An EV Quick Charger Based on CHAdeMO Standard with Grid-support Function

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Abstract — **An electric vehicle (EV) quick charger based on CHAdeMO standard with grid-support function is proposed in this paper. The current source modular converter configuration is used to perform the charging pulses with both positive and negative pulse to achieve required time for an EV which is less than 30 minutes. The use of current source converter can offer the inherit fault tolerance capability and bidirectional power flow. CHAdeMO protocol is modified for grid-support function. The 50 kW prototype is developed to validate the proposed notion. The simulation and experimental results illustrate that the proposed pulse frequency charging technique requires about 16 minutes to fully charge of the battery from 20% of SOC to 80% of SOC. The results suggest that the proposed technique can be applied for an electric vehicle quick charger station.**

I. Introduction

Recently, electric vehicles (EVs) have grown rapidly as demanded green energy form the world. More specially, in a large city, air pollution due to CO_2 emission is a concerned issue. For instance, Nissan LEAFs in June 2015, have a sales over 180,000 units since December 2010 which is abount 45% of worldwide market share in EV business. Therefore, higher number of EVs will be used in the next few years. It is expected that more than 5 million EVs will be utilized by 2020 [1].As can be seen , A quick charge operating as a gas station is required.There are three important issues for a charging station: quick charge (less than 30 minutes), long battery lifetime (low temperature rise during charge), and standardization (every EV provider can be used). Constant current (CC) and constant voltage (CV) method cannot meet the 30 minutes charging time and low temperature rise requirements from EV users. Thereupon, a pulse charging method is an alternative technique for a quick charger at high current. A pulse charge method can be injected higher peak voltage and current with the same of V/cell and I_{max} rated; therefore, a charging time is shorter comparing to CC and CV method [2]. There are some previous researches using pulse charge technique for a charger application. The hybrid method between regenerative pulse and equalization charger using a DSP has been developed in [3-4]. The experiments in [4] provided a good power factor and bidirectional power flow; however, the temperature rise of the battery did not discuss in the paper. Designs of battery pulse charge with varying frequency and duty cycles have been proposed in [5-6]. The developed technique has been applied for a small Li-Ion battery and could be applied for an EV battery. However, the temperature rise and the effect of frequency and duty cycle of pulse signal did not investigate. In addition, a review of charging algorithm for Nickel and Lithium battery charger has been performed in [7]. The methods discussed in [7] are also investigated mostly a small size applications for mobile phones, laptop computer, tablet PC, etc. One can see that a few researches have been reported for a pulse quick charge technique for EV applications. That is why, the EV quick charger station acting as a gas station with grid-support function is developed in this research.

One of possible charger stations can be illustrated in Fig. 1 which contains photovoltaic roof (PV), battery energy storage (BES) and a quick charger. The developed charger station can act as a microgrid; so, the station can manage the energy flow in a microgrid by controlling tie-line power flow at point of common coupling (PCC). PV roof can supply energy to a charger and also to a BES depending on the mode of operations. If there have a demand from a quick charger, the inverter will supply PV energy to the charger; whereas, the PV energy will charge a BES if there have no demand. If the there are not a demand and BES is fully charged, the inverter will not feed energy back to the grid. It can be noted that the proposed charger station is drawn energy from PV and BES in first priority; then, the station will draw energy from the utility grid if the required energy is not adequate. Additionally, the proposed charger station can reduce an impact to the grid due to high charging current and avoid a new distribution transformer.

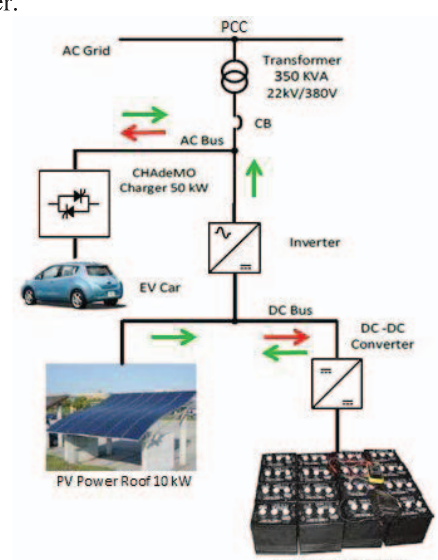

Fig.1 Diagram of the proposed EV quick charger station.

