2009년도 대한전기학회 하계학술대회 논문집 2009. 7. 14 - 17

무효전력을 보상하는 축소형 ITER 전원공급장치의 순차제어

허혜성[*], 박기원[*], 안현식[*], 장계용[*], 신현석[*], 최정완[**], 오종석[**]
(주) 포스콘[*], 국가핵융합 연구소[**]

Sequence Control of Small-scaled ITER Power Supply for Reactive Power Compensation

Hye-Seong Heo[*], Ki-Won Park[*], Hyun-Sik Ahn[*], Gye-Yong Jang[*], Hyun-Seok Shin[*], Jung-Wan Choi[**], Jong-Seok Oh[**]
POSCON Co.[*], National Fusion Research Institute[**]

Abstract - A technology based on thyristors will be used to manufacture the super-conducting coil AC/DC converters because of the low ratio of cost over installed power compared to a design based on GTO or similar technology. But phase-controlled converter suffers from fundamental disadvantage. They inject current harmonics into the input ac mains due to their nonlinear characteristics, thereby distort the supply voltage waveform, and demand reactive power from the associated ac power system at retarded angles. To overcome this disadvantage, in the case of two series converters at the DC side, connected to the same step-down transformer, apply for the sequence control. It is the most simple and efficient way to reduce the reactive power consumption at low cost. Analytical sequence control algorithm is suggested, the validity of the proposed scheme has been verified by experimental results with the small-scaled International Thermonuclear Experimental Reactor (ITER) Power Supply to minimize reactive power consumption.

1. Introduction

Reactive power variation is the main driver of the ITER power supply design. There are only two extreme technical options to perform such an action. One is the installation of STATCOM (Static VAr Compensator) at the AC side instead of conventional Reactive Power Compensation (RPC) systems and the other is reducing the reactive power and its variation at the level of the AC/DC converters.

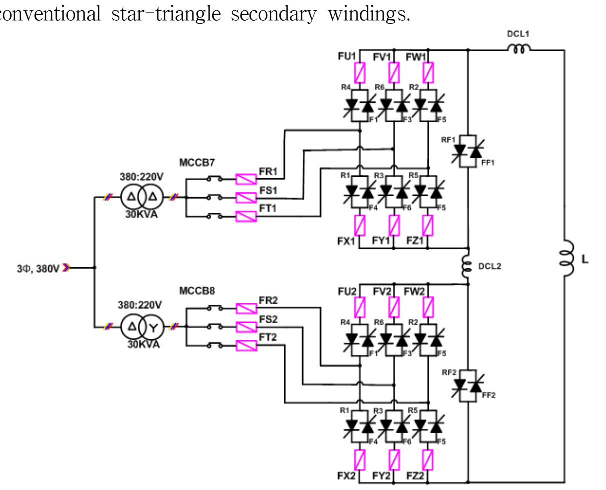
The cost of STATCOM is more than twice of this of conventional RPC systems at a given installed power (350 MVAr). Moreover, this large powerful STATCOM has never been manufactured by the industry. Up to now, a maximum STATCOM power of 100 MVA has been installed in Japan, for only up to 50 MVA in China and 0.5 MVA in Korea. Therefore, the reliability of such a system is not guaranteed and relies on high technology and long term experience. Moreover, because of the very fast variation of the reactive power (active power varying from 0 to Pmax within 10ms) there is also no guaranty on the final compensation results which requires anyway reducing part of the reactive power variation produced by the converters. The implementation of the reactive power variation reduction at the AC/DC converter level will also result in less reactive power consumption but, changes in the AC/DC converter design are required. Concern the splitting of the converters into two identical independent converters rated, each, at half power and connected in series at the DC side. The only simple and cheapest way to achieve it is to implement an improved sequential control mode between two series converters at the DC side, both connected to the same transformer[1].

In this paper, by comparing the simulation and experimental results from the conventional symmetrical and suggested sequence control, the effectiveness of the proposed algorithm is verified to minimize the reactive power consumption.

2. Sequence control

2.1 Two Series 12-pulse Converter

Each coil power supply is, in general, made of two series connected twelve-pulse independent converters. All independent converters are four quadrant operation converters under the exception of the TF converter, uni-directional in current. Since each coil needs sudden change of current to both direction every time for the generation of plasma and stability control. Each independent converter is made of series or/and parallel associations of six-pulse thyristor units interconnected at the DC side through DC decoupling reactors. One pair of six-pulse units is fed from two three-phase AC secondary winding, phase shifted of 30° angle, provided by conventional star-triangle secondary windings.

