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Automatic Power Direction Control of DAB Converter in Emergency Energy Supply

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***Abstract*—With the advantage of any direction of power flow of dual active bridge (DAB) converter, DAB converter can be applied in the energy router as the DC/DC transfer part for emergency energy supply to deal with the unexpected large power outage. Not only they can make sure the various power energy supplies, but also ensure the high-power conversion. However, the power direction of DAB converter is adjusted through changing the value of phase shift angle between the gate signals of switches which is controlled manually. Based on above reason, this paper proposes an automatic power direction control method of DAB converter to make the bidirectional power transmission can be done automatically without manual adjustment which significantly eliminates the constant human supervision and simplifies the operation. Ultimately, a comprehensive demonstration of the MATLAB/Simulink test is conducted to substantiate the viability of the proposed method.**

Keywords—DAB converter, Automatic Power Direction Control Method.

I. INTRODUCTION

Numerous unforeseeable incidents, including but not limited to natural disasters [1], unexpected power supply failures [2], power demand surpassing availability [3] and deliberate malicious events [4] can result in the urban power grid's incapacitation, which has a serious impact on people's lives. Various applications of electricity have been an essential part of human life, meaning that almost all industries require electricity to power the electrical equipment needed to carry out their work [5]. The damage caused by a large-scale power failure is also severe. It can lead to further economic loss and even life threat. Up to now, distributed power [6] and emergency power vehicle [7], which are emergency power distribution methods, have been widely used. However, a new method called energy router [8], has been introduced and substantiated as a viable option due to its capabilities, which encompass superior energy utilization, energy storage, and monitoring the status of the primary power grid [5].

In the context of an emergency energy supply system, achieving energy balance among various electric power sources is a fundamental requirement for an energy router. This implies that the regulation of power flow within the energy router constitutes a critical aspect when managing a range of emergency scenarios. In terms of the DC power transfer part in the energy router, DAB converter is applied according to its advantages [9]. The DAB converter can automatically adapt to bidirectional power flow adjustments and is responsive to rapid shifts in the power flow direction [10]. It also has wide voltage conversion gain range [11]. What is more, it owns the zero-voltage switching (ZVS) capability [12] and can achieve high efficiency [13], [14].

Power is transferred between them through a phase-shift pulse width modulation (PWM) technique [15]. Based on the lag/lead relationship of two or three pulse width waveforms, ports at DAB converter can realize the power transmission. With different lag/lead relationships, the direction of power transmission is also various because each port of DAB converter can make sure the bidirectional power flow [16]. So, an automatic power direction control method can realize the automatic power direction adjustment according to the states of the ports of DAB converter. In this paper, this saves manpower to monitor the status of the equipment and ensures that the equipment can automatically adjust the power direction to cope with different emergencies.

The paper is organized as follows. First, a brief explanation of the power direction principle of the DAB converter is presented. Second, the automatic power direction control method is showcased. Third, a MATLAB/Simulink simulation model that incorporates a DAB converter is constructed, and the paper concludes with a concise summary.

II. Principle of Power Direction of DAB Converter

Fig. 1 present the DAB converter topology. The topologies have two ports, each of which involves an active bridge with

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four switches. There is one inductor L and one high frequency transformer N in the DAB topology. Furthermore, a battery pack B_i (i=1, 2) are connected at the terminal of each port. Regarding the emergency energy supply system in urban areas, B_1 can be conceptualized as the primary power grid, while B_2 represents any form of emergency electric power source or energy storage unit within the energy router. In order to present a more straightforward and transparent analysis of processes and outcomes, this paper employs battery packs as the sources of ports for the DAB converter. It should be noted that the conclusions drawn from the use of battery packs can also be extended to the sources within an emergency energy supply system employing an energy router.

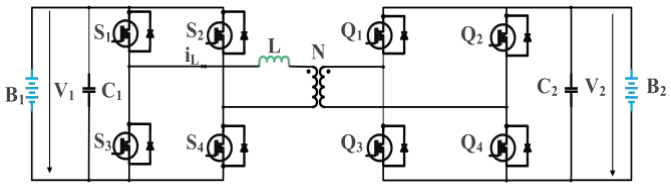

Fig.1 Topology of the DAB converter.