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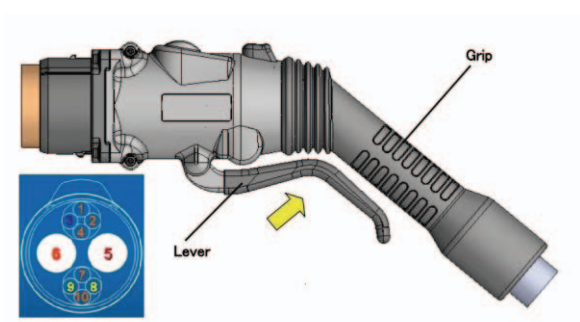
A standard of EV quick charger known as CHAdeMO [8] is widely used. CHAdeMO is a quick charging method (trade name) for battery EV rating up to 62.5 kW of high voltage dc current via a particular connector and protocol. Also, CHAdeMO is a global association proposing CHAdeMO standard which is firstly introduced in Japan since 2009 to be a global industry standard. Right now, more than 8,000 quick chargers have been installed around the world using CHAdeMO protocol in 38 countries. CHAdeMO also allows bidirectional power flow charging; therefore, vehicle to grid (V2G) and vehicle to home (V2H) are possible to implement for supporting smart grid in the future.

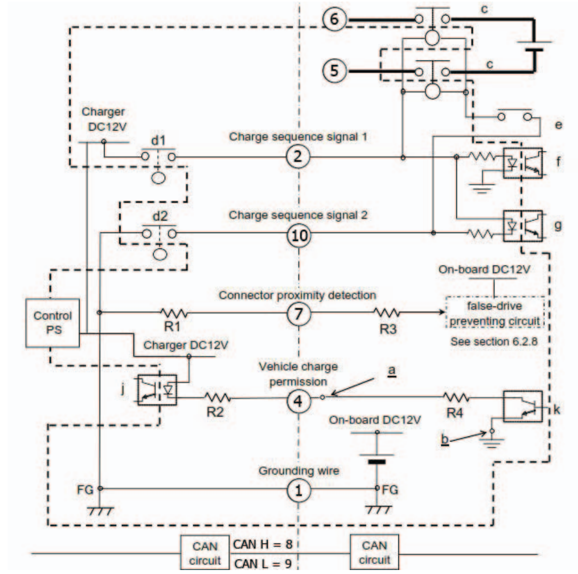
Thereupon, the proposed quick charger based on CHAdeMO with grid-support function is presented in this paper. The paper is organized into five sections: first, the introduction will be presented for the overview and review of previous works. Then, the timing diagram in a controller area network (CAN bus) according CHAdeMO protocol will be described. After that, Circuit topology and simulation study will be explained. Next, the experimental result will be validated. Finally, results and important remarks will be concluded.

II. Timing Diagram of CHAdeMo Protocol

The CHAdeMO standard contains two important parts which are a connector and protocol. For safety reasons, EV maker requires a specific connector for high dc current charger as depicted in Fig. 2. As can be seen, the holder is connected with the quick charger and a receiver is installed in an EV. The wiring diagram of connector is illustrated in Fig. 2 (b). This wiring diagram consists of power line for high current and also communication wires for CAN bus interfacing with an EV. A power line is a path of high current for charging the battery in a EV which controls and monitors via CAN bus (CAN 2.0B) based on ISO 11898 format transmission with 500 kbps transmission cycle of 100 msec ± 10%. It should be noted that the EV will provide all charging or discharging command to a quick charger; therefore, it is important to understand the timing diagram of an EV via communicating with CAN bus which is required by CHAdeMO protocol [8].



(a)



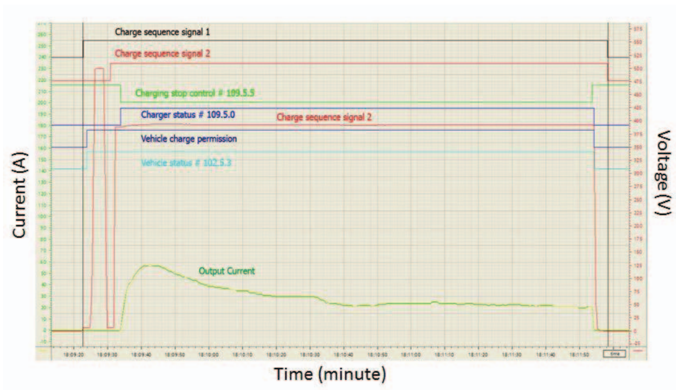
(b)

Fig. 2. Connector of CHAdeMO standard showing (a) holder and connector [8], (b) wiring diagram [8]

