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Design of Isoloated Power Converters for Dc-Distribution System

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Abstract*: With the advancement in power electronics switching and control devices now it is possible to replace a existing AC power distribution networks with the DC power supply for better energy efficiency. High demand for electrical power increases a pressure on the throughout energy supply and efficiency of power system. The application of DC distribution of electrical power has been suggested and the fact that, internally, many appliances operate using DC voltage. A suitable choice of rectifier facilitates the improvement of power quality as well as power factor at utility grid interface. This concept is inspired by absence of reactive power, possibility of efficient integration of small distributed generation unit. Renewable energy sources and storage devices can be fully utilized because they are more compatible with DC based system where generated energy can be directly used to loads and stored which results in less conversion loss. In this project report three isolated converters which are a single-phase grid interactive uni-directional AC-DC CLLC resonant converter with dc-bus voltage regulation and power compensation is proposed for dc distribution applications, a bidirectional DC-DC DAB converter for battery interface, and LLC resonant converter for a renewable energy simulator, with load is introduced. This report discusses three isolated power converters. The DAB converter can be operated in both buck and boost mode. The Battery is charged when bus voltage is greater than 380V and it get discharged when bus voltage is less than 380V. The three converters maintain the output voltage of DC bus in the range of 360-400V dc. Finally simulation results of CLLC resonant converter, DAB battery interface, & renewable energy simulator is presented.*

Keywords: 380V DC distribution system, DAB converter, Isolated power converter, LLC resonant converter.

I. INTRODUCTION

These days, renewable energy sources, DC electronic loads, and energy storage devices have been adopted to residential house and building applications. They have also been widely used in electrical vehicle and LED lighting applications in industrial fields and consumer areas. The DC distribution system can easily interface with different electrical systems composed of renewable energy sources and energy storage devices. The DC distribution system achieves higher power conversion and distribution efficiency because of the reduction of power conversion stages. In addition, it can easily integrate DC loads, electrical vehicle, and LED lighting into the distribution system, compared with the AC distribution system [1,2].

With the increasing demands for electric power in future automobiles, uninterrupted power supplies (UPSs), renewable energy sources, telecom and computer systems, and aviation power systems , bidirectional dc–dc converters (BDCs) exhibit as an ever-lasting key component to interface between a high-voltage bus where an energy generation device such as a fuel cell stack and/or a photovoltaic array is installed, and a low-voltage bus, where usually an energy storage device such as a battery or a super capacitor is implemented, to actively provide clean and stable power and to enable high reliability, effectiveness, and maneuverability of the power systems aforementioned[15-17]. In order to significantly reduce reactive component size and cost, high-frequency operation of BDCs is desirable. However, in a hard-switching converter, as the switching frequency increases, switching losses and electromagnetic interference increase. To resolve this problem, soft-switching converters are employed.

Several isolated BDC topologies have been suggested for applications of the dc power distribution systems. A boost full-bridge ZVS PWM dc-dc converter was developed for bidirectional high power applications. This topology is proper to the bidirectional power conversion because it has a boost mode for low to high voltage power conversion and a buck mode for vice versa. However, this topology requires a snubber circuit to suppress the voltage stress of the switches, which increases circuit complexity and decreases power conversion efficiency. A Bidirectional phase shift full-bridge converter was proposed with high frequency galvanic isolation for energy storage systems. This converter can improve power conversion efficiency using a zero voltage transition (ZVS) feature; however, it requires input voltage variations to regulate constant output voltage because this topology can only achieve the step-down operation. The isolated unidirectional CLLC resonant converter has useful characteristics for regulating the DC-bus voltage. This converter shows soft switching capabilities of the primary and the secondary switches employing zero voltage switching (ZVS) and soft commutation under entire load ranges. In addition, it has a simple switching mechanism to control the power flow directions in the converter [12, 14]. The DAB converter is good for power interfacing between battery stations and load sides because of its wide gain range and high boosting ratio. This converter has bidirectional buck and boost capability with high frequency isolation and simple structure with soft switching property [18, 23]. Finally, the LLC resonant converter is a frequently selected topology for high power DC-DC applications because of its outstanding performance in high power conversion efficiency and high power density. The soft switching feature for the proposed converter is realized only by a very simple CLLC resonant tank. In the proposed system without any other additional soft-switching auxiliary circuits and being snubber less, the overall component count can be dramatically reduced.

