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Circulating current suspression for parallel modular energy storage converter based on improved single neuron PID

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Abstract. To solve the parallel circulating current problem in the operation control of modular energy storage converter, the causes of the parallel circulating current are analyzed, and a new circulating current suppression method based on improved single neuron PID is proposed. The superiority of the method is verified theoretically by building simulation model. The test verification is carried out by developing 50kW power module and 150kW modular energy storage converter prototype. The results show that the method can effectively suppress parallel circulating current and solve the problems of difficult parameter adjustment and poor adaptability to power mutation in traditional PID control.

1. Introduction

With the continuous development of new energy grid-connected power generation, the importance of energy storage system is becoming increasingly prominent. Modular energy storage converters with excellent characteristics such as expandability and easy maintenance are becoming the trend in the industry, and how to ensure the safe and stable parallel operation of multiple power modules is the key factor to determine the development prospects of modular energy storage converters.

The circulation issue cannot be ignored in the process of parallel control of energy storage converters[1-4]. The literature [5,6] analyze the component of the circulating current in parallel operation of the T-type bridge arms and the I-type bridge arms separately, and indicate that the zero-sequence current component is one of the main components of the parallel circulating current, and mainly start from controlling the zero vector in the driving signal of SVPWM, different control methods are adopted to suppress the circulating current in parallel system of energy storage converter; the literature [7] presents a parallel topology of DC-side independent power supply converter, which disconnects the current loop that generates circulating current from the physical structure, but this method is not universal.

Based on the analysis of zero-sequence current of energy storage converter, the learning function is improved on the basis of single neuron PID control algorithm with self-adaptive ability. To a certain extent, this method makes up for the defects of traditional control method such as difficulty in parameter adjustment and poor adaptability to operating environment, and realizes the stable operation of modular energy storage converter. This paper mainly discusses the causes and suppression methods of parallel circulation, the principle of improvement methods, simulation verification and prototype test.

2. Circulating current suppression method for energy storage converter parallel system

For modular energy storage converter, circulating current suppression is crucial for parallel control, which may lead to power modules work unnormally, even lead to safety issue and diffculty on maintenance of energy storage batteries, the circulating current in parallel system is mainly caused by the inconsistency of instantaneous voltage output of multiple power modules.

A parallel energy storage converter system composed of two power modules is shown in figure 1. The system is in common DC and AC mode. Because the parameters of hardware circuit are complex, many parameters may cause circulation in parallel system. Therefore, the design of hardware parameters is not in the scope of discussion. In this paper, the parallel circulation is restrained only from the control method.

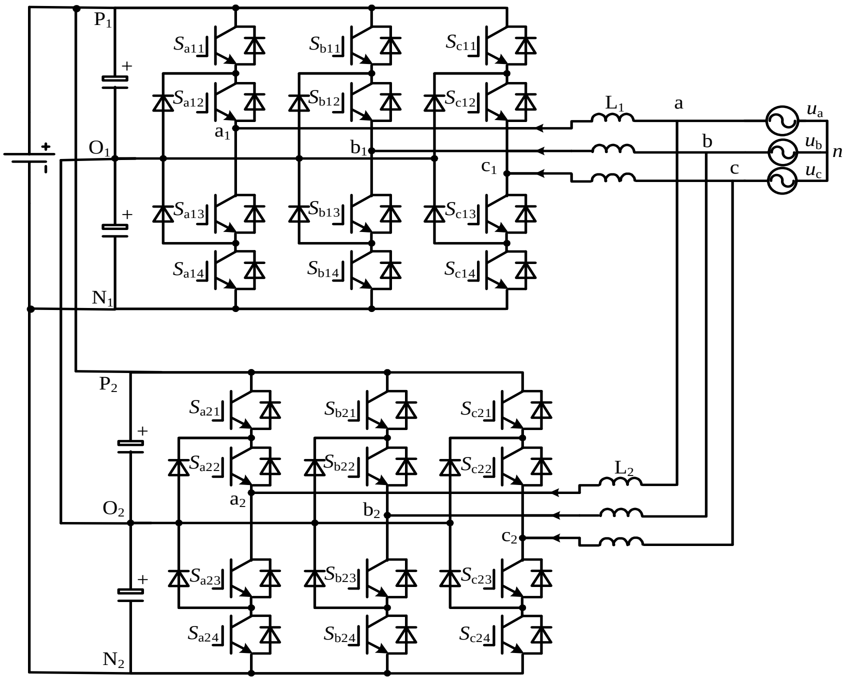

Figure 1. Topological structure of parallel system of modular energy storage converter

