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Design of Three Levels Electric Vehicle Charger Integrated PV System

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Abstract

Electric vehicles (EVs) become a solution for the rapid increase of the environment pollutions. EVs are energized by battery storage systems which are environment friendly and with more technological advancements; their price will be affordable by the consumers. However, as EVs become significant loads on the utility distribution system, maintaining the power quality becomes a challenge. This is due to the harmonics distortions that are produced when many loads connected to the grid. Moreover, for numerous reasons – such as energy costs and environmental matters – it is preferable to use Renewable Energy Sources (RES) to charge EVs. Therefore, in order to mitigate these issues, the battery charger of the EV needs to have a sufficient performance with minimized total harmonic distortion (THD). Thus, the electrical power of the proposed EV charger is provided by a photovoltaic (PV) system which converts solar irradiance into DC current. The proposed charger consists of two converters: (1) a three-phase sinusoidal pulse-width- modulation (SPWM) (2) a converter for the three-phase bridge rectifier. The charger provides a three-stranded level of EV charging (Levels 1, 2 and Level 3). Simulation work of the proposed EV charger was performed by using MATLAB–Simulink. A laboratory prototype was fabricated and controlled by using digital signal processor (DSP/TMS320F28335), to prove its function and performance. From the results, the proposed charger can deliver level 1, 2 and 3 battery charging with low THD.

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1. Introduction

Recently, quick machinery expansion has headed to major growth in energy consumption. The non-renewable energy resources such as fossil fuels are finite and expensive, thus they will ultimately become depleted. [1]. In addition

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to that, the emissions from the transport industry have been partly responsible for acid deposition, stratospheric ozone depilation and climate change. Thus, the transportation networks have the prime share in the greenhouse gas (GHG) emissions. However, RES is encouraging technology which can share the renewable energy sources in transport systems. Amongst the obtainable RES, energy from the sun is commercially sustainable because of its availability for high productivity. A photovoltaic (PV) system produces power via the straight conversion of the sun's energy into electricity.

Electrifying transportation networks is a potential strategy to address the environmental matter and energy crisis altogether [2]. Consequently, various countries have taken their own initiatives in developing their own EV industry, aiming to de-carbonize their transport sectors. For instance, China has brought forward a conservative development plan that is aimed to increase the number of EVs ownership to five million by 2020 [3]. However, the availability and convenience of EVs charging infrastructure are the key factors that affect the future development and popularization of the EVs. In addition, EV charging infrastructure insufficiency will hinder the widespread use of EVs. Therefore, all necessary advice and guidance have been provided to develop a convenient EV charging infrastructure network, especially, fast charging stations on the freeways, which can significantly enhance travel distance of EVs [4]. The performance qualities required for some EVs specifications greatly surpass the capabilities of traditional battery systems. Unfortunately, when the battery technology advances, the charging of these batteries turns out to be exceptionally complicated. This is due to the involvement of high voltage and currents flow in the system; as well as the necessity of complex charging techniques. This imposes great distortions in the connected AC power system, and thus an efficient and low-distortion charger is highly required. With respect to the issues stated above, the battery charging technology faces a lot of challenges as in how to steadily and efficiently charge the battery and improve its operational life.

The technology of battery varies in different ways. The commonly applied charging techniques are the constant-current and constant-voltage charging techniques. Since AC voltage of the charger fluctuates most of the time, it requires a tributary constant-current power supply for the charging process; which is known as a constant-current charger. The main idea is to maintain a constant battery voltage between the poles. Its main benefit is that it can automatically adjust charging current when the battery state-of-charge is altered. There are two EVs charging techniques namely A charging and DC charging [5-9]. EVs charging techniques are classified to two types; DC charging and AC charging. The power of AC charging is supplied via single-phase or three-phase by on-board rectifier. For DC charging, the power is supplied by DC power to the through off-board rectifier. The use of AC charging absolutely will expand charging accessibility of the EV and in the meantime, DC charging permit the use of higher rating circuits. There are three levels of charging mode, the current chargers are constructed only to charge one level of charging mode, and thus lack of flexibility to provide charging for the other modes. Level 1 charging is installed for slow charging. In United States (US), a standard 120 V/15 A single-phase grounded outlet is dedicated for Level 1 charging. Level 2 charging is preferred to be used for public and home facilities. This type of charging

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infrastructure can likewise be installed on-board to prevent excessive power through electronic devices. The current Level 2 devices provide charging from 208 V or 240 V (at up to 80 A, 19.2 kW). Level 3 charging system is installed for fast charging (within 60 minutes) and it is suitable to be installed at city refueling areas, corresponding to petrol stations, and also in highway rest areas. Normally, the charging system works with three-phase circuit of 480 V and 100 A or higher.