II. LITURATURE SURVEY

"AC Versus DC Distribution Systems-Did we get it Right" Published by Donald J. Hammerstrom, Senior Member, IEEE2007, author described and compared the AC and DC distribution system. Paper focused on distribution within premise and low-voltage distribution systems. Specifically addressed the conversion efficiency costs of adopting various premise ac and dc distribution system topologies. According to a simple predictive model formulated in paper, premise residential dc distribution will incur unfavorable total conversion efficiency compared with existing ac premise distribution. However, if a residence is supplied by a fuel cell or another dc generator, the total conversion efficiency within a residential dc distribution system could be similar to, or even better than, that for ac distribution. A simple model will then be suggested for the comparison of ac and dc premise systems [1].

"Building Scale DC Micro grids" published by Chris Marnay, Steven discusses trends and other factors that are pushing our power system towards a more decentralized paradigm, and one more reliant on DC systems. It is quite obvious that native DC loads are growing. Electronics everywhere, compact fluorescent and LED lamps are ubiquitous, and in addition, many emerging technologies, such as variable frequency drives (VFDs) that use DC are becoming commonplace. This trend is so clear not only because of the attractive capabilities, efficiency, and reliability of these devices, but also because public policies motivated by energy efficiency and related goals are reinforcing the trend. Likewise also stimulated by subsidies, the deployment of PV, a DC source especially amenable to building scale systems close to loads, continues to grow exponentially particularly interesting though, is the potential role of PEVs, which may prove to be a disruptive technology [2].

"DC Micro grid Management Using Power Electronics Converters" by R. K. Behera S. K. Parida says that the DC-based micro grids have some advantages like DC-based DGs such as photovoltaic cells and fuel cells can inject power directly to the DC micro grid, Asynchronous AC sources can be connected to the DC-grid by AC/DC converters without considering voltage phases, DC micro grid has the features of reducing the losses caused by the reactive power and overcoming the limitation of the power flow upto certain extent The grid can supply power to the power electronics equipment's directly. Hence, stand-by losses caused by the AC/DC conversion can be eliminated [3].

"Low-voltage bipolar-type dc micro grid for super high quality distribution ", IEEE transactions on power electronics, vol. 25, no. 12, December 2010, author said that low-voltage bipolar-type dc microgrid, which can supply super high quality power with three-wire dc distribution line. One system for a residential complex is presented as an instance of the dc microgrid. In this system, each house has a cogeneration system (CGS) such as gas engine and fuel cell. The output electric power is shared among the houses, and the total power can be controlled by changing the running number of CGSs. Super capacitors are chosen as main energy storage [4].

"Design and control of a bidirectional dual active bridge dc-dc converter interface solar, battery, and grid-tied inverters", in order to further reduce the size of today's power converters, wide bandgap semiconductor technologies are being explored. These devices, such as silicon carbide (SiC), have been shown to outperform their silicon counterparts when used in high frequency switching, high temperature, and high voltage applications. These properties make them highly desirable in the bidirectional dual active bridge power converter. Being an isolated converter topology, the dual active bridge employs a transformer to provide step-up/step-down functionality and galvanic isolation for the converter The aim of thesis is to demonstrate the performance benefits of SiC MOSFETs in the dual active bridge topology. A justification for the choice of topology is included in this work, along with all of the appropriate design considerations and analysis, leading to the design of a 2kW dual active bridge converter. Modern modeling techniques are also explored and used to develop an enhanced digital controller, implemented in a DSP, for steady state reference tracking and load disturbance rejection [9].

"Design Considerations for an LLC Resonant Converter", the LLC resonant converter has drawn a lot of attention due to its advantages over the conventional series resonant converter and parallel resonant converter: narrow frequency variation over wide load and input variation and Zero Voltage Switching (ZVS) of the switches for entire load range. This paper presents an analysis and reviews practical design considerations for the LLC-type resonant converter. It includes designing the transformer and selecting the components. The step-by-step design procedure explained with a design example will help engineers design the LLC resonant converter easily [10].

"Accurate Power Loss Model Derivation of a High-Current Dual Active Bridge Converter for an Automotive Application", An accurate power loss model for a high-efficiency dual active bridge converter, which provides a bidirectional electrical interface between a 12-V battery and a high-voltage(HV)dc bus in a fuel cell car, is derived. The nominal power is 2 kW, the HV dc bus varies between 240 and 450 V, and the battery voltage range is between 11 and 16 V. Consequently, battery currents of up to 200 A occur at nominal power. This paper describes the main reasons why the conventional method fails and documents the different steps required to predict the power losses more accurately. With the presented converter prototype, an efficiency of more than 92% is achieved at an output power of 2 kW in a wide input/output voltage range [16].

