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A Prototype Acceleration Power Supply for the KSTAR NB System

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An acceleration power supply for the ion source of KSTAR NBI system has been developed. The main requirements of this power supply are maximum current of 70 A and operational voltage of 30 - 120 kV with voltage and current ripples of 2% peak-to-peak during 300 seconds. The output voltage is controlled by a selection of the number of serially connected nine transformer-rectifier and forty IGBT chopper modules. This makes it possible to modulate the output voltage within the range of 20 kV with a step of 0.8 kV. In order to make sure turn-on and turn-off time of the current within the limited values to protect ion sources during breakdown, a hundred and forty of MOSFET modules(3 in parallel) connected in series are used as a high-voltage current switch. This and related circuits ensure 25 μsec on-off switching time. Some initial test results of the developed power supply with a dummy load have been described.

1. Introduction

Two Neutral Beam(NB) systems are planned to be installed in KSATR tokamak[1] to provide heating and current drive until the start of the upgrade phase. The needed deuterium beam power per a beam line is 8 MW with an energy of 120 keV during 300 seconds. DC power required to the ion source and associated auxiliaries comes from a motor flywheel generator(MFG).

In designing the acceleration power supply for the KSTAR NBI system, the following points are mainly considered;

1) safe operation,
1) protection of ion source,
2) limiting the ripple within 2 % over the output range from 30 kV to 120 kV,
3) and cost effectiveness.

To meet the above conditions and needed specifications, the acceleration power supply(APS) was designed on the basis of series connection of rectifiers /auto-section switches for rough control, and rectifiers /IGBT-chopper stacks for fine control. Each of the five rectifiers /auto-section switches is paired with high voltage transformer (HVTR), and 40 rectifiers /IGBT-chopper stacks are paired with 4 low voltage transformer(LVTR). In every LVTR tank there are 10 rectifier-chopper switch circuits. With the number of the connected HVTR by the auto section switches the output is controlled with the step of 22 kV, and with the number of the rectifiers in the LVTR chosen by the chopper switches the output is controled with the step of 0.8 kV. In order to limit the voltage ripple and overshoot during turn ON-OFF time within the regulated value, the chopper switches are feedback controlled with the rate of 10 kHz. This system is superior to other system[2] in the point of cost-effectiveness and ripple control.

Another important requirements of the NB power supply include rapid variation of rising and falling of the load voltage, and high current interruption for ion source protection from the frequent arcing between the grids. This power supply system meets these requirements by employing semiconductor MOSFET switches. The designed duty cycle is a 320 s pulse every 50 minutes. A new gate driver circuit with isolated pulse transformer is also cost-effective compared with other switch circuits[3], because it is not necessary to use a bias power supply for the driver circuit in the high voltage side. For the protection of the fast current switch(FCS) and the ion source from an accidential failure in turning off the current, a fast acting crowbar switch and a fault detection system are installed before the current switch. Also to minimize the transient effects during arcing through ion source grids a low-capacitance transmission line and a fast snubber circuit into the transmission line are installed.

2. Description of the power supply system

2.1. Overall Circuit

Fig. 1 shows a typical schematic diagram of the acceleration power supply for the KSTAR NB system. It consists of input circuits, high voltage circuits, and pulse output switches. Input circuits include vacuum circuit breaker(VCB) and precharge circuit, high voltage circuits include HVTR /rectifier tanks, LVTR /rectifiers, and chopper modules, and pulse output switches include a crowbar switch and a high voltage switch. The input circuits and HVTR /rectifier tanks are located in the outdoor yard, and other high voltage circuit and output switches are installed in the facility room. The output voltage before and after FCS, and the regulated voltage are measured to monitor and control the output. The currents through return pass in HVS tank and regulator/ chopper module are measured to monitor and control the choppers and switches. Current to ion source is also monitored to check the pass of the applied power.