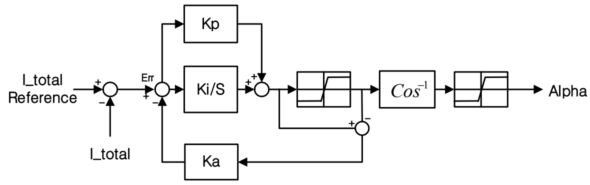


<figure 1> Two series converters at the DC side

Fig. 1 shows the small-scaled ITER supply that is made of two series associations of six-pulse thyristor units to test sequence control to verify minimizing reactive power consumption. Two two-winding transformers is installed in the same tank to get two phase shifted secondary windings star and triangle. And the main purpose of the DC inter-phase reactor is the limitation of the DC current derivative in a six-pulse unit.

2.2 Proposed Sequence Control Algorithm

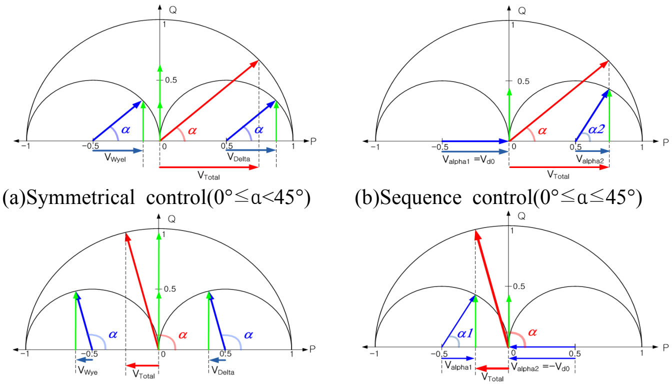
In the case of normal control (symmetrically fired thyristors) in six pulse bridge converter, the firing delay angle is the same for all the thyristors and the firing waves repeat at intervals of 60° for each thyristor. The firing delay angle of conventional symmetrical control is calculated from Fig. 2[2].



<figure 2> Two series converters at the DC side

Proposed sequence control algorithm distributes firing angle an alpha1 and alpha2 using the alpha of symmetrical control. The average dc voltage with a delay angle of symmetrical control is equal to the average dc voltage with delay angles alpha1, alpha2 of sequence control. The reason why don't be same firing angle is that full advance and full retard could spent the smallest reactive power.

It means that makes the most of symmetrical control's characteristics and besides could reduce reactive power consumption.



(a)Symmetrical control(0°≤α<45°) (b)Sequence control(0°≤α≤45°)

(c)Symmetrical control(90°≤α<135°) (d)Sequence control(90°≤α<135°)

<figure 3> Power diagram

Fig.3 illustrates the effect of the total power supplied by the individual bridges upon the reactive power consumption. Symmetrical control is shown in Fig. 3(a), (c) and sequence control shows Fig. 3(b), (d). The same total power (P) of the horizontal axis is guaranteed by Fig. 3(a), (c) and 3(b), (d). But reactive power (Q) of the vertical axis is verified to be reduced.

The average dc voltage with a delay angle of 6pulse converter is obtained as

$$V_{Wye} = V_{Delta} = \frac{3\sqrt{2}}{\pi} V_{LL}\cos\alpha = V_{d0}\cos\alpha \quad (1)$$

In case of the symmetrical control, the average dc voltage of 12pulse converter can be described as

$$V_{Total} = V_{Wye} + V_{Delta} = 2\times V_{d0}\cos\alpha \quad (2)$$

To make one of two series converters be full advanced or full retard, divide alpha into largely two parts.

- 0° ≤ alpha ≤ 90°

alpha1 = 0°

$$alpha2 = \cos^{-1}\left(\frac{V_{Total} - V_{alpha1}}{V_{d0}}\right) \quad (3)$$

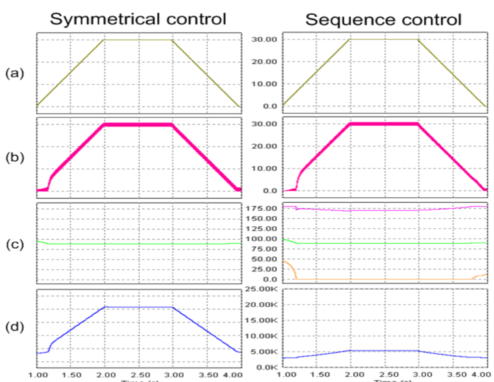
- 90° ≤ alpha ≤ 180°

$$alpha1 = \cos^{-1}\left(\frac{V_{Total} - V_{alpha2}}{V_{d0}}\right)$$

alpha2 = 180° (4)

If alpha is in the between 45° and 135°, V_{Total} is less than V_{d0}. So suppose that alpha2 is full retard, alpha1 should be in rectifying mode and vice versa. It is indicated in the Fig. 3(d).

