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AN ADVANCED CL&LC EV CHARGER IN DC MICRO GRIDS

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Abstract: Over the past ten years, there has been a lot of attention paid to the vehicle-to-grid concept. A typical load on DC micro grids is the electric vehicle (EV), which can function as a distributed energy storage system to increase the DC micro grid's stability and dependability, enable the integration of renewable energy sources, and boost overall system effectiveness. This paper suggests a novel three-level Capacitor- Inductor- Capacitor (CL&LC) resonant converter for off-board EV charger in order to achieve bidirectional power transmission between the DC micro grid and EV. The proposed converter adapts to the wide voltage range of EVs by incorporating resonant CL&LC components and combining the operating modes of the two three-level full bridges from 2500 V to 750 V. To examine the frequency characteristics of the resonant converter, an equivalent circuit model using a first harmonic approximation approach is built. Additionally, a working mode selection method based on the idea of the least transformer RMS current is suggested. In order to confirm the viability and benefit of the three-level CL&LC resonant converter, a 3.7 KW hardware prototype was built. The flying capacitor voltages of the proposed converter are well balanced, and its efficiency changes little over a wide output voltage range.

Keywords: CL&LC, Electric vehicle, three-level, wide output voltage range.

1.0 INTRODUCTION

Over the past five years, interest in DC micro grids has grown steadily in both academics and business. While AC micro grid performance has improved significantly over the past ten years, it is now widely acknowledged that DC micro grids are more desirable because to their higher efficiency, easier interaction with RES and ESS, and better compliance with consumer electronics. Additionally, when equipment is connected to a DC bus, problems like reactive power, poor power quality, and frequency regulation don't exist. In contrast to conventional AC grids, DC micro grids face some particular issues with DC circuit breakers, DC plugs, and DC electric arc detection. A typical DC micro grid structure is shown in Fig. 1. Electric vehicles (EV) are one of them and a typical load on DC micro grids. EV battery systems can perform the function of distributed ESS in addition to their traditional function as loads of DC micro grids [1-3]. Most of the time, electric vehicles are not moving. Energy storage systems can be made cheaper and smaller if electric vehicles are employed as ESS. If appropriately managed, they may promote the integration of RES and increase system efficiency while also increasing the dependability and stability of the DC micro grid. The off-board EV charger must have a bidirectional DC-DC converter that can function in both the charging mode (G2V) and discharging mode in order to fulfil the function of distributed ESS.

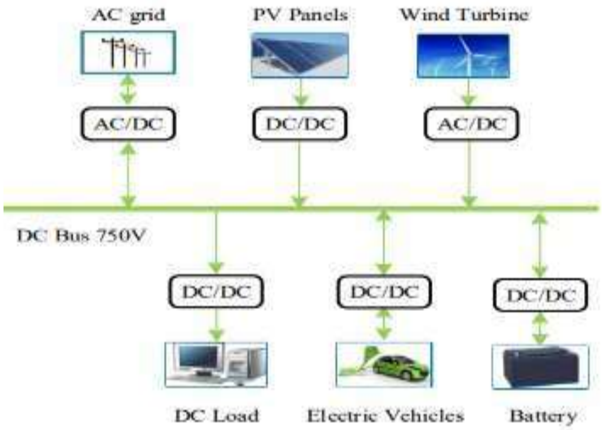


Fig.1: Structure of DC micro grid

POWER ELECTRONICS

Power electronics refers to the use of solid-state electronics for regulating and converting electric power. Electrical and electronic engineering refers to it as a research field because it deals with the designing, calculation, control, and integration of electronic systems where energy is processed with fast dynamics that are nonlinearly time variable. The first powerful electronic devices were mercury arc valves. Modern systems carry out the conversion using transistors, diodes, and other semiconductor switching devices that R.D. Middle Brook and others invented in the 1950s. In contrast to electronic systems that are focused with the transmission and processing of signals and data, power electronics processes significant amounts of electrical energy. An AC/DC converter is the most prevalent power electronics component found in many consumer electronics products, including battery chargers, personal computers, televisions, etc.[9,10]. Tens to several hundred watts are within its power range. The most common use in industry is for a variable speed drive to control an induction motor. A few hundred watts to tens of megawatts are the power capacities of VSDs.

