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Effect of A High Efficiency Passive (LLC) Converter in the Application of Transmission Lines

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Abstract: The proposed paper is a modified LLC converter with two series transformers, which has four operation configurations, covering the range of four times the minimum input voltage. To optimize the proposed LLC converter in attempt to achieve good efficiency. In order to minimize the magnetizing current and thus minimize the conduction and core losses, an optimal objective is proposed to find the maximum magnetizing inductance. Optimization procedure is given. Two conventional LLC converters are designed using fundamental harmonic approximation (FHA) and the proposed optimal design respectively to make comparison with the proposed LLC converter and validate the proposed optimal design. Matlab results show the proposed converter with proposed optimal design can achieve the peak efficiency up to 99%, while maintaining a very wide input voltage range. Utilization of this LLC converter in transmission lines is also introduced.

Index Terms: LLC converter, Micro-inverter, Optimization, DC Gain, transmission lines

I. Introduction

In recent decades, researches on the use of solar energy as an alternative source of energy have become a role of prominence in the field of electrical engineering. In parallel, new materials for the manufacture of photovoltaic panels and new methods of control are being developed to reduce costs and increase the efficiency of power converters. Among these techniques, a great effort has been spent with the algorithms for the maximum power tracking (MPPT) considering the variations of parameters such as temperature, solar irradiation or the load of the system. Several techniques for maximum power point tracking are based on the comparison between the measurements current and previous of the power delivered by photovoltaic panel. From these, other algorithms of control have been developed as the short circuit current or open circuit voltage techniques and perturbations methods. Thermo mechanical stresses have a significant impact on lifetime power switches. Consequently, there is a degradation of semiconductor devices, which finally forces them into a failed state: short circuit (SC) or open circuit (OC). Furthermore, faults may also happen on sensors and can be taken into account by active fault-tolerant control systems. Photovoltaic is the fastest growing energy technology in the world, with more than 30% annual increase in cumulative installed capacity over past 15 years. Among solar PV systems, PV panel is a key element, which not only determines the overall cost but also the connected inverter's specifications as well. Such failures occurring on single-power switches can affect the function of power converters and can spread through the traction chain elements. Based on the current PV technologies, the currently commercial PV panels are typically classified into two basic groups: (1) crystalline silicon PV panel; (2) thin film PV panel. The next issue is to investigate whether the innovative control methods can be reconfigured in a PV panels. The crystalline PV panels with production share reaching up to 83% whose power ratings commonly range from 160 Watts to 280 Watts, have low open-circuit and optimum operating voltages varying from 22V to 65V. In this paper, the proposed converter aims for the crystalline PV applications. Currently, there are three commonly used grid-tied PV inverters: the centralized PV inverters, the string PV inverters and the PV micro-inverters [3]. The PV micro-inverters are small grid-tied inverters of 150-300W that convert the output of a single PV panel to the AC grid. The need for meaningful performance comparisons of different photovoltaic (PV) devices has given rise to efficiency measurements performed under standard solar spectral irradiance and test conditions. The photovoltaic conversion efficiency, which is determined from the current versus voltage (I-V) characteristics of an illuminated cell, is typically measured with respect to a standard solar spectrum at a given intensity (100 mW cm-2). Several different standard spectra are in use by the PV community. These spectra represent direct normal and global irradiation under different atmospheric conditions. Several investigators have proposed measuring the PV performance over a period of time and reporting an energy rating based on a large number of measurements. Although these energy rating methods do not provide information on the efficiency with respect to a standard solar spectrum, they do provide information on the field performance over extended time periods under varying site specific solar insolation conditions. Basically PV micro-inverters can be categorized into three classes (1) micro-inverter architecture with DC bus (so-called two stage micro-inverter); (2) micro-inverter architecture with pseudo DC bus (so-called one stage micro-inverter); (3) micro-inverter architecture without DC bus. In this research, the front-end DC/DC converter for the PV micro- inverters in the first category is mainly focused. Among DC/DC converters, the LLC converter, capable of soft switching and achieving high switching frequency while maintaining high efficiency, has become a hot research topic in recent decades, which could be a good candidate for PV micro-inverter applications. However LLC converters can achieve high efficiency and high power density only if operating around the resonant frequency, resulting in a very narrow input voltage range and limited voltage regulation capability. This limitation previously kept the LLC topology from being used on PV micro-inverters, for which a very wide input voltage range is typically expected. For fixed resonant parameters and load condition, the peak DC gain decreases as the magnetizing inductance increases. To maintain the high DC gain, capable of wide input DC voltage range, the magnetizing inductance has to be set to a small value, which incurs high magnetizing current, resulting in higher conduction and core losses. It is very challenging for the conventional LLC converters to achieve high DC gain, while maintaining a very high overall efficiency. Several researches have been conducted to mitigate the problem of the conventional LLC converter. The proposed a hybrid scheme to achieve high

DC gain by simply changing full bridge to half bridge as shown in Fig.1. In this manner the DC gain will be doubled.