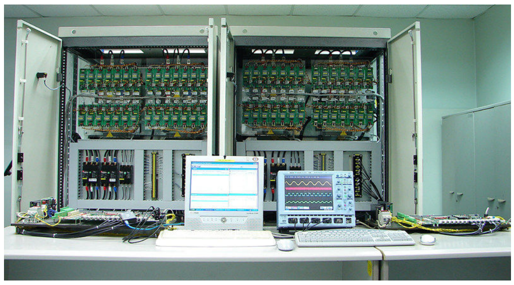
Fig. 4 shows the simulation results of the symmetrical and sequence control. (a) is the current reference, (b) DC/AC converter output current, (c) symmetrical firing angle(alpha) in symmetrical control and distributed firing angle(alpha1, alpha2) including alpha in sequence control, (d) reactive power consumption. According to Fig. 4(d), the reactive power consumption could reduce by the sequence control.



<figure 4> Comparison of simulated results at each control

3. Experimental Results

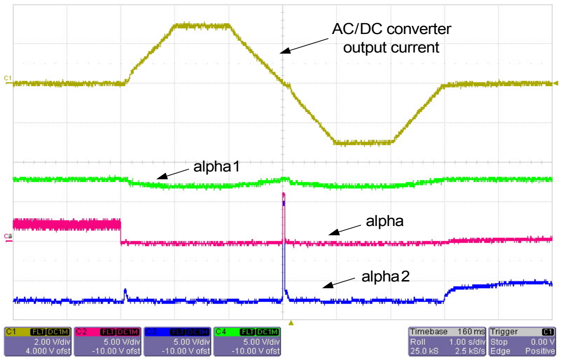
The small-scaled converter has been tested on the sequence control is designed as two series type with DSP-based controller. Fig. 5 shows the implemented system.



<figure 5> Implemented system for AC-DC converter

In ITER case, the minimum independent converter firing angle in rectifier mode is set equal to δ =15° angular. Moreover, as large current phase control thyristors are expected to be used, their intrinsic large recovery time around 700μs, requires a minimum margin angle of ε =15° angular in inverter mode[1]. But considering the inductance of AC side and the converter's stability, set the alpha range from 10° to 170° in the Small-scaled ITER Power Supply. So when calculates the distributed firing angle (alpha1, alpha2), alpha1 in (3) and alpha2 in (4) are decided as 10° and 170°.

The experimental results of the polarity change from positive to negative with sequence control are given Fig. 6. To avoid the danger of current extinction at zero crossing during the polarity change[3], dead-time must exist. Using the sequence control the AC/DC converter follows after the current reference well without any difference with the symmetrical control. As well as it could reduce the reactive power consumption due to distributing firing angle as shown in Fig. 6.



<figure 6> Symmetrical current control

4. Conclusion

Proposed sequence control algorithm distributes firing angle an alpha1 and alpha2 using the alpha of symmetrical current control. This control doesn't change existing topology and controller. So without any supplementary controller, it could realize having the output value of the existing control. By comparing the simulation and experimental results from the conventional symmetrical and suggested sequence control, the effectiveness of the proposed algorithm is verified to minimize the reactive power consumption. It is the most simple and efficient way to reduce the reactive power consumption at low cost. Those experiments are expected to apply to the structural design for power supplies of ITER.

[Reference]

[1] B. Bareyt, Technical specifications on AC distribution and AC/DC converter design: Draft 4, ITER_D_22HGHT versin4. 2006.

[2] Subhas Mukhopadhyay, "A New Concept for Improving the Performance of Phase-Controller Converters", IEEE Transactions on Industry Applications, Vol. 1A-14, No.6, pp.594-603, 1973, November.

[3] ITER Description Document - N 41 DDD 16 01-07-06R0.3,2001.