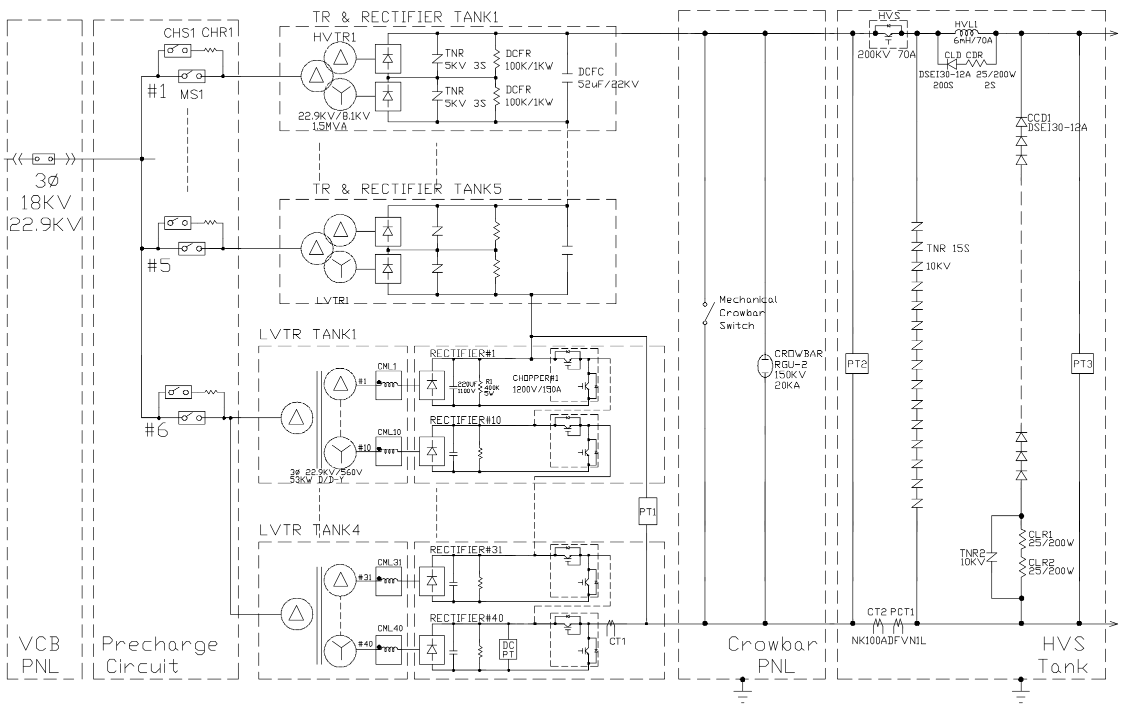


Fig. 1. Schematic of NB power supply.

2.2. Input circuit

Three-phase 22.9 kV from grids or 18 kV from MFG could be selectable as AC input of the power supply. Primary power control is performed by a high speed VCB and precharge circuits including current-limiting fuses(50 A). The fuses are the last resort to protect the power supply and man from an accident. The delay time to cut off the current after receiving the fault signal is controlled within 50 msec. Auto section switches(25.8 kV, 200 A) of the precharge circuit should be set before the operation depending on the needed DC output to the ion source. This operation mode is very critical in determining convenience or cost-effectiveness. In designing this power supply cost-effectiveness was considered more importantly than convenience. 30 kΩ(1 kW) resistors are used to limit the charging current during startup.

2.3. HVTR /Rectifiers

There are five HVTR /rectifier tanks. A HVTR /rectifier tank includes 22.9 kV/18 kV three-phase transformer, rectifier diodes and a capacitor, and surge protecting circuits as shown in Fig. 2. It consists of a cw 1.5 MVA 3-phase power transformer on a single iron core with a delta connected primary and two secondaries which are connected in wye and in delta, respectively. Insulation of 200 kV is done between primary and secondary circuit for the safety. A rectifier part consists of two full wave bridges of each transformer-rectifier connected in cascade for 12 pulse operation giving a voltage output of 22 kV, and one 52μF/ 22kV filter-capacitor to limit the voltage ripple within the specified value. The rectifier module is immersed in insulation oil, and cooling is done with natural convection. Two modules of Zenor diodes, of which operation voltage is 15 kV, absorb the transient spikes during ON-OFF of currents.