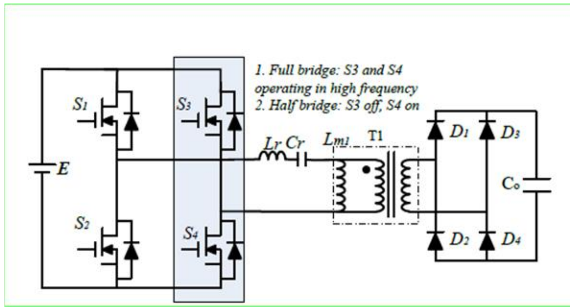

Fig.1: Reconfigured LLC topology from full bridge to half bridge

The rest of this paper is organized as follows: Section II describes the proposed controlling and modelling of a LLC converter and operation of the proposed converter. Section III describes the simulation results. Next Section IV describes conclusion and future scope of the system.

II. Description of circuit and operating principles

A. Description of circuit

A modified LLC converter with two transformers has four configurations to cover the range of four times the minimum input voltage range. To increase the efficiency of the system the converters are modified with two transformers. This will improve the dc gain and input voltage range of the system. As shown in Fig.2, a transformer T2 is inserted into the resonant tank in series connection with *Lr*, *Cr* and *T1*; a bidirectional switch, configured by S5 and S6, is paralleled with the primary winding of the transformer T2 to enable or disable T2 by controlling the bidirectional switch. The secondary sides of the transformers T1 and T2 are connected in parallel through two rectifier circuits to share the load. When the input voltage is less than the threshold *Vth*, the bidirectional switch keeps on and the transformer T2 is disabled so that it automatically blocks the rectifier 2. In this case, the LLC converter operates as a conventional one. When the input voltage is greater than the threshold *Vth*, the bidirectional switch turns off and the total magnetizing inductance in the primary side will increase from *Lm1* to *Lm1+Lm2*, reducing the magnetizing currents. In this way, the DC gain range is extended while keeping magnetizing current low. In addition, by keeping S4 conducted and turning off S3 permanently, the full bridge structure will change to half bridge structure, which will further double the DC gain. In summary, there are four operation configurations in this proposed topology illustrated as follows:

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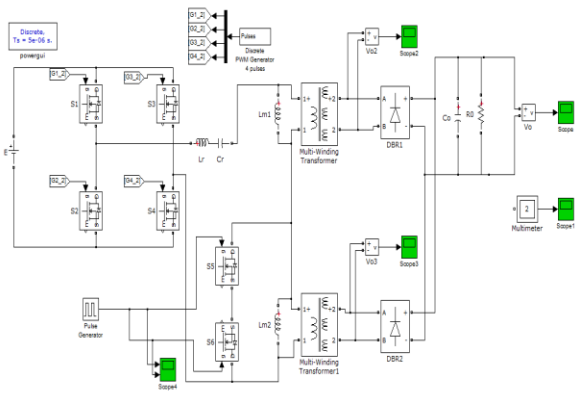

Fig.2: Proposed LLC converter.

The dc-dc converters are used to step up the voltage from small DC voltage. LLC converter has the capability of giving high efficiency. If the magnetizing inductance is small the magnetizing current will which in turn increase the core and conduction losses.

B. Operation of circuit

The circuit schematic of an LLC resonant converter in its half-bridge implementation is shown in Figure 1. In this paper we refer to this case in particular but, with obvious adaptations, the results that are provided are entirely applicable to the full-bridge implementation too. The half-bridge driver switches the two MOSFETs S1 and S4 on and off 180º out-of-phase at the frequency fs. The on time of each MOSFET is exactly the same and is slightly shorter than 50% of the switching period Ts = 1/fs. In fact, a small dead-time Td is inserted between the turn-off of either MOSFET and the turn-on of the other one. This is essential for the operation of the converter: it ensures that Q1 and Q2 do not cross-conduct and allows soft-switching for both of them, that is, zero-voltage switching at turn-on (ZVS). The resonant tank includes three reactive elements (Cr, Ls and Lp) and thus features two resonance frequencies.

