AC/DC Matrix Converter With an Optimized Modulation Strategy for V2G Applications

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Abstract—To adapt the battery voltage and increase charging efficiency in vehicle to grid (V2G) systems, an ac/dc matrix converter topology is presented. Aim to solve the problem of relatively large charging current ripple in the classical current space vector modulation strategy, a sectional optimized modulation strategy, is proposed, which can reduce the charging current ripple within the whole output range. And the comparative analysis is carried out between them. A simple controller with active damping is briefly introduced; it can work at two charging modes: constant voltage charging and constant current charging. The simulation and experimental results demonstrate the validity and effectiveness of the proposed method.

Index Terms—AC/DC matrix converter, charging current ripple, sectional optimized modulation strategy, vehicle to grid (V2G).

I. INTRODUCTION

Due to the increasingly serious energy shortages and environmental pollution issues, the relevant authorities have realized the importance of energy conservation and emission reduction. Developing the plug-in hybrid electric vehicles or electric vehicles is an effective way to solve the aforesaid issues [1], [2]. In the near future, vehicle to grid (V2G) will become an indispensable part in the electric vehicle (EV) industry [3], [4]. In the V2G system, a bidirectional battery charger plays a critical role. Electrical energy is supplied to EVs via the battery charger; meanwhile, energy stored in battery could return to grid to support the grid when the EV is parked at peaks of consumer energy demand [5].

Nowadays, most of the battery chargers on the market cause a large amount of current harmonics in the power grid, along with a large number of harmonic losses and electromagnetic interference problem. With the development of power electronics technology, lots of researchers start to focus on advanced battery charger based on bidirectional converters. To meet the V2G application requirements, charger converter must have such characteristics as follows: a controllable power factor (preferably unity) with a high quality sinusoidal current at the grid interface, rapid response to ensure that the power flow can transform frequently, high efficiency, simple construction, and high power density to meet the space limitation in EVs. Voltage–source-type pulse width modulation (PWM) rectifier is commonly applied in battery charger for EV [6], [7], this type of charger allows bidirectional energy flow, and the quality of its input currents improves greatly with the PWM technique. However, as it is a boost converter in essence, an additional chopper circuit is needed to match the charging voltage characteristics of battery, which increases the weight and cost as well as reduces the efficiency.

As a new topology of converters, matrix converter has received considerable attention in recent years; it has many merits such as controllable input power factor, sinusoidal input and output waveforms, four-quadrant operation, no need for large energy storage components, and so on [8]–[11]. Matrix converter is widely applied in the fields of variable-frequency drive, new energy generation, and distributed generation [12], [13]. AC/DC matrix converter is a converter derived from the indirect matrix converter [11] and inherits many advantages of the ac/ac matrix converter. It is a bidirectional current–source-type rectifier with inherent characteristics of direct current synthesis and one-stage buck conversion. Consequently, it has such features as fast response to power flow control and high efficiency, which make this solution quite attractive in V2G applications.

In view of the excellent characteristics of the ac/dc matrix converter, extensive research has been conducted on it. Literature [14] implements this rectifier function by using ac/ac matrix converter theory. The ac/dc matrix converter with high-frequency isolation is studied extensively in [15] and [16] where the relevant modulation strategy and commutation techniques are discussed. Dynamic characteristics of the matrix rectifier are investigated in [17]. Literature [18] analyzes the common mode voltage problem, and an improved modulation method to reduce the common mode voltage is presented in it. In [19], a new topology with fewer switches is presented, which is equivalent to ac/dc matrix converter in function. In [20], an ac/dc matrix converter with only three switches is proposed. To overcome the drawbacks caused by the complicated electrochemical battery characteristic, a fuzzy controller is adopted; however, the energy cannot be inverted to the power grid.

In this study, a sectional optimized modulation strategy is presented to reduce the charging current ripple; a comparative analysis is made between the classical current space vector modulation strategy and the proposed one. A simple controller with active damping is briefly introduced. Simulations and experiments are carried out to validate the proposed method.

This paper is organized as follows: Section II introduces the topology and modulation strategy of the ac/dc matrix converter; 

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Section III presents the comparative analysis of charging current ripples. Section IV introduces the system design for ac/dc matrix converter briefly. Section V shows the simulation and experimental results. Section VI draws the conclusion of this paper.