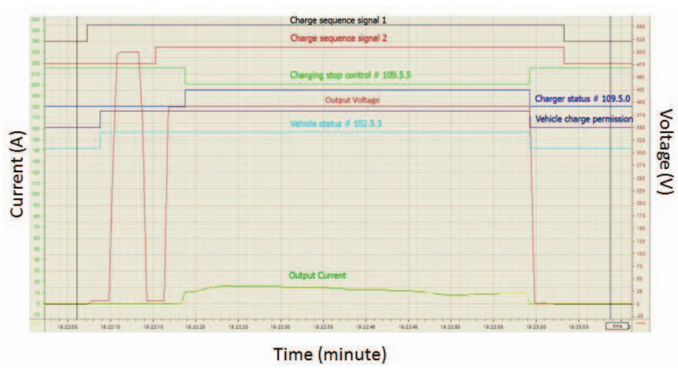
The timing diagram of CHAdeMO protocol is shown in Fig. 3. Each state of a diagram will communicate between an EV and Charger via Hexadecimal indicator as ID numbers. The communication wires include five pins with difference colors for sequential controlled signals (Pin # 1,2,4,7 and 10) and two pins (Pin # 8 and 9) for CAN bus. More detail can be reached in [8]. The sequential state of communication as shown in Fig. 3 (a) can be briefly explained as follows:

- Charging sequence signal 1 is a signal handshake from a charger sending to an EV,
- Charging sequence signal 2 is a confirmed signal from a charger to an EV after the connection is completed,
- Charging stop control is a data of operating status of a charger for showing operation in progress or stop operation,
- Charging status is a data for indicating charger status that can be operated or not (ready or not ready),
- Vehicle charging permission is a signal for permission from an EV for charging mode and indicates the relay status,
- Vehicle charging enable is a data for indicating communication status,
- Vehicle status is a data for showing an EV status.

In addition, an EV will be required to check a short circuit and ground fault. A quick charger will supply dc voltage about 10 V for checking the contractor which is connected with battery terminals. The contractor needs to be turn-off or open circuit. Then, A quick charger will supply a test dc voltage about 500 V for checking insulation status. The resistance of 100 kΩ is a threshold value between positive and negative bus of an EV battery. The graphical of short circuit and insulation validation is illustrated in Fig. 3.



(a)



(b)

Fig. 3. Timing diagram operation of CHAdeMO showing (a) sequential signals, and (b) short circuit and insulation test status.

III. PROPOSED CIRCUIT OPERATION

A. Circuit Topology

The proposed circuit diagram incorporating with related pulse width signals is shown in Fig. 4. The modified current source converter is applied using positive and negative thyristor based converter known as PN converter. The modified PN converter can operate in bidirectional power flow and provide better fault tolerance capability. Therefore, V2G and V2H smart grid function is achievable for using the proposed converter; however, this proposed converter has bigger size comparing to a switching mode power supply because the proposed converter required a interfacing transformer for better input current quality and galvanic isolation. It should be noted that the ground isolation is needed for an EV charging station based on CHAdeMO recommendations. The IGBT is used for providing bidirectional power flow during pulse charging operation which is key contribution in this paper. The turn-on time of IGBT is depended up on the battery condition. The pulse width and idle state can be controlled depending on the battery conditions (V/cell and I_{max}) and battery temperature rise (ΔT^o). The temperature rise during charge can effect a battery lifetime. There are three states of the proposed circuit operation as depicted in Fig. 4: charging mode, discharging mode, and idle mode. Charging mode will operate Q_1 converter for desired current and voltage command from an EV via CAN bus and CHAdeMO protocol; whereas, the discharging mode will operate Q_2 converter and turning on an IGBT for releasing energy back to the grid for performing pulse charging technique as reported in [9]. The idle mode will operate during resting time if the temperature of the battery is increasing over than threshold value which is 5 ^{o}C for Nissan LEAF case. The CHAdeMO will send all data status from an EV to the quick charger via CAN bus. The output voltage at battery terminals and related current during each operating mode of the proposed modified PN converter is illustrated in Fig. 5.