The switched current IS, that is, the tank current iR(t) when either MOSFET is switched off, and the fundamental component of the square wave voltage applied to the tank circuit have the same sign. In other words, the tank current has to lag behind the input voltage; this is often referred to as inductive-mode operation. Obviously, if the tank current leads the applied voltage, we have capacitive-mode operation, which prevents ZVS. The tank current lags behind the applied voltage by an angle large enough so as not to change sign during the dead times Td: in this way, after the rail-to-rail swing, the voltage of the half-bridge leg midpoint (the node HB in Figure 1) has no oscillations before the other MOSFET is switched on.

Configuration 1: The transformer T2 is disabled by turning on the bidirectional switch and the rectifier 2 is blocked. In this case the converter operates as a conventional LLC converter.

Configuration 2: The bidirectional switch is off and two transformers operate in series at the primary side and in parallel at the secondary side. In this manner, the total magnetizing inductance is the sum of two transformers' magnetizing inductance, *Lm1+Lm2*.

Configuration 3: The full bridge is changed to half bridge operation by switching off S3 and keeping S4 always on. Meanwhile, the transformer T2 is disabled by the bidirectional switch. In this manner, the DC gain will be halved compared to that in configuration 1.

Configuration 4: The converter operates in half bridge and transformer 2 is enabled by turning off the bidirectional switch. Similar to configuration 3, the DC gain is half of that in configuration 2.

The major benefit of LLC resonant converter is narrow switching frequency range with light load and ZVS capability with even no load. In this dissertation, some unexplored operating region of LLC resonant converter will be investigated. Within these operating regions, LLC resonant converter will have some very special characteristic, which makes it an excellent features for front end DC/DC application. The LLC Resonant converter becomes the most attractive due to its high efficiency and wide operation range. The DC characteristic of LLC converter is shown in Fig.2. For this converter there are two resonant frequencies. In this case, Lr and Cr determine the higher resonant frequency. The lower resonant frequency is determined by the series inductance of Lm and Lr. Now the higher resonant frequency is in the ZVS region, which means that the converter could be designed to operate around this frequency. The major benefit of LLC resonant converter is narrow switching frequency range with light load and ZVS capability with even no load. In this dissertation, some unexplored operating region of LLC resonant converter will be investigated. Within these operating regions, LLC resonant converter will have some very special characteristic, which makes it an excellent features for front end DC/DC application.

By utilizing the transformer magnetizing inductance, LLC converter modifies the DC (Gain) characteristic of series resonant converter (SRC).Comparing with SRC, the converter can achieve both Buck mode and Boost mode. Unlike the pulse width modulation converters soft switching techniques are used. Here auxiliary circuits are used to reduce the switching losses and EMI, in the proposed resonant converter, not only such circuits are not used, but also all of the parasitic elements are merged in the converter's main components. Therefore, its price, size, and weight are reduced as well.

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III. Simulation Results

A MATLAB based simulation circuit was modelled and simulated using MATLAB 2014a version. The proposed circuit parameters & simulation results are listed below.

Input Voltage	25-100V
Resonant Inductor Lr	3.16µH
Resonant Capacitor Cr	408nF
Magnetizing Inductance Lm1	15.8µH
Magnetizing Inductance Lm2	5.49 µH
Switching Frequency Fs	80-140KHz
Resonant Frequency Fo	140KHz
Threshold Voltage	37.5V
Output Voltage Vo	210V
Rated Power	250W

The proposed LLC converter can be used in many applications where the desired voltage is about 400v. One of the main applications is to use this converter in the transmission lines. The following fig shows the simulation diagram of transmission system with number of busses.