II. TOPOLOGY AND MODULATION

A. Topology

The topology of ac/dc matrix converter is shown in Fig. 1, where the bidirectional switches are generally implemented by two insulated-gate bipolar transistors (IGBTs) with anti-parallel freewheeling diode connected in series with common emitter. A second-order LC input filter is used to prevent the high-frequency harmonic currents generated by the converter from propagating into grid, as well as to prevent the high frequency-harmonics in the grid from disturbing the converter. \( L_o \) and \( C_o \) is the inductor and capacitor of the output filter, respectively, which is to smooth the charging current.

In V2G applications, the ac/dc matrix converter needs to work in two modes: charging mode and discharging mode. In essence, this converter allows bidirectional power flow. However, the relevant commutation is complicated relatively. According to the features of this converter, when it works in charging mode, all the switches \( s_1', s_2', \ldots, s_6' \) could be turned OFF, and then the ac/dc matrix converter can be simplified to a simple topology as shown in Fig. 2. Analogously, when it works in discharging mode, all the switches \( s_1, s_2, \ldots, s_6 \) are turned OFF, and then the remaining parts form the topology shown in Fig. 3. Thus, the tedious four-step commutation could be avoided, and the reliability and efficiency of the converter are also improved greatly.

B. Modulation Strategy

1) Classical Current Space Vector Modulation Strategy:

First, the classical current space vector modulation strategy is introduced. According to the desired input current vector \( \vec{i}_s \), six active vectors \( I_1 \sim I_6 \) and three zero vectors \( I_7 \sim I_9 \) are used to synthesize it, where each vector corresponds to a switching state of the rectifier. The classical current space vector modulation schematic is shown in Fig. 4. The principles of the sector division in this modulation strategy are as follows: sector 1 is between \( I_1 \) and \( I_2 \); sector 2 is between \( I_2 \) and \( I_3 \), and so forth.

In a particular sector, two adjacent active vectors and a zero vector are always used to synthesize the input current vector. For example, when the input current vector is located in sector 1, \( I_1 \), \( I_2 \), and \( I_7 \) are used. Based on the principle of capacitor charge
balance, the duty cycles are expressed as follows:

\[
\begin{align*}
    d_1 &= \frac{T_1}{T_s} = m_v \sin \left( \frac{\pi}{3} - \theta_i \right) \\
    d_2 &= \frac{T_2}{T_s} = m_v \sin (\theta_i) \\
    d_0 &= \frac{T_0}{T_s} = 1 - d_1 - d_2
\end{align*}
\]

(1)

where \(T_1, T_2,\) and \(T_0\) are the durations of the vector \(I_0, I_2,\) and \(I_7,\) respectively. \(d_1, d_2,\) and \(d_0\) are the duty cycles of the vector \(I_1, I_5,\) and \(I_7,\) respectively. \(T_s = \frac{1}{f_s}\) is the switching period and \(f_s\) is the switching frequency, \(m_v\) denotes the modulation index with \(0 \leq m_v \leq 1,\) \(\theta_i\) is the input current vector angle with reference to the vector \(I_1\) in sector 1. When the desired input current vector is in the other sector, the corresponding duty cycles could be obtained in the same way as mentioned before.

2) Sectional Optimized Modulation Strategy: For a given current vector, many different active vectors and zero vectors could be selected to synthesize it according to the principle of capacitor charge balance. The choice of vectors is mainly based on two considerations. (1): the ability to synthesize the desired current vector. (2): the relevant performance of the converter, such as input current and charging current quality, and energy conversion efficiency. If charging current ripple is small, the lifespan of battery could be prolonged. Usually, charging current ripple is related to the filter and modulation strategy. In this study, if a larger inductor \(L_o\) is used, the charging current ripple will be reduced. However, a large and heavy inductor is not preferred. In this section, a sectional optimized modulation strategy is presented to reduce the charging current ripple.

The proposed optimized modulation is shown in Fig. 5. And its principle is explained as follows:

1) when the desired input current vector \(\vec{i}\) is located within the regular hexagon region GHJJKL in Fig. 5(a), two vectors with phase difference of 120° of the six basic active vectors and a zero vector are always used to synthesize the desired current vector in each switching period;

2) when the desired input current vector \(\vec{i}\) is located within the bigger regular circle ABCDEF but outside the regular hexagon region GHJJKL in Fig. 5(a), three sequentially adjacent vectors of the six basic active vectors are used to synthesize the desired current.

The principle of the sector division is as follows: Denote the area the 30° range of before and after each active vector as a sector. For instance, fan-shaped region AOB is regarded as sector 1. Analogously, the fan-shaped region BOC is called sector 2, and so forth.