As shown in figure 1, if the driving signals of A-arm of two power modules are not synchronized, the voltage imbalance at points a1 and a2 will occur, and the current will flow through L1, a and L2, that is, the circulating current component exists in phase A, and the same principle exists in phase B and C.

In the commonly used SVPWM driving mode of parallel system of energy storage converter, there exists zero vector which has no effect on the output sinusoidal current, but zero vector can affect the output voltage of power module at a certain time. Therefore, by adjusting the distribution of zero vectors, the circulating current can be controlled when the energy storage converter is parallel. The specific method is to take zero-sequence current as input and the proportion of two zero vectors as output. The zero-sequence current can be controlled by PID control, so that the parallel circulating current suppression of modular energy storage converter can be realized.

3. Circulating current suppression method based on single neuron PID control

The traditional PID control method has some problems such as difficult parameter setting and overshoot under some conditions. With the continuous development of adaptive and self-learning algorithms, the self-adaptive algorithms represented by neural networks are constantly infiltrating into other fields[8-10]. Therefore, combining the neural network PID control algorithm, using the neural network to optimize the parameters of the PID control and applying it to the parallel system of modular energy storage converter has become a research hotspot in recent years [11-14].

3.1. *Introduction of single neuron PID controller*

The single neuron PID controller is shown in figure 2.

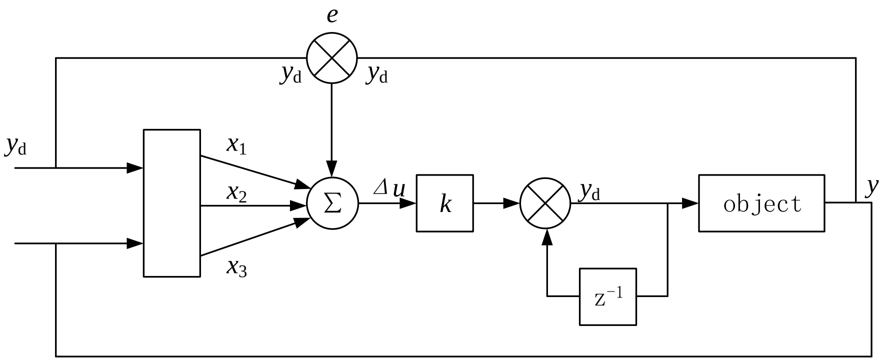

Figure 2. Single neuron PID controller

Single neuron PID controller realizes self-adaptive function by adjusting weighting coefficient. The adjustment of weighting coefficient can refer to the typical learning rules of neural network. The single neuron PID control algorithm and learning algorithm with supervised HBB learning rules are as follows:

$$u(k)=u(k-1)+K\sum_{i=1}^{3}w_i^{'}(k)x_i(k) \tag{1}$$

$$w_i^{'}(k)=w_i(k)/\sum_{i=1}^{3}\left|w_i(k)\right| \tag{2}$$

$$w_1(k)=w_1(k-1)+\eta_I z(k)u(k)x_1(k) \tag{3}$$

$$w_2(k)=w_2(k-1)+\eta_P z(k)u(k)x_2(k) \tag{4}$$

$$w_3(k)=w_3(k-1)+\eta_D z(k)u(k)x_3(k) \tag{5}$$

$$x_1(k)=e(k) \tag{6}$$

$$x_2(k)=e(k)-e(k-1) \tag{7}$$

$$x_3(k)=\Delta^2 e(k)=e(k)-2e(k-1)+e(k-2) \tag{8}$$

Incremental PID control mode is chosed in the formula u(k) ,the control system realizes the control of the object by changing the increment, it has strong adaptability to most scenarios. However, the control of zero-sequence current belongs to the control method of fixing a certain value at a certain position, which is closer to the position. Therefore, the above-mentioned method can not be directly applied to the zero-sequence current controlling of the parallel system of modular energy storage converter.

