Compact Power Supplies for Tokamak Heating

Ge Li[1], Yingui Zhou[2], Haitian Wang[3], Peng Fu[1] and Liang Cao[3]
[1]Institute of Plasma physics, Chinese Academy of Sciences (ASIPP), PO Box 1126, Hefei, Anhui 230031, PRC
[2]National Synchrotron Radiation Lab, University of Sci. & Tech. of China, Anhui Hefei 230029, PRC
[3]Department of Electrical Engineering, Shanghai Jiaotong University, Shanghai, 200240, China

ABSTRACT

As extension of power transformers, efficient large-scale contactless power transfer between stationary and reference frames is a problem of world-wide importance, to such applications as electric vehicles, materials handling and plasma heating for fusion science. Tokamak is the common developed fusion device where heating is recognized as one of its key technologies for its future reactor roadmap. Snubber is often used as protection device in NBI system for Tokamak heating [1-3]. The present NBI generally use 50/60 Hz High Voltage (HV) Insulation Transformers to configure its dc power supply to offer the bias current to the snubber, which could use the full flux swing of the core from the negative saturation point to the positive one of its BH major loop. The snubber weight could then be decreased to its half by using the bias power supply. But this 50/60Hz HV insulation transformer is much heavier than High Frequency (HF) High Voltage (HV) Insulation system. The paper gives the requirement, design and test of this Compact Power Systems based on HF HV Zero Current Switching (ZCS) technologies for Experimental Advanced Superconducting Tokamak (EAST) NBI snubber as well as its potential for its compact HVDC power supply. Its new control strategy is also implemented with one macro pulse composed by the digital defined continuous micro pulses. Some experimental evaluations have been done to verify the analysis results, which have been extended to over 100s and could be used for detail engineering design of power supplies for EAST based on IGBT.

Index Terms - **Compact power supplies (PS), core snubber, experimental advanced superconducting Tokamak (EAST), international thermonuclear experimental reactor (ITER), inductively coupled power transfer (IPT), high voltage (HV) insulation transformers, high frequency (HF), neutral beam (NB), microwave, pulse mode, IGBT, zero current switching (ZCS)**

1 INTRODUCTION

THE Experimental Advanced Superconducting Tokamak (EAST) is being upgraded with 4 MW microwave (4.6 GHz/10-1000 s) and 4 MW neutral beam (NB, 50-80 keV/10-100 s) heating systems as a part of the ongoing EAST Enhancement Programme. This is one of the largest upgrades of the EAST machine carried out within the EAST framework, two positive ion neutral injectors will be implemented in the near future as illustrated in Figure 1. In order to get the solid test foundation of the complex engineering system for about 100 s long pulse or even 3600 s, just as the requirement of ITER [1-4], one test platform is being constructed, which includes the HV snubber as well as its bias power supply. This system will be inserted between the ion source and 80 kV HV Pulse Step Modulator (PSM) power supply [5-6], as a means for protecting the expensive ion source while sparking in operation. Due to the narrow space around the EAST machine, one compact power supply is developed based on high frequency HV insulation transformer implemented with IPT, i.e. inductively coupled power transfer technology. IPT can be used for bi-directional contactless power transfer between one frame and another reference one, and has the merits of being clean, spark free, environmentally benign and low maintenance. It is a solution to the power transfer problem, which has been investigated using coaxial transformers at the University of Wisconsin-Madison, USA [7] and a coupled coil arrangement at Auckland University, New Zealand [8]. This paper describes a new system structure for plasma heating, which gives the requirement, design and test of this bias Power Systems implemented with power electronics based on IPT, where its theories are essentially the same as that of the transformers although IPT deals with the motion case with varied coupling factor. Its control strategy is also described. Some experimental evaluations have been done to verify the analysis results, which could be used for detail engineering design for plasma heating.

Manuscript received on 27 September 2010, in final form 17 November 2011.

