Improved Model-based Single Phase Shift Control of Dual Active Bridge Converter for Pulse Power Loads

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ABSTRACT

Voltage stability is one of the key issues for the dc grid when supplying to pulse power loads. This study introduces a method of error compensation using model-based single-phase shift control to increase the stabilization and achieve a fast transient response of output voltage in the dual active bridge converter. The model-based phase shift control is used to change the phase shift angle ratio against the influence of disturbances under different operating modes. The output voltage is controlled by the proposed controller without changing the model and control parameters. The proposed method is a combination of load current feed-forward, voltage feedback control, and error compensation to enhance the performance. The effectiveness of the proposed method is verified through a 1.5kW prototype simulation to prove its advantages.

Keywords: dual active bridge, model-based phase shift control, voltage feedback control, load current feed-forward.

1. INTRODUCTION

In military grid systems, besides traditional pulse power loads (PPL), there are integrated pulse loads such as integrated electromagnetic weapons, radar, and sonar [1]. Additionally, the development of economies around the world increasingly needs more and more the shipboard power of ships [2]. These types of loads are short-lived and cause a lot of noise to the bus voltage on the dc grid. Therefore, it is necessary to require more efficient dc converters, and the dual active bridge (DAB) is emerging as a potential application converter. The DAB converter has been widely used due to its advantages such as high performance, wide control range, galvanic isolation. Furthermore, utilization of the leakage inductance and high-frequency transformers reduce the loss and volume of the converter [3]. The topology of the DAB converter is depicted in Fig. 1.

One of the important issues that attract many researchers is to stabilize output voltage and achieve fast transient response under different operating modes. There are many methods offered: one of the conventional methods is proportional-integral (PI) control [4]. However, this method has a few disadvantages that reduce performance because the fixed gain value in the controller cannot be optimally controlled over a wide load range. To improve performance and the transient response of the output voltage when load changes, the model-based phase shift control (MPSC) using the load current feed-forward (LCFF) control combined with the voltage feedback (VF) control is proposed in the literature [5], [6], [7].

This paper proposes a combination of error voltage compensation, LCFF control, and VF control, where the error compensation factor plays an important role when compensating for the change of load to make the output voltage adhere to reference value and ensure a fast transient response. The effectiveness of the proposed method is verified by PSIM simulation. The contributions of this paper are as follows: (a) To provide voltage deviation suppression and fast transient response of output voltage. The change in phase shift angle ratio of compensation factor adapts to the load power variable. (b) The proposed control structure is simple and easy to be implemented. The paper is organized into four sections. The proposed method is presented in section II; the simulation is performed in section III, and the conclusion is drawn in section IV.

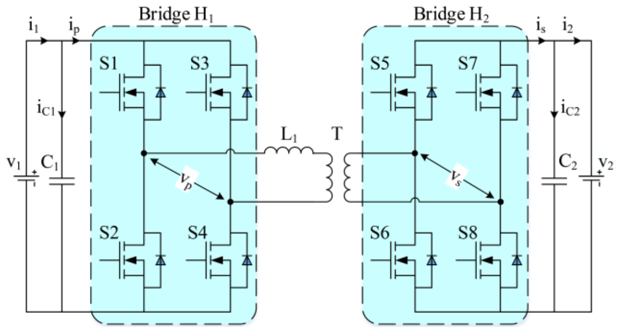


Fig. 1: DAB Converter.

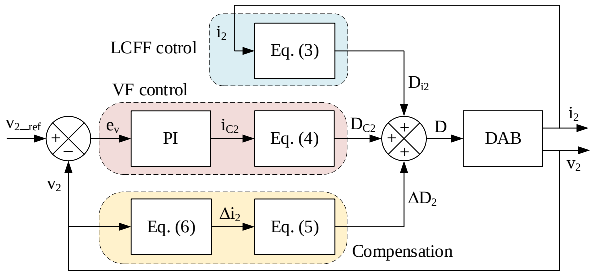


Fig. 2: The proposed method

2. PROPOSED METHOD

The proposed algorithm is developed step by step. Firstly, the transferred current in the steady-state can be expressed as follows:

$$i_s = \frac{nv_1}{2f_sL_1}D\left(1-|D|\right) \tag{1}$$

$$i_s = i_2 + i_{C2} = \frac{nv_1}{2f_sL_1}\left[D_{i2}\left(1-|D_{i2}|\right)+D_{C2}\left(1-|D_{C2}|\right)\right] \tag{2}$$

where D is the phase shift angle ratio in single-phase shift control.

From (1) and (2), The phase shift ratio can be expressed as the following equations:

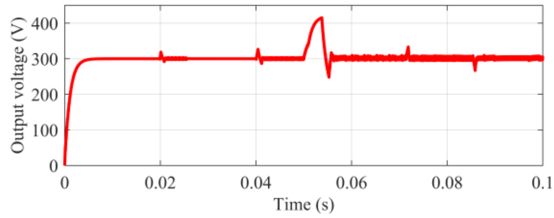
$$D_{i2} = 0.5-\sqrt{0.25-\frac{2f_sL_1}{nv_1}i_2} \tag{3}$$

$$D_{C2} = 0.5-\sqrt{0.25-\frac{2f_sL_1}{nv_1}i_{C2}} \tag{4}$$

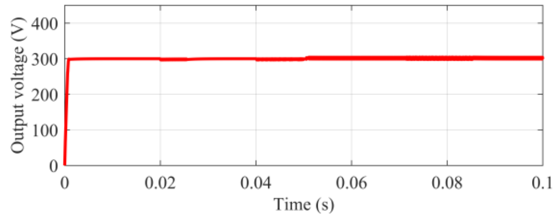
where $0 \le i_2, i_{C2} \le nv_1/(8f_sL_1)$.