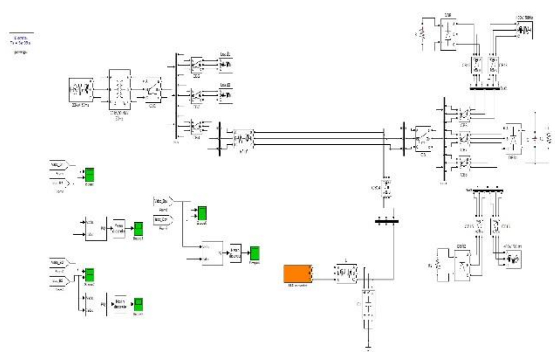
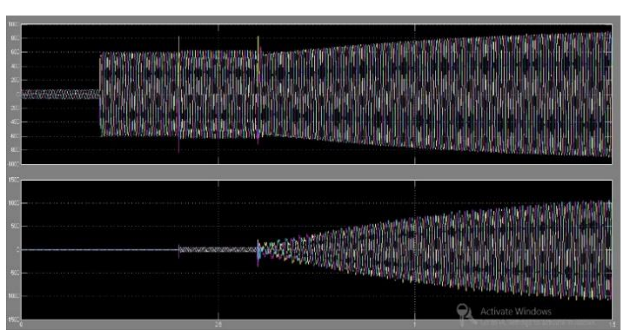
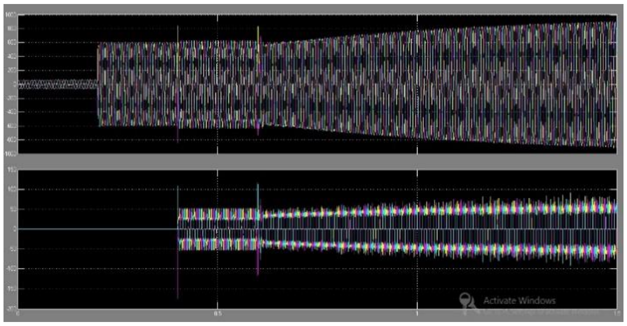


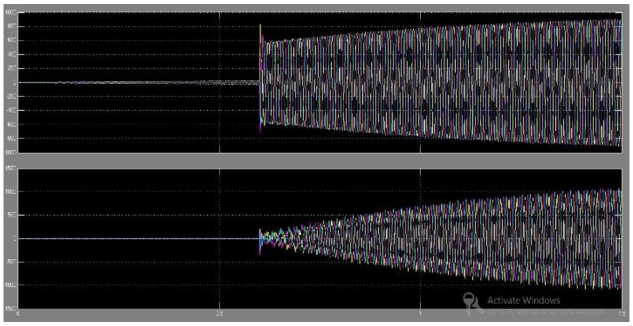
Fig.3: Simulation diagram of LLC converter in transmission application.



$a)\ V_{abc}, I_{abc}\ @Bus\ 1$



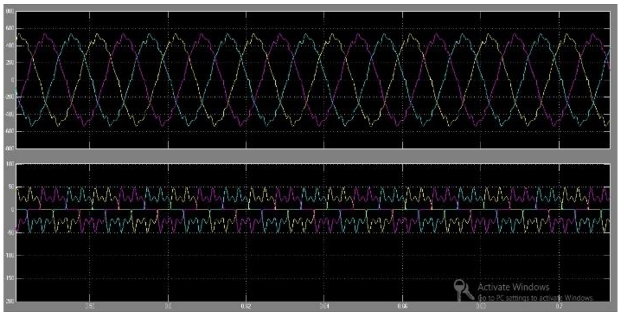
$b)\ V_{abc}, I_{abc}\ @Bus\ 2$

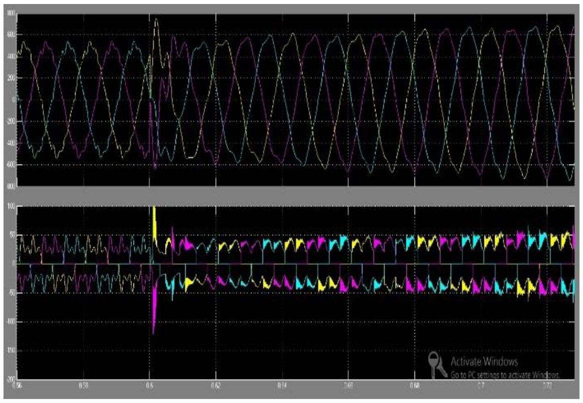


$c)\ V_{abc}, I_{abc}\ @Bus\ 3$

Fig.4: Three phase voltages and currents at different busses.

Without LLC Converter@ Bus2:





With LLC @Bus2:

Fig.5: Three phase Voltage and Current at Bus2 with and without LLC converter.

IV. Conclusion

The proposed circuit is easy to understand and low cost compared to other techniques, which requires many components. The proposed system efficiency is high because it is operated with soft switching technique. The paper proposes a modified LLC converter with two transformers in series in attempt to achieve high conversion efficiency while maintaining a wide input voltage range. To optimize the design, a numerical calculation with high accuracy is developed. Optimization criterion and procedure are given on guiding the LLC converter design. The efficiency is compared. The Matlab results show the proposed LLC converter, operating from 25V to 100V, can achieve up to 99% peak efficiency and got smooth output voltage waveforms with LLC converter when compared with without LLC converter.

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