3.2. *Circulating current suppression method based on improved single neuron PID*

In practical application, if supervised HBB learning method is adopted, the learning effect of proportional coefficient and integral coefficient may not be ideal[15]. Therefore, in this paper, the learning functions of the proportional and integral coefficients are improved as follows:

$$w_1(k)=w_1(k-1)+\eta_P{}^{*}u(k-1)^{*}x_1(k)^{*}x_4(k) \tag{9}$$

$$w_2(k)=w_2(k-1)+\eta_I{}^{*}u(k-1)^{*}x_1(k)^{*}x_4(k) \tag{10}$$

$$x_4(k)=e(k)+e(k-1) \tag{11}$$

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In the final output, the single neuron PID control method has two main ways: position control and incremental control. Considering that the circulating current suppression is achieved by controlling the distribution of zero sequence vectors in SVPWM algorithm, this paper chooses position PID control method, whose output is as follows:

$$u(k) = K(k)^{*}(w_1(k)^{*}x_1(k) + w_2(k)^{*}x_5(k)) \quad (12)$$

$$x_5(k) = x_5(k-1) + e(k)^{*}T \quad (13)$$

The $x_5(k)$ is the result of error integral calculation.

In formula (12), K is the ratio coefficient of neurons. The choice of K is very important,when K is larger, the control speed will be better, but the overshoot of PID control will be larger, even the system may oscillate. When K is too small, the speed of the system will deteriorate and the speed of regulation will be too slow.

In order to avoid the above situation, this paper sets K as the function of e, that is ,K = f (e), considering the range of K and the error range, the choice of function f is limited. Meanwhile, function f should have a larger slope when e is close to 0, so as to ensure that the system has better sensitivity when the error is near 0.

In summary, this paper chooses S-shaped function to establish the relationship between neuron coefficient K and error E. The specific function expression is shown in formula (14).

$$K(k) = \frac{3}{1+e^{-x_1(k)}} \quad (14)$$

For verifying the above relationship, the simulation model shown in figure 3 is built in MATLAB/Simulink.

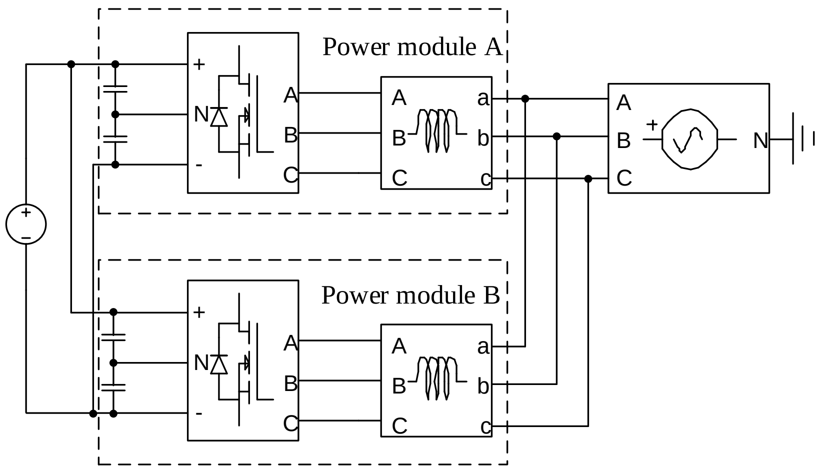


Figure 3. Algorithm validation simulation model

The simulation time is 3s, SVPWM is adopted, the inductance is 4mH, the maximum output current of each power module is set to 30A, and the parallel mode of common DC and AC is used to connect directly to the power grid. Both power modules are in the current source mode, which is equivalent to two current sources in parallel.

