Multiple-input DC/DC converter topology for improving power quality for hybrid energy system

Shailesh Kumar Nag[1], Anjanee Kumar[2]

[1]Raipur Institute of Technology, Department of Electronics and Telecommunication,
Raipur, Chhattisgarh, India
shai.nag4537@gmail.com

[2]Raipur Institute of Technology, Department of Electronics and Telecommunication,
Raipur, Chhattisgarh, India
anjanee.rit@gmail.com

Abstract: *A multiple DC/DC converter topology is proposed multiple-input for energy diversification from renewable storage energy sources independently or simultaneously. It can be working in buck, boost and buck boost modes of operation with the ability of bidirectional energy flow to have required voltage level on load side. The development of topology based on multiple-input state has been discussed. A power quality and voltage profile scheme for the proposed converter has been presented. The algorithm works on the principle of varying the duty ratios of switches to regulate the average voltage drawn from each input. The proposed concept has been investigated through simulation using the MATLAB/Simulink software method and validated.*

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

1. Introduction

Hybrid energy system (HES) is an upcoming technology that has the impending to meet future energy necessities. energy systems is in advance popularity in the field of power electronics because of its consistent operation, durability, cleanliness and capable operations as balance with single source energy systems [10]. A well planned HES provides good power handling capability during steady-state operation and better dynamic response during transients [2]. The addition of more than one energy source to form HES, closely depends on power electronic edge which integrates several energy sources having different V I feature [3].

Multiple-input DC/DC converters (MICs) are singing important role in interfacing and diversification of different energy sources. The energy sources like fuel ultra capacitor, battery, cell and renewable energy sources of same or different type with separate V – I feature are usually connected together through individual DC/DC converter and their outputs are connected to common dc line either in series or parallel [4]. However, such configurations are bulky, costly and comparatively complex in design and reduce overall efficiency as well as consistency of the system. Multiple single-input DC/DC converters can be effectively replaced by a single multiple-input DC/DC converter. MIC offers simple and more compressed design and reduces the cost and complication of the system. In addition, efficient dc power distributions at regulated output voltage enhance reliability [5, 7].

Rest of the paper is organized 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. Finally remarks are present in section 5.

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, switch S_1 and S_2, diode D_1 and D_2. These parts synthesize a multilevel dc voltage. Part 2 consists of controlled switcher S_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).
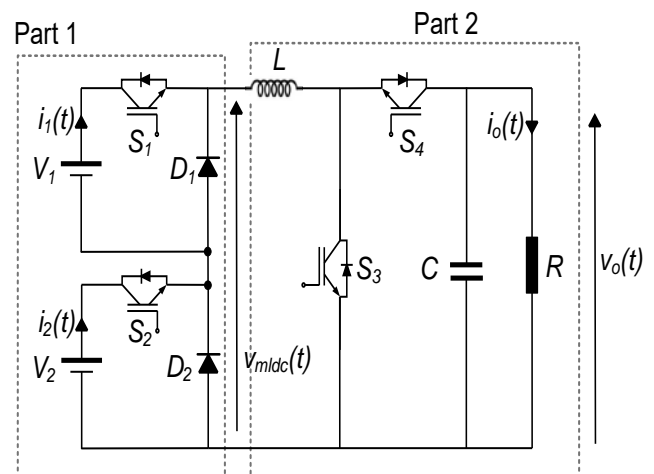

Figure 1: Circuit diagram of proposed MIC topology

2nd International Seminar On "Utilization of Non-Conventional Energy Sources for Sustainable Development of Rural Areas
ISNCESR'16
17th & 18th March 2016

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 1, 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 1. There are two input sources 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 and voltage are characterize as $i_o(t)$ and $v_o(t)$ 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 given asymmetric 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 $\mu(t)$ for the switch S_3 can be define as:

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

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

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

The average power drawn for any given load current (and hence inductor current) can be controlled with the help of switching function $\mu(t)$ and hence the duty ratios d_1 and d_2 for the switches S_1 and S_2 must be chosen to satisfy the following relationship:

$$d_1V_1 = d_2V_2 \tag{3}$$

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.