DC to AC converters

DC to AC converters turn a DC source into an AC output waveform. Applications include solar generators, active filters, flexible AC transmission systems (FACTS), voltage compensators, and adjustable speed drives (ASD). Voltage source inverters and current source inverters are two unique groups of topologies for these converters. The independently controlled output of voltage source inverters, also known as VSIs, is a voltage waveform. The controlled AC output of current source inverters (CSIs) is unique in that it has a current waveform. The DC to AC power conversion is accomplished by static power converters, which are typically fully controllable semiconductor power switches. Due to the discrete values used in the output waveforms, quick transitions rather than smooth ones are produced. The modulation approach controlling how long and when the power valves are on and off allows for the creation of almost sinusoidal waveforms around the fundamental frequency. The carrier-based technique, also known as pulse width modulation, the space-vector technique, and the selective- harmonic technique are all common modulation methods. Both single-phase and three-phase applications can effectively use voltage source inverters. Power supplies, single-phase UPSs, and complex high-power topologies when utilized in multi cell arrangements are all common uses for single-phase VSIs, which employ half-bridge and full-bridge configurations. Applications requiring sinusoidal voltage waveforms, such ASDs, UPSs, and some FACTS devices like the STATCOM, use three-phase VSIs. Additionally, they are utilized in active filters and voltage compensators, two devices that call for arbitrary voltages.

Buck Converter:

In Fig. 2.a, a buck converter (DC-DC) is depicted. Only a switch, which uses a device from the transistor family as previously mentioned, is presented. Additionally, when the switch (i.e., a device) is turned off, a diode (known as a freewheeling diode) is used to permit the load current to flow through it. It is an inductive (R-L) one load. A battery (or back emf) may occasionally be connected in series with the load. Because of the load inductance, the load current requires a path, which the diode provides; otherwise, the switching device could be harmed by the high induced emf of the inductance as the load current tends to decrease. This circuit is known as a step-down chopper if the switching device used is a thyristor since the output voltage is often lower than the input voltage.

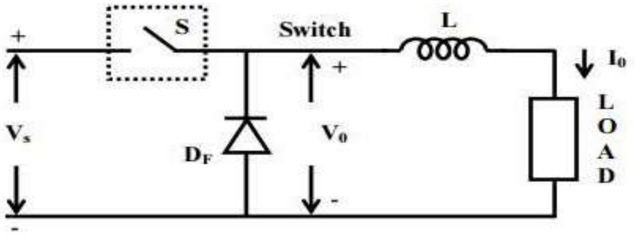


Fig.2a: Buck converter

Boost Converter (DC-DC):

In Fig. 2.b, a boost converter (DC-DC) is depicted. Only a switch, which typically employs a transistor-family device, is displayed. The load is connected in series with a diode as well. The load is of the same type as that previously described. The load has a low inductance. Assumed to be in series with the input supply is an inductance, L. You may want to take note of where the switch and diode are located in this circuit in comparison to where they are located in the buck converter.

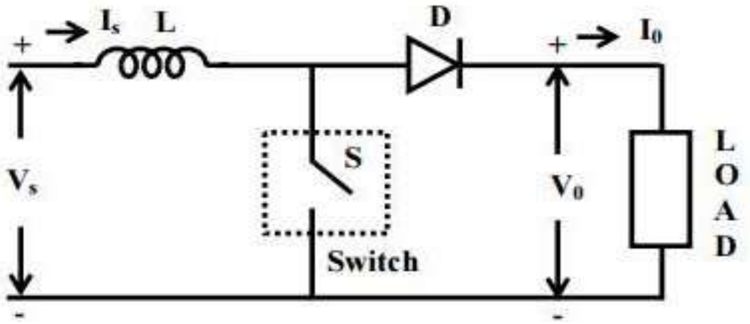


Fig.2b: Boost Converter

Fig. 2.c depicts a buck-boost converter (DC-DC). Only a switch, which typically employs a transistor-family device, is displayed. The load is connected in series with a diode as well. You can observe how the diode is connected by comparing it to how it is connected in a boost converter.