For simplicity, one specific example is used to explain the modulation in details. Assume that the desired input current vector \(\vec{i}\) is located in sector 1, as shown in Fig. 5(b) and (c). Sector 1 is further divided into two regions: When the input current vector \(\vec{i}\) is located within the triangle OGH, \(\theta_i \in [0, \frac{\pi}{3}],\) \(T_1', T_2', T_3'\) are the durations of the vectors \(I_1, I_3, I_5,\) and zero vector \(I_8\) will be used for synthesizing it; when it is located in the rest region of sector 1, or the polygon ABHG, as can be seen in Fig. 5(c), the vectors \(I_1, I_2,\) and \(I_3\) will be used to achieve the goal. The expressions for duty cycles in each region can be derived, respectively, as shown in (2) and (3)

\[
\begin{align*}
    d_1' &= \frac{T_1'}{T_s} = m_v \sin \left( \frac{\pi}{2} - \theta_i \right) \\
    d_3' &= \frac{T_3'}{T_s} = m_v \sin \left( \theta_i + \frac{\pi}{6} \right) \\
    d_0' &= \frac{T_0'}{T_s} = 1 - d_1' - d_3'
\end{align*}
\]

where the input current vector \(\vec{i}\) is located within the polygon OGH, \(\theta_i \in [0, \frac{\pi}{3}],\) \(T_1', T_2', T_3'\) are the durations of the vectors \(I_1, I_3, I_5,\) and zero vector \(I_8\) will be used for synthesizing it; when it is located in the rest region of sector 1, or the polygon ABHG, as can be seen in Fig. 5(c), the vectors \(I_1, I_2,\) and \(I_3\) will be used to achieve the goal. The expressions for duty cycles in each region can be derived, respectively, as shown in (2) and (3)

\[
\begin{align*}
    d_1'' &= \frac{T_1''}{T_s} = 1 - m_v \sin \left( \theta_i + \frac{\pi}{6} \right) \\
    d_2'' &= \frac{T_2''}{T_s} = 1 - d_1'' - d_3'' \\
    d_3'' &= \frac{T_3''}{T_s} = 1 - m_v \sin \left( \frac{\pi}{2} - \theta_i \right)
\end{align*}
\]

3) Switching Pattern Arrangements: The performance of converter not only depends on the selected vectors to produce the desired current vector but also the switching pattern arrangement. Several commonly used switching patterns are shown in Fig. 6. Switching patterns are unilateral in both \(P_0\) and \(P_1\) mode, in which switches should commutate three times during each switching period. The switching patterns are bilaterally symmetrical in \(P_2\) or \(P_3\) modes, and four times commutations occur
in each switching period. In order to guarantee good input and output characteristics, such as low input current distortion and small charging current ripple, a symmetrical switching pattern is applied as usual.

The optimized target in this study is to reduce the charging current ripple, thus the switch pulse sequence shown in the $P_2$ mode is used under the classic modulation strategy, as shown in Fig. 7. And the switching pattern in Fig. 8 is applied under the proposed modulation strategy (assuming that the input current vector is in sector 1).

III. Charging Current Ripple Analysis

A. Output Charging Current Ripple Characteristics

To verify the validity of the proposed scheme, two simulations are carried out in MATLAB and Simulink. In the first one, a fixed output voltage control is considered; in the second one, the closed loop output current control is investigated.

Neglecting the voltage drops due to the switch devices and assuming the terminal voltage $u_B$ is constant. The equivalent circuit of ac/dc matrix converter’s output part is shown in Fig. 9. The output voltage of the converter $u_{dc}$ is pulsating with its average $\bar{u}_{dc}$

$$\bar{u}_{dc} = 1.5U_m m_v, \quad (4)$$

Here $U_m$ is the magnitude of the input phase voltage and the charging current can be expressed as

$$L_\alpha \frac{di_{dc}}{dt} = u_{dc} - u_B. \quad (5)$$

As can be seen in (4) and (5), by adjusting modulation index $m_v$ to control the output voltage $u_{dc}$ of the converter, where the battery terminal voltage $u_B$ is approximately constant, the goal of controlling the output inductor current $i_{dc}$, as well as power flow of the converter is achieved.

Assume the charging current in this study is continuous, its obtained waveforms in one switching period is shown in Fig. 10, where $I_{dc}$ is the average current and $\Delta i$ is the peak ripple current. Fig. 10 is only a schematic diagram on the classical modulation strategy; the specific waveform depends on modulation index, switching pattern, and other factors. Waveforms in one switching period under the proposed modulation strategy can be derived in the same way according to Fig. 8.

