Fusion Engineering and Design 96–97 (2015) 425–432

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Power supply system for KSTAR neutral beam injector

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HIGHLIGHTS

- The power supply system in KSTAR NBI consists of DC power supplies for ion source.
- For operation NBI, DC High Voltage based on the low voltage transformer with chopper.
- The surge absorber near the ion source limit the energy deposited to accelerator grid.

ARTICLE INFO

Article history:
Received 19 September 2014
Received in revised form 29 May 2015
Accepted 11 June 2015
Available online 23 June 2015

Keywords:
KSTAR
NBI
Power supply
HV
DC power supply
HVS

ABSTRACT

The power supply system in KSTAR neutral beam injector consists of low voltage and high current DC power supplies for plasma generator of ion source and high voltage and high current DC power supply for accelerator grid system. The arc discharge is initiated by an arc power supply supplying the arc voltage between the chamber wall and 12 filaments which are heated by individual filament power supply. The negative output of arc power supply is common to each positive output of 12 filament power supplies. To interrupt the arc discharging for the fault condition of the arc current unbalance, DCCT current monitor is placed at the positive output cable of the filament power supply. The plasma grid (G1) power supply has the maximum capability of 120 kV/70 A which consists of low voltage regulator with IGBT-switched chopper array system for the voltage control in unit of 600 V and the high voltage rectified transformers to supply DC voltage of 20 kV, 30 kV, and 50 kV. The output voltage of the G1 power supply is also connected to the input of the voltage divider system which supplies the gradient voltage to the gradient grid (G2) in the range of 80–90% of G1 voltage by changing tap of winding resistors in unit of 1%. The charged G1 voltage is turned on and off by the high voltage switch (HVS) system consisting of MOSFET fast semiconductor switches which can immediately be opened less than 1 μs when the ion source grid breakdown occurs. The decelerating grid (G3) power supply is inverter system using capacitor-charge power supply to supply maximum −5 kV/5 A. The important component in power supply system is the surge absorber near the ion source to limit the arc energy deposited to accelerator grid. This paper presents configuration and features of power supply system, main controller, and interlock system of KSTAR NBI.

1. Introduction

The NFRI (National Fusion Research Institute) is the task force institute responsible for the commercialization of nuclear fusion energy in Korea. The functions of the NFRI include the completion and operation of KSTAR (Korea Superconducting Tokamak Advanced Research), the management of the supply chain within Korea, and the application of the nuclear fusion derivation technology related to the ITER (International thermonuclear experimental reactor). Nuclear fusion researchers around the world are interested in KSTAR because it is the only organization worldwide that uses the same structures and materials as the ITER. NBI (neutral beam injector)—the main heating device of KSTAR—is the most direct and effective heating device [1], and it uses a high voltage, which enables it to emit high-speed pulses. To do this, the NBI requires a special power supply. In this paper, we propose a special power supply for the NBI.

For the first time, we have developed a KSTAR NBI system for the Experimental Advanced Superconducting Tokamak (EAST) device. The arc discharges of the ion source were also characterized for the EAST NBI. The design requirements of the ion source for the EAST NBI system are an 80 kV/70 A deuterium ion beam and a 100-s beam pulse length, and the nominal operation requirements for the ion source are a 50–80 kV/40–70 A deuterium beam and a 10–100-s pulse length [2]. JT-60 and JT-60 U (Japan) use positive and negative ion sources, respectively [3,4]. The positive-ion-based NBI system

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http://dx.doi.org/10.1016/j.fusengdes.2015.06.055
0920-3796/

for JT-60, which consists of 14 beamline units and has a beam energy of 70–100 keV, started operations with hydrogen beams, and a neutral beam power of 27 MW was injected at 75 keV into the JT-60 plasma. Then, the NBI system was modified to enable it to handle deuterium beams as part of the JT-60 upgrade modification. After performing research into this matter, deuterium beams of 40 MW were injected at 95 keV [5]. The positive-ion-based sources of the proposed KSTAR NBI system are each designed to have a 120 kV/80 A and 300-s pulse length. The first ion source of the KSTAR NBI was employed by the Korea Atomic Energy Research Institute (KAERI) using a test stand system. The bucket-type positive ion source was developed by KAERI during the early stages of the KSTAR construction phase, and it has been demonstrated with 55 A of hydrogen ion beams at an energy of 100 keV and pulse duration of 2 s. The source was also operated with an extended pulse duration of 300 s for the reduced beam energy of 90 keV and a beam current of 33 A. By performing different KSTAR campaigns, we successfully developed ion sources and installed three positive ion sources. In 2014, the aim of KSTAR NBI was to realize a neutral beam extraction of 5 MW power and a 50-s pulse length.