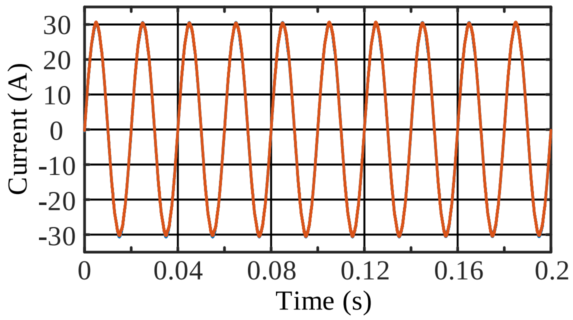


Figure 4. Phase A current of power module

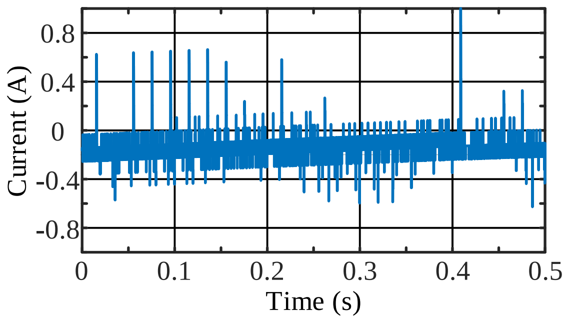


Figure 5. Zero-sequence current of power module

In the waveform of figure 4, it can be seen that the A phase currents of the two power modules do not show obvious distortion, and the peak value of the output current remains stable at the set value. From the wave shown in figure 5, it can be seen that the zero-sequence current is stable within (+1A), which shows that this method has good zero-sequence current control effect.

4. Simulation verification

For verifying the accuracy of this method furtherly and compare the difference between the traditional PID control method and the improved single neuron PID control method proposed in this paper, based on the parallel topology shown in figure 1, the traditional PID control and the improved single neuron PID control are simulated by MATLAB/Simulink respectively. The simulation results are shown in figures 6, 7 and 8.

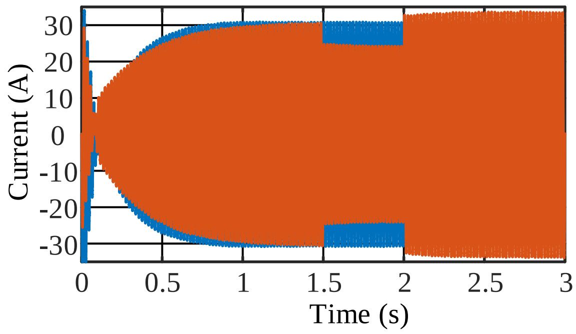


Figure 6. Phase A current waveform of power module of energy storage converter

The output current of two power modules in phase A is shown in figure 6. Since both control modes can realize the control of zero-sequence current, the changes of current in the two control modes are consistent.

