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CHARACTERIZATION AND IMPLEMENTATION OF RESONANT ISOLATED DC/DC CONVERTERS FOR FUTURE MVDC RAILWAY ELECTRIFICATION SYSTEMS

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ABSTRACT

To improve their efficiency and increase railroad traffic, new dc electrification has recently been proposed at high power application. It is now necessary to prepare the migration of infrastructure and rolling stock, using power electronic transformers (PETs), for adaptation to this voltage level. For this application, high efficiency and reduced volume are essential. This article clearly demonstrates that it is now possible to achieve a compact, high-power, isolated dc–dc converter using MOSFET power modules with high efficiency. After a preliminary study based on simulations, this article focuses on the characterization and implementation of elementary isolated dc–dc converters the proposed topology is a series-resonant converter rated for a nominal power. First, laboratory testing using an "opposition method" is used to evaluate the elementary converters up to their nominal power using both electrical and thermal measurements to accurately determine losses and efficiency. At the nominal output power, an efficiency of 98.93% is obtained. In isolated bidirectional DC-DC converter, soft switching is provided for reduce the switching losses and stresses on switches.

KEYWORDS: *PETS, Isolated DC–DC Converters, Soft Switching*

INTRODUCTION

The increase in regional and freight traffics, more and more traction power is required. The dc power systems suffer from the relatively low-voltage levels that draw high currents, and in order to avoid an excessive line-voltage drop, the distance between substations must be minimized, and the overhead lines must have a large cross section. For example, at 1.5-kV dc, it is not uncommon to find overhead-line cross sections of up to 1000 mm2 and a substation spacing of around 15 km. Thus, the mechanical infrastructure of the overhead line is heavy and expensive, whereas the onboard traction converter of a dc locomotive is simple and reduced to an input filter and a three-phase voltage source inverter. On the other hand, lines electrified in ac benefit from higher voltage levels and lower overhead-line cross sections. Nevertheless, ac operation entails reactive power and, therefore, inductive voltage drops. In the 25-kV/50-Hz system, the substations are only based on a single-phase transformer, but, in order to rebalance the power on the upstream three-phase transmission lines, the substations are supplied by different phases.

In recent years, the attractiveness of medium-voltage dc (MVdc) networks compared with MVac power systems has grown steadily. The potential applications are mainly onboard electrical networks for ship propulsion, offshore wind farms, or smart girds , and it is clear that, in the future, MVdc power grids will contribute to the deployment of renewable energy sources and associated storage systems, as well as charging stations for electric vehicles. Regarding the breaking of dc fault currents, several projects, in particular for HVDC grids, have led to the development of hybrid circuit breakers (CRs) (semiconductors and mechanical switch).

Meanwhile, on the power converter side, multilevel voltage-source inverters are already used in variable speed MV drives for industrial motors operating from 6 to 10 kV. For a new fleet of vehicles, a new traction chain operating directly under 9-kV dc could be based on multilevel inverters and medium-voltage traction motors [13]. Furthermore, in the context of sustainable development and the evolution of a global energy mix, the choice of an MVdc power system offers a new opportunity for railway lines: they can now act as energy hubs by facilitating the connection.

In all the cases mentioned earlier, PETs will evidently play an essential role, but, first, the feasibility of such devices at power levels of several megawatts must be investigated and demonstrated. Therefore, after a preliminary study based on electrothermal simulation on the PLECS software, this article focuses on the characterization and implementation of an isolated dc–dc converter based on a resonant-single-active-bridge topology (R-SAB) using 3.3-kV SiC MOSFET modules. This converter, with a nominal power of 300 kW, is sized to operate at 15 kHz and 1.8 kV. An opposition method is proposed to test this converter. Electrical and thermal measurements are used to accurately determine losses and efficiency. Different solutions for the output rectifier are evaluated: Si-diodes, SiCdiodes, or SiC MOSFETs in synchronous rectifier operation. Finally, two elementary converters are associated with the input series/output parallel (ISOP) configuration in order to evaluate the performance of a 3-/1.5-PET.