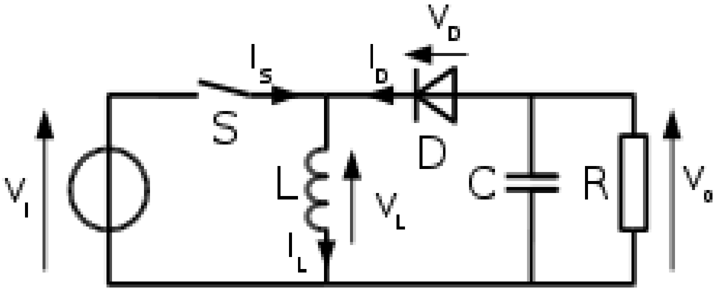


Fig.2b: Buck Boost Converter

3.0 PULSE-WIDTH MODULATION (PWM)

A message is encoded using this modulation method and turned into a pulsing signal. This modulation method can be used to encode data for transmission, but its primary function is to enable control over the power sent to electrical equipment, particularly to inertial loads like motors. PWM and maximum power point tracking are the two main algorithms used in photovoltaic solar battery chargers,[1] with PWM being one of them. By rapidly flipping the switch between the supply and the load on and off, the average amount of voltage (and current) provided to the load is managed. The total power provided to the load increases while the switch is on for a longer period of time compared to when it is off. The load (the device that consumes the power) must perceive the resultant waveform as smoothly as possible, so the PWM switching frequency must be much higher than what would affect the load. Depending on the load and application, the rate (or frequency) at which the power supply must switch can vary significantly. For instance, an electric stove requires switching several times per minute; a lamp dimmer requires 120 Hz; a motor drive requires switching at a rate of a few kilohertz (kHz) to tens of kHz; and audio amplifiers and computer power supplies require switching at rates well into the tens or hundreds of kHz.

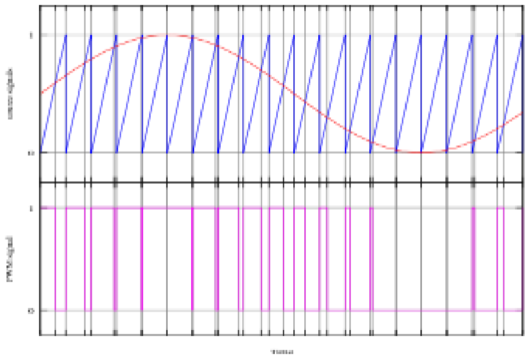


Fig.3a: PWM Pulses

The intersective approach, which just needs a comparator and a sawtooth or triangle waveform (easily produced with a basic oscillator), is the easiest way to create a PWM signal. The PWM signal (magenta) is in the high state when the reference signal (the red sine wave in fig. 3) has a value greater than the modulation waveform (blue), and in the low state otherwise.

Delta

In the use of delta modulation for PWM control, the output signal is integrated, and the result is compared with limits, which correspond to a Reference signal offset by a constant. Every time the integral of the output signal reaches one of the limits, the PWM signal changes state.[3] Figure 3

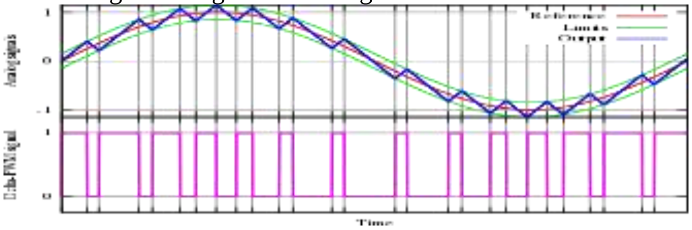


Figure 3b : Principle of the delta PWM.

