International Journal of Smart Home
Vol. 10, No. 5 (2016), pp. 1-8
http://dx.doi.org/10.14257/ijsh.2016.10.5.01

The Study of Current Mode Rectifier Control Technology

Luo Min[1], Liu Bang-tao[1*] and Xia Yu Cheng[2]

[1]Sichuan Medical University, Luzhou, 64600,Si Chuan,China
[2]UOG-UESTC join School,Chengdu,611731, Si Chuan,China
lbt_lzmc@163.com

Abstract

The accumulator battery test requests its system converter to output excellent charging/discharging current. According to special request, PWM converter with current mode control is analyzed and designed in this paper. Morever, a loop-locked control strategy is put forward based on dq coordinate conversion to SVPWM converters in the power accumulator battery testing system. low ripple and fast response testing current in a wide adjustable range is achieved, and high power factor is obtained. Considering resonance of LC filter, the passive damping is designed, which is based on the series resistance of capacitor. Simulation results verify the feasibility and validity of this strategy.

***Keywords**: Index terms-Current source rectifier(CSR), SVPWM, Batteryt,Passive damping,LC resonance*

1. Introduction

Accumulators battery are widely used in renewable energy sources, Uninterrupted Power Supply.However, in order to utilized it effectively, it requires battery test with excellent charging/discharging current control strategy. To improve the accuracy of accumulators test, save energy and reduce the cost and reduce the pollution to the power system,it has important value significant to research charge and discharge technology of accumulators.Three-phase current PWM rectifier(CSR) proposed in [1] is usually utilized as the topology of the battery test .Because of a DC energy storage inductance and alternating current(AC) LC filter existing in the CSR topology, so the structure and control of CSR is more complex than the relative voltage PWM rectifier (VSR) [2], and the loss of the system is increased. However, due to the VSR is boost type rectifier circuit, the rectifier output voltage is greater than the grid side AC peak voltage, therefore, it is not directly used to the battery charging [6-10]. And the fast development of superconducting technology has solved the problem of large CSR loss[3]. At the same time, the energy storage coil in the power supply system has the characteristics of current source, without the DC inductance. Besides, the current PWM rectifier is superior to the voltage type PWM rectifier in the current protection [4-5].

Aiming at three-phase current source PWM rectifier which is used for battery,a tri-logic PWM technology and double closed-loop control method were used.Due to the resonance of LC filter, the passive damping is designed, which is based on the series resistance of capacitor.The current adjustment ability and response speed and power factor hasbeen improved.this strategy has good output characteristic.

ISSN: 1975-4094 IJSH

2. Topology of Three-Phase Current Source Rectifier

The topology of three-phase CSR is shown in Figure 1.A large inductance is used in the DC side of the CSR, which makes current of the DC side is approximately smooth. Alternating current(AC) side have a low pass filter, which is composed of inductance and capacitors to filter out the harmonics in the current. Switching device is composed of a controllable device and a diode in series to improve the reverse blocking capability of the device.And the line impedance is ignored [11].

In this paper,the model of accumulator is given [10-11].Accumulator internal resistance composed of metal electrochemical resistor R1 and electrochemical R2 and their resistance value vasry from dozens of ohm to thousands of ohm.The value of polarization capacity C depends on the capacity of accumulator and the typical value is 1.5F/100A [12-13].

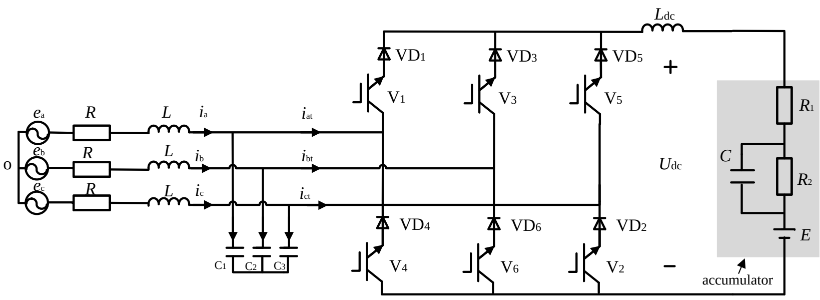


Figure 1. Topology Structure of Three-Phase CSR in the Power Accumulator Battery Testing System

3. The Theory of Trilogic Single

Voltage source rectifier(VSR) signal occurs with bilogic signals. In a moment,only one power switch will on on the same bridge arm.For one bridge arm, the two switchs not on or off at the same time.Definition of bilogic switching functions *p*:

$$p = \begin{cases} 1 & \text{The upper switch turn on, lower switch turn off} \\ -1 & \text{The upper switch turn off, lower switch turn on} \end{cases}$$