The Existing System

Using an isolation transformer in the grid-connected inverter can solve the Problem of the leakage current caused by the earth parasitic capacitance in solar modules. There are two types of grid-connected inverter with an isolation transformer. a) Line frequency transformer b) High-frequency transformer

Line Frequency Transformer

Figure 1 shows a grid-connected photovoltaic generation system with a line frequency transformer. The solar modules can be grounded directly and there is no current path for leakage current because the line frequency transformer is isolated. This system supplies no dc current to the grid and has the advantage of a simple control circuit. However, the line frequency transformer's disadvantages are large volume, high weight, and high cost.

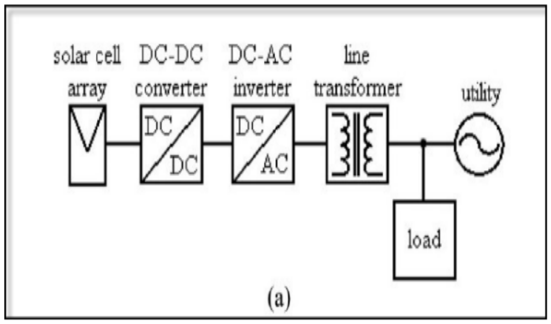

Figure 1: Existing Grid-Connected Photovoltaic Generation System with an Isolation Transformer (Line frequency transformer)

HIGH FREQUENCY TRANSFORMER

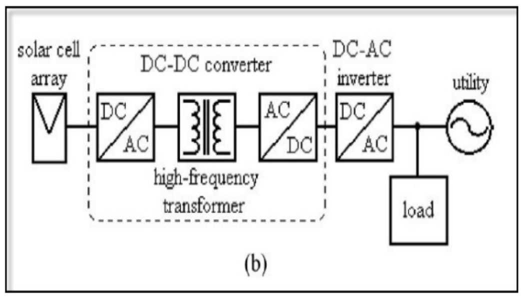

Figure 2: Existing Grid-Connected Photovoltaic Generation System with an Isolation Transformer (High-Frequency Transformer).

Figure 2 shows a grid-connected photovoltaic generation system with a high frequency transformer. The transformer is incorporated in a dc–dc converter and is operated at high frequency to reduce volume and cost. However, the control circuit of this grid-connected photovoltaic generation system is complicated due to the use of a transformer-isolated dc–dc converter. Besides, the high-frequency transformer is not placed at the output of the grid-connected photovoltaic generation system, so it cannot prevent the dc current from injecting the grid.

The use of an isolation transformer in the grid-connected photovoltaic generation system should be avoided due to cost, size, and efficiency. In general, the bridge-type dc–ac inverter is used in the grid-connected photovoltaic generation system. However, a conventional bridge-type dc–ac inverter, without an isolation transformer, results in the problem of leakage current because it cannot sustain the voltage of its negative terminal at a constant value. Recently, many dc–ac inverter topologies have been proposed to solve the problem of leakage current. This paper proposes a transformer less grid-connected power converter with negative grounding for a photovoltaic generation system.

DRAWBACKS OF EXISTING SYSTEM

- Efficiency of the system low.
- Output voltage not constant in utility side.
- Cost of the system increase

- Transformer losses also increase the total losses of the system
- Modes of operation is high

LITERATURE SURVEY

Jinwei He et al [1]Introduce a hybrid voltage and current control method (HCM) to improve the interfacing converters performance in distributed generation units. Nowadays current controlled method (CCM) used in grid connected converters. Proposed method allows the coordinated closed –loop control of the DG unit fundamental voltage and harmonic currents. Overcome the disadvantages of fossil energy based centralized power generation was large number of renewable energy sources (RES) have been integrated into the power distribution system in the form of distributed generations. RESs are unregulated DC power or AC power at variable frequencies. The robust interconnection of these RESs, the interfacing converter with LCL filter is normally placed between RESs and the main grid.

