3.5 Power Supply for Fast Plasma Position Control (FCPS)

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3.5.1 Design Overview

According to the physical design there are three plasma configurations in EAST operation, that is the circular, big volume and high-elongated plasma. The fast plasma position control is of fundamental importance for suppression of inherent vertical instability of plasma, especially for high-elongated plasma, and to realize plasma equilibrium controlling and positioning in vertical direction.

The fast plasma position control system consists of Poloidal Field Coils (PFC), Vacuum Vessel (VV), Passive Stabilizing Plate (PSP), Inner Vertical Coils (IVC), and Plasma (Pl). An active control system must be incorporated to compensate for resistive decay of the eddy currents of passive VV and PSP, and to maintain plasma at a reference vertical position.

The main task of Power Supply for Fast plasma position Control (FCPS) is to energize the active control system and to realize the fast current tracking under the command from central control for plasma vertical position control in real time.

The system scheme and interfaces of fast plasma position control system is shown in Fig. 1.

![System Scheme and Interfaces of Fast Plasma Position Control](image)

The system characteristics of fast plasma position control are as the followings:

- Strong electric-magnetic coupling between Poloidal Field coils (PFC), Vacuum Vessel (VV), Passive Stabilizing Plate (PSP), Inner Vertical Coils (IVC), and Plasma (Pl) ----Multi-Variable system
- Plasma inherent instability and randomness of disturbance ----Non-linearity and Time-variant system
- Requirement of fast response (~ms) and high accuracy (<1cm) for plasma vertical position control----Fast Tracking and Fine Control
• Inherent dead time and limit of Switching Frequency----Time delay of power supply
• Delay time of Measurements, Diagnostics, and Calculations----Time delay of Central Control
• Complexity of fault conditions and importance of protection such as I_p Disruption, Insulation failure, Malfunction, etc. ----Over-voltage, Over-current, Over-load (Heat) may be caused.
• Complexity of Ultra-High-Power High-Frequency Switching Power Supply -----Optimization of Topology and Parameter, Power Module, Multi-parallel and Phase-shifting, Load Matching, Control Strategy and Arithmetic
• Electro-Magnetic Compatibility (EMC)

3.5.2 Design Requirement

1) Physical Requirement (see physics design)

2) Technical Requirement
• Peak Ampere-Turns AT_m ≅ 20 KAT
• Current Response t_d [5ms
• Error of Current Tracking I_m % [5%
• 4Q-Operation (Bi-directional Current)
• Peak Power P_m ≅ 2MW
• U_m, I_m
• U_n, I_n, P_n D/T
• Fault Condition
• Plasma Disruption

3) IVC Parameters (Preliminary Design)

![Cross-section view of EAST](image)

Fig.2 Cross-section view of EAST
• IVC: \((R, Z)=240\text{cm}, \pm 60\text{cm},\) anti-series
• Specification of Copper Lead: \(S_{cu}=5 \times 5\text{cm}^2\) -(single turn)
• Current density: \(\varphi_{max}=8\text{A/mm}^2\)
• Bus-Bar: to and back, side by side, \(l=2.50\text{m}=100\text{m}(\text{site})\)
• Equivalent Parameters: \((L_1=L_2=14.35\ \propto H, M_{12}=2.67\ \propto H)\)

<table>
<thead>
<tr>
<th>Turns</th>
<th>Coil</th>
<th>Bus-Bar</th>
<th>Summary</th>
<th>Current(KA)</th>
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<tr>
<td></td>
<td>(Lc)</td>
<td>(Rc)</td>
<td>(\tau_c)</td>
<td>(L)</td>
</tr>
<tr>
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<td>0.28</td>
<td>83.43</td>
<td>2.0</td>
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<td>2.0</td>
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<td>4.48</td>
<td>83.43</td>
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</table>

* Bus-Bar should be taken into account

3.5.3 R & D Basis and Program

In order to face the challenge of FCPS the R & D have been carried out. The technical bases for FCPS are the recent progress of power conversion technique; advanced technology of switching power supply; and power electronic devices.

![Fig.3 Power Conversion Technique](image)

1) Power Conversion Technique----AC/DC/AC converter
2) Advanced Technology of Switching Power Supply
   • Pulse Width Modulation Control (PWM)
   • Power Module
   • Multi-Parallel and Phase-Shifting
   • Parallel Operation and Current Balance
   • Soft-Switching
3) Power Electronic Devices
The IGBT is likely the best option of power electronic devices for FCPS at present.

4) R & D Program

Fig. 4 Power Electronic Device Capabilities

Fig. 5 R & D Program of FCPS
The principle design, digital simulation and principle experiment have been fulfilled now. The engineering design and R & D of prototype will be carried out from 2003 on.

3.5.4 R & D Progress

R & D on FCPS has been made progress on AC/DC/AC converter topology and its control in the end of 2002.

The current-source, three-phase PWM rectifier (AC/DC) and multi-parallel and phase-shifting PWM H-bridge inverter (DC/AC) topology has been studied and developed.

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**Fig.6** Scheme of FCPS AC/DC/AC Converter

1) The current-source, sine-wave and unit power-factor, three-phase PWM rectifier (AC/DC)

The circuit topology and its current vector control are shown in Fig.7 and Fig.8.

**Fig.7** Scheme of Current-Source, Three-Phase PWM Rectifier (AC/DC)
2) Current-Source Multi-Parallel and Phase-Shifting PWM H-Bridge Inverter (DC/AC)

The circuit topology and the principle of SPWM modulation are shown in Fig.9 and Fig.10.
3) Simulation

The simulation in different turns of IVC and different modules of converters has been carried out. It shows that two-turn IVC (N=2) is likely the most preferable option for system design because of the reduced current rating, adequate voltage rating and capacitor size. The simulation result is summarized in Tab.1.

Table 1. Simulation Result in current response of 100Hz

<table>
<thead>
<tr>
<th>N</th>
<th>ΔI_m%</th>
<th>U_c (V)</th>
<th>C (μF)</th>
<th>ΔI_m%</th>
<th>U_c (V)</th>
<th>C (μF)</th>
<th>ΔI_m%</th>
<th>U_c (V)</th>
<th>C (μF)</th>
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<tr>
<td>1</td>
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<td>1500</td>
<td>1000</td>
<td>2.5%</td>
<td>3000</td>
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<td>≤2%</td>
<td>700</td>
<td></td>
<td>≤2%</td>
<td>1300</td>
<td></td>
</tr>
</tbody>
</table>

Remarks:

N----Number of IVC Turns
M----Number of Modules
ΔI_m% ----Maximal Current Tracking Error Percentage
C—Filter Capacitor
U_c—Terminal Voltage of Filter Capacitor

The peak power is about P_m=3.5MW and the peak current are I_m=20, 10, 5 KA in different turns respectively.

4) Principle Experimental Result (only in 10A output and four modules)
5) Summary

The previous result of R & D has shown that the high-power high-frequency current-source PWM converter (AC/DC/AC) will be satisfied with all the requirements of FCPS and has some unique advantages as the followings:

- 4Q-operation (Bi-directional Current)
- Fast current tracking----up to 100Hz and even higher
- Accurate regulation----Error of current tracking \( I_m \% \leq 5\% \)
- Easy for parallel-operation and current-balance----Based on the current-source property
- Easy for capacity enlargement and redundancy design
- Multi-parallel and phase-shifting SPWM to realize high frequency modulation with low switching frequency of devices
- Sine-wave and Unit PF in AC input
- High Feasibility, High Reliability and High Flexibility