For the three-phase CSR,ac current control can be realized by trilogic switching functions.At a time,both two switch of one bridge arm are allowed to on or off at the same time.But two or three bridges arm on or off at the same time is not allowed.So, there are four cases for A bridge arm:the upper switch on and the lower switch off; the upper switch off and the lower switch on;both the upper switch and the lower switch on;both the upper switch and the lower switch off.Trilogic switching functions are defined, thenσ

$$\sigma = \begin{cases} 1 & \text{The upper tube turn on, lower tube turn off} \\ 0 & \text{On the downside, all the tube is turned on or off} \\ -1 & \text{The the upper tube turn off, lower tube turn on} \end{cases}$$

Trilogic switching functions σ j (j = a, b, c)

$$\sum_{j=a,b,c} \sigma_j = 0 \tag{3}$$

The

$$\sum_{j=a,b,c} \sigma_j = \frac{1}{2} \sum_{k=a,b,c} (p_j - p_k) = 0 \qquad (k \neq j) \tag{4}$$

The expanded form of the Equation(4),

$$\begin{aligned}\sum_{j=a,b,c}\sigma_j &= \frac{1}{2}[(p_a - p_a) + (p_b - p_b) + (p_c - p_c)] \\ &= \frac{1}{2}[(p_a - p_b) + (p_b - p_c) + (p_c - p_a)] \\ &= \sigma_a + \sigma_b + \sigma_c\end{aligned} \tag{5}$$

So,the state switching in trilogic PWM signal generation of three-phase CSR by using the conversion between bilogic and trilogic switching functions can be described as:

$$\begin{bmatrix}\sigma_a \\ \sigma_b \\ \sigma_c\end{bmatrix} = \frac{1}{2}\begin{bmatrix}1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1\end{bmatrix} \bullet \begin{bmatrix}p_a \\ p_b \\ p_c\end{bmatrix} \tag{6}$$

Table 1. The Conversion Between Bilogic and Trilogic Switching Functions

bilogic	**trilogic**	The upper switch state			The lower switch state			The sequenced
p_a p_b p_c	σ_a σ_b σ_c	V_a	V_b	V_c	V_a'	V_b'	V_c'	of **trilogic**
+1 +1 -1	0 +1 -1	○	●	○	○	○	●	#1
+1 -1 +1	+1 -1 0	●	○	○	○	●	○	#2
+1 -1 -1	+1 0 -1	●	○	○	○	○	●	#3
-1 +1 +1	-1 0 +1	○	○	●	●	○	○	#4
-1 +1 -1	-1 +1 0	○	●	○	●	○	○	#5
-1 -1 +1	0 -1 +1	○	○	●	○	●	○	#6
-1 -1 -1	0 0 0	●	○	○	●	○	○	#7(#0)
		○	●	○	○	●	○	#8(#0)
+1 +1 +1		○	○	●	○	○	●	#9(#0)

Note: represent switch on; represent switch off.

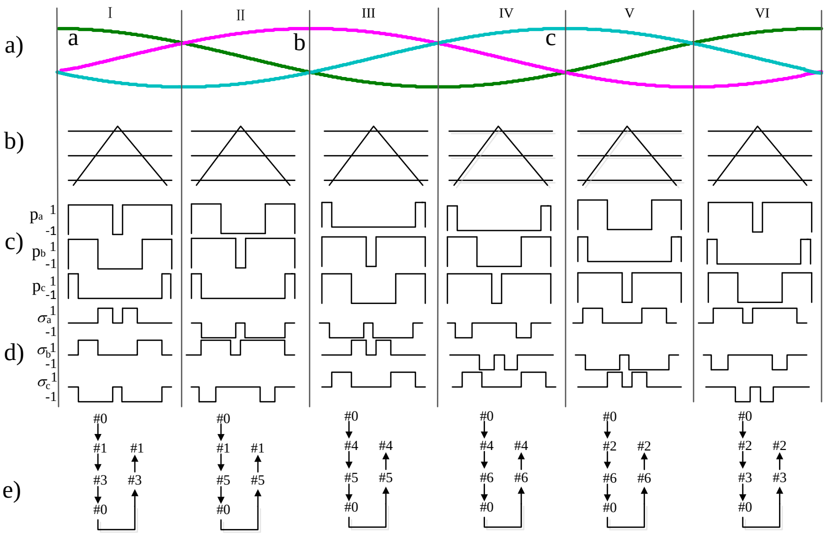


Figure 2. Bilogic PWM Waveform Transformed into Trilogic State of a Sine Wave Modulation Signal Period

(a)Three phase sinusoidal modulation signal;(b)Triangular carrier modulation;(c)Bilogic switching function;(d)trilogic switching function;(e)Trilogic state switching in each interval.

