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Unidirectional DC/DC Converter for Microgrids

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Abstract

Microgrids are local small scale electricity systems that can operate independently and separated from the main electricity grid. This paper presents a novel unidirectional DC/DC converter that can be used to transfer power from distributed resources such as Solar PV or Fuel Cells into a DC microgrid. The converter is based on the LLC topology but designed to operate in a specific region of the gain curve that provides several benefits to integration of renewable energy sources into a constant DC bus. The isolated converter shows very high efficiency, full range of zero current switching, and simple control. The novel topology also has the inherent attribute of balancing the voltage on a bipolar DC bus by automatically shifting the processed power to the pole with the lower voltage.
Keyword- Unidirectional DC/DC Converter, Microgrids, LLC Topology

I. INTRODUCTION

The main components forming a microgrid are DC components such as batteries, renewable energy sources, and small DC generators. In addition, the majority of loads already use DC power provided by rectifiers or can be made more efficient if implemented as DC connected [1]. Consequently, DC microgrids will become in the near future the optimum solution for local small electricity systems because of their efficiency, cost, and reliability [2]. The success of DC microgrids is associated, amongst other factors, with the development of more efficient and reliable power electronics converters that contribute to the safety, availability, and reliability of the installation. Large attention has been dedicated to the high level operation, stability, and energy management of the microgrid, while conventional converters are used to demonstrate the concepts.

However, as different topologies are considered and progress is achieved in other aspects of the microgrid, advanced power converters developed specifically for the application are needed. Furthermore, isolation between the distributed power sources or loads and the DC bus is fundamental to achieve a reliable and robust microgrid system. This paper presents an isolated, unidirectional high efficiency DC/DC converter based on the LLC topology. The components for the LLC tank have to be carefully selected to operate the resonant circuit for the full load range in a region that provides multiple advantages when used for the integration of renewable resources with a DC microgrid[3]. A commercial DC/DC converter has been used to validate the proposed converter and is presented including the practical results. The paper also discusses additional advantages for the proposed converter when used to connect with a bipolar DC microgrid.

II. LLC RESONANT CONVERTER

In contrast to hard switched converters that interrupt the current flow to control the power, resonant converters process power by softly commutating the power devices. The softswitching operation results in lower energy loss and reduced electromagnetic interference. Series, parallel, and series parallel are some of the most common resonant converter topologies. Each one has its own advantages and disadvantages well discussed in the literature [3]. Other more elaborated topologies provide additional benefits at the expense of increased complexity and cost, which leads to lower reliability. A simple circuit, easy to control, and with fewer components would be a stepping stone for achieving more extensive use of DC microgrids. The LLC resonant converter is a multi-resonant converter that presents a unique DC gain characteristic, which results in performance advantages such as: Extensive range of softswitching operation, high achievable efficiencies, wide voltage gain range, and simple control. Moreover, the LLC topology enables easy and cost effective integration of magnetic isolation by using the transformer leakage and magnetizing inductances as part of the LLC circuit The LLC circuit has two resonant frequencies fr1 and fr2 depending on which inductances participate in the resonance. The frequency axis in Fig. 2 has been normalized to the higher resonant frequency fr1. The LLC converter is mostly used to transfer power and regulate the output voltage in applications where the input voltage has a wide range. For these regulators the converter is operated close to the resonant frequency fr1 where the voltage gain is almost unaffected by the load applied to the converter. This characteristic results in very fast dynamic response for the converter [4]. Deviations in input voltage are compensated by small changes in the switching frequency to regulate the output voltage under different loads. Operating the LLC converter at frequencies much lower than fr1 brings practical complications when regulating the output voltage because the voltage gain would greatly depend on the load applied to the converter. Changes in load will require fast response of the controller and larger filter components in order to regulate the voltage dynamically. In addition, operating at frequencies lower than the resistive mode line in Fig. 2 sets the converter in what is defined as capacitive mode where the switching losses increase if using majority carrier power devices such as MOSFETs. Because of that, the range of operation is normally kept close to fr1 and in a region with voltage gain of no more than 2.

