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Designing a Dual Active Transformer DC-DC Forward Converter for DC Micro-Grid Applications Using LTSPICE

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Abstract

The most important part of a Micro-grid system is the DC-DC converter. This paper presents a dual transformer integrated DC-DC forward converter topology for operating in the area between the power storage system and the DC bus part of micro-grid applications. The whole idea of these system is based on the combination circuits, which are able to provide; easier connection among all the possible sources of power and DC Micro-grid, isolation, stability of DC Micro-grid line, the reduction of output voltage and current ripples, the reduction of power losses, high switching frequency for the reduction of output filter size, and high ratio conversion. There are some technologies of DC-DC power converters, which are used for reaching to a suitable structure of converter systems to provide higher performance of DC Micro-grid system. This paper presents models of DC-DC Forward converters which lead to a better topology to reduce the output voltage and current ripple and being in the high conversion ratio and suitable regenerative power. The combination presented in this paper is integrated of a DC-DC Forward converter with double transformer which is analyzed via LTSPICE.

Keywords: DC Micro-grid, Boost converter, Integrated DC-DC Forward Converter

I. INTRODUCTION

With recent development of power electronics such as DC-DC converters, rectifiers and inverters, it is possible to combine power generation with distributed energy resources in the small scale integration. Therefore, this combination has initiated Micro-grid system as the new system of power generation [1].

A micro-grid is a group of power sources which normally operates by being connected to and synchronous with the traditional grid, but is able to disconnect from the interconnected grid and to act independently in "island mode" in some especial economic condition . In this regard, micro-grids improve the security of supply part of power generation and can supply emergency power. Broad research has already been done and still going on to accomplish the features of Micro-grid system [2]. As it is obvious, the efficiency and performances of Micro-grid system are mostly relied on the quality of different parts of Micro-grid system such as so many types of new energy sources, power DC-DC converters and power electronic interfaces [3]-[4]. Therefore, the new form of electrical energy based upon renewable sources is welcomed for its ability to amend the fossil-fuel energy shortage and to protect environment by producing a cleaned energy without a lot of pollutant gasses such as (CO_2) [5]-[6]. Nowadays, different types of renewable energy sources such as photo voltaic (solar energy), wind turbines, Micro hydropower turbines, and biofuels have improved the functions and efficiency of Micro-grid system which is operating in secluded mode. Secluded (islanded) Micro-grid system is presented as a perfect solution to supply energy for the most parts of the local area and to prevent the outage of power by compensate the load for the peak demand hours of loads [3]- [7]-[8].

From the standalone point of view of Micro-grid system, there are various types of Micro sources which are compatible with Micro-grid [9]. The development of the new renewable energy sources becomes one of the most significant solutions to prevent the large area outage of power and compensate the shortage of fossil fuel energy and to save the environment from the dangerous gases [10]. Micro sources based upon renewable sources of energy have improved the development of DC Micro-grid systems integrating with DC-DC power converters. For instance, a DC-DC boost converter can step up the voltage of the micro-grid system the needed voltage by using MPPT methods such as fuzzy logic control, P&O and so on [11]-[12]. The basic goal of this paper is to review the different methods performed for different topologies of DC-DC power converters which connects the Micro sources of energy with DC Micro-grid bus, and deriving an integrated DC-DC Forward converter to improve efficiency and reliability of DC-DC converters applied to DC Micro-grid bus [13].The paper is written in a way that the introduction highlights the importance of DC Micro-grid for Micro sources development, the next part stress the reliability of DC-DC converters in DC Micro-grid systems and the part III is about to the DC-DC Forward converters, and finally a new topology based on interleaved technology is simulated with LTSPICE in parts IV and V.

II. DC MICROGRID SYSTEM

The performances evaluated between Micro-grid power distribution and the utilities especially composed of AC and DC loads, are mainly characterized by the power quality and stability level. In the DC Micro-grid bus the losses of distribution and transmission is lower, and provides low cost system with possibility to operate across long distances places [14], [15]. The DC Micro-grid is also suitable to operate where most of the loads are sensitive DC electronics. One of the advantages of DC Micro-grid is that all the loads, energy sources, and energy storage are able be connected through simpler and more efficiency power electronic interfaces [16]-[17].