DAB is mainly controlled by the single-phase shift (SPS), which means DAB realizes the flow of energy by changing the lead/lag relationship between the port 1 and the port 2. Fig. 2 shows an example when DAB conducts forward energy transmission, where S_1, S_2, S_3 and S_4 are the signals that controls the MOSFETs at the port 1, Q_1, Q_2, Q_3 and Q_4 are the signals that controls the MOSFETs at the port 2 which lag S_1, S_2, S_3 and S_4 for the phase shift angle φ_1. V_1 is the voltage at the port 1, V_2 is the voltage at the port 2, i_{Lc} is the current through the inductance of the port 1. According to Fig.1, in one switching period T_{sp}, there are four different modes of inductor current.

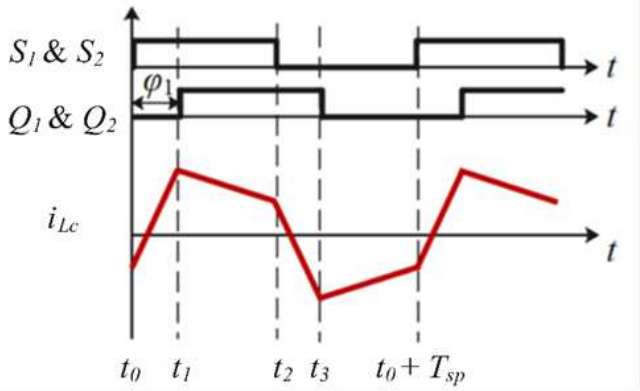

Fig. 2. Typical waveforms of a DAB converter

When $t_0 \le t \le t_1$,

$$i_{Lc}(t) = \frac{V_1+V_2}{L}(t-t_0) + i_{Lc}(t_0) \quad (1)$$

where $t_1=t_0+(\varphi_1 T_{sp})/2\pi$.

When $t_1 \le t \le t_2$,

$$i_{Lc}(t) = \frac{V_1-V_2}{L}(t-t_1) + i_{Lc}(t_1) \quad (2)$$

where $t_2=t_0+T_{sp}/2$.

When $t_2 \le t \le t_3$,

$$i_{Lc}(t) = \frac{-V_1-V_2}{L}(t-t_2) + i_{Lc}(t_2) \quad (3)$$

where $t_3=t_2+(\varphi_1 T_{sp})/2\pi$.

When $t_3 \le t \le t_0+T_{sp}$,

$$i_{Lc}(t) = \frac{-V_1+V_2}{L}(t-t_3) + i_{Lc}(t_3) \quad (4)$$

From Fig. 2, the equation $i_{Lc}(t_0) = -i_{Lc}(t_2)$ can be obtained [17]. Through integral, forward power P_+ and reverse power P_- can be circulated.

$$\begin{cases} P_+ = \frac{1}{T_{hs}}\int_0^{T_{hs}} V_1 i_{Lc} dt = \frac{\varphi_1(\pi-\varphi_1)V_1V_2}{2\pi^2 f_{sp} L} \\ P_- = \frac{1}{T_{hs}}\int_0^{T_{hs}} V_1 i_{Lc} dt = \frac{\varphi_1(\pi+\varphi_1)V_1V_2}{2\pi^2 f_{sp} L} \end{cases} \quad (5)$$

where $f_{sp}=1/T_{sp}$ represents the switching frequency. D is the phase shift ratio ($D = \varphi_1/180°$) and T_{hs} is the half of the switching period.

