A NEW CONTROL METHOD FOR CURRENT SHARING IN THE 12-PULSE PHASE-CONTROLLED RECTIFIER

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ABSTRACT - This paper presents the new current sharing control method of a 12-Pulse phase-controlled rectifier(PCR) for a UPS. The control circuit of the 12-Pulse PCR with a parallel operating rectifier system is proposed to balance input currents and to reduce the harmonics of input currents.

The PCR is used widely in the industrial world, since its cost is much lower than that of the PWM converter and the composition of control circuits is simple.

This system is developed and tested for a 3-phase 400KVA UPS system and the experimental results in this application are included.

1. INTRODUCTION

In case of applying the rectifier for a UPS (Uninterruptible Power Supply), the PCR using thyritors is usually used to ensure constant DC output voltage regardless of the change of load condition.

A PCR has some advantages as follows; (1) it is easy to compose control circuit, (2) it is cost-effective, (3) the designers can vary freely the DC out voltage according to the purpose of the system. However, since the input current waveform of a 6-pulse PCR is rectangular, it contains lots of harmonics about 30%. So other equipment connected to same input power line may have harmful influences, and the larger power source impedance or output capacity of the UPS is, the more serious the bad effect on other facilities becomes.

To reduce the undesirable input current harmonics like this, now the application of the PWM converter using IGBTs(Insulated Gate Bipolar Transistor) is proposed, however, because it is complicated to design the control circuit and it requires some expensive switching semiconductor devices, there are some problems to apply it in the industrial world. For these reasons, in case of applying the PCR to the UPS of large output capacity, 12-pulse PCR which is composed of two 6-pulse PCRs connected in parallel is used widely. In this application, the current balance control between two 6-pulse PCRs is a key technique.

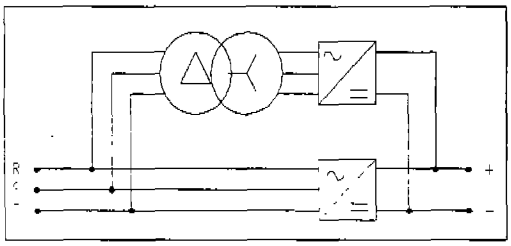
This paper presents the new current sharing method of the 12-pulse PCR for UPSs. The current sharing control circuit for the 12-pulse PCR consisted of two 6-pulse bridges in parallel is proposed to balance the input currents and to reduce the harmonics of input current. The optimal PI gain in the control circuit is obtained by using the simulation tool Design Center. Also, this paper deals with the power circuit of the PCR and the control circuit of the DC output voltage, and then some kinds of current sharing control methods are described and comparison for performance between proposed method and other ones is made.

This system which is consisted of a three-winding transformer, two 6-pulse PCRs and a control circuit board etc. is developed and tested for the 3-phase 400KVA UPS using IGBT as power semiconductors and the experimental results in this application are included.

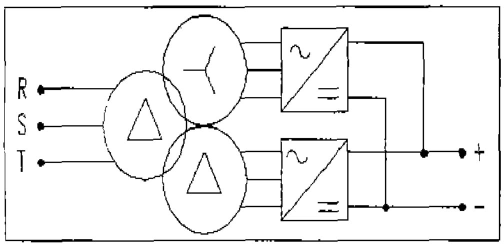
2. CONFIGURATION AND DESIGN

Power circuit

The power circuit of a 12-pulse PCR can be classified two categories i.e. the configuration without galvanic separation and with galvanic separation as Fig. 1.



(a) Configuration without galvanic separation



(b) Configuration with galvanic separation

Fig. 1. Power circuits of 12-pulse PCR

Since we construct a system with galvanic separation in this paper, the rectifier side of the system is electrically isolated from the input power source by using a 3-winding transformer. The entire block diagram is shown in Fig. 3.

The block diagram shows that the input voltage is 3-phase 380VAC, the line commutation choke is installed in front of the rectifier for the natural commutation and a 12-pulse rectifier is composed of two 6-pulse rectifiers which have difference of phase angle of 30 degree each other by the 3-winding transformer of △ // △ // Y connection.

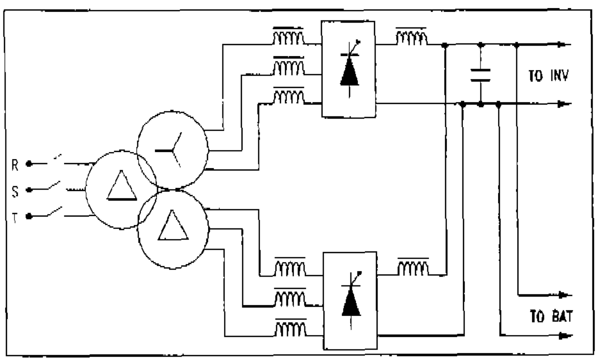


Fig. 2. Block diagram of the system

Control structure

The system control units consist of AVM (Actual Value Monitoring) board, RCU (Rectifier Control Unit) board and gate driver. Fig. 3 shows the control block diagram of the system.