The integration between PV and EVs can be categorized into three types based on the scale of the study: large scale (such as cities or entire countries), medium scale (such as residential neighborhoods), and small scale such as (parking lots and charging stations). Many high step-up converters in a PV system are proposed to optimize energy conversion efficiency and to achieve the high gain.

Recently, the harmonic distortion that caused by EVs load have been studied by many researchers. For example, in [10], the scholars presented a statistical analysis to analysis the harmonic voltages of distribution system produced by EV charging. In [11], the researchers examined the lifecycle of distribution network based on THD values of EVs charging. In [12], the researchers proposed a Monte Carlo approach to investigate the THD caused by level 1 charger, which has critical impact on the power quality

This work presents a novel of charger which designed based on SPWM technique integrated PV system for effective operation of three-level charging, as shown in Figure 1. The principles of the proposed control method of the converter are described with the SPWM method and the whole system simulation is carried out using MATLAB/Simulink software. Finally, the implementation of the experimental setup in the laboratory is carried out to assess the work of the proposed design presented in this paper. In this step, all the hardware's components including converter circuit, sensors, driver, and also the implementation of the proposed technique in a digital signal processor (DSP) are explained in detail.

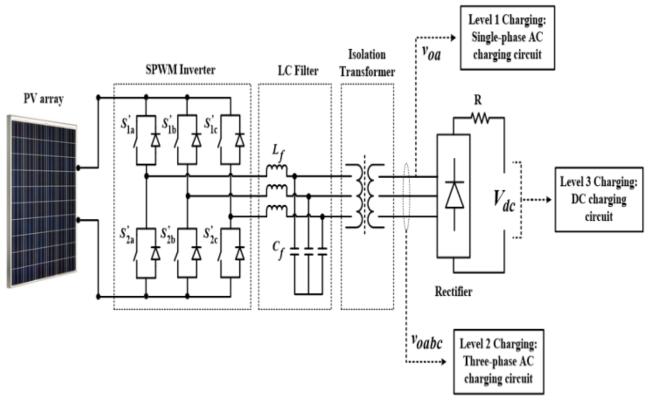

Figure 1: PV universal charger

2. Methodology

Programmable Solar Array Simulator

In this paper, the solar array simulator is used to tune the maximum power point tracking (MPPT). The main advantages of this simulator are extremely stable and has fast transient response. The Programmable Solar Array Simulator (PSAS) can be setting (along with-it instilled software) based on by a variety of climate circumstances such as temperature, irradiation, and rain, which will change the I-V curve output. The core characterized of the PSAS module is detailed in Table 1.

Table 1: The characteristics of the proposed PV

Patterns	Values
Number of cells per module	36
Open circuit voltage, VOC	22.8 V
The voltage at maximum point, VMPP	18.5 V
Current at maximum point, IMPP	3:00 AM

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Power at maximum point, MPP Short circuit current, I_{SC}	44 W
The temperature coefficient of V_{OC}	3.1 A
The temperature coefficient of I_{SC}	-0.0722 V/^{o}C 0.00118 A/^{o}C

SPWM technique of Three-phase Inverter

As shown in Figure 2,the first stage is developed by connecting the PV to the input of the three-phase inverter. The inverter is controlled by applying the SPWM technique. A proportional-integral (PI) is used to control the DC-link voltage by comparing the measured V_{dc} with its pre-determined reference valueV_{dc_ref}. The SPWM inverter provides a pulse waveform, where its width varies periodically. The pulse waveform is filtered by the LC filter, so that sinusoidal waveforms can be produced. In order to introduce a better sinusoidal waveform, a high switching frequency is required. This results in pulse-width patterns of the output voltage. The required output voltage is obtained by changing the frequency and amplitude of a modulating voltage. However, the modulation pattern will remain sinusoidal. The PWM output actually has been filtered by a LC filter before reaching the transformer. The LC circuit is applied to tune the high frequency elements and will leave behind only fundamental element (50 Hz signal). The amplitude and frequency variations of the reference voltage will change continuously. An auto transformer (three-phase, 50 Hz) is used to keep isolation between the EV and grid, which can set-up and step down the required voltage.