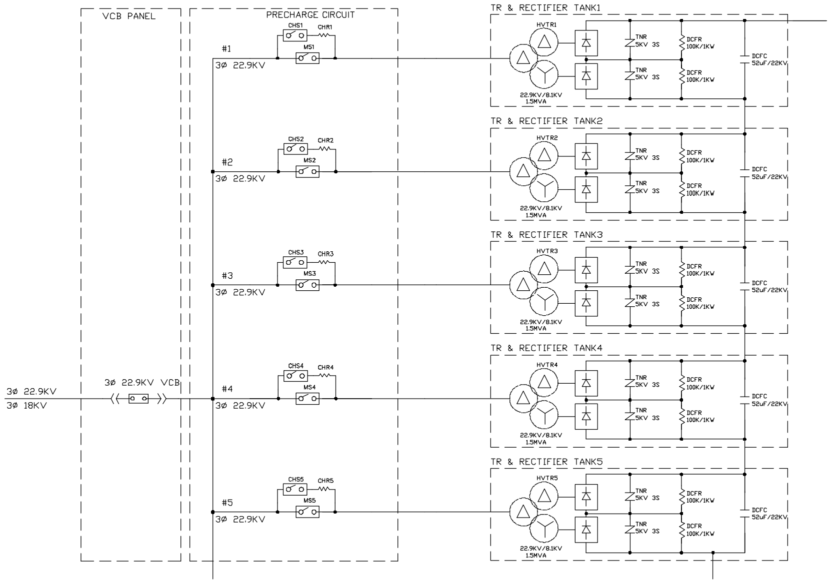


Fig. 2. Schematic of High voltage generation part.

2.4. LVTR /rectifiers and Choppers

There are 4 LVTR tanks. A LVTR has been designed to have 10 outputs per an input(22.9kV/18kV AC) to make the maximum voltage of 8.0 kV DC with 10 chopper and rectifier modules as shown in Fig 3. It consists of a cw 0.53 MVA 3-phase power transformer on a single iron core with a delta connected primary and two secondaries which are connected in wye and in delta. Insulation of 60 kV is done between primary and secondary circuit for the safety. A rectifier part consists of two full wave bridges of each transformer-rectifier like HVTR giving a voltage output of 0.8 kV or 0.5 kV depending on the tab position, and one 190μF/ 1.1kV filter-capacitor to limit the voltage ripple within the specified value. Serially connected four LVTR and rectifier/chopper modules modulate the output voltage within 32 kV or 20 kV. The main purposes of the choppers are to limit the output ripple within 2 % over large operation range, and to decrease the overshoots below 5 %. The control of the chopper is done by internal feedback control circuit. But depending on operation mode of the power supply, pulse modulation is also possible within the limited voltage. In order to minimize the switching noise to outside, 150 μH common mode choke is installed in the secondary line of LVTR. 1200V, 145A IGBT switches are used as chopper switch considering the maximum current rate of 70 A.

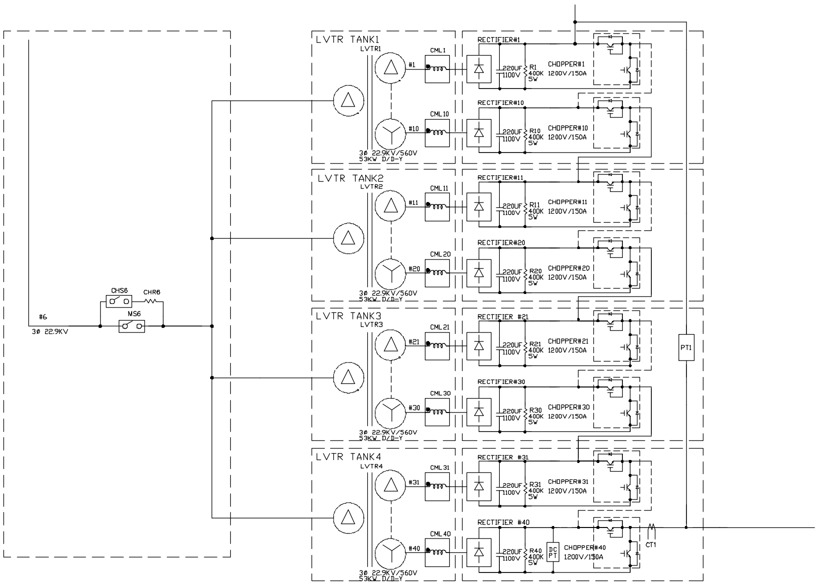


Fig. 3. Schematic of low voltage generation part.