The AVM board plays a role to transmit the monitoring analog values and control signals to the RCU board. The RCU board examines the main power and the system status by using these values and signals and performs the phase control and current sharing control of the each rectifier 1, 2. And then this control signal is transmitted to the gate driver. The gate signals are amplified and isolated from the gate driver and then trigger the thyristors.

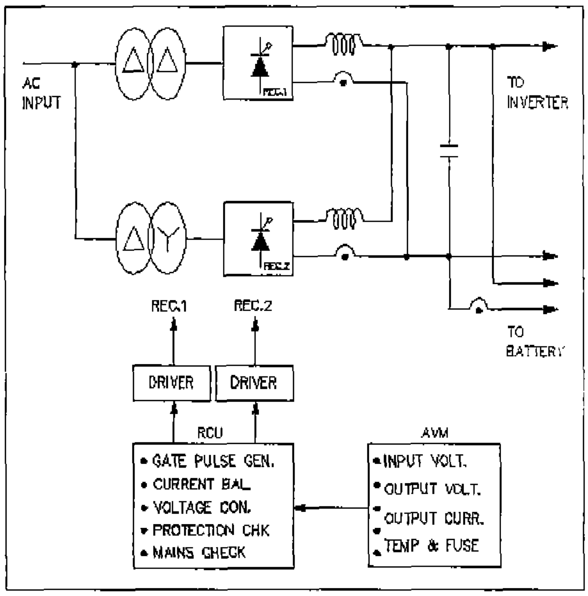


Fig. 3. Block diagram of the control structure

The voltage control for keeping up the reference value at any time is performed by controlling the thyristor's phase through the control signal generated from comparison of the reference value with the actual sensing value.

To maintain quick adaptability and linearity, the output voltage, the output current and the current flowing to the battery bank are detected and controlled by the PI controller and the comparator and then transmitted to the current sharing control circuit.

Current sharing

The traditional current sharing methods are classified into two types. The first one((a) of

Fig. 4) is the method to control one rectifier control signal by shifting the phase as well as the phase displacement. This method has good current sharing performance in ideal case, but actually since various constants and characteristics of each power semiconductor and other components are different from each other, it is difficult to get good performance. The other one ((b) of Fig. 4) is the method to detect currents of two rectifiers and to change the control gain of each rectifier. This method is one to improve the first method and shows good characteristics under condition of only initial establishment load, but it shows a no good tendency of the decrease of DC current according to the increase of the load.

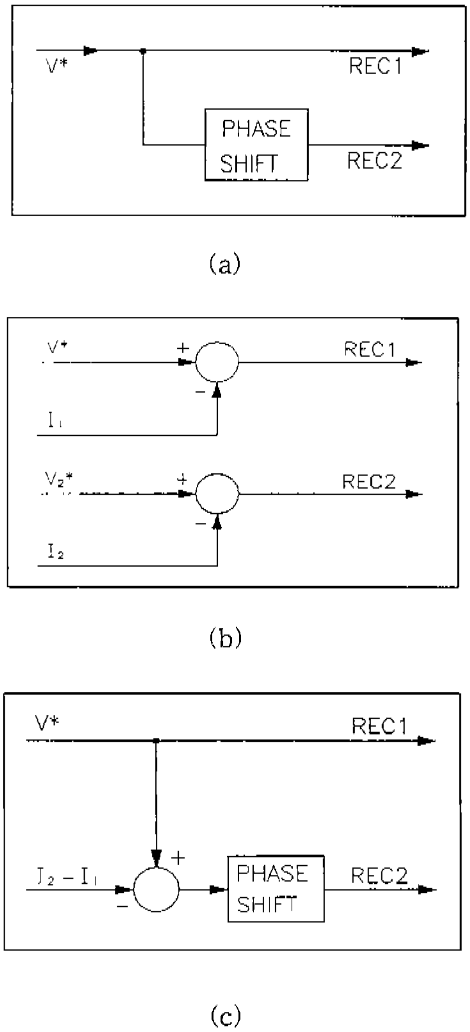


Fig. 4. Concept of current sharing method

This paper represents a new current sharing method to improve the second one(Fig. 4 (b)) to show good performance regardless of the load condition. Fig. 5 shows the control block diagram of a new control method and Fig. 4(c) is its conceptional diagram. The currents of each rectifier are detected and filtered and amplified and then the controlled deviation value is generated through the differential amplifier and the PI controller. This deviation value is compensated for the reference value(V^*) transmitted in the voltage control circuit. The controlled signal is shifted in the phase shift circuit as much as the phase displacement generated in the power circuit and then phase angle is controlled through the drive circuit of the rectifier 2. According to the above mentioned control procedures, consequently good output DC voltage control and excellent current sharing control are performed.