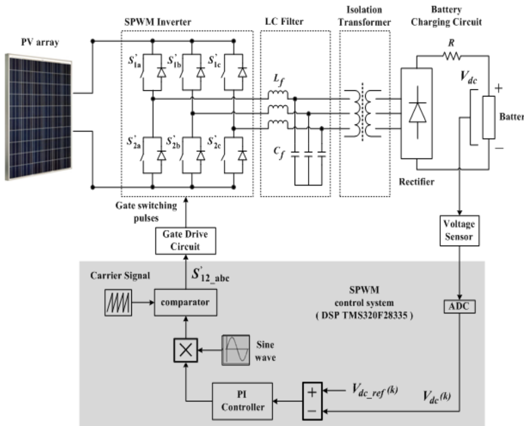

Figure 2: PV connected to the charger of three-phase SPWM inverter

The modulation technique is determined by comparing a triangular carrier signal with a sinusoidal modulating signal, as shown Figure 3. At any instance, if the modulating signal is greater than the carrier signal, the upper switch of the rectifier will be turned “on” and the lower switch “off.” By contrast, if the modulating signal is less than the carrier signal, the upper switch will be turned “off” and the lower switch “on.” This shows that the operation of the upper and lower switches of the rectifier complements each other pulses when the two signals intersect each other. The switching time is obtained based on the intersection locations of switching state. According to Figure 4, the three-phase PWM technique is generated by comparing the triangular voltage waveform (V_T) with the three-phase sinusoidal voltages (v_a , v_b andv_c). The generated pulses are applied to each phase leg of the inverter in order to control switching operating. The inverter composes of six switches S_1through $S_6$and the inventor output is located at the center of every phase. The comparators deliver the switching pulses to control the inverter process by applying a switching frequency of 12 kHz. The switches operations in each phase are performing in complement array approach: when the upper leg is closed, the lower leg will be opened. This means that only two switches will be operating in each switching state. The output voltages of the inverter are: v_{pa} , v_{pb} and v_{pc}. It is important to take note that the peak of the sinusoidal modulating signals is maintained lower than the peak of the triangle carrier signal. This is to ensure that the modulation process is executed within the linear modulation range. The logic for the switches control signals is shown as follows:

A. Switch number one(S_1) is ON if $v_a > V_T$; Switch number fourS_4 is ON if $v_a < V_T$

B. Switch number three(S_3) is ON if $v_b > V_T$; Switch number six(S_6) is ON if $v_b < V_T$

C. Switch number five (S_5) is ON when $v_c > V_T$;Switch number two(S_2) is ON if $v_c < V_T$

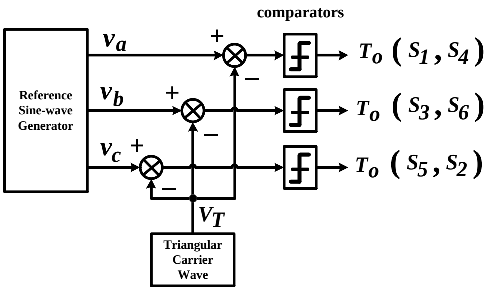

Figure 3: Control signal generator for SPWM controller

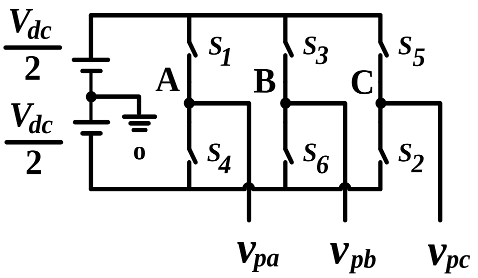

Figure 4: Three-phase sinusoidal PWM inverter

3. Results and Discussions

Simulation Results

The simulation work and control algorithm of the proposed charger are performed by using the SimPower toolbox of MATLAB/Simulink, as shown in Figure 5. The main parts of the simulation circuit are capacitors, inductors, IGBT switches, three-phase autotransformer, and battery. In the simulation work, the EV charger is tested for three levels of charging: Levels 1, 2 and 3.