Moon-Young Kim et al [2] Presented a Chain Structure of Switched Capacitor for Improved Cell Balancing Speed of Lithium-Ion Batteries. Nowadays many applications used for rechargeable batteries. And the lithium-ion battery is one of the most attractive batteries due to its high energy density, low self-discharge rate. Existing method series connection of the lithium-ion batteries is required to meet the demanded voltage level. Proposed method chain structure of switched capacitor for improved cell balancing speed.

Kyung Min Lee et al [3] developed a Active cell balancing of Li-ion batteries using LC series resonant circuit. Series connected li-ion batteries have high energy density, high cell voltage, long life cycle. All cell battery operated in a safe operating area (SOA) and charging voltage limit (CVL) ,discharging voltage limit(DVL).Charging over CVL burns or burns the battery , and discharging below DVL damages its chemical properties. Proposed a new active cell balancing method for Li-ion batteries. Comparison with conventional circuits confirmed that the proposed circuit is a good candidate for balancing Li-ion batteries.

Wangxin Huang et al [4] proposed a energy sharing state-of charge (SOC) balancing control scheme based on a distributed battery energy storage system architecture where the cell balancing system and the DC bus voltage regulation system are combined into a single system. The small power converters are utilized to achieve both SOC balancing between the battery cells and DC bus voltage regulation at the same time. The battery cells' SOC imbalance issue is addressed from the root by using the energy sharing concept to automatically adjust the discharge/charge rate of each cell while maintaining a regulated DC bus voltage

Nilanjan Mukherjee et al [5] presented a Control of second-life hybrid battery energy storage system based on modular boost multilevel buck converter. Second life batteries on the grid system a hybrid battery scheme needs to be considered for several reasons; the uncertainty over using a single source supply chain for second life batteries, the differences in evolving battery chemistry and battery configuration by different suppliers to strive for greater power levels and the uncertainty of degradation within a second life battery. In order to suitably integrate and control these widely different batteries, a suitable multi-modular converter topology and associated control structure are required. This paper addresses these issues proposing a modular boost-multilevel buck converter based topology to integrate these hybrid second life batteries to a gridtie inverter. The proposed converter and control architecture are found to be flexible enough to integrate widely different batteries to an inverter dc-link

Proposed System

Several studies have been carried out, in the field of railway electric traction over the last ten years, concerning the topology of elementary isolated dc/dc converters, with the goal of replacing the input transformer of locomotives operating on ac power lines (25 kV/50 Hz or 15 kV/16.7 Hz). Considering the characteristics of silicon devices (6.5-kV IGBTs), these studies have highlighted that a resonant topology, as shown in Fig. 5.1, is well suited. Indeed, the total leakage inductance of the transformer (Ls) is associated with a series capacitor (Cr) to form a resonant circuit. Resonance frequency f0 is then chosen to obtain a sinusoidal waveform for the current in the ac link and provide a soft-switching operation of the transistors and the diodes, thus reducing the switching losses. As a result, with high-voltage devices, it is possible to achieve a switching frequency much higher than that commonly used in hard-switching. The availability of high-voltage SiC devices makes it possible to achieve high-efficiency isolated dc/dc converter operation with a switching frequency fsw above 10 kHz. This allows, on the one hand, transformer size reduction and, on the other hand, acoustic noise reduction. Even if recent work has demonstrated the advantages of SiC devices in this application. it was, nevertheless, important to build a prototype at a significant power level in order to better understand the constraints of using these new devices and accurately measure system efficiency.

This prototype is based on 3.3-kV/750-A SiCMOSFET modules a water-cooled medium-frequency transformer (MFT). To prepare the design of this prototype, considering the characteristics of the MFT, a preliminary sizing study of the resonant circuit has been carried out. Then, simulations with PLECS software were carried out with the view to assess the losses and choose the converter operating mode leading to the best efficiency.

