Minimization of Reactive Power Fluctuation in JT-60SA Magnet Power Supply

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Abstract This paper describes an asymmetric control method for the firing angle and a start/stop timing shift control of four thyristor converters called “Booster PS” to minimize the reactive power fluctuation during plasma initiation in JT-60SA. From the simulation using the “PSCAD/EMTDC” code, it is found that these control methods can drastically reduce the reactive power induced by the four units of the “Booster PS”. In addition, the voltage fluctuation of the motor-generator connected to the “Booster PS” is expected to be suppressed. This can also contribute to achieve stable control of the JT-60SA magnet power supplies.

Keywords: JT-60SA, power supply, poroidal field coil, reactive power fluctuation, asymmetric control, PSCAD/EMTDC

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1 Introduction

In the JT-60SA project [1,2], the European Union (EU) and Japan make a joint effort to contribute to the early realization of fusion energy by supporting the ITER (International Thermonuclear Experimental Reactor) project.

During plasma initiation in JT-60SA experiments, four units of thyristor converters called “Booster PS” fed by a motor-generator (MG) are activated for fast current control in poloidal magnetic field coils (PFC) [3,4]. Since the four units of “Booster PS” apply the negative highest voltage of −5 kV to the coils during plasma initiation, the large reactive power fluctuation induced by the “Booster PS” is the cause of a large voltage fluctuation across the terminals of the MG connected to all the PFC power supplies.

In this paper, to reduce the reactive power fluctuation induced by the “Booster PS” during plasma initiation, an asymmetric control method for the firing angle and a start/stop timing shift control of each “Booster PS” are adopted as a “Booster PS” control.

To evaluate these two proposed control methods for the “Booster PS”, their effects on reactive power were analyzed using the “PSCAD/EMTDC” code [5]. In addition, the output voltage fluctuation of the MG was also estimated using the obtained active/reactive powers.

2 Active/Reactive powers in PFC power supplies

The total active/reactive power waveforms of PFC power supplies during a typical plasma operation scenario are shown in Fig. 1. A large reactive power fluctuation was observed, especially from \( t = -10.0 \) s to \( t = 15.0 \) s. A reactive power fluctuation of \( \sim 250 \) Mvar (its peak amplitude: \( \sim 330 \) Mvar) was observed. This phenomenon was caused by the “Booster PS” operation. Since the MG connected to all PFC power supplies has a capacity of 400 MVA and an available discharge energy of 2.6 GJ, this MG can provide the needed power to the PFC power supplies. However, large voltage fluctuation across the terminal of the MG is much concerned. To suppress a large voltage fluctuation at the output terminal of the MG, the reactive power fluctuation induced by the “Booster PS” must be reduced.

![Fig.1 Total active/reactive powers and energy consumption in PFC power supplies (color online)](image-url)

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3 Asymmetric control for Booster PS

The typical circuit configuration of the PFC power supply including the “Booster PS” is shown in Fig. 2. The specifications of each converter for Booster PS are summarized in Table 1. The “Booster PS”, which is reused and modified from the power supplies for vertical magnetic field control in JT-60U [6], consists of four thyristor converters in two series and anti-parallel.

The basic principle of the asymmetric control is shown in Fig. 3. This control method is applied to the converters in series, such as two converters “PSV11” and “PSV12” in Fig. 2. Generally, the control angles for series-connected converters are the same. This control method is called the symmetric control. Meanwhile, in the asymmetric control, the control angles for converters are different to reduce the reactive power.

![Fig. 2 Typical circuit configuration of the PFC power supply (for EF1 coil)](image)

**Table 1. Specifications of Booster PS**

<table>
<thead>
<tr>
<th>Units</th>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSV11</td>
<td>Trans. winding voltages</td>
<td>18 kV/3.16 kV</td>
</tr>
<tr>
<td></td>
<td>No load output voltage</td>
<td>4.27 kV</td>
</tr>
<tr>
<td></td>
<td>Rated current</td>
<td>16.5 kA</td>
</tr>
<tr>
<td>PSV12</td>
<td>Trans. winding voltages</td>
<td>18 kV/2.1 kV</td>
</tr>
<tr>
<td></td>
<td>No load output voltage</td>
<td>2.84 kV</td>
</tr>
<tr>
<td></td>
<td>Rated current</td>
<td>16.5 kA</td>
</tr>
<tr>
<td>PSV21</td>
<td>Trans. winding voltages</td>
<td>18 kV/2.9 kV</td>
</tr>
<tr>
<td></td>
<td>No load output voltage</td>
<td>3.92 kV</td>
</tr>
<tr>
<td></td>
<td>Rated current</td>
<td>4.0 kA</td>
</tr>
<tr>
<td>PSV22</td>
<td>Trans. winding voltages</td>
<td>18 kV/2.9 kV</td>
</tr>
<tr>
<td></td>
<td>No load output voltage</td>
<td>3.92 kV</td>
</tr>
<tr>
<td></td>
<td>Rated current</td>
<td>4.0 kA</td>
</tr>
<tr>
<td>Reactor</td>
<td>Inductance</td>
<td>1.45 mH</td>
</tr>
<tr>
<td>(PSV11,12)</td>
<td>Resistance</td>
<td>9.82 mΩ</td>
</tr>
<tr>
<td>Reactor</td>
<td>Inductance</td>
<td>7.0 mH</td>
</tr>
<tr>
<td>(PSV21,22)</td>
<td>Resistance</td>
<td>28.6 mΩ</td>
</tr>
</tbody>
</table>

In the “Booster PS” control system, to simplify the control algorithm, the control angle for one of the two series-connected converters is kept to the minimum ($\alpha_{\text{min}}$: 30 deg.) or the maximum ($\alpha_{\text{max}}$: 140 deg.) and the other is varied according to the needed output voltage. As an example, the control scheme of the asymmetric control for converters “PSV11” and “PSV12” in the “Booster PS” is shown in Fig. 4.