"Experimental Comparison of Isolated Bidirectional DC–DC Converters Based on All-Si and All-SiC Power Devices for Next-Generation Power Conversion Application", In paper, the application performances of isolated bidirectional dc–dc converters (IBDCs) based on all-Si and all-SiC power devices for next-generation power conversion application are comparatively analyzed and validated through experiments. Both the comparative theoretical analysis and experiments show that the SiC-based converter has better performance than the Si-based IBDC. The efficiency of all-SiC-based IBDC is higher than that of the previous reported IBDCs [21].

III. SYSTEM OVERVIEW

- **DC DISTRIBUTION SYSTEM**

The transmission and distribution of electric power have long been dominated by ac, while dc power systems were only being used for limited applications. The utilization of dc for distribution systems was not popular until recent times; the rising concern for energy savings has led to the evolution of dc systems being used in distribution. The load profile in offices, commercial facilities, and residential systems is undergoing a significant change in recent years, with more electronic loads being used. Today's homes incorporate LED-based lighting, computers, laptop and cell phone chargers, etc., and these consumer electronics run on low-voltage dc (LVDC). Commercial structures like telecom towers, data centers, and some offices require an uninterrupted source of dc power. With a dc distribution system, the loads can be supplied directly with a single power conversion stage, thereby reducing losses. Renewable sources like solar PV and fuel cells are dc in nature. These sources could be directly coupled to the dc bus, thereby avoiding a dc-ac conversion stage.

ADVANTAGES AND OPPORTUNITIES FOR DC DISTRIBUTION

1 Utilization of Renewable Energy Resources.

2 Incorporation of Distributed Generation, Micro-grids, Energy Storage Systems, Electrical Vehicles.

3 Power Quality.

4 Transmission Corridors and Landscaping.

5 Grid Stability.

- **EXISTING DC POWER SYSTEMS**

There are several power systems that typically employ DC distribution. Some of these systems include

1. Spacecraft-:Spacecraft systems involve a large number of solar panels, DC-DC converters, batteries, battery chargers and DC loads Hence, DC distribution is employed. A good example is the NASA International Space Station (ISS) requiring over 100 kW. The ISS is composed of two relatively independent DC systems with different voltage levels. The American system runs at 120 V and has solar power modules with a capacity of 76 kW. Whereas, the Russian system is divided into two voltage levels; 120 V and 28 V components, and it has 29 kW solar power modules. The two systems are linked with bi-directional DC-DC converters to enable power transfer.
2. Data centers-:Some current data center power systems are AC and some are DC. They store and transfer huge amounts of digital information such as internet, cellular communications, and credit card transactions. The main feature that must be maintained in a data center power system is reliability moreover low cost has to be also ac considered since the energy consumption of data centers is expected to be around 20percent of the total cost. The high penetration of UPS systems in data centers makes DC distribution a more economical and efficient option because of the eliminated conversion stages.
3. Telecommunication-:Telecommunication power systems, similar to data center power systems, are designed to transfer tremendous amount of data. They also require high reliability and efficiency at a low cost. Therefore, DC distribution is used. An example is the 48V power system in the telecommunication central office. The reliability of that system is five nines.

4. Traction-:DC distribution is used in traction power systems, such as trolleybuses, trams, underground railways, mainly because DC motors are typically used in this application. Evenfor traction systems that use induction motors, interfacing with DC supply is much easier and reduces conversion stages. Consequently, system efficiency and controllability will be increased. Moreover, using DC distribution help designers use a single conductor since the Rails can be used as the return path for the current. DC distribution in traction power systems supplies the vehicles and other auxiliary loads on them. Their supply voltage ranges among 600 V, 750 V or even up to 1 kV.

IV. SYSTEM METHODOLOGY

The proposed DC distribution system requires three isolated DC-DC power converters such as the bidirectional CLLC resonant converter for DC-bus voltage control, the DAB converter for battery power interface, and the LLC resonant converter for the renewable energy simulator. As mentioned above, these converters can achieve high power conversion efficiency through ZVS over entire load range or at a specific load condition, high dynamic performance, good bidirectional operation, and good isolation characteristics.