2.5. Pulse Output switches

A FCS is employed between the high voltage supply and the ion source not only to switch the beam repeatedly but also to protect the accelerator by isolating it from the power supply during breakdown events. Newly developed high voltage and high gain BIMOSFET IXBH42N170(1700V, 75A), namely bipolar MOS transistor, was selected in developing the 120 kV/70 A fast switch. This MOSFET is produced by IXYS and has the advantage of higher blocking voltage, lower conduction loss, higher current handling capability, and shorter turn-on and turn-off time compared with those of the similar rating IGBTs relatively. To satisfy the voltage and current ratings during 320 seconds, 3 in parallel and 140 in series connections were made with appropriate protection circuits. Surge protection circuit includes a zenor diode and a free wheeling diode arrays which are in parallel with the load. High frequency transformers isolated from 120 kV were used in triggering the gate drive circuits of the MOSFETs as shown in Fig. 3. This simple gate drive system makes it possible to trig the switch without any bias power supply in the high voltage side. Also the output of the arc detection circuit, in which Pearson CT and Hall CT are used as current measuring devices, is used in controlling the FCS. To limit the switching current less than the maximum turn-off currents (200 A) during the delay time (2 µsec) of the switch, a high voltage reactor(6 mH, 70 A, 200 kV) is installed. All modules are immersed in oil tank for cooling and isolation.

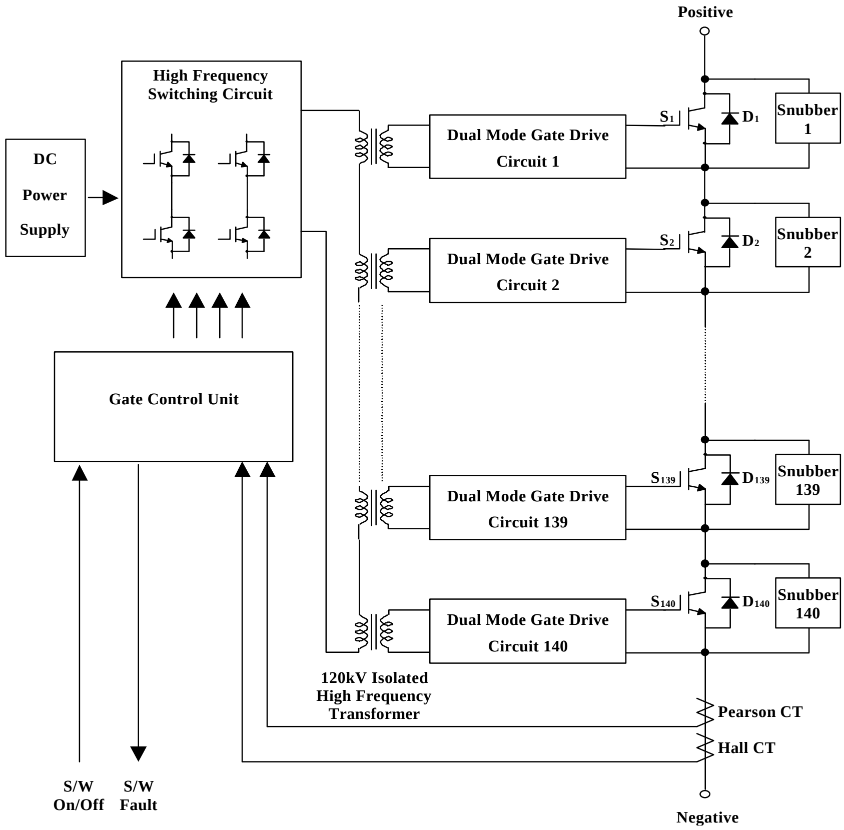


Fig. 4. Schematic diagram of the control and gate driver circuit of the current switch.