![Fig. 3 Basic principle of an asymmetric control](image)

![Fig. 4 Asymmetric control for PSV11 and PSV12 in Booster PS](image)
The asymmetric control is advantageous for the reduction of reactive power. However, the 5th and 7th AC harmonic currents induced by the two series-connected converters are increased. The AC harmonic currents may cause an increase of the stray load loss in the MG and overheat on the rotor surface or the damper winding. To suppress low order AC harmonic currents in the asymmetric control, the power supply configuration composed of many thyristor converters in series with phase-shift to each other is assumed to be introduced [7]. However, due to the limitation of the number of reused converters units available for the “Booster PS”, it is difficult to apply this solution to the “Booster PS”. Thus, in the future, it is necessary to estimate precisely the windings’ heat generation in the MG with the effect of AC harmonic currents taken into consideration.

4 Timing shift control for Booster PS

For the plasma operation shown in Fig. 1, the four units of the “Booster PS” were started or stopped simultaneously. The timings to start and stop all Booster PSs were \( t = -10.0\) s and \( t = 15.0\) s, respectively. In this case, the large reactive power variation of \( \sim 250\) Mvar was observed.

As a countermeasure, the timings to start or stop each “Booster PS” are shifted sequentially to reduce the reactive power fluctuation, as shown in Table 2. In this study, the shift interval between adjacent start/stop timings for each unit is defined as 0.5 s considering the time constant of the MG.

Table 2. Timing shift control for Booster PS

<table>
<thead>
<tr>
<th>Booster PS</th>
<th>Timings to start/stop each Booster PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF1</td>
<td>( t = -11.5) s / ( t = 13.5) s</td>
</tr>
<tr>
<td>EF6</td>
<td>( t = -11.0) s / ( t = 14.0) s</td>
</tr>
<tr>
<td>EF2</td>
<td>( t = -10.5) s / ( t = 14.5) s</td>
</tr>
<tr>
<td>EF5</td>
<td>( t = -10.0) s / ( t = 15.0) s</td>
</tr>
</tbody>
</table>

5 Estimation of reactive power fluctuations

To evaluate the proposed control methods, their effects on the active/reactive power were analyzed using the “PSCAD/EMTDC” code. The total active/reactive powers are calculated as shown in Fig. 5 using individual detailed models for each PFC circuit because the integrated simulation model including all the PFC power supplies needs quite a long computation time in “PSCAD/EMTDC”. In this simulation, each PFC circuit is connected to the ideal AC power source of 18 kV. From the simulation results, the peak reactive power decreased from \( \sim 330\) Mvar to \( \sim 230\) Mvar. The largest reactive power variation is reduced from \( \sim 250\) Mvar to \( \sim 60\) Mvar.

6 Estimation of the MG output voltage fluctuation

The output voltage fluctuation of the MG in the typical plasma operation scenario was evaluated by a simplified simulation model as shown in Fig. 7. This model consists of the MG, two units of the thyristor converters and the externally controlled ideal current source. The calculated active and reactive powers shown in Fig. 5 can be obtained by independently changing the control angle for the thyristor converter and DC output current of the ideal current source. These parameters are calculated by the following equations:

\[
\alpha = \cos^{-1}\left(\frac{P}{\sqrt{P^2 + Q^2}}\right),
\]
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\[ I(\text{kA}) = \sqrt{\frac{P^2 + Q^2}{\sqrt{3} \times 18(\text{kV})}} \times \frac{1}{K}, \quad (2) \]

where “\(\alpha\)” is the control angle for the converter, “\(P\)” is the active power (MW), “\(Q\)” is the reactive power (Mvar), “\(I\)” is DC current value (kA) fed by the ideal current source, and “\(K (=0.907)\)” is the conversion factor between the DC output current and the AC current in the primary side of two transformers.

From the simulation results, it is confirmed that stable control performance for converters in the JT-60SA magnet power supply is expected to be achieved because the output voltage fluctuation of the MG can be drastically suppressed.

7 Summary

To minimize the reactive power fluctuation during the plasma initiation, an asymmetric control together with timing shift control was adopted for four thyristor converters called “Booster PS”. From the simulation results, it is found that the maximum reactive power fluctuation can be drastically reduced from \(~\times 250\) Mvar to \(~\times 60\) Mvar. Moreover, the maximum output voltage fluctuation of the MG can also be reduced from 17.4% to 5.3%. Thus, a stable control of JT-60SA magnet power supplies connected to the MG is expected to be achieved.

As the next step, the heat generation in exciter, rotor and damper windings in the MG caused by the reactive power and AC harmonic currents will be studied in the near future.

References


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