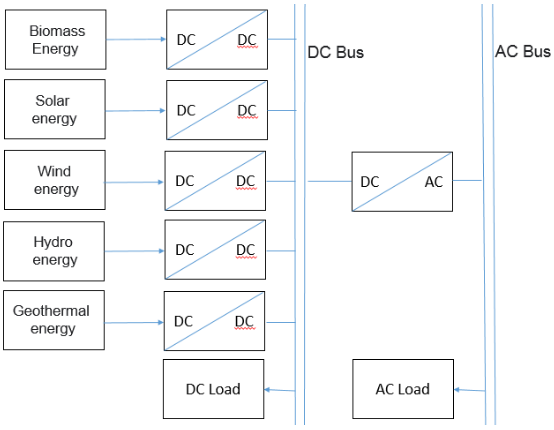


Figure l: Example of a local Micro-grid

The topology of Micro-grid is shown in Fig. 1. By considering the structure of Micro-grid in Fig. l, it is crystal clear that the DC-DC converters and inverters are the most effective part of DC Micro-grid. Therefore, power electronics converters are implemented to provide much better interconnection and reliability of various renewable sources to DC Micro-grid bus line [18]. In this regards, Micro-grid technology willing to focus in developing novel topologies of DC Micro-grid structures with high effectiveness of DC-DC power converters for a suitable distribution control and to be compatible with various renewable sources.

To isolate the converter, the topologies integrating the transformer as isolation has also more contributed in high boosting voltage and storage which in this case the increasing voltage can be reachable by increasing the duty cycle and the turns ratio of the transformer at the same time.

III. DC-DC FORWARD CONVERTERS IN DC M1CROGRID SYSTEM

A forward converter transforms a DC voltage at the input to a DC voltage at the output. The operating principle is similar to the buck converter, but an additional transformer is used to achieve galvanic isolation of the input and output. The basic topology of Forward converter is a structure consist of the three windings transformer, a switch based on the semiconductor technology and the output LC filters. Forward converter presents some drawbacks such as; the leakage inductance, parasitic capacitances and transient effects are probably occurred by switching activity normally operated at high frequency [19]. These above flaws cause the power losses which therefore decreases the performances of the Micro-grid system. The voltage conversion rate is generally determined according to the Eq. 1, presented below for Forward converters [20].

$$\frac{V_{DC}}{V_{in}} = \frac{n_2}{n_1} \quad (1)$$

$$\frac{V_{out}}{V_{in}} = \frac{n_2}{n_1} D \quad (2)$$

In the Eq. 1 and 2, D is duty cycle, n1, n2 are respectively the turns of primary and secondary windings and V_{DC} is the DC Micro-grid voltage. It is obvious that the duty cycle for a DC-DC Forward converter will not go more than 50% of the duty cycle in order to fulfill complete demagnetization in transformer. Besides, the DC-DC Forward converters present more performances to other converters; some drawbacks make DC-DC Forward converter to be far from the best topologies reserved to Micro-grid application. Since, most works have been promoted to find out the appropriate model matching with DC Micro-grid system and enhancing the quality of conversion. In that way various circuit topologies of DC-DC Forward converters have been experienced to find the best and more perfect design. Because of the importance of storage energy in DC Micro-grid, the DC-DC Forward converter is often required to maintain the stability of super-capacitor bank voltage integrating DC Micro-grid in order to complement the energy supplied by Micro-sources to DC Micro-grid bus [21]- [22]. These storage elements complete the charging and discharging operations of the DC Micro-grid bus. In the normal conditions, DC Micro-grid integrates a bank of batteries for acting as a backup device due to its high energy density and a super-capacitor bank for acting as a quick discharge device due to its high power density, in providing energy to the DC Micro-grid bus.

IV. DC-DC BOOST FORWARD CONVERTER

Bidirectional current flow, Lower number of active components, low output voltage and current ripple, isolation, high transfer ratio, reducing power losses caused by switching, forced us to experience new parallel integrated topologies to increase the performance and efficiency of DC Micro-grid [23].

In this paper, because of the promising results, integrated dual transformer DC-DC Forward converters have been used for connecting Micro-sources to DC Micro-grid bus. There are two topologies of DC-DC Forward converters as follow:

1. A model based on bidirectional techniques is provided to increase the conversion rate of the power.

2. A Regenerative model for recycling power by using the appropriate elements in the converter.

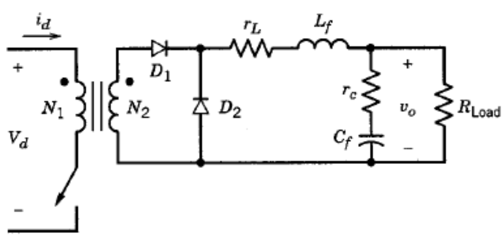


Figure 2: Isolated forward converter [24]

According the Fig.2 the DC-DC Forward converter is consist of a transformer to cause the isolation between the renewable sources and DC Micro-grid bus line. The transfer of power in this topology will be controlled by the MOSFET semi-conductor switch. Also, the stability of power transfer to the load is done by the output LC filter, includes of output inductor (L out) and output capacitor (C out). When the switch is off, the energy stored by output inductor (L out) and output capacitor (C out) provides the needed energy in the load part and the current recycles through diode D2 and the resetting of the windings occurred in diode D3. One of the most important factors of micro-grid is to reach the stability of the DC micro-grid bus. However, the stability of the DC Micro-grid bus is so sensitive with the change of loads and lack of reliability between Micro-sources, storage elements and DC Micro-grid bus [25]-[26].