Level 1 Charging

According to Figure 6, the single-phase is provided for level 1 charging based on the simulation results of the proposed charger, which consists of sinusoidal output current and output voltage. The output current in Figure 6 (a)is sinusoidal shape with THD 2.52 %, while the maximum peak of the charging current is 20 A. The output voltage of level 1 charging is shown in Figure 6 (b), which it can be observed that the peak voltage value is 240 V AC.

Level 2 Charging

The simulation results obtained for Level 2 charging is shown in Figure 7. According to Figure 7(a), the output current obtained for all the phases are in sinusoidal shape with THD value less than 5 %, complying with IEEE standard 519. The maximum peak value of the charging current is 70 A per phase. Figure 7 (b) is the waveform of the output voltage for level 2 charging, which it can be observed that the peak value of output voltage is 450 V AC.

Level 3 charging

Constant DC current and constant DC voltage are represented level 3 charging. The battery of Lithium-ion is used to test the charging performance of the proposed charger. The simulation results obtained for Level 3 charging current is shown in Figure 8 (a), where the maximum peak value of the charging current is 125A DC. The output voltage of level 3 charging is shown in Figure 8(b), which it can be observed that the value of output voltage is 650V AC.

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Experimental Results

This EV charger was fabricated to evaluate the accomplishment of the proposed technique. Figure 9 shows the experimental work of the proposed charger.The laboratory prototypes are constructed where the controller and power electronics circuits are constructed to function as three levels charger, similar to the one that is modeled in MATLAB/Simulink. The experimental set up consists of the measurements circuit implementation, driver circuits and DSP board. The current and voltage sensors are developed to measure the DC current and voltage of the power supply. This work uses a current sensor of (LA-125P) and a voltage sensor of (LV-25P), respectively. All the signals used by the SWPM inverter are processed through DSP. The power switching device of SPWM inverter is module IGBT (CM200DU-24F), which needs to be isolated from digital based circuit, or specifically DSP. Thus, for this purpose, a driver circuit is designed by using an opt coupler of (LM4041C12ILP).

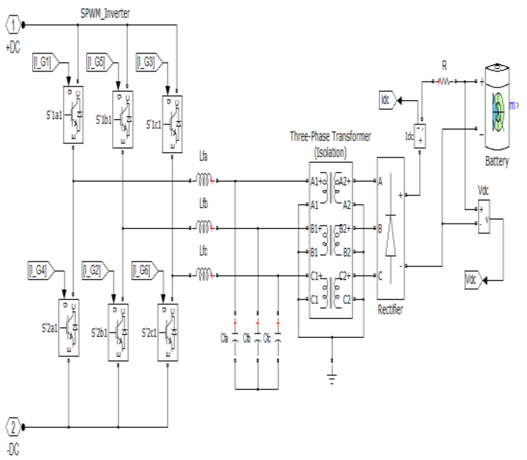

Figure 5: Simulation model for the proposed universal battery charger

Figure 10 shows the measurements of three-phase voltages and currents of SPWM inverter without LC filtering (captured using average function of practical oscilloscope). Meanwhile, Figure 11 shows the measurements of three-phase voltages and currents after LC filtering. However, in this case, the waveforms are captured using average function of practical oscilloscope to remove the ripples of the PWM waveforms. Thus, the sinusoidal waveforms are obtained, respectively. This is done to provide an equal comparison to the waveforms obtained before LC (Figure 10) and after LC filtering (Figure 11). Based on Figures 10 and 11, by using LC filter, the waveforms obtained do not show any observable ripples.