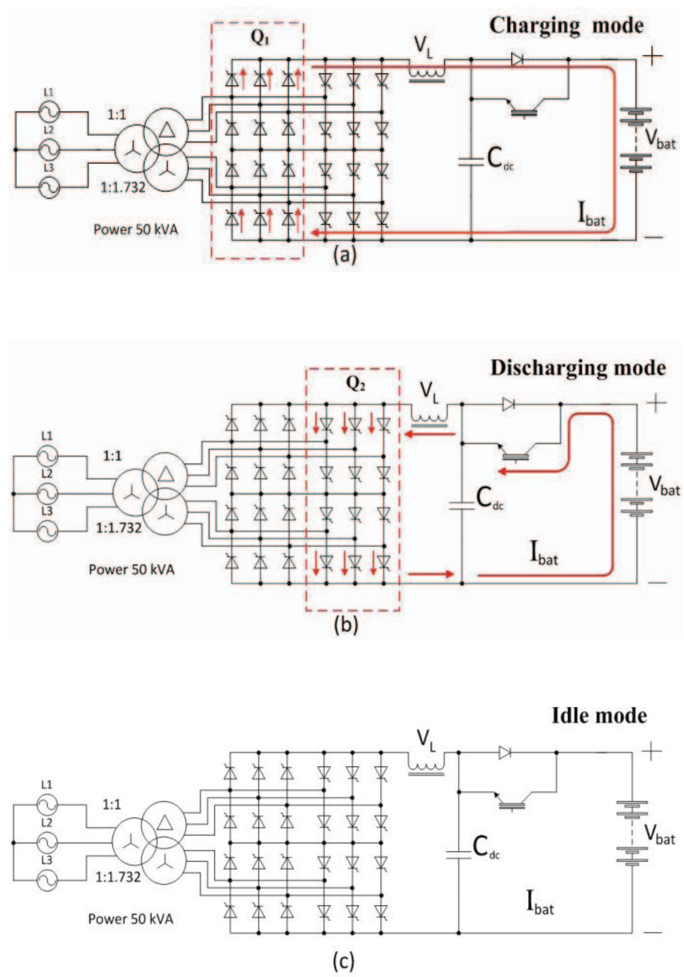


Fig. 4. Circuit topology showing (a) charging mode, (b) discharging mode, and (c) idle mode.

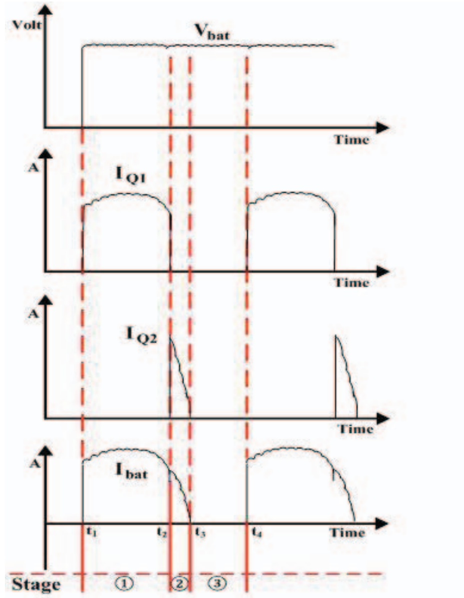


Fig. 5. Output voltage at battery terminals and related current in each operating mode.

Fig. 6 also shows a flow chart diagram of proposed quick charging paradigm. As can be seen, temperature rise control is used during idle mode: this would not cost battery lifetime. The positive pulse width is depended upon V/cell; whereas, the idle state is referred with battery temperature rise. The pulse frequency can be generated from a modulation between desired positive pulse and negative pulses and a triangle waveform. The positive and negative pulse width can be controlled depending on the battery conditions (V/cell and I_{max}) and battery temperature rise (ΔT^{o}).

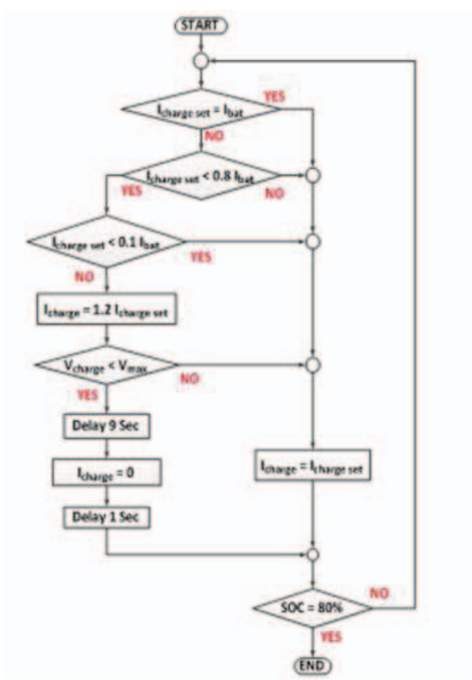


Fig. 6. Flow chart diagram of proposed quick charging technique.