There are different ways to provide soft switching to achieve the fast demagnetization of energy stored in windings of transformer such as, clamped inductor, clamped capacitor, active clamped techniques, Reset Clamped Diode (RCD), and zero voltage Switching (ZVS). Moreover, all the above different techniques in DC Micro-grid help the reduction of the input and output current and voltage ripples [27].

The bidirectional strategy increases the conversion rate in a way the voltage stress on the switching element becomes lower for the high ratio of conversion. DC-DC boost converter is made from boost topology to improved topology leading to the high conversion rate and provide amending of voltage stress on the switches. Furthermore, the series resistance (ESR) of the output capacitor or super-capacitor and inductor also cause lower efficiency. Therefore, to overcome all the above challenges, many topologies based on integrated paralleled techniques have been implemented to have a better efficiency and performance [28].

V. SIMULATION AND RESULTS OF PROPOSED CONVERTER

The integrated technique is based on paralleled transformer, where the two forward converter feeds one load. There are two ways for implementing integrated forward converter topology; one way is to have one output LC filter and two parallel individual power stages [29]. The other approach is to parallel the power stages and the LC output filters which is shown in Fig. 3. However, the integrated DC-DC Forward converter with double transformers is implemented to decreases considerably output current ripple and output voltage ripples [9].

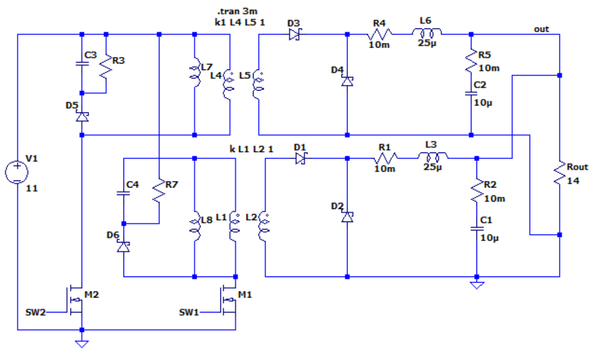


Figure 3: Implementation model of two-transformers forward converter

In this paper, the DC-DC forward converter consist of two transformers and two output filter will be presented and simulated by LTSPICE for DC micro-grid systems. In the proposed topology of DC-DC Forward converter with double transformer the magnetizing inductor is $2\mu H$, the amount of output inductor Lout is $25\mu H$, the output capacitor C out is $10\mu F$, the input voltage is 11 volts, the output load is 14 ohms, and the carrier frequency is 10 kHz.

The operation of the two DC-DC converters is controlled by two MOSFET switches. Also, the two PWM pulse (Pulse Width Modulation) are used to change the switching operation of transformers of each converter. PWM is triggered MOSFETS with 180 degree shifted pulse. The number of turns is the same for three windings of the transformer. All components of the double transformer DC-DC converter are the same to the single transformer shown in Fig. 4 and both transformers are fed by unique power source to share the current between two transformers in the perfect way. In addition, the leakage inductance of windings and leakage capacitance which are occurred in switching element and through windings are neglected [30]. For the simulating the DC micro-grid bus line, the two outputs of the proposed circuit are connected together with one load of 14 ohms. Furthermore, for the two MOSFET switches, the conduction time of the switch l and the conduction time of the switch 2, are completed each other with 180 degrees.

