



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 3, March 2023

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

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Review of Transformer-less Multi-level Inverter for Electric Vehicle Charger Application

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ABSTRACT:- The present scenario of dwindling resources of fossil fuels and the pollution of the environment demands the harvesting of clean and green energy. To this end, governments, industries, policymakers, and research communities steadfastly endeavour to promote the use of renewable energy sources (RES), which encompass solar, wind, tidal energies, etc. Of these RES', solar energy reaps benefits such as abundance (practically infinite), low maintenance requirement, silent operation, etc. The PV source outputs electrical energy in the form of DC, which is of limited use unless it is converted into the AC form. In a solar PV-based power generating system, this task is accomplished by an inverter. In this context, transformer-less PV inverter topologies are poised to become popular owing to their high-power density and high efficiency. Recent developments in inverter technology resulted in the Multilevel Inverters (MLI), which strive to produce an output that is closer to a sinusoid, compared to the conventional two-level voltage source inverters (VSI).

KEYWORDS:- Renewable Energy Sources, Multilevel Inverters, transformer-less

I. INTRODUCTION

The extensive use of fossil fuels from the fast depleting conventional energy sources have increased the carbon-dioxide emission which in turn eventually leads to greenhouse gas effect [1]. Ever increasing effects of greenhouse gases from the conventional IC engines paved to the booming of pollution free Electric Vehicle (EV) in the automobile industry [2]. The invention of Electric vehicle starts with the invention of electric motor for small model car by Anyos Jedlik in 1828 followed by the invention of small scale electric car powered by non-rechargeable batteries in 1835 by Professor Sibrandus Stratingh from the University of Groningen, Netherlands. Later in 1990, General motors president introduced "Impact" two seater electric vehicle at Los Angeles Auto Show. The modern highway electric vehicle era started with the launch of Tesla Roadster from Tesla motors in 2008 in California followed by Mitsubishi i-MiEV in 2009 in Japan. Major automobile industries like Nissan, BMW, Renault, Ford, Volkswagen and Chevrolet competitively launched their EVs and thus, the global stocks of plug-in electric cars have reached 5.1 million units in December 2018. Usually, traction batteries are used in electric vehicles which can handle high power and energy within a limited space and weight. Hence, extensive research is going on in the advancement of battery technology suitable for EVs [3].

Formerly, Lead acid batteries are exclusively used in EVs. Low specific energy and short cycle life of lead acid batteries has reduced its use in EV and thus it was replaced by nickel batteries, which has high power density and reliability. But nickel batteries have the problem of high self-discharge and heat generation at high temperatures. Currently, lithium batteries are preferred due to its high power density, light weight and size. It overcomes the problems of low specific energy, poor temperature characteristics and chemical leakage [4]. Also, its fast charging capability, long life cycle and low self-discharge rate and wide range of operating temperature increases its usage in EV industry. Out of the various lithium batteries, lithium ferro-phosphate and lithium titanate batteries are commonly used. Lithium ferro-phosphate battery has superior thermal stability in the fully charged condition and it has low risk when accidentally over charged. Lithium titanate battery has wide range of operating temperature and faster recharge capability [5, 6].

Complications in charging the batteries and its cost and life cycle limit the use of EVs [7]. As per SAE J1772 standard, charging methods of EV are categorized in different power levels and it is summarized in Table 1.1. AC Level 1 is the most common household slow charging method where the EV can be plugged into any convenient power outlet. Semi

fast charging method which requires 240 V / 400 V outlet is the AC Level 2 charging. AC Level 3 is the three phase fast charging method which works at 208/415 V. DC fast charging method used in charging station is intended for public and commercial usage [8]. EV battery chargers are broadly classified as on-board and off-board chargers. An off-board charger is installed only at the fixed location, whereas on-board charger is located inside the vehicle. Size, weight, space and cost are some of the constraints related to the on-board charger. In order to eliminate these constraints, this charger can be integrated with the motor drives in EV, in which, the motor winding itself can be used as the filter inductors or isolated transformer [9]. Charging system can be further classified into conductive and inductive system. Conductive system has the direct contact between the charger inlet and EV connector.