Fig. 3 shows the relationship between D and the power P. It is obvious that when D is between -0.5 and 0.5, P and D are positively correlated. So, D is usually set between -0.5 and 0.5 which means that φ_1 is between -90° and 90°

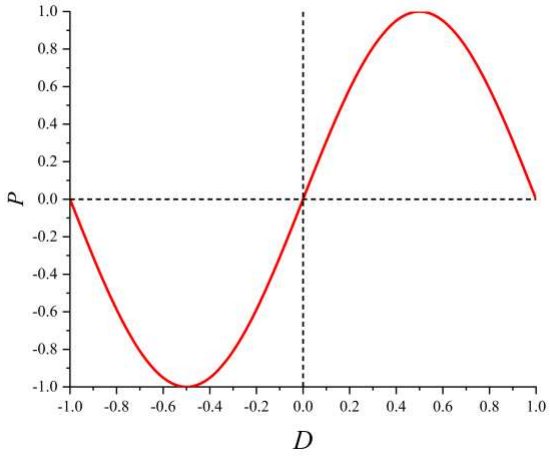

Fig. 3. The relationship between P and D

III. Automatic Power Direction Control Method of DAB Converter

In order to automatically adjust the power direction without manual adjustment, this paper proposes an automatic power direction control method of DAB converter. In the field of emergency energy supply, there are many unexpected accidents, so people cannot quickly change the power direction of the DAB converter to deal with all the unexpected situations. An automatic power direction control method can help to adjust the power direction according to the setting value in advance.

According to the above introduction of power direction of DAB converter. It is clear that when $-90°<\varphi<0°$, power transfers from port 2 to port 1. When $0°<\varphi<90°$, power transfers from port 1 to port 2. Fig. 4 shows the proposed automatic power direction control method. In this method, there are two variables SOC_2 and MS controlling the power direction of DAB converter. When MS is equal to 0, $-90°<\varphi<0°$ and power transfers from port 2 to port 1. Otherwise, when MS = 1, $0°<\varphi<90°$ and power transfers from port 1 to port 2.

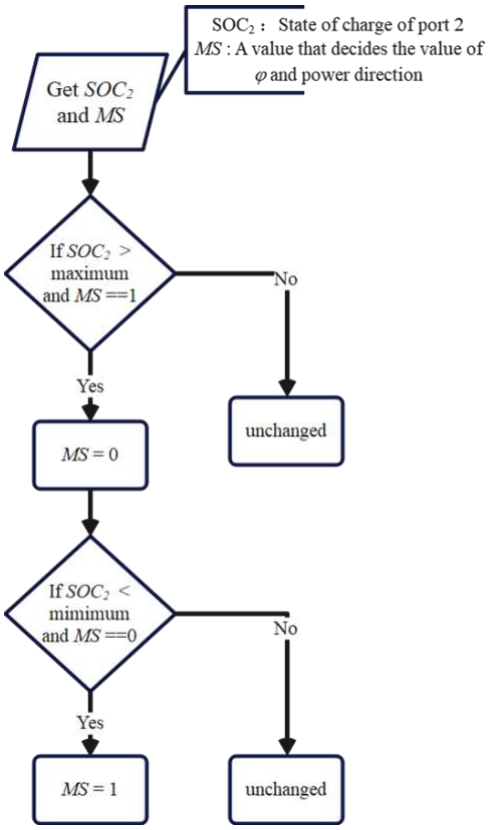

Fig. 4. Flow chart of the automatic power direction control method of the DAB converter

According to Fig. 4, there are always two if judgements in the whole process. The first if judgement is if SOC_2 is more than maximum setting value and MS is equal to 1, then MS is equal to 0 which means that power direction changes from forward to reverse. Otherwise, the power direction is still forward. The second if judgement is if SOC_2 is less than minimum setting value and MS is equal to 0, then MS is equal to 1 which means that power direction changes from reverse to forward. Otherwise, the power direction is still reverse. With this automatic power direction control method, the power direction of DAB converter is controlled by the state of charge (SOC) of Port 2 SOC_2 to make sure bidirectional automatic power transmission within a certain range.

IV. Simulation Results

The simulation model of DAB converter is designed in MATLAB/Simulink to examine the feasibility of the proposed automatic power direction control method. The designed models are the same as depicted in Fig. 1.

The system configurations of DAB converter model are exhibited in TABLE I, where the voltages of the two battery packs are set to 180 V, 200 V, respectively, with an initial SOC of 50%. Moreover, the transformer turns ratio is N=1 and Initial value of MS is 1. The range of SOC_2 is set between 60% and 40% to get the simulation results more quickly.