Fig.1. shows the configuration of electrical interface among three power converters in the DC distribution system. To control bidirectional power flows and to regulate the DC-bus voltage, the DC distribution system requires an isolated bidirectional AC-DC converter to interface between the DC-bus and the AC-grid. The converter regulates the DC-bus voltage during the powering mode and the generating mode, which are power flows from the AC-grid to the DC-bus and vice versa, respectively, according to the status of output current. To ensure the stable operation of the residential DC distribution systems and to provide clean and safe electric power to loads, an energy storage system should be required. A bidirectional isolated DC-DC converter interfaces DC sources such as AC-DC power converters, renewable energy resources, and energy storage systems. In addition, it controls charging and discharging current according to the status of the DC-bus voltage. Finally, to simulate the power generation from renewable energy sources, a variable DC current source was adopted. In general, renewable energy sources provide variable output current according to their power generation. The isolated unidirectional AC-DC rectifier controls the current flows to emulate the power generation from renewable energy sources according to specific time sequence, which provides electric power to the DC-bus.

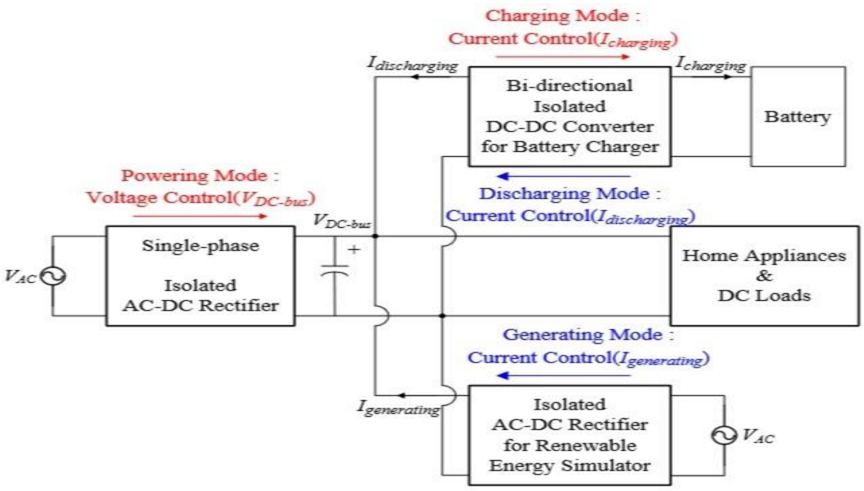

Fig.1. Configuration of system

1. CLLC Resonant converter

Resonant converters use a resonant circuit for switching the transistors when they are at the zero current or zero voltage point this reduces the stress on the switching transistors and the radio interference. To control the output voltage, resonant converters are driven with a constant pulse duration at a variable frequency. The pulse duration is required to be equal to half of the resonant period time for switching at the zero-crossing points of current or voltage. There are many different types of resonant converters. For example the resonant circuit can be placed at the primary or secondary side of the transformer. Another alternative is that a serial or parallel resonant circuit can be used, depending on whether it is required to turn off the transistor, when the current is zero or the voltage is zero. Since the converter is controlled through frequency modulation, the impedance of the resonant network will be changed by changing the switching frequency in response to load changes. Consequently the output voltage can be regulated by changing impedance of the resonant tank circuit.

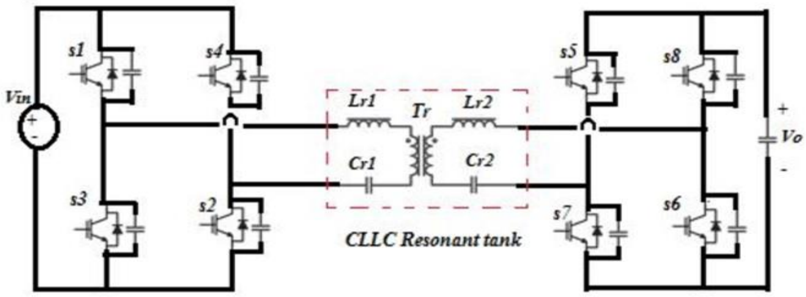

Fig 2. Full bridge CLLC resonant converter.