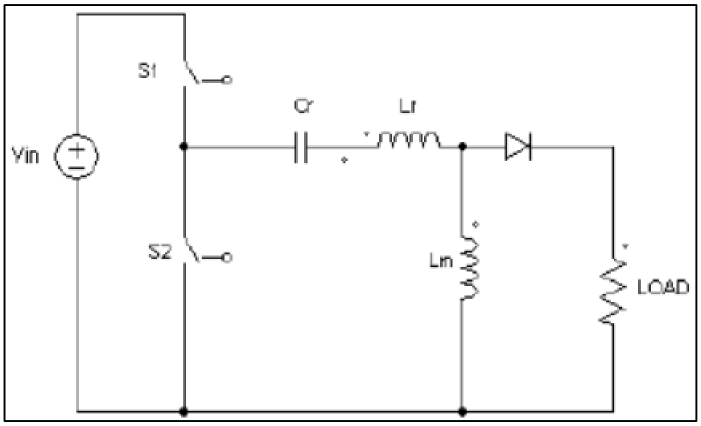

Fig. 1

III. NEW OPERATION MODE FOR THE LLC CONVERTER

If the LLC circuit is operated close to fr1, using it to transfer power between voltage sources is difficult to achieve. This is because all the load curves cross at the same operating point (located at fr1) making it practically impossible to regulate the load. A characteristic that represents a major advantage in the classic output voltage control application of the LLC circuit is a disadvantage when controlling power between constant voltage sources. However, the LLC converter can be operated in a region closer to the lower resonant frequency, where it will have new characteristics that make it attractive to transfer power between two voltage sources. Shows that in the new region of operation there is separation between the load curves enabling the use of frequency control to regulate the power flow between input and output.

Although modeling the load as a resistor is not appropriate when transferring power between voltages sources, an equivalent load resistor can be calculated for each operating point based on the output voltage source and the load current so that the DC gain curves in Figure.

To achieve power control between constant sources, the circuit has to be always operated with gain above unity in order to keep separation between the different load curves. In addition, the range of frequency control in the new operating region is reduced and a controller with high resolution in the frequency control is needed to provide precise and smooth control of the power transferred from input to output [5].

In the region with gain above unity, the resonant capacitor is charged in every cycle to a voltage level higher than the input voltage enabling transferring power at voltages higher than the input voltage. The Waveforms for the different regions of operation for the LLC circuit are presented in [6].

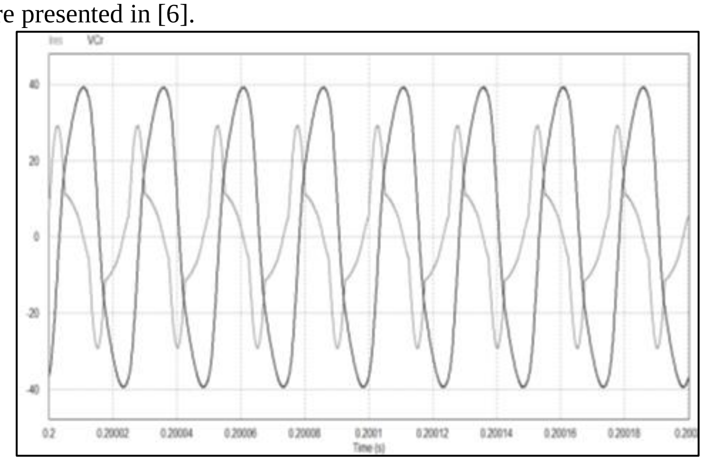

Fig. 2

Another characteristic of the LLC circuit operated in the proposed region is that, with respect to the design point. Additional power can be transferred by the same circuit under lower gain conditions.

This property fits the application of connecting alternative energy resources to a fixed DC bus since lower input voltages (higher gain requirements) are associated with lower power capability for the renewable power source. When using a DC/DC converter to connect distributed resources such as solar photovoltaic modules or fuel cells with a DC microgrid, it is fundamental to include galvanic isolation in the converter. The isolation will ensure that faults in the resources are segregated to the specific converter serving the faulted resource while the rest of the microgrid continues operating normally.

IV. CONCLUSION

A new and patented mode of operation for the LLC resonant converter has been introduced. The new region of operation is especially attractive for interconnecting alternative energy resources with a fixed DC bus such as a DC microgrid configuration. For enabling power control and operation over the full specified range of power, the LLC circuit has to be operated at gains above unity and the resonant tank components have to be carefully selected. Isolation can be incorporated by matching the resonant tank components with the leakage and magnetizing inductances of the transformer. The proposed topology and operating mode has the following advantages when used to connect power sources to a DC microgrid:

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