To mitigate the overshoot and long settling time in the output voltage due to the slow dynamics of the conventional PI control, an additional compensation component is defined as ΔD_2, which needs to be added whenever output voltage is different from the reference value. The expression for calculating ΔD_2 is described as follows:

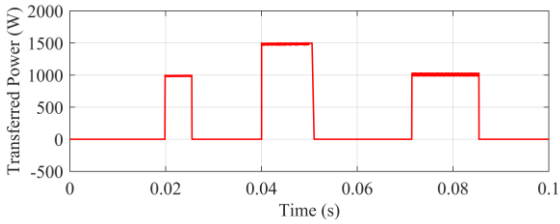
$$\Delta D_2 = 0.5-\sqrt{0.25-\frac{2f_sL_1}{nv_1}i_2} \tag{5}$$



(a) Conventional MPSC method



(b) Proposed method (α = 7500)



(c) Output power

Fig. 3: Dynamic response of output voltage when the load power changes.

In (5), the fluctuation of the output current Δi_2 is in the range $\left[0 \sim nv_1 / \left(8 f_s L_1\right)\right]$ and is calculated by the following formula:

$$\Delta i_2 = \alpha \left(1 - \frac{v_2}{v_{2\_ref}}\right) \tag{6}$$

where α is a constant.

In summary, the proposed method is shown in Fig. 2.

3. VERIFICATION BY SIMULATION

To demonstrate the advantages of the proposed controller, the simulations performed on PSIM with parameters are presented in Table I. The dynamic response of output voltage is depicted in Fig. 3. When the reference voltage is 300V, the pulse power loads power is regulated as shown in Fig. 3(c). In Fig. 3(a), the conventional MPSC shows a voltage overshoot and dip. In this method, the LCFF and VF control are applied to change immediately D, but there are the overshoot and dip of the output voltage.

Fig. 3(b) shows the dynamic response of the output voltage of the proposed control which provides the additional voltage regulator. The voltage error can be considered to be approximately zero and it is achieved through the combination of the LCFF method, VF method, and compensation with the suitable compensation gain. The compensation plays an important role when the output voltage is different from the reference value, especially when the load heavily changes, the compensation value is immediately updating the phase shift angle ratio D. Undoubtedly, the proposed controller has proven its outstanding performance.

4. CONCLUSION

In this paper, an effective output regulation scheme for PPL is presented, which is a combination of LCFF, VF, and error compensation. The proposed method gives outstanding output regulation and good dynamic response of the output voltage under variable output power without updating the value of the model parameters and control parameters. The effectiveness of the proposed compensation is verified through a 1.5kW prototype simulation. In the subsequent work, the optimal design of the error compensation gain will be further investigated and hardware verification will be appended.

Table I: Circuit and control parameters

Description and Symbol	Value	Unit
Input voltage (v_1) / Output Voltage (v_2)	100/300	V
Switching frequency (f_s)	20	kHz
Transformer turn ratio (1:n)	1:3	
Maximum output power (P_{max})	1.5	kW
Leakage inductance (L_1)	278	μH
Capacitance (C_2)	27	μF
Cut-off frequency (ω_c)	2000π	rad/s
Designed phase margin (ϕ_m)	60	deg
Transport delay time (T_d)	50	μs
Proportional gain (K_P)	0.17	
Integral gain (K_I)	607.6	

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REFERENCE

[1] L. Chen, S. Shao, Q. Xiao, L. Tarisciotti, P. W. Wheeler, and T. Dragičević, “Model Predictive Control for Dual-Active-Bridge Converters Supplying Pulsed Power Loads in Naval DC Micro-Grids,” *IEEE Trans. Power Electron.*, vol. 35, no. 2, pp. 1957–1966, 2020.

[2] V. Salehi, B. Mirafzal, and O. Mohammed, “Pulse-load effects on ship power system stability,” *Ind. Electron. Conf.*, pp. 3353–3358, 2010.

[3] B. Zhao, Q. Song, W. Liu, and Y. Sun, “Overview of dual-active-bridge isolated bidirectional DC-DC converter for high-frequency-link power-conversion system,” *IEEE Trans. Power Electron.*, vol. 29, no. 8, pp. 4091–4106, 2014.

[4] V. M. Iyer, S. Gulur, and S. Bhattacharya, “Small-signal stability assessment and active stabilization of a bidirectional battery charger,” *IEEE Trans. Ind. Appl.*, vol. 55, no. 1, pp. 563–574, 2019.

[5] R. G.-M. J. Guacaneme, G. Garcerá, E. Figueres, I. Patrao, “Dynamic modeling of a dual active bridge DC to DC converter with average current control and load-current feed-forward,” *Int. J. Circuit Theory Appl.*, pp. 1311–1332, 2014.

[6] N. Vazquez and M. Liserre, “Peak Current Control and Feed-Forward Compensation of a DAB Converter,” *IEEE Trans. Ind. Electron.*, vol. 0046, no. c, pp. 1–1, 2019.

[7] Z. Ji, Q. Wang, D. Li, and Y. Sun, “Fast DC-bias current control of dual active bridge converters with feedforward compensation,” *IEEE Trans. Circuits Syst. II Express Briefs*, vol. 7747, no. c, pp. 1–1, 2019.