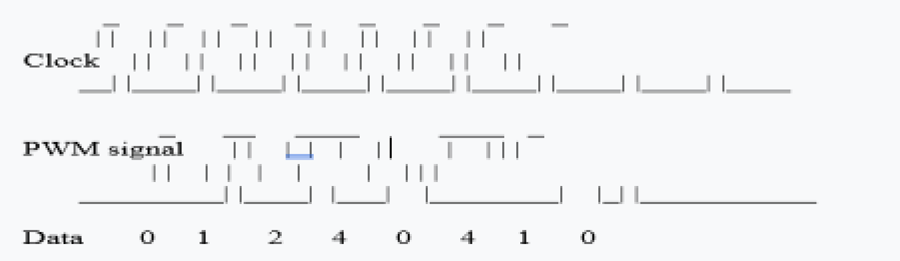
The output signal (blue) is compared with the limits (green). These limits correspond to the reference signal (red), offset by a given value. Every time the output signal (blue) reaches one of the limits, the PWM signal changes state. **PWM sampling theorem**

`The process of PWM conversion is non-linear and it is generally supposed that low pass filter signal recovery is imperfect for PWM. The PWM sampling theorem [7] shows that PWM conversion can be perfect. The theorem states that "Any band limited baseband signal within ±0.63 can be represented by a pulse widthmodulation (PWM) waveform with unit amplitude. The number of pulses in the waveform is equal to the number of Nyquist samples and the peak constraint is independent of whether the waveform is two-level or three-level."

Telecommunications

In telecommunications, PWM is a form of signal modulation where the widths of the pulses correspond to specific data values encoded at one end and decoded at the other.

Pulses of various lengths (the information itself) will be sent at regular intervals (the carrier frequency ofthe modulation).



The inclusion of a clock signal is not necessary, as the leading edge of the data signal can be used as the clock if a small offset is added to the data value in order to avoid a data value with a zero-length pulse.

Power delivery

Without experiencing the losses that would come with linear power delivery using resistive methods, PWM can be utilized to regulate the amount of power given to a load. This method has drawbacks in that the energy given to the load is not continuous and neither is the power drawn by the load, which is discontinuous rather than constant (see Buck converter). However, if the load is inductive, the pulse train can be smoothed and the average analogue waveform retrieved by employing additional passive electronic filters at a high enough frequency when necessary.

DC-DC CONVERTERS

a DC-DC converter with a high step-up voltage that can be applied to a variety of things, including battery backup systems for uninterruptible power supplies, fuel cell energy conversion systems, solar energy conversion systems, and the headlights of cars. The step-up voltage gain of a dc-dc boost converter is constrained by the impact of power switches and the equivalent series resistance of inductors and capacitors in practice. Theoretically, a dc-dc boost converter can achieve a high step-up voltage with a high effective duty ratio. To obtain a high-step-up voltage gain with a high duty ratio, a conventional boost converter is typically used. However, the reverse recovery issue with diodes and the losses of power switches and diodes, as well as the equivalent series resistance of inductors and capacitors, limit the efficiency and voltage gain. Due to high voltage stress and power dissipation caused by the active switch of these converters, the transformer's leakage inductance.

4.PROPOSED THREE-LEVEL CLLC RESONANT CONVERTER

A. The topology of the three-level CL&LC resonant converter the proposed three-level CL&LC resonant converter is shown in Fig. It consists of two three-level full bridges, an intermediate frequency transformer, two resonant inductors and two resonant capacitors. Lr1 and Lr2 represents the sum of the resonant inductance and the transformer leakage inductance in the primary side and the secondary side, respectively. n is the transformer turns ratio. The magnetizing inductance of the transformer is much larger than Lr1 and Lr2, so the excitation current is neglected in the discussion below. Cr1, Cr2, Lr1 and Lr2