II. LITERATURE REVIEW

Liwei Zhou et al. [1], the transformerless fast charging solution for plug-in electric vehicles (PEVs) is the focus of this paper. The chargers in a PEV system can be categorized into three levels: dc level 3 (more than 19.2 kW) and ac level 1 (less than 1.92 kW) [1]. Due to its volume and weight, an on-board charger is not feasible for the high-power level 3 fast charging system. For fast, high-power DC charging (up to 22 kW), we suggest two topologies for an off-board, non-isolated DC charger. The AC/DC rectifier and DC/DC converter are the two stages in the topology that is being proposed. The AC/DC rectifier topologies can be divided into single-phase and three-phase applications based on the requirements of the grid. The DC charger's design makes use of the same hardware for both the grid interface and the DC/DC stage for the three-phase grid interface. The symmetric layout of the circuit's two stages reduces development and manufacturing costs. The proposed topologies solve the non-isolated system's leakage current problem, and the transformerless structure significantly reduces both volume and weight. This paper demonstrates the design procedures and a typical three-phase prototype to validate the proposed structures.

Jitendra Gupta et al. [2], this work demonstrates a transformer-free single-stage charging method for E-Bike, E-Cycle, E-Cart, and E-Rickshaw light electric vehicles (LEVs). Low voltage battery packs with varying Amp-hour (Ah) ratings typically power these electric vehicles (EVs). In order to achieve the necessary voltage gain between the input and output sides, the conventional charging system for LEVs makes use of transformers that operate at either line frequency or high frequency. However, the charger's cost, power density, and efficiency are all compromised when transformers are used, and the semiconductor components are put under a lot of stress. As a result, a switched inductor modified zeta AC-DC converter-based transformerless single stage power factor corrected (PFC) charger topology is developed, analyzed, and implemented for the LEV charger application. The charging/discharging of inductors in series, parallel, and other configurations is used to achieve the required voltage gain in the presented charger topology. It is important to note that switches and diodes, which are semiconductor components, experience less current and voltage stress. Additionally, the use of discontinuous inductor current mode (DICM) operation allows for the best possible volume of magnetic components. Utilizing minimal sensors and gate drive circuitry also reduces the controller section's implementation costs and complexity. In conclusion, test results are presented to confirm the charger's desired performance and the effectiveness of the configuration presented.

Jitendra Gupta et al. [3], a bridgeless switched inductor Cuk (BSIC) converter-based charger is presented in this article to provide a low-cost, smaller, and more efficient supply-side charging option for light electric vehicles (LEVs). In most cases, an additional converter is included in the chargers of LEVs like E-Rickshaws, E-Bikes, and E-Cycles to charge the batteries at low voltages (24–72 V). The charger's step-down dc voltage gain and reliability at such low voltages are both enhanced by the switched inductor configuration. By operating the charger in the discontinuous current mode condition, it is noteworthy that both the size of the magnetic components and the cost of the sensors are significantly reduced. Additionally, the charger's cost, size, and efficiency are further enhanced by the high-gain transformerless configuration. A laboratory prototype with an 850 W rating and 220 V, 50 Hz nominal supply voltage conditions is used to evaluate the charger's efficiency. Under various operating conditions, the charger's steady-state and dynamic behaviors are examined. In addition, in order to guarantee a soft start, the charger's actions during the initialization phase of the charging process are examined. To highlight the advantages of the presented charger configuration over the existing one, a basic comparison is made to the LEV chargers that are currently in use.

N. Langmaack et al. [4], the increasing drive power and charging power requirements of new electric vehicles are characteristics of their powertrains. The transition from 400 V power systems to 800 V power systems appears to be inevitable in the medium term due to increasing currents and wire cross sections. DC fast charging of approximately 350 kW is likely to be possible as a result of this, and AC onboard charger possibilities are also intriguing. An onboard

charger demonstrator for 22 kW AC charging conforming to IEC 61851-1 "Mode 2" is described in this publication. In a single stage transformerless topology, coupled filter inductors and power devices made of silicon carbide are utilized. A charging system with a power density of approximately 7 kW/l is the result of this design.

R. Kushwaha et al. [5], as an increased voltage across and current through the semiconductor devices are seen, most single-stage single switch power factor correction (PFC) solutions have limited applications in high power ac–dc converters, resulting in lower efficiency. The electric vehicle (EV) charger described in this article is a modified isolated Luo PFC converter with two switches and input clamping diodes at the primary of an isolation high frequency transformer (HFT). The advantage of relatively low switch voltage stress, clamped at the input voltage, is made possible by this arrangement. In order to obtain built-in PF correction capability at ac mains, the proposed converter was chosen to operate in discontinuous conduction mode (DCM). Due to the decreased number of sensors, the operation of the converter in DCM significantly reduces control complexity. The proposed modified Luo converter's improved power quality (PQ) performance is tested with a working prototype. In constant current-constant voltage modes, improved low-ripple-based charging is provided, extending the battery's service life over time. The converter's performance is found to be strong enough to prove that charging works both at steady state and in different ranges of line voltage variation. It has been observed that the improved PQ indices meet the IEC 61000-3-2 international standards.