B. Comparative Analysis in Charging Current Ripple

Since the charging current is an integral of the inductor voltage, it can be seen from Fig. 10 that the charging current ripple relates to the instantaneous output voltage of the converter, i.e., depends on modulation strategy. The charging current ripples are different with various modulation strategies. Compared with unilateral switching pattern, bilaterally symmetrical switching patterns have smaller charging current ripple without increasing too much switching losses. Thus, in this study, the bilateral
Fig. 10. Waveforms under the classical modulation strategy. (a) Average voltage is lower than the second largest line–line voltage. (b) Average voltage is higher than the second largest line–line voltage.

symmetric patterns as shown in Figs. 7 and 8 are adopted for the classical modulation strategy and the proposed one, respectively. The corresponding charging current ripples calculation based on different modulation strategies will be discussed in the next section.

1) On the Classical Modulation Strategy: Without loss of generality, assume that the desired input current vector lies in sector 1 with unity power factor. When $0 \leq m_v \leq \frac{\sqrt{3}}{2}$, because voltage $u_{ab}$ and $u_{ac}$ are always larger than the average voltage $\bar{u}_{dc}$, the charging current decreases over $T_0$ interval as shown in Fig. 10(a), then peak charging ripple current can be expressed as

$$\Delta i \approx \frac{\bar{u}_{dc}}{L_o} T_0$$

$$\Delta i = 1.5 \frac{\bar{u}_{dc}}{L_o f_s} (1 - m_v \cos(\theta_i - \frac{\pi}{6}))$$. (7)

When $\frac{\sqrt{3}}{2} < m_v \leq 1$, the average voltage $\bar{u}_{dc}$ is larger than one of the two nonzero voltage $u_{ab}$ and $u_{ac}$, but less than the other. To make the charging current small, the smaller nonzero voltage is placed at both ends in one switching period as shown in Fig. 10(b). According to Fig. 10(b), under the condition of $u_{ab} \leq \bar{u}_{dc} \leq u_{ac}$, the peak charging ripple current could be calculated as follows:

$$\Delta i = \max\{|\Delta i_1|,|\Delta i_2|\}$$ (8)

where $\Delta i_1$ is expressed as

$$\Delta i_1 = \frac{u_{ab} - \bar{u}_{dc}}{L_o f_s} d_1 = 1.5 \frac{m_v U_m}{L_o f_s} \times \left(\frac{2}{\sqrt{3}} \cos \theta_i - m_v\right) \sin \left(\frac{\pi}{3} - \theta_i\right).$$ (9)

And $\Delta i_2$ could be written as

$$\Delta i_2 = \frac{\bar{u}_{dc}}{L_o f_s} d_0 = 1.5 \frac{m_v U_m}{L_o f_s} \left(1 - m_v \cos \left(\theta_i - \frac{\pi}{6}\right)\right).$$ (10)

If $u_{ac} \leq \bar{u}_{dc} \leq u_{ab}$, we change the position of $u_{ab}$ and $u_{ac}$ in Fig. 10(b), and the charging current ripple can be derived in a similar way as mentioned earlier.

According to the analysis, the ripple current in one complete sector with $m_v \in [0, 1]$ under the classical modulation is depicted in Fig. 11(a) and the maximal current ripple is given
by

\[ i_{\text{max}} = \frac{3m_vU_m}{2L_o f_s} \left( 1 - \frac{\sqrt{3}}{2} m_v \right). \] (11)

2) On the Proposed Modulation Strategy: In this modulation, three active vectors are used to produce the desired input current vector, the switching pattern is arranged as shown in Fig. 8, where the second largest line–line voltage is placed at both ends, and the smallest one is placed in the middle. Such an arrangement will make the charging ripple current small. Due to space limitations, its detailed derivations are omitted here, but the ripple current in one complete sector with \( m_v \in [0, 1] \) is illustrated in Fig. 11(b).

Comparing the ripple currents shown in Fig. 11, it is clear that the ripple current in the proposed modulation strategy is lower than that in the classical modulation, especially at the area around \( m_v = 0.5 \). It could also be found that both the 3-D plots are symmetrical with respect to \( \theta_i = \frac{\pi}{2} \).

IV. SYSTEM DESIGN

A. Output Filter Design

A well-designed output filter is required for minimal current ripple and for proper dynamic response. An LC filter is applied in the ac/dc matrix converter as can be seen in Fig. 1.