B. Simulation study

PSIM 9.0.3 is used to simulate the notion of the proposed system as illustrated in Fig.7. The modified PN converter is used to perform a quick charging mode via control output voltage at battery terminal and charging current flowing to a battery as shown in Fig. 8. As can be seen, the fine output voltage and charging current were achieved; also, the actual charging current and current commands were in good agreement. The simulation results suggest that it is possible to use the modified PN converter for a quick charging in an EV application.

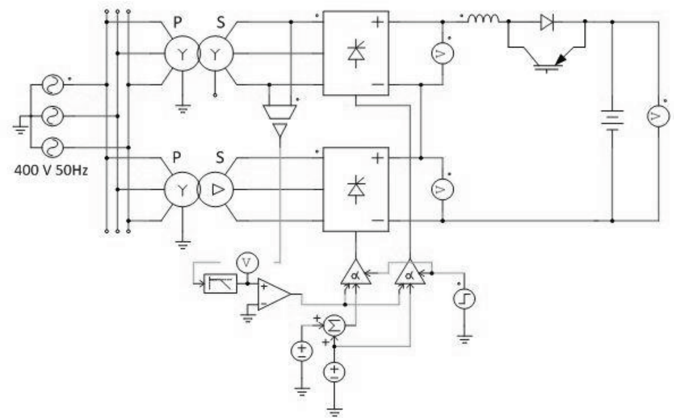


Fig. 7. Simulation model.

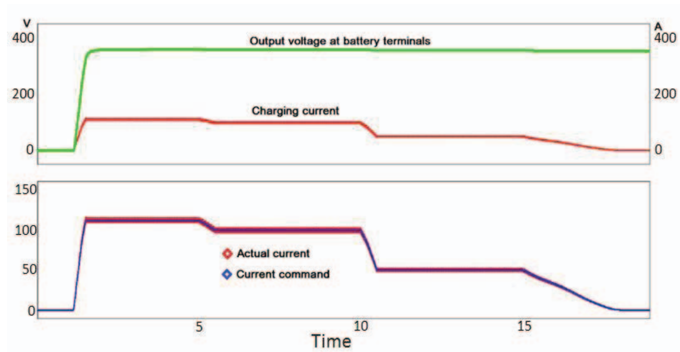


Fig. 8. output voltage at battery terminal and charging current flowing to a battery

IV. EXPERIMENTAL VALIDATION

The developed 50 kW prototype of a quick charger using pulse charging technique is shown in Fig. 9. The EV from Nissan known as LEAF model 2012 was used to validate the charging time of the developed charger. The LEAF has 24 kWh laminated lithium ion battery and requires 30 minutes at 50 kW charging time for a quick charge mode. The proposed modified converter can performed both conventional CC/CV charging mode and pulse frequency charging mode. The technical specification of the proposed quick charger is listed in Table I.

Fig. 9. Experimental setup.

TABLE I.
TECHNICAL SPECIFICATION

System Type	Single DC fast-charging station
Environment	Indoor / outdoor
Input	
AC Power Connection	3P+PE
Input voltage range	400 Vac +/- 10%
Nominal input voltage	400 Vac
Nominal input Current	70 A
Nominal input power	50 kVA
Nominal input frequency	50 Hz
Output for Car	
Maximum output power	50 Kw
Maximum output current	120 A
Output voltage	50-500 V
Output for EBike	
Maximum output power	900 w
Maximum output current	15 A
Output voltage	10- 60 V
General	
DC connection standard	CHAdeMO compliant
DC cable length	3 m
DC plug type	JEVS G105
RFID system	13.56MHz, ISO 14443A

The developed prototype was also performed conventional CC and CV experiment to compare with the pulse charging mode. Fig. 10 shows experimental results of battery charging and discharging using CC and CV technique; whereas, Fig. 11 illustrates the experimental results using the proposed pulse charging technique. The LEAF was validated at a same circumstance. The LEAF was charged from 20% of SOC to 80% of SOC in both quick charging modes. As can be seen, the terminal voltage was regulated for both charging methods. The charging process was performed until the LEAF was fully charged. The battery terminal voltage were regulated at 400 V and maximum charging current (I_{max}) was limited at 120 A as shown from Fig. 10 and Fig. 11.