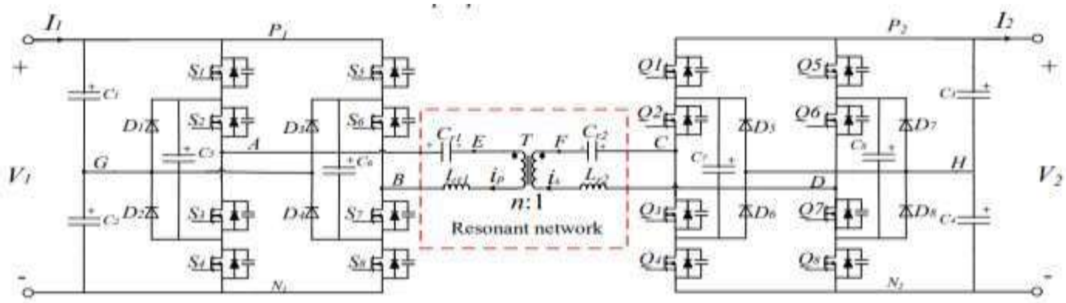


Figure 4: Topology of the three-level CLLC resonant converter

form a series resonant network. Meanwhile, Cr1 and Cr2 are also used to offset the DC component produced by the two three-level full bridges. In a practical application, the V2 DC port is connected to EV, the voltage of which varies over a wide range, such as 210 V to 710 V. The V1 DC port is connected to a DC bus in a DC microgrid, which usually maintains a constant voltage, such as 740 V. Obviously, the proposed CL&LC converter can operate in two power directions due to the fully symmetrical structure. When the converter works in G2V mode, the primary bridge operates as an inverter and the secondary bridge operates as a rectifier. When the converter works in V2G mode, the primary bridge operates as a rectifier and the secondary bridge operates as an inverter. The three-level leg can operate in four switching states, as shown in TABLE I. For instance, the positive voltage level could be achieved by turning on S1 and S2 and turning off S3 and S4.

State	S1	S2	S3	S4	v_{AG}
P	On	On	Off	Off	$0.5V_1$
O_1	On	Off	On	Off	0
O_2	Off	On	Off	On	0
N	Off	Off	On	On	$-0.5V_1$

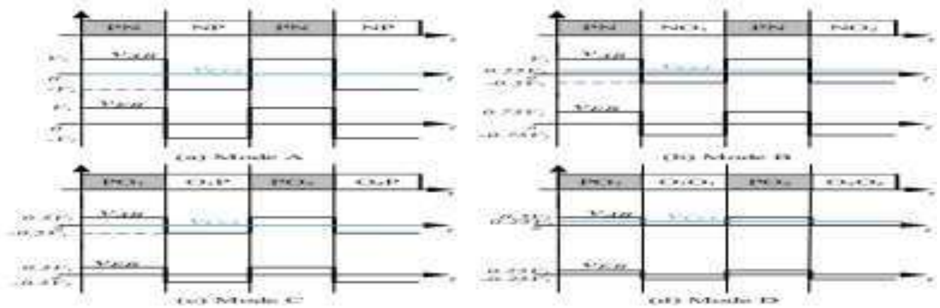


Table 4.1 Switching states of a three-level leg of the primary bridge

Figure 5: Four working modes of the primary three-level full bridge in no load condition. vEB is a quasi-square wave with the amplitude equal to V1, 0.75V1, 0.5V1 and 0.25V1

The flying capacitor C5's voltage is unaffected by the output current ip in States P and N. The voltage of the flying capacitor is affected differently for States O1 and O2 by the output current ip. For instance, C5 will charge in State O1 and discharge in State O2 if ip is positive. Therefore, in order to maintain the flying capacitor voltage at 0.8V1, the two zero-level switching states need be chosen alternately. In Modes E and G, the DC component of the capacitor voltage, vCr2, is equal to 0, and in Modes F and H, it is equal to 0.28V2. The DC component of vFD is always grounded due to the capacitor Cr2's DC blocking function.