The design of output filter is based on two considerations: the suppression of current ripple and the system dynamic response. A large LC filter is commonly used to minimize the output current ripple; however, it may make the output current response slow. So a tradeoff should be made between these two aspects.

The current flowing through \( L_o \) consists of a full dc (load) current \( I_{dc} \) and a current ripple \( \Delta i \); the current ripple is hoped to be limited to \( \gamma I_{dc} \), where \( \gamma \) is current ripple index and is defined as

\[ \gamma = \frac{\Delta i}{I_{dc}} \] (12)

\[ I_{dc} = \frac{P}{\bar{u}_{dc}} \] (13)

where \( P \) is the output power. The current stresses across \( L_o \) under the proposed modulation are determined by

\[ i_{\text{max}} = \frac{3m_vU_m}{2L_o f_s} (1 - m_v), \quad \text{when} \quad 0 \leq m_v \leq 0.8287 \]

\[ i_{\text{max}} = \frac{3U_m}{2L_o f_s} \left( \frac{2}{\sqrt{3}} - m_v \right) (\sqrt{3}m_v - 1), \]

\[ \text{when} \quad 0.8287 < m_v \leq 1 \] (15)

\[ i_{\text{max}} = (1 + \gamma)I_{dc}. \] (16)

Here \( \gamma = 0.4 \) is adopted to make a compromise between performance and volume of the inductor. So the output inductor is given by

\[ L_o \geq \frac{1.5U_m}{f_s \gamma I_{dc}} \left( \frac{2}{\sqrt{3}} - m_v \right) (\sqrt{3}m_v - 1). \] (16)

The voltage ripple across the output capacitor is determined by

\[ \Delta u_{c_{\text{max}}} = \frac{\Delta i_{\text{max}}}{8C_o f_s} = \frac{3U_m}{16f_s^2 L_o C_o} \left( \frac{2}{\sqrt{3}} - m_v \right) (\sqrt{3}m_v - 1) \] (17)

and the output capacitor is given by

\[ C_o \geq \frac{3U_m}{16f_s^2 L_o \Delta u_{c_{\text{max}}}} \left( \frac{2}{\sqrt{3}} - m_v \right) (\sqrt{3}m_v - 1). \] (18)

Considering the rated input voltage, output power, output voltage, and switching frequency, a 0.6-mH inductor and a 10-\( \mu \)F capacitor are selected in the prototype based on the aforesaid analysis.

B. Controller Design

According to Fig. 1, the mathematical model of the charger system based on state space average modeling method could be expressed as follows:

\[ L \frac{d\bar{u}}{dt} = \bar{u}_s - \bar{u} \] (19)

\[ C \frac{d\bar{v}}{dt} = \bar{i} - i_{dc} \bar{d} \] (20)

\[ L_o \frac{di_{dc}}{dt} = \frac{3}{2} \bar{u} \cdot \bar{d} - u_B \] (21)

where \( \bar{u}_s \) is the grid voltage vector, \( \bar{u} \) is the input voltage vector, \( \bar{d} \) is the duty ratio vector, and \( i_{dc} \) is the charging current.

The control schematic diagram is illustrated in Fig. 12, which includes a digital phase-locked loop (PLL), two PI controllers, an additional stabilization controller, and a detector to monitor the state of the charge (SoC). The purpose of using PLL is two-fold: one is to get the information of grid phase, and the other is to stabilize the system when operating in discharging mode. An additional stabilization controller is mainly used to increase the damping of the system in charging mode implemented with the constructive stabilization method [21]. When the converter works in motor mode, a correction term \( f(u) = k(u - \bar{u}) \) is added on the expected input current vector to modify the input impedance, where \( u \) is the magnitude of the input voltage vector and \( \bar{u} \) the steady value of \( u \). In discharging mode, because the additional stabilization controller will degrade the stability, it should be disabled. The design criteria are as follows. i) The correction term should be designed to guarantee that the system...
is stable. ii) The correction term should be as small as possible not to affect the performance of the converter. The switching of enabling/disabling the stabilization controller is decided by the mode of the converter: When working in motor mode (charging), the stabilization controller is enabled. When in generator mode (discharging), the stabilization controller is disabled. The proposed controller has two operation modes for charging, one is used for constant voltage charging, the other is used for constant current charging. The switching in the two charging modes and the reference charging current are determined by SoC and the characteristics of specific battery.