TABLE I. Parameters of the DAB Simulation Model

Parameter name	Value
V_1/V_2 (Battery pack voltages)	180/200 V
SOC_1/SOC_2 (Initial state of charge)	50%
N (Transformer turns ratio)	1
f_{sp} (Switching Frequency)	50 kHz
L (Series inductance)	82 μH
C_1/C_2 (Series capacitance)	50 μF
SOC_{2max}/SOC_{2min} (Maximum and minimum state of charge)	60%/40%
Initial value of MS	1

In this Simulink simulation, the initial value of MS is 1 and the initial value of phase-shift angle φ_1 are lagging the port 1 bridge waveform shown in Fig. 2. Therefore, power from B_1 is transferred to B_2 which means that SOC_2 is increasing. After SOC_2 reaches the maximum allowable value, MS will be changed into 0 and φ_1 will lead the port 1 bridge waveform according to the automatic power direction control method shown in Fig. 5. During this period, SOC_2 will decrease, and the power flow is reverse until the SOC_2 reaches the minimum allowable value. In this situation, MS will be changed back into 1 and the power flow will be forward again. Additionally, the current waveform of port 2 I_2 are exhibited in Fig. 6.

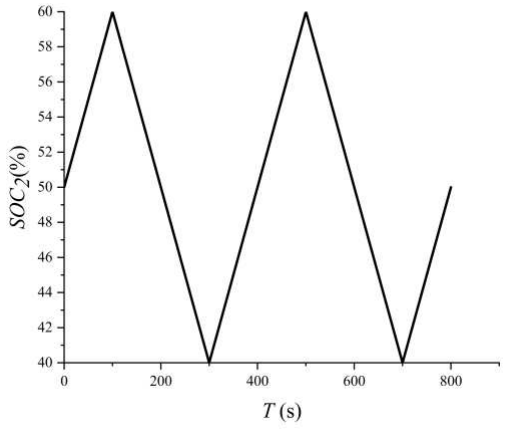

Fig. 5. SOC_2 waveform in automatic power direction control of DAB converter

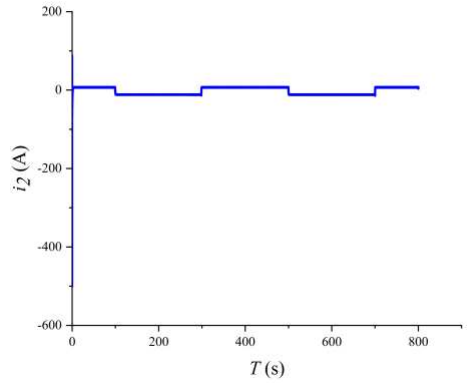

Fig. 6. i_2 waveform in automatic power direction control of DAB converter

Fig. 5 presents the variation of SOC for the B_2 in the whole simulation process, from which it can be investigated that B_2 is charging at the first time, and it will change its charge and discharge status when SOC_2 reaches the peak point at each time which is consistent with the analysis in the previous sections. According to Fig. 6, during the steady state, the current of port 2 also switches between positive and negative values which also shows the power direction of DAB converter and the time in forward and reverse direction is completely consistent with the conclusion obtained by the waveform of SOC_2.

VI. Conclusion

This paper presents an automatic power direction control method of DAB converter which is designed to perform the energy balancing and power direction automation functions of an energy router. Power conversion is accomplished through phase-shift PWM, with direction control being managed by the newly introduced automatic power direction control method. The power flow direction within the three ports is regulated based on the lead/lag status of the converter switches and the SOC of each port. The proposed power direction control method has a more rapid directional control solution and a significant saving in manpower costs to monitor and regulate the status of the energy router. This means that emergencies arising in the grid can be responded to and resolved more quickly. To verify the feasibility of the automatic power direction control method in the DAB converter, a simulation model implemented in MATLAB/Simulink is used. In addition, the change of direction is based entirely on the SOC status of the individual ports of the DAB converter, which ensures that the customer can decide on his own power consumption plan depending on the different situations and no longer draws power singularly from the main power grid.

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