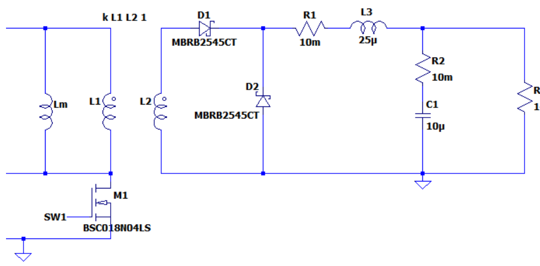
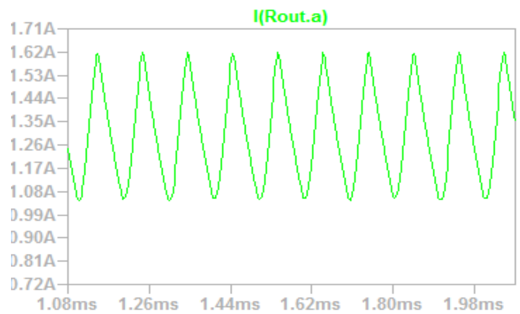
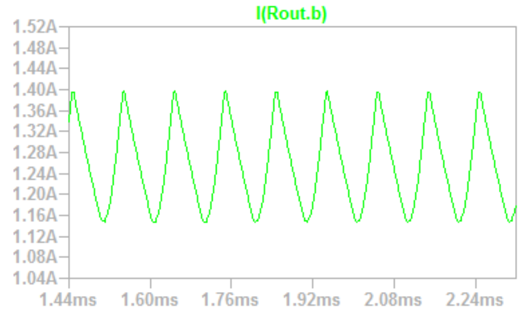


Figure 4: Single DC- DC Forward converter

By the comparison between proposed method with classic DC-DC forward converter through LTSPICE simulation in Fig. 5 and Fig. 6, it is obvious that in the integrating method, there is less ripples in the output current and output voltages. Plus, by frequency doubling the reduction of the size of output LC filter can be achieved.

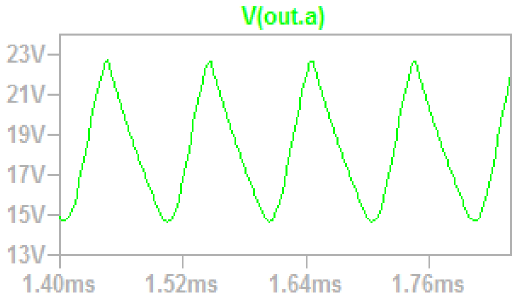


(a)

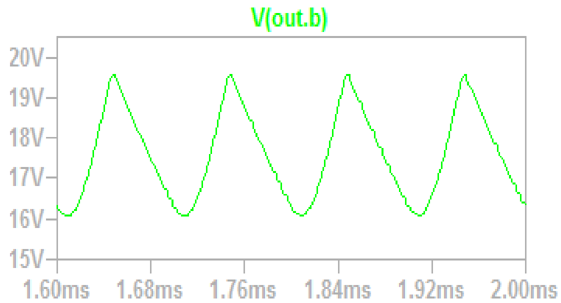


(b)

Figure 5: Waveforms of the output current ripple of DC-DC Forward converter: (a) Single transformer current ripple. (b) Two transformer current ripple.



(a)



(b)

Figure 6: Waveforms of the output voltage ripple of DC-DC Forward converter: (a) Single transformer voltage ripple. (b) Two transformer voltage ripple.

Fig. 5 and Fig. 6 indicate that the peak to peak output voltage and current ripple in the proposed DC-DC forward converter with two transformers is much lower than the peak to peak output voltage and current ripple in the DC-DC forward converter with single transformer. The equation for calculating current and voltage ripple in the single and double transformer of Forward converter are as follow:

$$\Delta I_{out} = (1-D)\frac{V_{out}}{L_{out}C_{out}f} \quad (3)$$

$$\Delta V_{out} = (1-D)\frac{V_{out}}{8L_{out}C_{out}f^{2}} \quad (4)$$

$$\Delta I_{out} = (1-2D)\frac{V_{out}}{L_{out}C_{out}f} \quad (5)$$

$$\Delta V_{out} = (1-2D)\frac{V_{out}}{8L_{out}C_{out}f^{2}} \quad (6)$$

Eq. 3 and 4, shows the Current and voltage ripples for the single transformer of Forward converter and Eq. 5 and 6, expressed the Current and voltage ripples for the double transformer of Forward converter, where parameter D is the duty cycle. The output ripples of DC-DC Forward converter with double transformers is less than one transformer and the frequency of double transformer DC-DC Forward converter is twice than one transformer. Then, the size of the transformer is decreased for the improved DC-DC Forward converter based on proposed topology.

VI. CONCLUSION

This paper presents the topology of Dual transformer DC-DC Forward converter to enhance the DC Micro-grid system. The proposed topology consists paralleled and integrated configuration of some stages of the DC-DC Forward converter to reach a more suitable design to provide a high efficiency in connecting the renewable sources to the DC Micro-grid bus line system. The results from simulation under LTSPICE, indicate much better performances by implementing the proposed DC-DC Forward converter with two transformers such as the reduction of output current and voltage ripples, doubling frequency which makes the reduction of output filter and transformer size. The proposed system presents the high efficiency for the stability of DC Micro-grid expressed in terms of current and voltage ripples cancellation and reliability with sources. This benefit can be also extended to the wide DC Micro-grid buses.

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