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

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

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 and buck 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

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

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 of d_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:

$$P_1 = V_1I_1 = V_1 \times d_1I_L$$
$$P_2 = V_2I_2 = V_2 \times d_2I_L \tag{7}$$

$$P_o = P_1 + P_2$$

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

$$P_o = V_0^2/R \tag{8}$$

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 of power sharing among connected sources can be controlled. The performance of the system will be 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

From figure 1, let the voltage sources be binary with values $V_1 = 24V$ and $V_2 = 12V$. Accordingly, as per equation (2), d_2 should be taken twice of d_1. Hence d_1 is taken to be 0.1 while d_2 is taken as 0.2, for a switching frequency of 10 kHz. Thus, as per equation (3), the average value of multilevel dc link would be $V_1d_1 + V_2d_2$ i.e. 4.8V. Now, let us say that the average output voltage required at load is 18 V, then it means that the multilevel dc link voltage is to be boosted and hence the switch S_3 has to be operate with a duty ratio d_3 , obtain by using the standard expression for boost conversion,

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

2nd International Seminar On "Utilization of Non-Conventional Energy Sources for Sustainable Development of Rural Areas
ISNCESR'16
17th & 18th March 2016

Hence, under the condition described, d_3 should be chosen to be 0.73.

In order to justify the concepts proposed, a simulation study is performed using MATLAB/Simulink software along with SimPowerSystem toolbox. The parameter are summarize in Table 1.

Table 1: Parameters of MIC for simulation study

Parameter	Value	Unit
Source V_1	24	[V]
Source V_2	12	[V]
Inductance L	14.4	[mH]
Capacitance C	216	[μF]
Frequency f	10	[kHz]
Resistance R	10	[Ω]
Duty ratio d_1	10	[%]
Duty ratio d_2	20	[%]
Duty ratio d_3	73	[%]
Output voltage V_o	23	[V]

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 17.23 transient condition obtained can be eliminated by properly controlling the operation of switch S_3 as shown in figure 3,that will minimizes the transient and improves the output voltage is 23. The inductor voltage and currents are shown respectively, the load power and powers drawn from sources V_1 and V_2 are shown in figure 3.
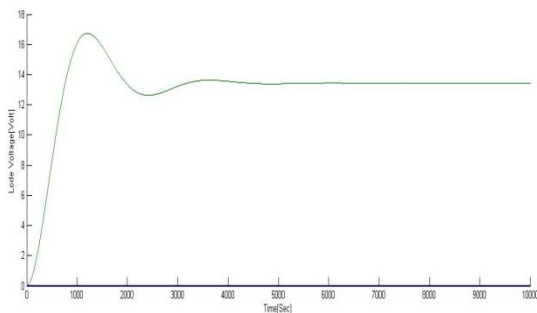

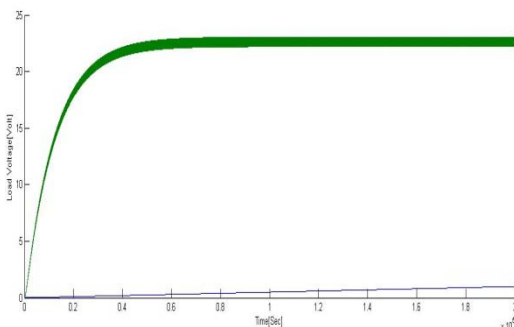**Figure 2:** Simulated waveform for the load voltage

Figure 3: Simulated waveform for the load voltage

5. Conclusion

In this paper, a methodology to minimizes transit condition in output voltage profile and improve the output power quality from two input dc sources in a dc-dc converter topology is presented. The sources voltages may be different or same and accordingly the currents are drawn from the given sources such that the output powers drawn are constant and hence their lifetimes are enhanced. Because of the presence of multiple switching modes, both the objectives are obtained: minimization of transit condition in output voltage and output power quality improvement. It can also be extended for multiple inputs that are more than two inputs. Proposed concepts are validated with the help of modeling and software simulations carried out with the help of MATLAB/Simulink software package. That's gives results satisfactory.