A. V. J. S. Praneeth et al. [6], in electric vehicles, on-board chargers (OBCs) alleviate the need to charge the battery packs frequently. A single-phase nonisolated OBC with a two-switch topology is presented in this paper for electric transportation. This OBC's main advantage is that it can convert a wide range of output voltages with high input power quality. The two-switch converter shown here can operate with output voltages both above and below the input peak. This paper discusses the converter's analysis, various operating modes, and design considerations for achieving wide output voltages. In addition, the controller's design can benefit from small-signal analysis of the converter in various modes. Using PI controllers, this paper demonstrates a two-mode control scheme with automatic mode selection and an average current-mode (ACM) control structure. The experimental outcomes of a 1-kW laboratory prototype with an output voltage range of 150-450 V are presented as proof of concept. The prototype has an efficiency of 96 percent and a high input power factor of 0.99.

B. R. Ananthapadmanabha et al. [7], a boost converter for power factor correction (PFC) is followed by a dc-dc converter with universal input voltage in the majority of electric bike battery charging two-stage converters. The increased component count and low efficiency of these two-stage conversions are problems. A single-stage Cuk converter-based PFC converter with a high step-down gain, low current stress, high efficiency, and fewer parts is proposed in this paper. Continuous current mode is used for the operational analysis and design equations for various components of the proposed converter. The proposed 500 W, 48 V/10.4 A converter is the subject of mathematical modeling, analysis, simulation, and experimentation in this paper. Its performance is examined in terms of power quality indices like voltage total harmonic distortion (THD), current THD, and total power factor with a variety of loads, including resistive loads and battery loads, in both constant voltage (CV) and constant current (CC) modes. In addition, the proposed converter's dynamic performance while charging the battery is examined across a wide range of supply variations in CV mode and CC mode.

Zhou et al. [8], electric vehicles (EVs) are rapidly evolving, and the number of EV owners is rapidly rising. The electric traction inverter and the charging converter are two crucial parts of the EV system that will have a significant impact on the vehicle's performance. The research focuses on integrated charging systems without transformers, which have the potential to reduce cost, volume, and efficiency. The proposed idea allows for bidirectional operation and does not require a charging rectifier or isolating transformer, making it suitable for providing V2G services to the grid. Since both the grid and the vehicle chassis are grounded during charging, the absence of galvanic isolation makes it possible for common mode currents to flow through the charging system in charging mode. Using an active filtering secondary converter, these currents are well controlled. Additionally, the absence of an isolating transformer improves the vehicle charger's efficiency. On an experimental test bench and by simulation, the proposed topology is confirmed.

III. TRANSFORMERLESS PV INVERTER

The classification of single-phase transformerless PV inverter topologies is presented in Figure 1. The inverter topologies are also broadly classified based on the type of filter connected to the output. An asymmetrical output filter

is used in half-bridge, commonground, and unfolding-type configurations whereas a symmetrical type filter is employed in full-bridge-based configurations.