2. Neutral beam injector power supply

The NBI is the most efficient and directly affected heating device of assisted-heater devices. It was commissioned in 2010 for operation on KSTAR, and neutral-beam injections in excess of 5 MW were tested in 2014. The NBI is comprised of an ion source, a beam line for injecting neutralized high-energy ion beams obtained from the ion source into a tokamak, and a power supply. The NBI's heating device (NBI-1) that is installed on KSTAR has three ion sources. Separate power supplies are used to drive each ion source, namely a plasma-generator power supply (arc and filament power supply) for plasma generation in the ion source, and a high-voltage accelerator power supply (a G1 accelerator power supply, a G2 voltage-divider power supply, and a G3 deceleration power supply) to accelerate the ions to high energy from the existing plasma. With the exception of these, NBI-1 consists of a high-voltage switch system that can cut the interlock situation very quickly (in less than 10 μs), which may be necessary if there are arcs or faults in the acceleration electrode, a surge blocker (snubber), which protects ion sources by cutting the electrical overcurrent when there is a phase fault, a high-voltage measuring and control device, and transmission systems for the transfer of high voltages [6,7]. Fig. 1 shows a diagram of the power supply used to drive one ion source. Table 1 presents the specifications of different KSTAR NBI-1 power supplies.

The voltage and current waveforms at the filament and arc power supplies, the accelerating power supply, and the decelerating power supply are also shown in Fig. 2. Fig. 3 shows the usual variation in the beam extraction using the pre-arc discharge.

2.1. G1 power supply

The G1 power supply, which allows up to 120 kV/70 A of DC power to the accelerating electrode, consists of three high-voltage transformers and rectifiers that can each supply 50 kV DC, 30 kV

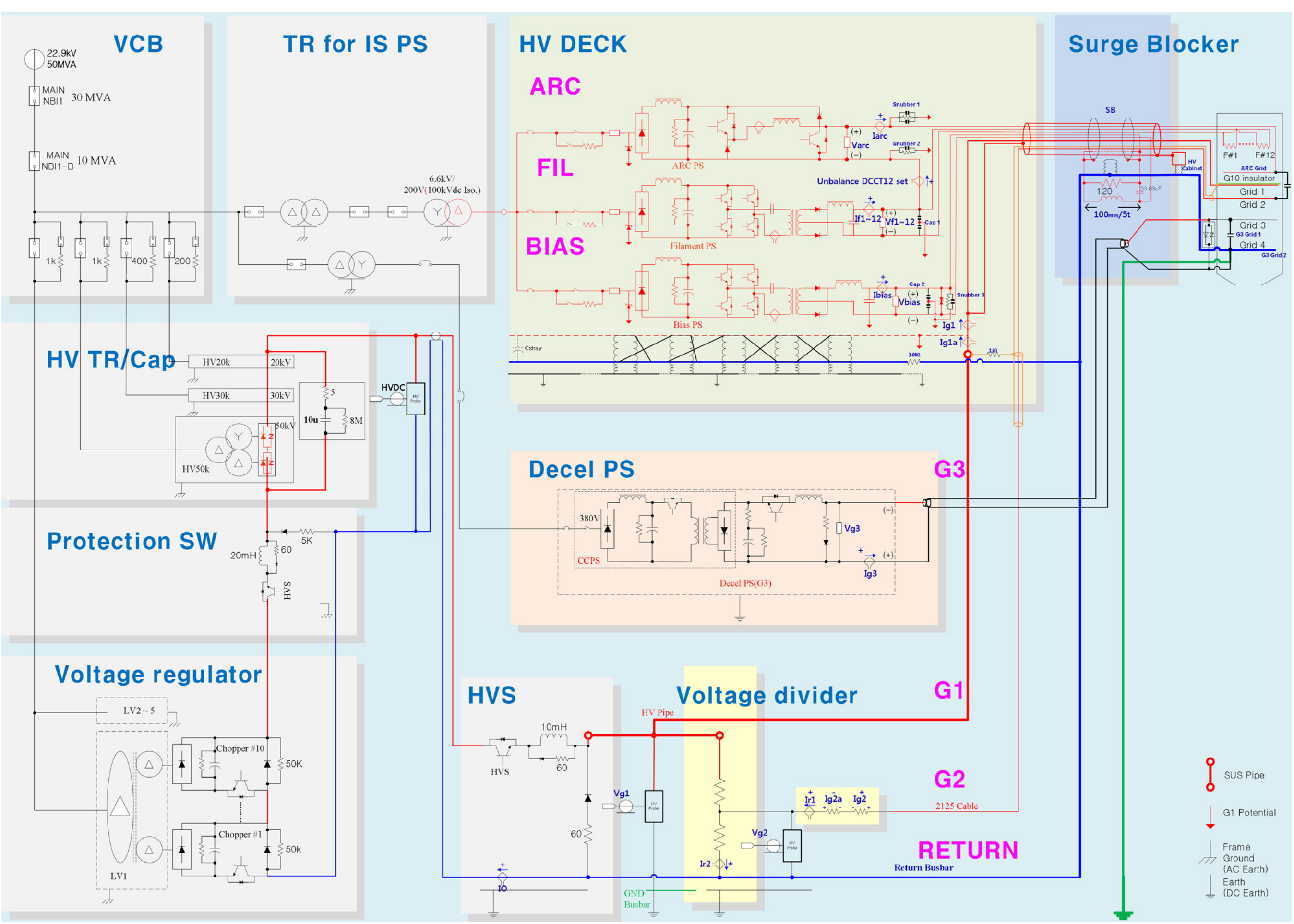

Fig. 1. KSTAR NBI-1 power-supply system single-line diagram.