Through the analysis, the state switching in trilogic PWM signal generation of three-phase CSR by using the conversion between bilogic and trilogic switching functions..However, the fundamental component of ac current lag the modulation wave signal on the phase,and lost characteristic of linear transmission of c PWM modulation.So,the decoupling pretreatment need to be introduced to realized to linear transmission.

4. Dual Loop Control Strategy

The main control objective of accumulator is given: firstly, the DC current need to track given value and keep constant by a Dc current feedback path; Secondly, high power factor and low harmonics need to obtained by controlling the AC current,that is to achieve AC current waveform control. According to the AC current control, current control strategy of current mode PWM converter can be divided into indirect current control and direct current control.As mentioned above, the indirect control algorithm depends on the CSR's main circuit parameters. Once these parameters changed,the AC side current control performance will be affected.So,the direct control of three-phase CSR's AC side current is controlled by the closed-loop control of the network side current.The input current of the AC is calculated.Because the closed-loop control not only has the following characteristics to the instruction ,but also has some inhibition effects on the disturbance(including parameter disturbance) in the control loop.So,the direct current control method is adopted, and the static and dynamic characteristics of AC side current control can be improved.It is assumed that the PWM switching frequency of the control system is much higher than that of the single phase CSR power network,and only the fundamental component of the CSR is considered, and the influence of the CSR on the dynamic performance of the system can be neglected.

Figure 3 shows the Closed loop transfer structure of direct current control system for single phase CSR, where $R_1(s)$ and $R_2(s)$ are transfer functions of the inner loop controller and the outer loop controller respectively,K_{pwm} is PWM proportional gain and m is modulation ratio.

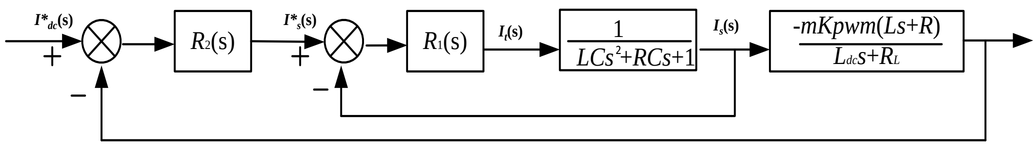


Figure 3. Closed Loop Transfer Structure of Direct Current Control System for Single Phase CSR

According to the structure of the transfer function shown in Figure 3,the inner loop and outer loop parameters can be calculated.This paper adopted PI regulator to reduce the static error and improve dynamic response speed.

5. Passive Damping Design of LC Filter

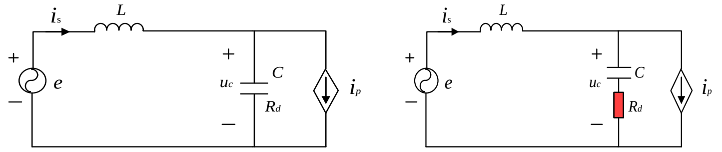
According to the working principle of three-phase current source PWM rectifier,network side equivalent circuit can be separated into single phase equivalent circuit,as shown in Figure 4,the equivalentresistance of grid inductance and power supply circuit are neglected.In order to analyze the filteringcharacteristics and damping characteristics of the LC filter, the $i_s(s)/i_p(s)$ transfer function is obtained by the LC filter:

$$\frac{i_s(s)}{i_p(s)} = \frac{1}{LCs^2 + 1}$$

The resonant frequency is: $f_{res} = 1/2\pi\sqrt{LC}$

The gain of LC filter at the resonance frequency f_{res} is large,which shows that the LC filter has a strong amplification effect on harmonics where frequency be equal to f_{res}.In the high power CSR,because of the low switching frequency,the frequency of the harmonic distribution is lower,and the resonant frequency is close to the LC filter, which is more likely to lead to the LC filter oscillation,which affects the stability of the system and the THD of the network side current.In view of the resonance of the LC filter,passive damping method and active damping are usually used to solved this problem.