References

[1] P. Gueguen, "How power electronics will reshape to meet the 21st century challenges?," In Power Semiconductor Devices & IC's (ISPSD), 2015 IEEE 27th International Symposium on , vol., no., pp.17-20, 10-14 May 2015.

[2] F. Blaabjerg ; A. Consoli ; J.A. Ferreira ; J.D. van Wyk, "The future of electronic power Processing and conversion," In Power Electronics, IEEE Transactions on , vol.20, no.3, pp.715-720, May 2005.

[3] J. Cao; A. Emadi, "A New Battery/Ultra Capacitor Hybrid Energy Storage System for Electric, Hybrid, and Plug-In Hybrid Electric Vehicles," In Power Electronics, IEEE Transactions on, vol.27, no.1, pp.122-132, Jan. 2012.

[4] F. Valenciaga; P.F. Puleston, "Supervisor control for a stand-alone hybrid generation system using wind and photovoltaic energy," In Energy Conversion, IEEE Transactions on , vol.20, no.2, pp.398-405, June 2005.

[5] S. Kumar; H.P. Ikkurti, "Design and control of novel power electronics interface for battery-ultracapacitor Hybrid Energy Storage System," In Sustainable Energy and Intelligent Systems (SEISCON 2011), International Conference on, vol., no., pp.236-241, 20-22 July 2011.

[6] S.H. Choung; A. Kwasinski, "Multiple-input DC-DC converter topologies comparison," In Industrial Electronics, 2008. IECON 2008. 34th Annual Conference of IEEE, vol., no., pp.2359-2364, 10-13 Nov. 2008.

[7] Wu Hongfei; Xu Peng; Hu Haibing; Zihu Zhou; Yan Xing, "Multiport Converters Based on Integration of Full-Bridge and Bidirectional DC–DC Topologies for Renewable Generation Systems," In Industrial Electronics, IEEE Transactions on , vol.61, no.2, pp.856-869, Feb. 2014.

[8] H. Tao; A. Kotsopoulos; J.L. Duarte; M.A.M. Hendrix, "Family of multiport bidirectional DC-DC converters," In Electric Power Applications, IEEE Proceedings - , vol.153, no.3, pp.451-458, 1 May 2006.

[9] J.T. Hawke; H.S. Krishnamoorthy; P.N. Enjeti, "A multiport power sharing converter topology for renewable-to-grid interface," In Energy Conversion Congress and Exposition (ECCE), 2014 IEEE , vol., no., pp.4992-4999, 14-18 Sept. 2014.

2nd International Seminar On "Utilization of Non-Conventional Energy Sources for Sustainable Development of Rural Areas
ISNCESR'16
17th & 18th March 2016

[10] L. Kumar; S. Jain, "Multiple-input DC/DC converter topology for hybrid energy system," In Power Electronics, IET, vol.6, no.8, pp.1483-1501, September 2013.

[11] O. Hegazy; M. El Baghdadi; J. Van Mierlo; P. Lataire; T. Coosemans, "Analysis and modeling of a bidirectional multiport DC/DC power converter for battery electric vehicle applications," In Power Electronics and Applications (EPE'14-ECCE Europe), 2014 16th European Conference on , vol., no., pp.1-12, 26-28 Aug. 2014.

[12] K.K. Gupta; S. Jain, "A Novel Multilevel Inverter Based on Switched DC Sources," In Industrial Electronics, IEEE Transactions on , vol.61, no.7, pp.3269-3278, July 2014.

[13] K.K. Gupta; S. Jain, "Topology for multilevel inverters to attain maximum number of levels from given DC sources," In Power Electronics, IET, vol.5, no.4, pp.435-446, April 2012.

[14] M. Angulo; P. Lezana; S. Kouro; J. Rodriguez; B. Wu, "Level-shifted PWM for cascaded multilevel inverters with even power distribution," In Proceedings of the IEEE Power Electronic. Spec. Conf., pp.2373 - 2378.

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.

Anjanee Kumar is an assistant professor in the Department of Electronics and Telecommunication Engineering, Raipur Institute of Technology. His current area of interest is Power Electronics.