State	Q5	Q6	Q7	Q8	$v_{DH}(i_s<0)$	$v_{DH}(i_s>0)$
R0	Off	Off	Off	Off	$0.5V_2$	$-0.5V_2$
R_1	Off	Off	On	Off	0	$-0.5V_2$
R_2	Off	On	Off	Off	$0.5V_2$	0

Table: Switching states of a three-level leg of the secondary bridge

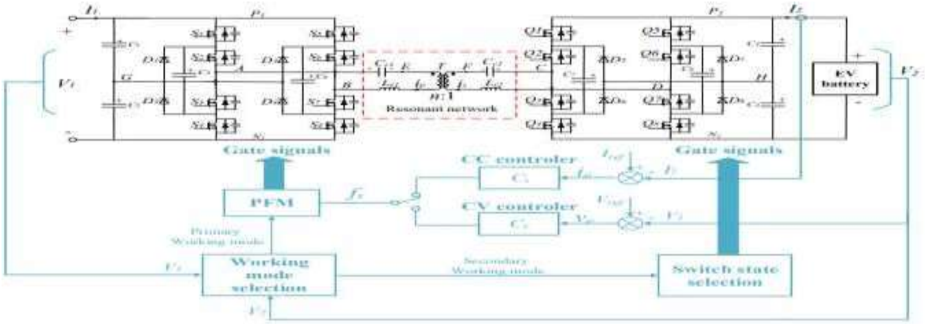


Figure 6: The control block diagram when the converter operates in G2V mod

SIMULATION RESULTS:

The results are taking of two types of controllers like PI and PID controllers

PI controller: A P.I Controller is a feedback control loop that calculates an error signal by taking the difference between the output of a system, which in this case is the power being drawn from the battery, and the set point. The figure above shows a software level block diagram of the P.I control algorithm:

PID controller:

A proportional–integral–derivative controller (PID controller or three-term controller) is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value as the difference between adesired set point (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively), hence the name