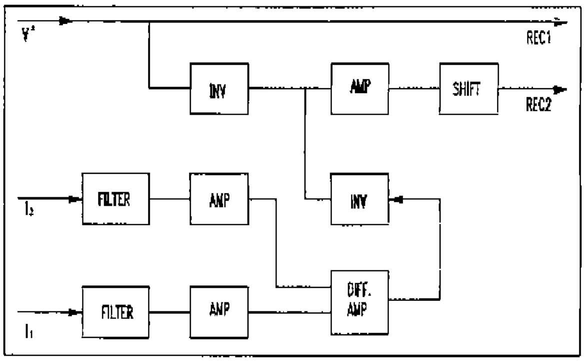


Fig. 5. Control block diagram of the new current sharing method

In this case, since the control value given to the rectifier 1, the output reference value (V^*) from the voltage control circuit is transmitted directly.

3. EXPERIMENTAL RESULTS

To confirm the control circuits and so on, the above mentioned characteristics were verified by tests with an actual capacity model which has specifications listed in Table 1. And we used the inverter for the 3-phase 400KVA UPS as load of the 12-pulse PCR.

Table 1. System specification

Item		Specifications
Output rating		350KW
Input	Voltage	3PH, 380V±10%
	Frequency	60Hz±5%
Output	Voltage	432VDC

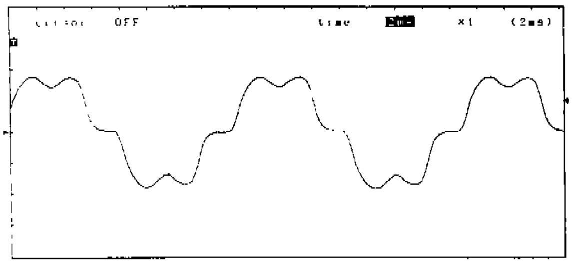
Table 2 shows test results for the actual model of the Table 1.

Table 2. Test results for several items

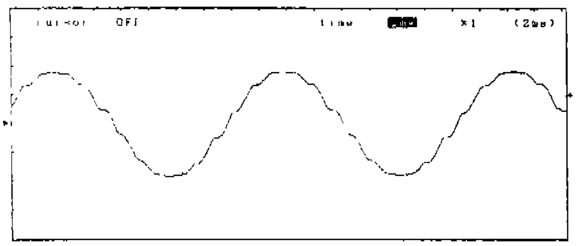
Test items		Measured value	Remark
THD	Input current	5.23%	Rated load
	Input voltage	3.15%	〃
Temperature	Transformer (core)	36℃	〃
	Heat sink	58.5℃	〃
Ripple	Output voltage	12.7Vpp	〃
Efficiency	Transformer	99.1%	〃
	System	98.8%	〃
Current sharing ratio		≤3.02%	Full load range

Harmonic currents

Fig. 6 (a) shows source current of a 6-pulse PCR and (b) shows source current of a 12-pulse PCR. As we can see from those waveforms, the harmonic characteristic of the 12-pulse PCR is superior to that of the 6-pulse PCR. Measured total harmonics distortions are 5.23%, 13.71% respectively.



(a) 6-pulse PCR



(b) 12-pulse PCR

Fig. 6. Waveforms of source currents

Voltage and current

Fig. 7 shows the source voltage(upper), the source current(center) and the PCR input current (lower). Where, the source voltage and the current means the primary side voltage and current of the 3-winding transformer and the PCR input current means the secondary side current of the 3-winding transformer in Fig. 2.