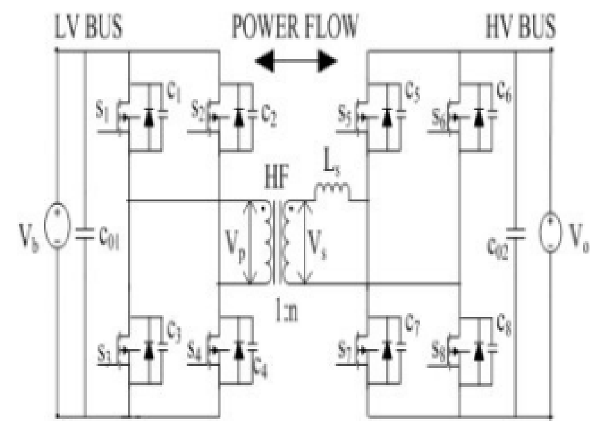

Figure 3: Proposed System Power Flow Circuit Diagram.

SIZING OF THE SERIES-RESONANCE CIRCUIT

1) Choice of Resonance Frequency and Converter Operating Mode

A preliminary design of a 400-kVA transformer rated for a frequency of 15 kHz and a nominal voltage of 1.8 Kv. The parameters are For the resonant dual H-bridge topology, as presented, three modes of operation were considered. For all cases, taking into account the switching behavior of the SiC MOSFETs, a ZVS operation is chosen (controlled turn-off and spontaneous turn-on at zero voltage crossing). In the resonant dual-active-bridge (R-DAB) mode, the two H-Bridges are simultaneously controlled, and the phase shift of voltages V1 and V2 controls the power flow in order to regulate the output voltage Vout. The ZVS operation is achieved by choosing a switching frequency higher than the resonance frequency f0. Nevertheless, this operating mode leads to having switching losses in both H-Bridges. To improve the efficiency of the converter, it can be interesting to have controlled commutations only on one H-Bridge, the second H-bridge working as a diode rectifier. This mode is called R-SAB operation. In this case, the output characteristic of the dc/dc converter is similar to that of a voltage source with an internal resistance depending on the impedance of the ac stage (transformer winding resistance, leakage inductance, and series resonance capacitor). The output power of the converter only depends on the load consumption, and no output voltage control is required (open-loop operation). If f0 is lower than fsw, a continuous conduction mode (CCM) is obtained. On the contrary, if f0 is higher than fsw, a discontinuous conduction mode (DCM) results. In this case, the MOSFET turn-off losses theoretically depend only on the magnetizing current of the transformer.

2) Capacitor Sizing for R-DAB and R-SAB CCM

For the operations in R-DAB and R-SAB CCM, the frequency ratio (fsw/ f0) was set at in order to ensure sufficiently selective filtering of the current in the transformer while limiting the capacitor voltage. For the R-DAB operation, the impedance of the series resonance circuit has to be high enough to guarantee proper controllability of the output current and the ZVS mode over the operating range of the converter. As a result, the phase shift angle δ was set to 40◦ for the nominal output current, which leads to having a series-resonance circuit impedance of 5.5 . Thus, the total inductance of the series-resonance circuit must have a value of 120 μH, which requires placing an additional inductor outside the transformer. For the R-SAB operation in CCM, to limit the on-load voltage drop, the impedance of the series resonance circuit has to be minimum, and only the leakage inductor of the transformer is used. All equations were established by assuming the current iac to be perfectly sinusoidal.