In order to avoid the complex control algorithm of active damping,a simple passive damping resistor in series with capacitor branch is designed to avoid the complex control algorithm of LC filter.The method is mainly used to avoid the complex control of active damping[16].



a) Without damping resistor   b) The series damping resistor of capacitor branch

Figure 4. The Single Phase Equivalent Circuit of CSR

The damping resistance series in capacitor branch shown in Figure 6, and the transfer function of $i_s(s)/i_p(s)$ is obtained from the equivalent circuit of the network side[11]:

$$\frac{i_s(s)}{i_p(s)} = \frac{R_dCs + 1}{LCs^2 + R_dCs + 1}$$

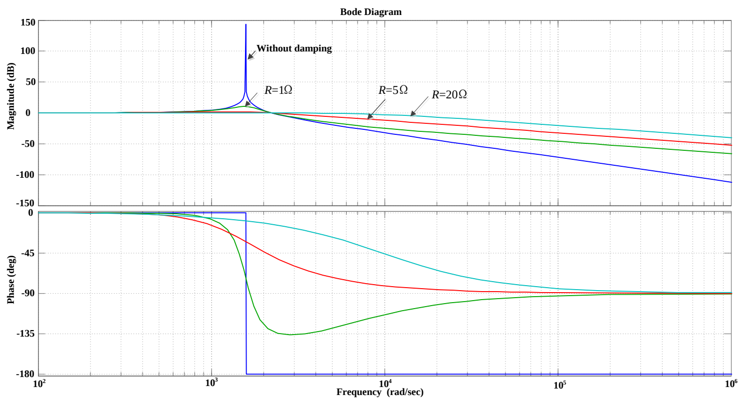


Figure 5. LC Filter With and Without Damping

As shown in Figure 5,without damping resistance, the transfer function exists resonant peak.But,the damping resistor R_d increases, the attenuation degree of the resonant peak is increased,the size of the damping resistor is not affected by the whole frequency range of the transfer function.In short,the scheme of the series damping resistance of capacitor branch is feasible in two aspects, which are both damping characteristics and high frequency filtering.

5 Simulation Results

The parameters of the main circuit are shown in Table 2.

Table 2. System Parameters

System Parameters	Simulation	System Parameters	Simulation
Grid voltage U_N	220V,50 Hz	Accumulator capacitance C_1	1.5F
Switching frequency f	3000Hz	Metal resistance R_1	0.09Ω
Filter inductance L	20mH	Electrochemical resistance R_2	0.01Ω
Filter capacitance C	200uF	Anti electromotive force E	24V
Dc-link inductance L_{dc}	400mH	Damping impedance R_d	5Ω
Line impedance R	0.1Ω		

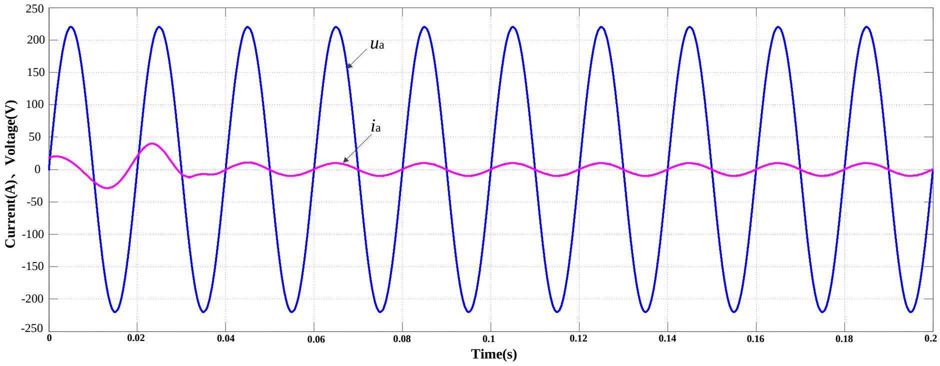


Figure 6. Emulated Voltage and Current Waveforms From the Power Grid When the Charge Current idc=20A

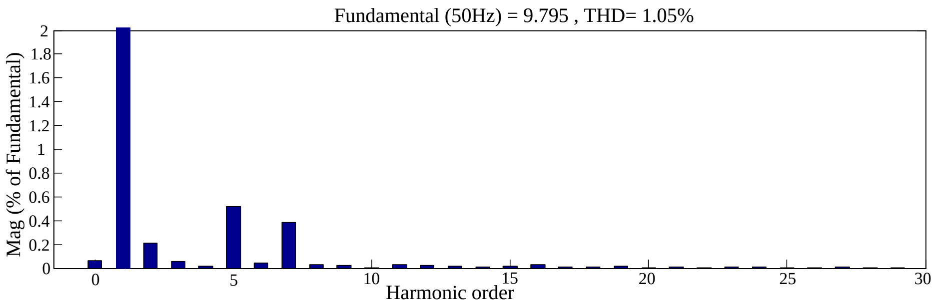


Figure 7. Double Closed-loop SVPWM Charging Test When the Definite Current Value is 20A

As shown in Figure 6,the response speed of the dc side current at 0.03s and have small overshoot.The steady-state deviation is smaller and have small ripple current that is about 0.25% ,which can control in 0.5%,stable performance is better. Figure 7 shows that the grid side current and voltage phase are the same, the high power factor control effect is achieved by Dual closed-loop control with direct current control.And the network side harmonic content is low,and the control requirements are realized.