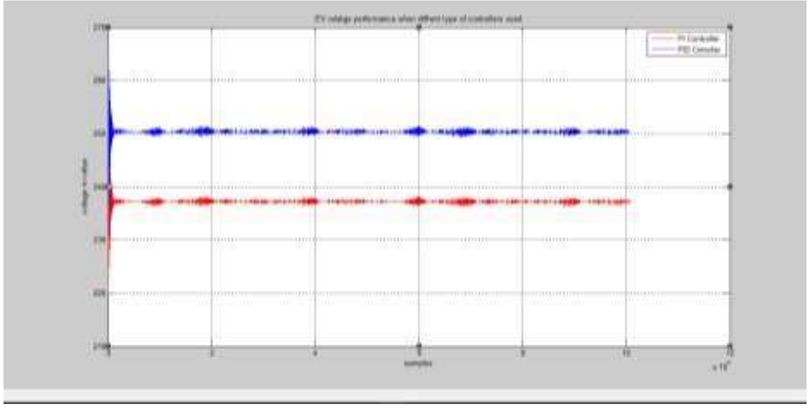


Figure 7: EV voltage of two different controllers

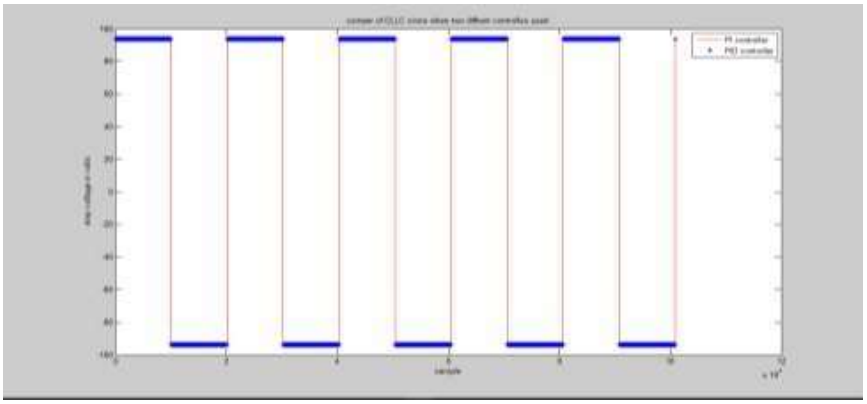


Figure 8: DC to DC convert voltage of two different controllers

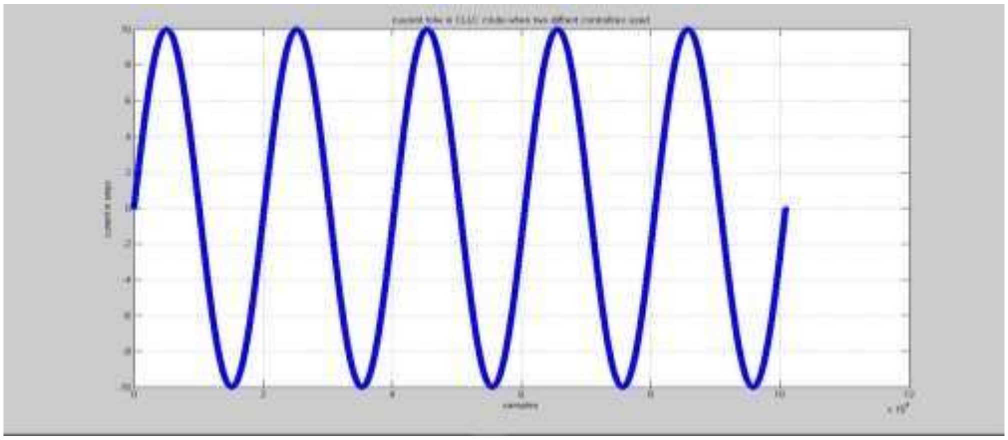


Figure 9: DC to DC convert voltage of two different controllers

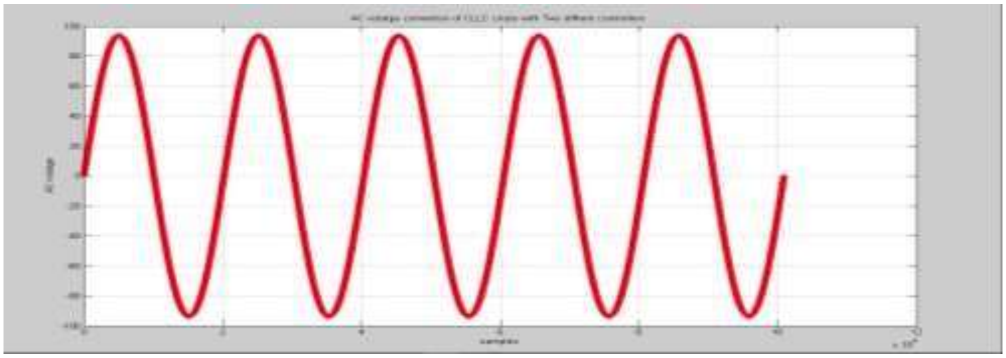


Figure 10: DC to DC convert current of two different controllers

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation Algorithm development Data acquisition Modeling, simulation, and prototyping Data analysis, exploration, and visualization Scientific and engineering graphics Application development, including graphical user interface building. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar no interactive language such as C or FORTRAN.

CONCLUSION

For an off-board EV charger on DC micro grids, a three-level CL&LC resonant converter is presented in this study [1-3]. The converter's two three-level complete bridges each have four operating modes. The suggested converter adapts to a wide range of output voltage range applications by combining the two full bridges' operating modes. To examine the frequency characteristics, an equivalent circuit of the three-level CL&LC resonant converter is presented. On the basis of the minimum transformer RMS current principle, a working mode selection algorithm is proposed. A 3.7 K. W hardware prototype was built to validate the proposed converter. Simulation results show that the converter can operate stably in a wide output voltage range, and the efficiency of the proposed converter changes little over a wide output voltage range. Moreover, the flying capacitor voltages of the three-level CL&LC resonant converter is balanced well by selecting different switching states in different switching cycles.

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