3) PLECS Thermal Model of the Resonant Isolated DC/DC Converter

In the simulation circuit, PLECS consider an ideal switch model. To calculate the semiconductor losses, PLECS records the semiconductor's operating condition before and after each switch operation. It then uses these parameters to read the resulting dissipated energy from a 3-D lookup table considering switched current, blocking voltage, and junction temperature. During the ON-state, the dissipated power is computed from the device current and temperature. This combination of ideal switch models with detailed loss data provides an efficient and accurate alternative to detailed device simulations. The required data tables are entered via an integrated visual editor from the manufacturer's datasheet. Once the dissipated power is calculated, the thermal model is used to compute the junction temperature of the device. Thus, PLECS software performs an iterative calculation to obtain the operating point in a steady state. Table III shows the electrical and thermal characteristics of the 3.3-kV/750-A SiC MOSFET implemented in the model of the resonant isolated dc/dc converter. Regarding the calculation of the transformer losses, the PLECS model used for the simulations is based only on constant values of series resistance and core loss equivalent resistance.

SIMULATION RESULT

HIGH FREQUENCY INPUT OUTPUT

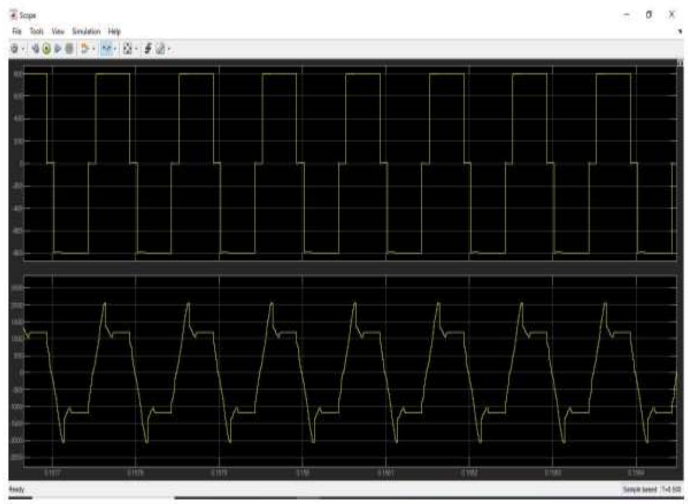

Figure 4.

OUTPUT VOLTAGE

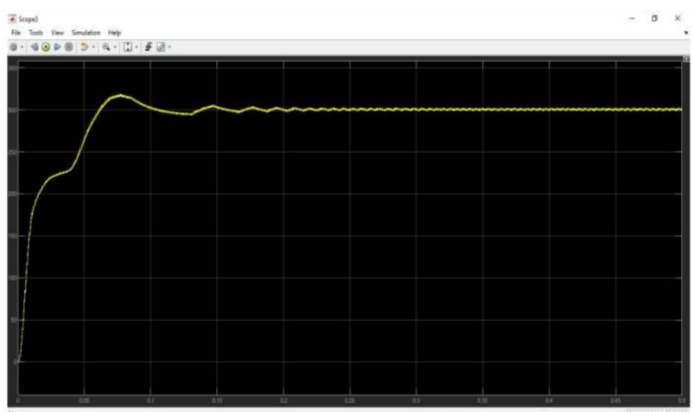

Figure 5.

CONCLUSIONS

This project deals with the integrated operation of BI DIRECTIONAL converter. The proposed converter is a DC-DC converter in which the output voltage may be greater than, lesser than or equal to that of input voltage. The experimental results presented in this article have demonstrated the short-term feasibility of an industrial solution since 3.3-kV SiC MOSFET modules are now in production and MFT technology is the state of the art for traction-transformer manufacturers. In order to take advantage of the SiC-MOSFETs present in the power modules used in the output rectifier, a synchronous-rectifier operation has also been tested. It was then possible to reach an efficiency of 98.93% for an output power of 300 kW. This is quite remarkable for an isolated dc–dc converter operating under 1.8 kV with a switching frequency of 15 kHz. Finally, two elementary dc–dc converters were associated with ISOP configuration to form a 3.6-

/1.8-kV PET. These tests, performed on an SNCF testbed, required the series connection of two six pulse rectifiers and the use of a resistive high power load bank. The natural power-sharing between the two converters has been demonstrated. The results presented in this article are promising, and they encourage the SNCF to continue with the MVdc electrification project.

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