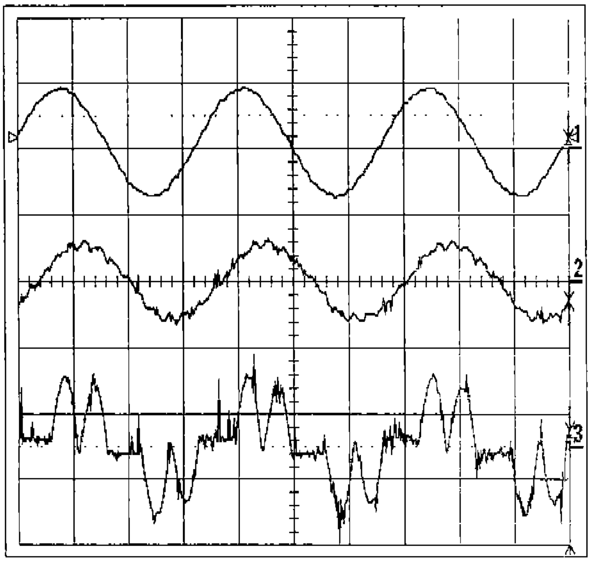


Fig. 7. Source voltage, source current and PCR input current

Dynamic characteristic

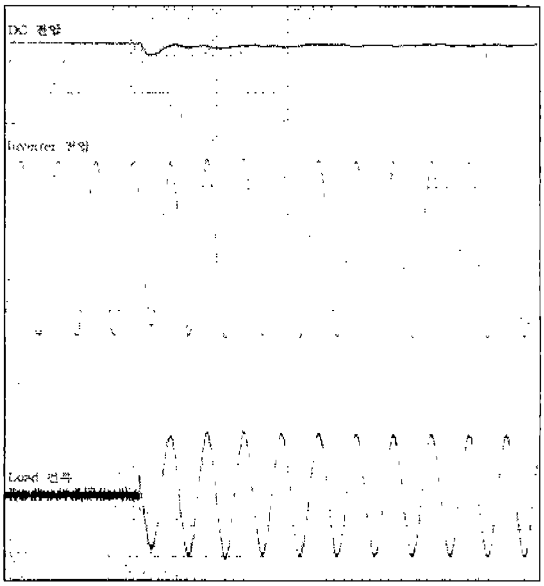


Fig. 8. Dynamic characteristic of DC voltage and load

Fig. 8 shows an oscillogram obtained at the step load change with 100% load(320KW). In the Fig. 8, Maximum DC voltage drop(upper) is as small as about 8V. And the dynamic characteristic is fully satisfied with the specification.

Current sharing characteristic

Fig. 9 shows PCR 1, 2 input AC currents and we can see that the phase angle of PCR 2 current is shifted by 30°. Measured rms currents of PCR 1, 2 are 68.9A, 70.1A respectively.

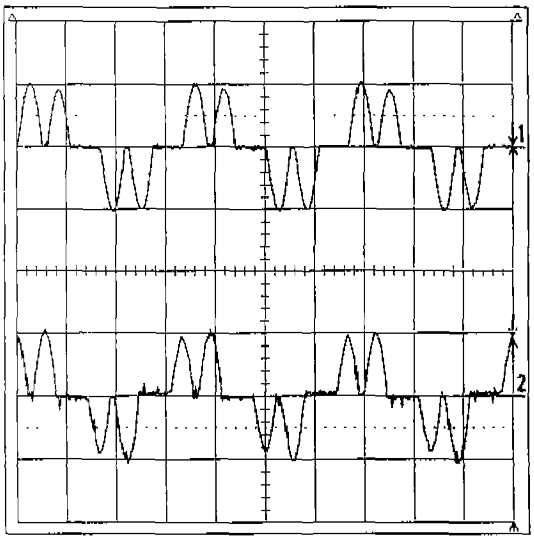


Fig. 9. Input AC currents of PCR 1, 2

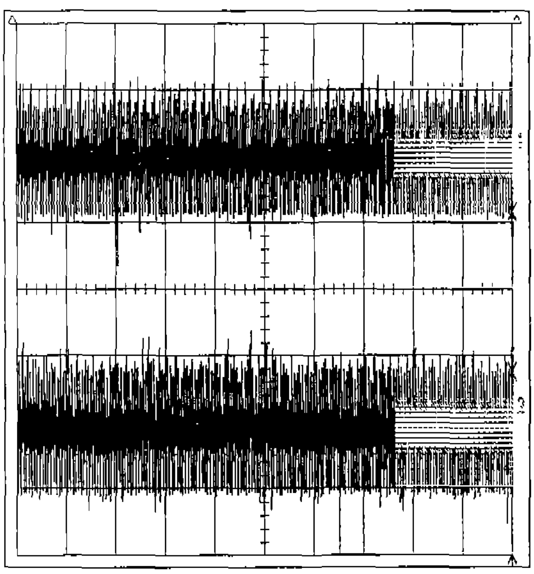


Fig. 10. Output DC currents of PCR 1, 2

Fig. 10 shows output DC currents of PCR 1, 2 sensed by a DC shunt and we can find out that two DC currents are almost same.

From Fig. 9, 10 it is clear that proposed current control method has good performance.

4. CONCLUSION

In this paper, a new current sharing control method for the 12-pulse PCR was proposed and it was applied to rectifier of the 3-phase 400KVA UPS system. The experimental results showed good current sharing performance in the 12-pulse PCR and the effectiveness of the proposed method was proved. Also we developed some good products which had low cost, high reliability. As we can see to the experimental results through the type-test, it is sure that characteristics of THD, heat sink temperature, DC ripple, current sharing and efficiency are excellent. Especially, the characteristics of the current sharing is outstanding namely, the deviation between two PCRs is very small (maximum 3%).

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