V and $V_2 = 12$ V. Accordingly, as per equation (7), $d_1$ should be taken twice of $d_2$. Hence $d_1$ is taken to be 0.1 while $d_2$ is taken as 0.2, with a switching frequency of 10 kHz. Thus, as per equation (3), the average value of multilevel dc link would be $V_{mldc} = V_1d_1 + V_2d_2$ 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 $S_3$ has to be operated with a duty ratio $d_3$, obtained by using the standard expression for boost conversion:

$$V_o = \frac{V_{mldc}}{1-d_3}$$  \hspace{1cm} (8)$$

Hence, under the conditions described, $d_3$ 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 summarized in Table 1.
Table 1: Parameters of MIC for simulation study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source $V_1$</td>
<td>[V]</td>
<td>24</td>
</tr>
<tr>
<td>Source $V_2$</td>
<td>[V]</td>
<td>12</td>
</tr>
<tr>
<td>Inductance $L$</td>
<td>[mH]</td>
<td>14.4</td>
</tr>
<tr>
<td>Capacitance $C$</td>
<td>[$\mu$F]</td>
<td>216</td>
</tr>
<tr>
<td>Frequency $f$</td>
<td>[kHz]</td>
<td>10</td>
</tr>
<tr>
<td>Resistance $R$</td>
<td>[$\Omega$]</td>
<td>10</td>
</tr>
<tr>
<td>Duty ratio $d_1$</td>
<td>[%]</td>
<td>10</td>
</tr>
<tr>
<td>Duty ratio $d_2$</td>
<td>[%]</td>
<td>20</td>
</tr>
<tr>
<td>Duty ratio $d_3$</td>
<td>[%]</td>
<td>73</td>
</tr>
<tr>
<td>Output voltage $V_o$</td>
<td>[V]</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 2: Power readings

<table>
<thead>
<tr>
<th>Load</th>
<th>Source $V_1$</th>
<th>Source $V_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 W</td>
<td>17 W</td>
<td>17 W</td>
</tr>
</tbody>
</table>

The instantaneous output voltage obtained from the simulation model is shown in figure 2. The ripples are seen to be within the range of 5-10% while the average output voltage is 17.25 V. The inductor voltage and currents are shown respectively in figures 3 and 4. In addition, the source currents from sources $V_1$ and $V_2$ are shown in figures 5 and 6. The load power and powers drawn from sources $V_1$ and $V_2$ are shown in Table 2 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.

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</table>

5. Conclusion

In this paper, 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 and even power sharing among the input dc sources. Proposed concepts are validated with the help of modeling and simulations carried out with MATLAB/Simulink software package. Obtained results are satisfactory.
References


Author Profile

Shailesh Kumar Nag received B.E. degree in Electronics and Telecommunication Engineering from Chhattisgarh Institute of Technology, Rajnandgaon, Chhattisgarh, India in 2011 and is currently a M.E. scholar from Raipur Institute of Technology. His current area of research is Hybrid Energy System.

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