6. Conclusion

In this paper,in the light of the specific characteristics of accumulator, the topology of three-phase CSR is studied in depth,the SVPWM control strategy based on dq coordinate system is designed.And then the paper shows a simple passive damping with a resistor in series with the filter capacitance and the validity is proved by the Bode diagram.At last, Matlab/simulink is used to simulate the feasibility and effectiveness of the design.

References

[1] L. Zhang,X. Yan,W. Kang and H. Li, "Converting Technology Based on the Current Mode SVPWM on the Power Accumulator Battery Testing System", Transactions Of China Electrotechnical Society, vol. 25, no. 9 , **(2010)** September.
[2] M. V. Aware and D. Sutanto, "Improved controller for power conditioner using high-temperature super con-ducting magnetic energy storage (HTS-SMES) [J], IEEE Trans on Applied Superconductivity, vol. 13, no. 1, **(2003)**, pp.38-47.
[3] X. Jiang, X. Chu, X. Wu,Y. Dai,H.Lan, "A 20kJ/15kw SMES SYSTEM", Automation of Electric Power Systems, vol. 28, no. 4, **(2004)** Feb. 25.
[4] V. KARASIK and K. DIXON, "SMES for power utility applications a review of technical and cost considerations", [J]. IEEE Trans on Applied Superconductivity, vol. 9, no. 2, **(1999)**, pp. 541-546.
[5] J. C. WISEMAN, B. WU and G. S. P. CASTLE, "A PWM cur-rent-source rectifier with active damping for high power medium voltage applications", [C]//PESC, no. 4, **(2002)**, pp. 1930-1934.
[6] L.-chengTan,Y.-hua Li, P.Wang and C.-wei Liu, "Novel Power Factor Control Method for Three Phase Pulse Width Modulation Current Source Rectifier.Proceedings of the CSEE, vol. 29, **(2009)**.
[7] Y. Zhang and C. Qu, "Model Predictive Direct Power Control of PWM Rectifiers Under Unbalanced Network Conditions", EEE Transactions On Industrial Electronics, vol. 62, **(2015)**.
[8] X. Zhou,G. Wang and S. Lukic, "Multi-Function bi-directional battery charger for plug-inhybrid electric vehicle Application", [J].Proceedings ofthe IEEE Energy Conversion Congress and Exposition, no. 9, **(2009)**, pp. 3930-3936
[9] Y.-Joo Lee, A. Khaligh and A. Emadi, "Advanced integrated bidirectional AC /DC and DC /DC converter for plug-in hybrid electric vehicles", [J].IEEE Transactionson Vehicular Technology, vol. 58 no. 8, **(2009)**, pp. 970-3980.
[10] Y. Liu,T.-Yu Wang,Y. Yang, X. Wang, "Modeling and simulation of electric vehicles'charge and discharge system", [J].Power System Protection and Control, vol. 42, **(2014)**.
[11] J. Wen, H. Qin, S. Wang and B. Zhou, "Basic connections and strategies of isolated phase-shifting transformers for multipulse rectifiers: A review, 2012 Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC), **(2012)**.
[12] L. Jiang, Y. Li and Z. Qi, "Precessing Of Complex Functions In Servomotor Control System", Advanced Technology Of Electrical Engineering And Energy, vol. 19, no. 1, **(2000)**.
[13] J.-X. LU, C.-T. LIN, Q.-S. CHEN and X.-D. HAN, "Comparison study of 3 types of battery models for electrical vehicle", Chinese Journal of Power Sources, vol. 7, **(2006)**, pp. 535-538.
[14] G. Alber, "Internal cell parameter measurements Are they a substitute or supplement to capacity testing", NE Utilities Battery Conference, Alberny, New York, **(1994)**.
[15] G. Alber, "Ohmic Measurements：The History And The Facts. Alber. corp Report", America, (2003), **(2010)**, pp. 2-7.
[16] Wu Xiaojie, S. Wei, D. Peng and Zhou Juan, "an active damping methoof virtual resistor in parallel with capacitor", [J].Transactions of China Electrotechnical Society, **(2010)**.