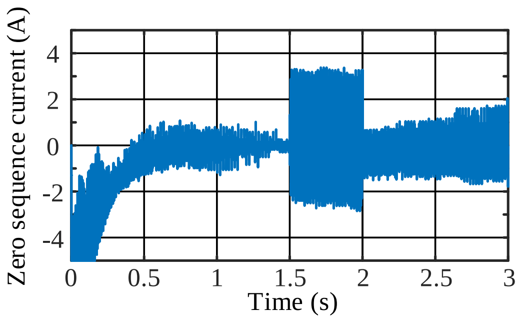


Figure 7. Traditional PID

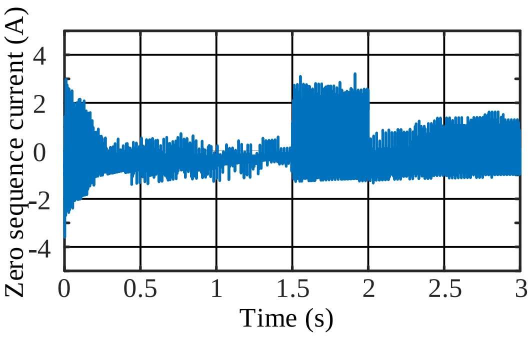
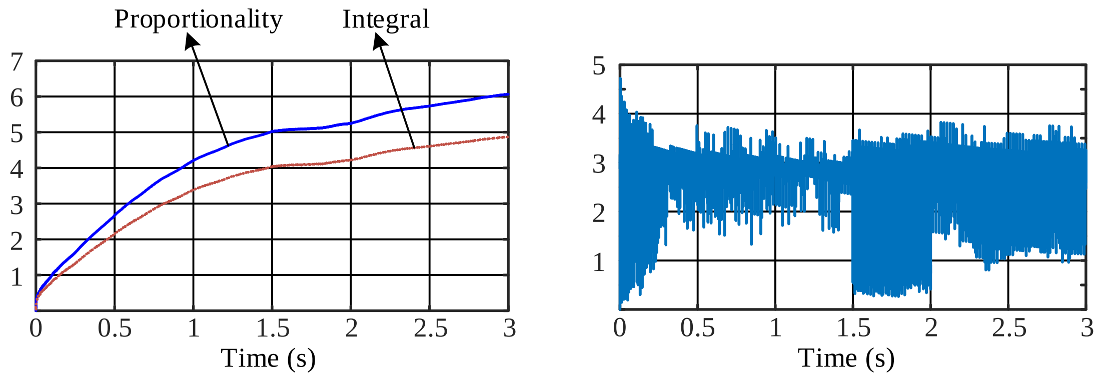


Figure 8. Improved single neuron PID

The changes of the zero-sequence current of two parallel power modules with time under different control modes are shown in figure 7 and 8. It can be seen that the traditional PID control method will make the zero-sequence current at the initial time larger, and then it will play a normal control effect; while the zero-sequence current using the improved single neuron PID control method has been very stable, although the output current has increased significantly, it is still within the controllable range.

The changes of proportional coefficient, integral coefficient and neuron proportional coefficient K with time in the improved single neuron PID control are shown in figure 9, it can be seen that the proportional coefficient and integral coefficient can be adjusted with the output of the power module, and the stability is good, and the neuron proportional coefficient K fluctuates within the set range with the change of the error (zero-sequence current in this paper).



a. Proportional and integral coefficients **b.** Neuron proportional coefficient K

Figure 9. Simulations of proportional coefficient, integral coefficient and neuronal proportional coefficient K of improved single neuron PID

The above simulation results show that the improved single neuron PID control method has better adaptability than the traditional PID control method when the modular energy storage converter runs steadily and the operating conditions change.

5. Test verification

In order to verify the practical effect of the improved single neuron PID control method in the operation control of modular energy storage converter, a 50 kW energy storage power module was developed(figure 10), and a 150 kW modular energy storage converter was composed of three power modules in parallel with common DC and AC (figure 11). The actual parallel operation waveform of the prototype is shown in figure 12.

Figure 10. 50 kW energy storage power module

Figure 11. 150 kW modular energy storage converter

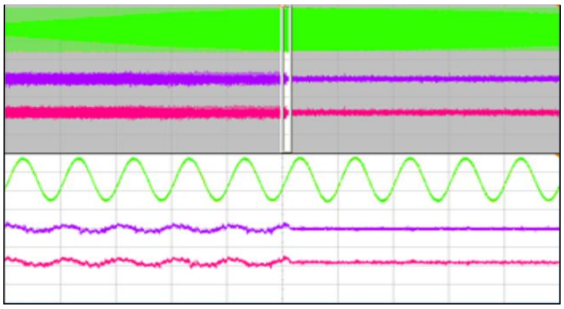


Figure 12. Output current waveform of two power modules

As shown in figure 12, by improving single neuron PID circulating current suppression method proposed in this paper, the output current waveform of each power module is stable and the output power distribution is average, so that the system can run in a stable power matching state, and the system can continue to operate stably when the transmission current changes.

6. Conclusion

Firstly, this paper analyses the cause of parallel circulating current of energy storage converter, points out that the asynchronization of driving signal is an important factor to cause circulating current in parallel system, and analyses the feasibility of suppressing circulating current by controlling zero vector in SVPWM control method.