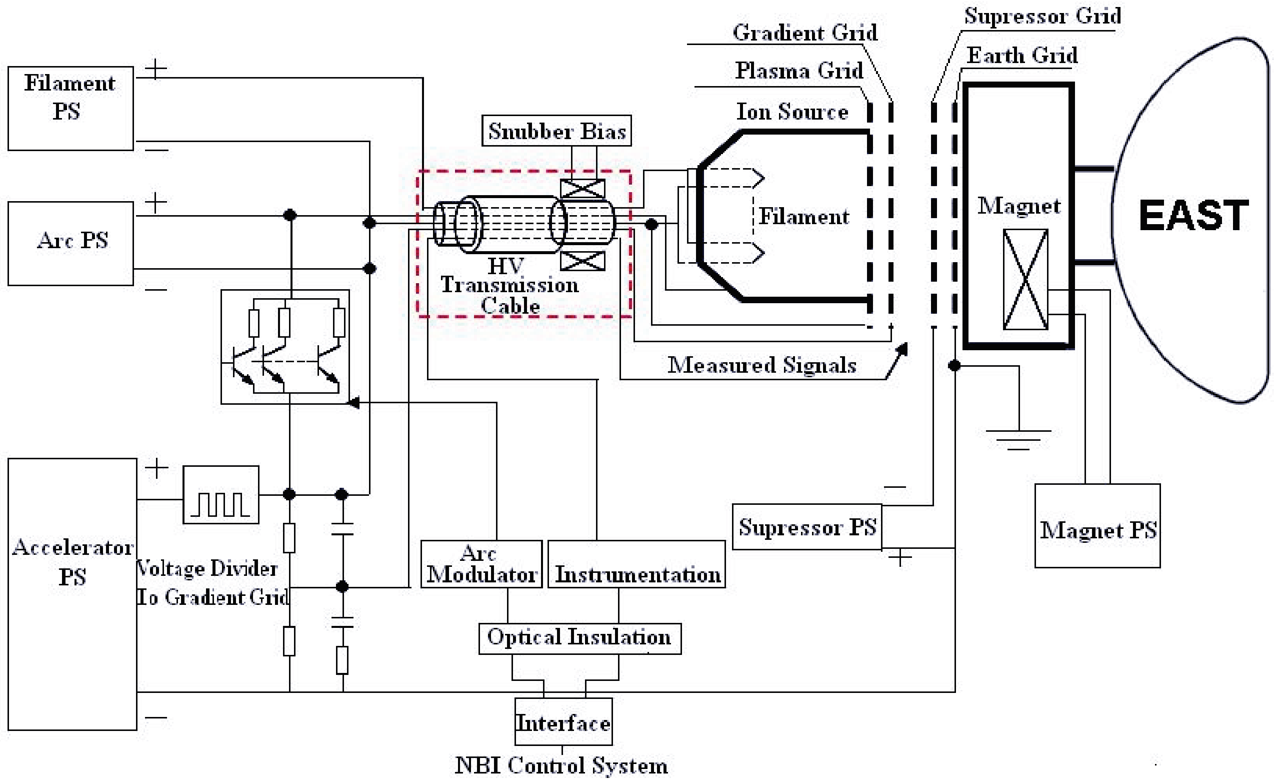

Figure 1. The EAST NBI Configuration with Power Supplies.

The inductively coupled system can be modeled by the equivalent circuit shown in Figure 2. The induced voltage in the secondary coil is given by:

$$V_2 = j\omega M I_1 \tag{1}$$

The maximum possible real current, i.e. the short circuit current

$$I_{sc} = \frac{j\omega M I_1}{j\omega L_2} = \frac{M I_1}{L_2} \tag{2}$$

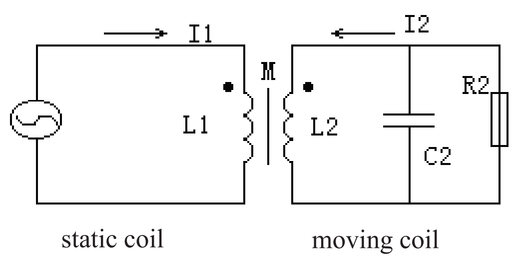

Figure 2. Equivalent circuit of the inductively coupled system.

while the load voltage is

$$V_2 = j\omega M I_1 Q_2 \tag{3}$$

The potential Volt-Ampere capacity for the system can be expressed as [5]:

$$S_2 = V_2 I_{sc} = \frac{j\omega M^2 I_1^2 Q_2}{L_2} = \frac{j\omega k^2 L_1 L_2 I_1^2 Q_2}{L_2} \tag{4}$$

$$= j\omega k^2 L_1 I_1^2 Q_2 = k^2 V_1 I_1 Q_2$$

where k is the coupling factor of the IPT system.

Due to higher insulation requirement in HV IPT system, the leakage inductance is generally fabricated much larger than common transformers. This limits the maximum input primary current and leads to a little low coupling factor between the primary coil and the secondary coil suspended in HV potential. At fixed input voltage, these parameters are two keys to implement IPT theory into power engineering. Increasing the frequency can scale down the physical size of the IPT system, but present IGBT limit realistic operating frequencies below 100 kHz for power levels up to 500 kW. It is clearly shown from equation (4) that the peak power transfer is proportional to the square of the coupling factor. Therefore, increasing the coupling factor between the static frame and the HV one is essential for high power systems.

2 THE MAIN REQUIREMENTS OF EAST NBI POWER SUPPLY

As shown in Figure 1, the power supply system of EAST NB injector includes power supplies for ion source, power supplies for extracting beams and power supply for bending magnet where Ground grid with less than 0.4 Ω ground resistance is used instead of Earth grid for the 100 kV system. Power supplies for ion source are composed by Filament PS, Arc PS, PS for gas supply and Langmuir probe PS. Their functions are supply electricity to these sub systems of ion source by floating on the accelerated PS as specified in Table 1. So, all these power supplies require HV insulation to the ground. Power supplies for extracting beams include Accelerated PS, Gradient PS, Suppressor PS and Snubber PS as listed in Table 1, where stability is the Voltage/Current ripple to their rated values during long pulse period.