V. SIMULATION AND EXPERIMENTAL RESULTS

A. Simulation

To valid the proposed method, simulations based on MATLAB/Simulink environment are implemented in this section. The models of semiconductor device and battery are from the SimPowerSystems/Power Electronics library. The schematic diagram of the ac/dc matrix converter in simulation is shown in Fig. 1, and the parameters of the ac/dc matrix converter used in simulation are listed in Table I. The loads are the 100-Ah capacity lead-acid battery with three different nominal voltages: 72, 48, and 24 V, respectively.

To compare the charging current ripples with different modulation strategies and different modulation indexes, three kinds of battery voltages are selected to make the modulation indexes to be 0.9, 0.3, and 0.6, which lies in three different modulation regions shown in Fig. 5(a). All charging current reference of battery is set to be 15 A to guarantee the charging current to be constant, the simulation results for charging currents in one section are shown in Fig. 13. It is clear that the charging current ripple in the classical modulation is always greater than that in the proposed one. It could be found that the waveform of charging current is symmetric in each sector. And the charging current in any other sectors are the same as that shown in Fig. 13.

B. Experiments

An ac/dc matrix converter prototype rated at 10 kVA is built in lab for experimental verification, as shown in Fig. 14. The parameters setting is the same as the simulation, the power

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude of input phase voltage</td>
<td>60 V</td>
</tr>
<tr>
<td>Input filter inductor</td>
<td>0.6 mH</td>
</tr>
<tr>
<td>Input filter capacitor</td>
<td>30 μF</td>
</tr>
<tr>
<td>Output filter inductor</td>
<td>0.6 mH</td>
</tr>
<tr>
<td>Output filter capacitor</td>
<td>10 μF</td>
</tr>
<tr>
<td>Switching and Sampling frequency</td>
<td>10 kHz</td>
</tr>
</tbody>
</table>
Fig. 15. Waveforms of output voltage and charging current ripple with the classical (left) and the proposed modulation strategy (right). (a) Input phase voltage is 20 V. (b) Input phase voltage is 23 V. (c) Input phase voltage is 40 V.

switches used in the main circuit are 1MBH60D-100, the control of the converter was realized by a combination of digital signal processor TMS320F28335 and field programmable gate array FPGA EP2C8T144C8 N.

To verify the proposed method within a large modulation index range, some experiment conditions have to be constructed. A set of 24-V lead-acid battery and a three-phase transformer with multioutput winding (20 V and 40 V) are used here. Three kinds of input phase voltages from the transformer are constructed, which includes 20 V (Y-Y), 23 V (40 V:Y-Δ) and 40 V (Y-Y).

Fig. 15 shows the waveforms of charging current and output voltage of the ac/dc matrix converter with the classical modulation (left) and the proposed method (right), where battery voltage is 24 V and reference charging current is 5 A. In such case, the equivalent modulation indexes are 0.97, 0.6, and 0.32, which represent three regions of the proposed modulation strategy, respectively. As can be seen from Fig. 15, the experimental results mentioned earlier are in good agreement with simulation results. In conclusion, the charging current ripple is reduced by the proposed method.

Fig. 16 shows the experimental waveforms of input phase voltage and input current under different modulation indexes with the proposed modulation strategy. It is clear that the input current is almost sinusoidal and in phase with the input voltage (unity power factor operation).

Fig. 17 shows the dynamic performance of the converter. Fig. 17(a) depicts the experimental results in the case of reference charging current changing from 5 to 10 A; Fig. 17(b)
illustrates the results when reference charging current steps down from 10 to 5 A. From Fig. 17, it can be found that the response to the reference changing is fast.

Fig. 18 shows the results under the constant voltage charging mode. The reference voltage is set to 27 V with input phase voltage being 40 V. In this case, the charging current is around 7.8 A.

Fig. 19 shows the measured waveforms of input current and input voltage when working in discharging mode, where the discharging current is 10 A. The input current is almost 180° out of phase with the ac input voltage, which indicates the power is delivered to the power grid.

VI. CONCLUSION

In this paper, ac/dc matrix converter is used as an interface in V2G system. Two simplified topologies are derived to avoid the tedious commutation; meanwhile the reliability of the converter is improved greatly. A sectional optimized modulation strategy that reduces charging current ripple is proposed, and comparison between the classical current space vector modulation strategy and the proposed one is quantitatively analyzed. The related control algorithm for ac/dc matrix converter is introduced briefly. It allows charging and discharging, and it supports two charging modes: constant current charging and constant voltage charging. The simulation and experimental results verify the proposed method. Meanwhile, it indicates that the ac/dc matrix converter with the proposed modulation is a good candidate for V2G application.

REFERENCES

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