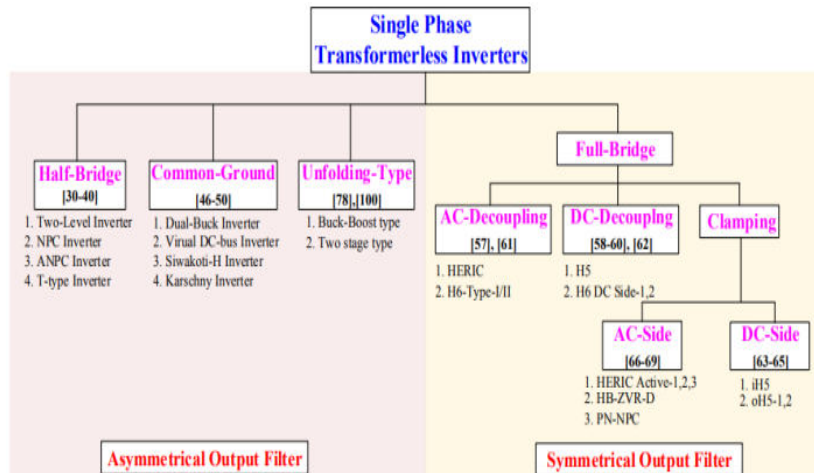


Figure 1: Classification of single-phase transformer-less PV inverter topologies

Full-bridge Transformer-less Inverter

Single-phase full-bridge inverter configurations can be operated either with a unipolar PWM scheme or a bipolar PWM scheme. The unipolar PWM scheme [9] improves the harmonic performance of the inverter. The unipolar PWM strategy results in a reduced current ripple which further reduces the requirement of the size of the filter at the output. However, in a unipolar PWM scheme, the occurrence of an active zero state in each switching cycle causes the common-mode voltage to oscillate at the switching frequency. These voltage transitions result in a high leakage current for PV inverter applications which violates safety standards and affects the lifetime of the PV panels. In contrast, the bipolar PWM scheme [10] eliminates all the high-frequency transitions from the common-mode voltage. This reduces the leakage current in the parasitic elements of the PV panel which allows its applicability for PV-based applications.

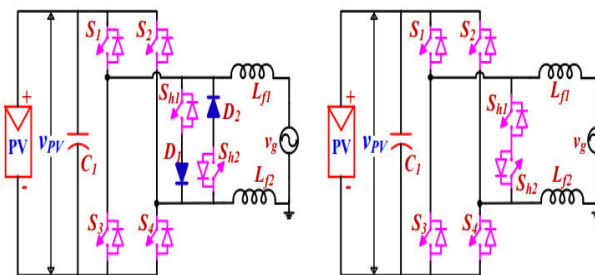


Figure 2: HERIC inverter with variants (a) HERIC inverter variant-1 (b) HERIC inverter variant-2

Multilevel inverter

Multilevel inverter configurations with dc-decoupling are introduced in [11]. A 5L inverter topology is presented in [12], which employs a cascaded half-bridge (HB). The basic configuration has been modified with dc-decoupling [13] and ac-decoupling [14]. The alleviation of the leakage current is achieved by the employment of the modified modulation techniques in these papers. However, the output voltage of both of these inverter configurations suffers from two major disadvantages: (a) high total harmonic distortion (THD) and (b) high dv/dt across the switches w.r.t the conventional staircase type multilevel output voltage. In addition, these configurations require two PV sources which further increases the complexity to implement the MPPT. Besides that, as the presented configuration is a cascaded structure, the power ratings of the PV panels are unequal, which restricts the applicability of this type of power converter configuration.

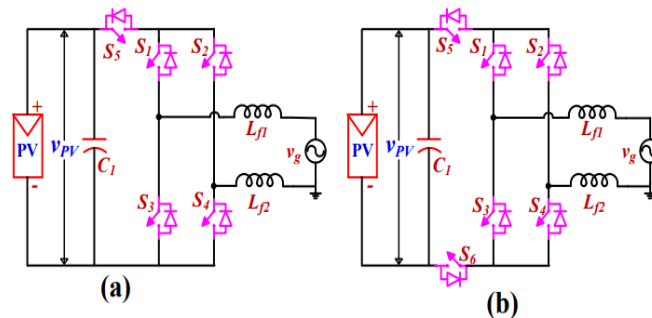


Figure 3: (a) H5 inverter (b) H6 inverter

IV. CONCLUSION

Transformer less grid connected photo voltaic inverter is the most sought after design due to its characteristic features such as high efficiency, small size, low cost and light weight. Transformer less photo voltaic inverter is one of the best design for feeding the utility grid. However, the reduction and minimization of ground leakage current and DC offset injection is still a challenge. One of the significant advantages of multilevel configuration is the harmonic reduction in the output waveform without increasing the switching frequency or decreasing the inverter power output. The elementary concept of a multilevel converter to achieve increased power is to use a series of power semiconductor switches with several low voltage dc sources to perform the power conversion by synthesizing staircase output voltage waveforms. The Diode clamped inverter and flying capacitor inverter creates voltage in balance problems. Cascaded inverter is another type of multilevel inverter which is commonly used. By increasing the number of voltage levels, the quality of the output voltage is improved and the voltage waveform becomes closer to sinusoidal waveform.

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