Secondly, aiming at the circulation problem in parallel operation, a circulating current suppression method based on improved single neuron PID is proposed. By improving the learning function of single neuron PID and the proportional coefficient of single neuron, the zero-sequence current control for parallel operation of modular energy storage converter is realized, which avoids the increase of circulation when the output power changes, and the feasibility of the method is verified by simulation means and prototype test methods.

In summary, the parallel control method of modular energy storage converter based on improved single neuron PID proposed in this paper can effectively reduce the circulating current of parallel system, and has better adaptability to working conditions than conventional PID control method.

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References
[1] Li Hui, Li Jianming, Li Zhi, et al. Pulse Width Modulation Wave Reconstruction and Circulation Suppression of Parallel Converters [J]. Power System Automation, 2017, 41 (15): 143-149.
[2] Gu Zhifeng, Wang Huiyong, Zhu Changqing, et al. Nonlinear L2 Gain Loop Current Suppression Control of Parallel Pulse Width Adjusted Rectifier [J]. Control Theory and Application, 2017, 34 (12), 1614-1620.
[3] Ma Lu, Liu Li, Leilei, et al. Research on Double Zero-Variable Vector Control for Circulating Current of Parallel Three-Phase Inverter [J]. Power System Protection and Control, 2017, 45 (21): 74-81.
[4] Zhang Housheng, Zhang Lei, Jiang Jishun, et al. Zero-sequence circulating suppression and current sharing control of two-parallel three-phase PWM rectifiers [J]. Electric Power Automation Equipment, 2018, 38 (2): 153-160.
[5] Xing Xiangyang, Chen Alian, Zhang Zicheng, et al. Research on Circulating Current Suppression and Midpoint Balance of Parallel T-type Three-level Inverter [J]. Journal of Electrical Engineering of China, 2016, 36 (14): 3909-3919.
[6] Hou Lijun, Pang Renjie, Liu Xinfang, et al. Zero-Sequence Circulation Control under Parallel Connection of Microgrid Energy Storage Inverter [J]. Electrical Drive, 2017, 47 (3), 32-36.
[7] Wei Yongqing, Zhang Xiaofeng, Yu Fei, et al. Control Strategy of Hybrid Inverter Inverter with Independent DC Side Supply [J].Transactions of China Electrotechnical Society, 2017,32(34):139-145.
[8] Zhang Yongzhen, Su Hansong, Liu Gaohua, et al. PID Control Parameter Adjustment Based on BP Neural Network [J]. Journal of Nankai University (Natural Science Edition), 2018, 51 (3): 26-30.
[9] Jiao Jun, Chen Wudao, Wang Jixian, et al. AGV steering single neuron PID control based on RBF on-line identification [J], Journal of Instruments and Instruments, 2008, 29 (7): 1431-1435.
[10] Deng Xiao, Zheng Song, Zhang Wang. Simulation of Industrial General Control Platform for Single Neuron PID Controller [J]. Control Engineering, 2017, 24 (S0): 98-102.
[11] Yao Youling, Zhang Lin, Fei Minrui. Application of Single Neuron PID Controller in Gas Pressure Control of Bar Heating Furnace [J]. Power Grid Technology, 2007, 31 (Supplement 2): 388-390.
[12] Chen Kui, Niu Yanjie, Li Geqiang, et al. Study on Synchronization Control of Shield Propulsion System Based on Single Neuron PID [J]. Journal of Engineering Design, 2017, 24 (3): 330-336.
[13] Shen Fu, Yin Bin, Sun Weiguang. Photovoltaic MPPT Based on Single Neuron Adaptive PID [J]. Journal of Power System and Automation, 2017, 29 (2): 89-95.
[14] Cheng Qiming, Zheng Yong. Multi-model PID Neural Network Control System of Ball Mill [J]. Journal of Electrical Engineering of China, 2008, 28 (2): 103-109.
[15] Liu Jinkun. MATLAB simulation of advanced PID control [M]. Beijing: Electronic Industry Press, 2016:311-313.