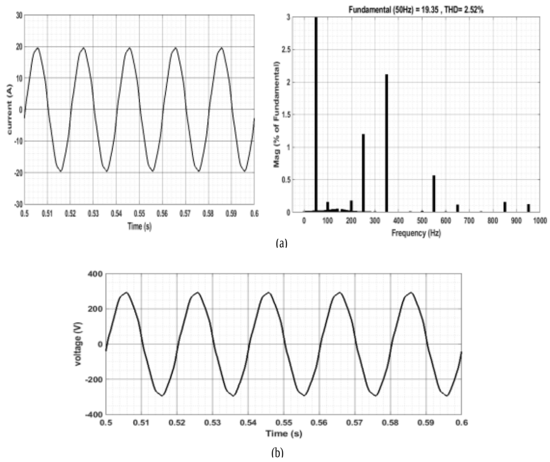

Figure 6: The simulation result of level 1 charging: (a) charging current with FFT analysis, (b) output voltage

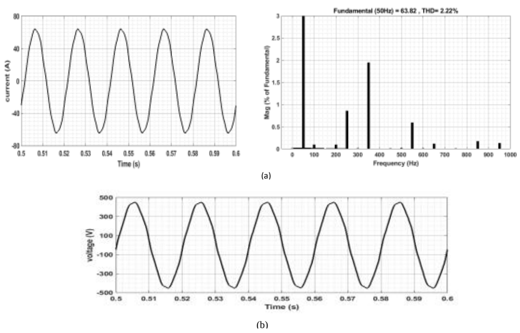

Figure 7: The simulation result of level 2 charging: (a) charging current with FFT analysis of phase A, (b) output voltage of phase A

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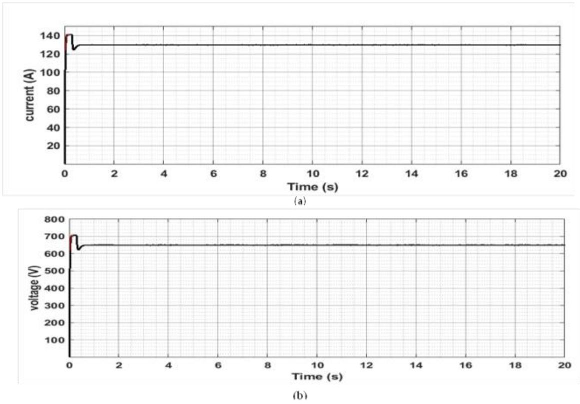


Figure 8: The simulation result of level 3 charging: (a) charging current, (b) output voltage