Fig. 10 illustrates the results of conventional CC/CV charging mode. As known, the CC will perform first then the CV mode will operate to keep temperature rise. The charging time required is about 22 min. It should be noted that EVs will control the charging process via CHAdeMO using CAN bus communication. Meanwhile, the pulse charging mode results are illustrated in Figure 11. Clearly, the pulse charging mode will perform during constant voltage region which is not over the current limitation. The results illustrate that the required charging time is about 15 min. Additionally, the temperature rise of a proposed pulse charging technique was about 3.92 ^{o}C ;whereas, the temperature rise was 4.13 ^{o}C for CC/CV method. The energy consumption of CC/CV was about 9.7 kWh; whereas, the pulse charging was about 9.3 kWh for energy consumption.

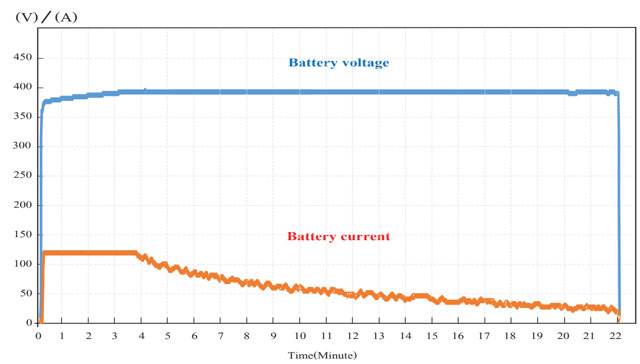


Fig. 10. Voltage at battery terminals and charging current operating in CC/CV charging mode.

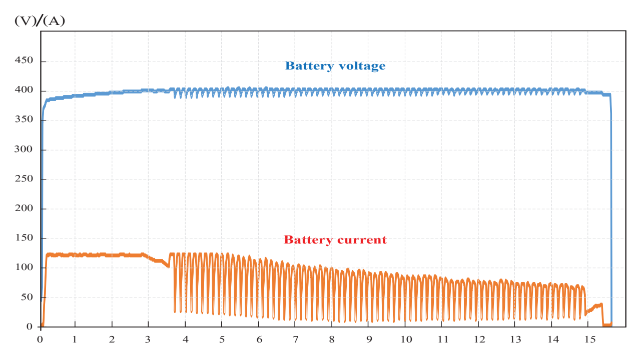


Fig. 11. Voltage at battery terminals and charging current operating in proposed pulse charging mode.

The comparison of experimental results between CC/CV method and pulse charge method is shown in Fig. 12. Clearly, the proposed pulse technique can change the test batteries from

20% of state of charge (SOC) to 80% of SOC quicker than conventional CC/CV method about seven min. Moreover, the temperature rise of proposed charging technique is less than a CC/CV method about 1 ^{o}C. Furthermore, both charging techniques are consumed almost a same level of energy. The results show the proposed technique can perform better charging performance in term of charging time and temperature rise. The experimental results suggest that the proposed pulse technique and modified PN converter are a promising technique to apply for a quick charger for EVs.

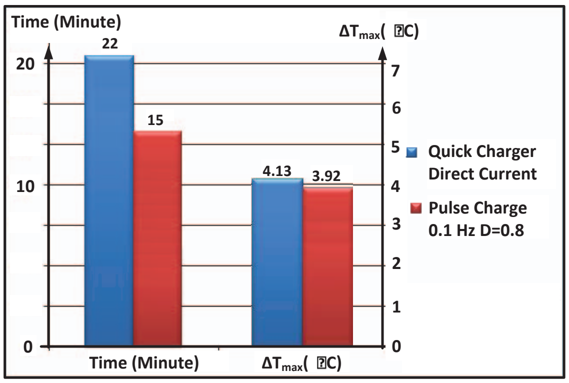


Fig. 12. Comparison of experimental results between CC/CV method and pulse charging method.

V. Conclusion

An electric vehicle (EV) quick charger based on CHAdeMO standard with grid-support function has been proposed. The modified PN converter has been applied to perform the charging pulses with both positive and negative pulse to achieve time required for an EV which should be less than 30 minutes. CHAdeMO protocol has been explained for providing grid-support function. The proposed CHAdeMO modification can allow the EV to perform grid- support function. The experimental validation has also been validated comparing to CC/CV charging mode. The proposed pulse technique can change the test batteries from 20% of state of charge (SOC) to 80% of SOC quicker than conventional CC/CV method about seven min. Moreover, the temperature rise of proposed charging technique is less than a CC/CV method about 1 ^{o}C. Furthermore, both charging techniques are consumed almost a same level of energy. The experimental results illustrate that the proposed pulse technique and modified PN converter are a promising technique to apply for a quick charger for EVs.

Acknowledgment

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