2. DAB Converter

Bidirectional isolated dc-dc DAB converters were initially proposed in and as candidates for high power density and high power dc-dc converters. The DAB topology is attractive because it has zero-voltage switching (ZVS), bidirectional power flow, and lower component stresses. A DAB converter consists of two H-bridges and one high frequency transformer. One H-bridge converts the input voltage to an intermediate high-frequency ac voltage, while another H-bridge converts the high-frequency square wave ac voltage back to the output voltage. A high-frequency transformer is used along with high-frequency switching devices because it reduces the weight and volume of passive magnetic devices. Beside galvanic isolation, the high-frequency transformer also has some leakage inductance in its primary and secondary windings, which together act as an energy storage component. The leakage inductance also helps achieve soft switching. During switching transients, transformer current resonates with the capacitors in parallel with switching devices, limiting the dv/dt and di/dt across the switches. Soft switching helps to reduce switching loss and achieve higher power efficiency.

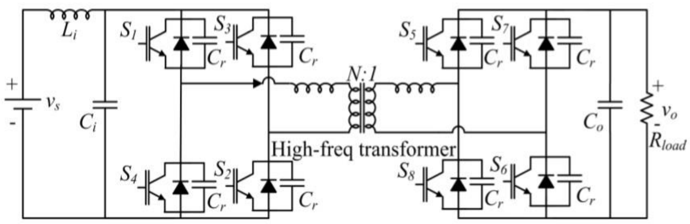

Fig 3: Dual Active Bridge converter

3. LLC Resonant Converter

Recently, the LLC resonant converter has drawn a lot of attention due to its advantages over the conventional series resonant converter and parallel resonant converter: narrow frequency variation over wide load and input variation and Zero Voltage Switching (ZVS) of the switches for entire load range.

Configuration of the unidirectional AC-DC converter composed of a single-phase unidirectional rectifier for grid interface and a bidirectional DC-DC converter for high frequency isolation. The full-bridge unidirectional CLLC resonant converter is proposed for the galvanic isolation of the DC distribution system with high efficiency unidirectional power conversion.

The proposed unidirectional CLLC resonant converter has a high frequency transformer for galvanic isolation, which has the symmetric structure of the primary and secondary sides. During the powering mode, the primary side operates under the inverting switch operation to transfer electric power to the secondary side. Then, all the secondary switches do not operate and the secondary current is rectified by anti-parallel diodes of the secondary IGBTS. This simple switch operation for the unidirectional power flows can reduce the control burden of the power switches of the controller.

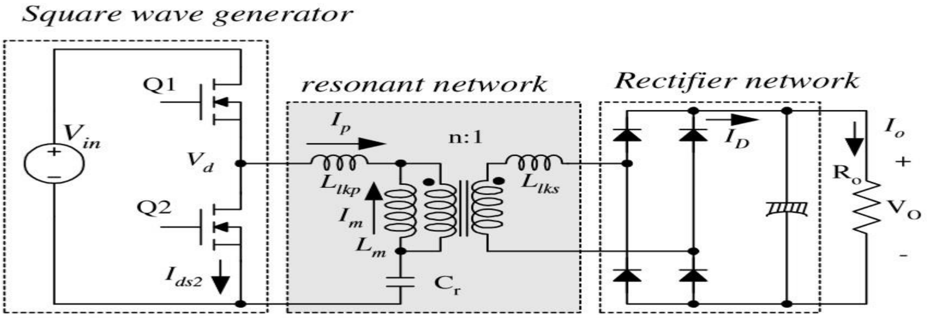

Fig 4: Schematic of LLC resonant converter

CONCLUSION

The simulation model of 380 V Dc distribution system is implemented using isolated DC-DC converters, such as CLLC resonant converter for regulating the DC-bus voltage, the DAB converter for the battery power interface, and the LLC resonant converter as renewable energy simulator, as well as with load. The three isolated converters which have functions of interfacing the DC bus with the AC grid, charging and discharging the battery system, and emulating power generation of renewable energy. The CLLC resonant converter is explained in terms of topology for powering mode and with controller. DAB converter is explained with topology and control algorithm is developed for charging and discharging mode of battery. LLC resonant converter is explained with topology and PV is connected to this converter. The energy emulation from PV is done by this converter. Finally performance of these three converters are verified in MATLAB. CLLC resonant converter were tested with 5 W and 5000 W load, with load variation. The simulation result shows that CLLC resonant converter successfully regulate the output voltage. The control algorithm for battery decides the charging and discharging operation of battery. Inspite of variable output of PV, the LLC resonant converter successfully maintain the dc bus voltage to 380V.

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