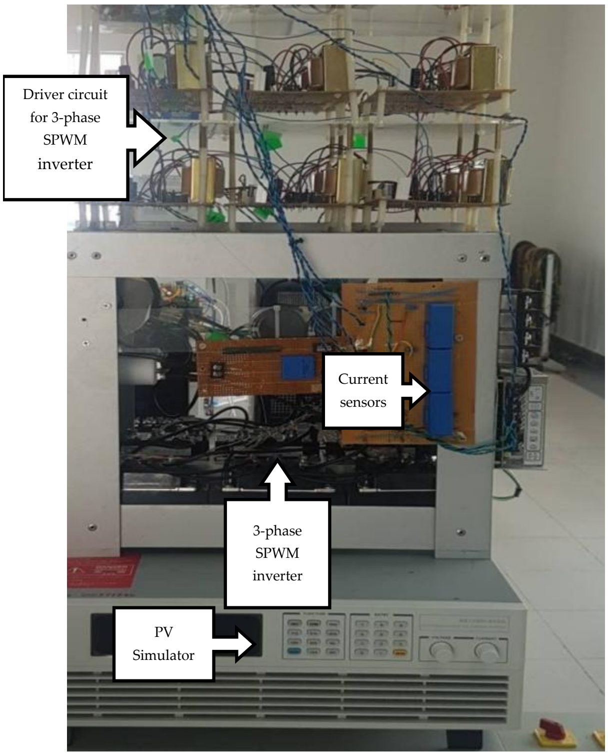


Figure 9: Experimental setup of EV universal charger circuits

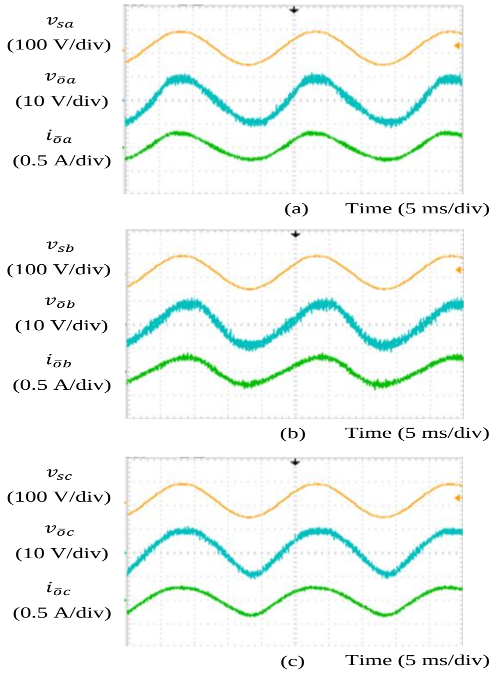
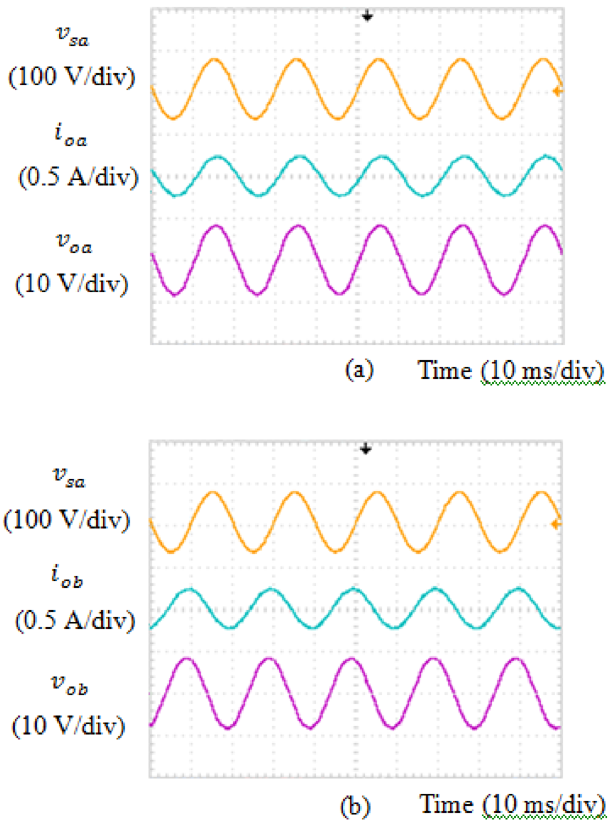


Figure 10: Measurements of output voltages and currents of SPWM inverter without LC filtering (captured using Average function of oscilloscope) for (a) phase A, (b) phase B and (c) phase C



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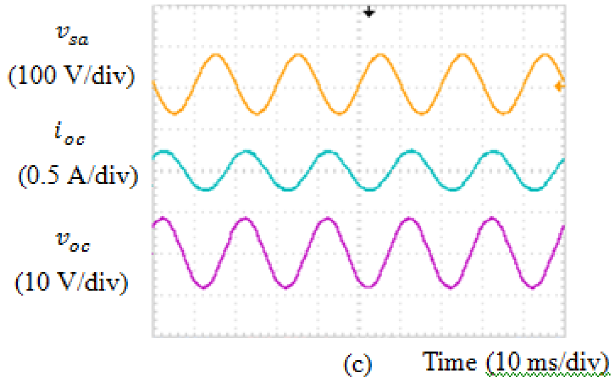

Figure 11: Measurements of the output voltages and currents of SPWM inverter with LC filtering for (a) phase A, (b) phase B and (c) phase C\

4. Conclusion

The proposed EV charger was successfully designed in this paper. All the objectives have been achieved successfully. The EV charger in this work, which is powered via PV, was tested in the lab environment. The proposed charger can produce a constant and controllable charging voltage for many types of EVs, which is comprised of three modes of charging: (1) 650 V/120A DC, (2) three-phase 450V/60A ACAND (3) single-phase 240V/20A AC. As a remarkable result of this project and from the findings, the SPWM technique correctly synchronizes the output DC voltage. In addition, it guarantees sinusoidal input current with minimum harmonic distortion. The charging power factor is almost unity, and the THD for the input current is less than 2.5%.

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