3. Control System

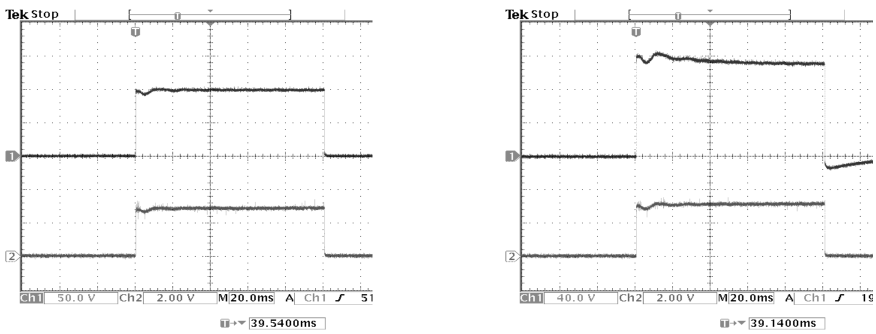
The control system of the power supplies, including acceleration power supply, arc power supply, filament power supply, deceleration power supply, and bending magnet power supply, is based on PC and VME bus system as shown in Fig. 5. VME bus controller supported by VxWorks RTOS(Real Time Operating System) do the following functions;

1. ethernet communication with the main system,
2. user interface with PC,
3. communication with power supplies,
4. power supply control and timing generation,
5. and inter-locks algorithm managements between power supplies.

The operational parameters including setup voltages, currents, timings, time delays, interlock limits, and others could be installed to the VME bus controller from the PC or from the main NB control system via ethernet. Not only independent operation by itself but also slave operation belong to the main NB control system is possible. Real time interlock algorithm executable within 1 msec between power supplies and other system could be programmable depending on operation scenario. Fig. 6 shows the sequence diagram realized by the control software in CPU Board with VxWorks and VME bus controllers.

4. Test results

The constructed power supply has been installed and are being tested. For the commissioning of the power supply a number of tests will be performed to check the performances. As one of the initial testing results, Fig. 7 shows the nominal output voltages and currents into a resistive load(1.69 kΩ, 2 kW) under the condition of 100 kV and 120 kV outputs. Unregulated voltage drifts could be seen in the voltage signals, but they could be controlled to the limited value by tuning the chopper controller. The current rising behavior could be seen in Fig. 8. It shows that the rising time is less than 25 μs. The unperiodic oscillations in the current signal are caused by picked-up noises in the measuring circuit. Because of the limitation of the dummy load, long pulse operation in a full power was not tried yet. First experiments with ion source will be followed after finishing perfomance test with dummy load.



(a) (b)

Fig. 7. Test result of high voltage switching system
(Ch1.: 50kV/div(a), 40kV/div(b), Ch2.: 40A/div., time: 20ms/div.).

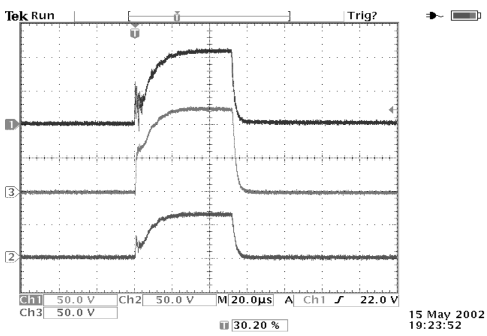


Figure 8. 100kV test result of high voltage switching system
(Ch1, Ch3 : 50kV/div., Ch2.: 50A/div., time: 100us/div.).

5. Conclusion

The acceleration power supply for the long pulse ion source of the KSTAR NBI system has been developed. A simple serial connection of the rectifier blocks by auto section switches and chopper switches makes it possible to control the output voltage from 30 kV to 120 kV with maximum current of 70 A within the voltage and current ripples of 2% cost-effectively. High voltage and high current switch module, made by semiconductor MOSFETs, ensures 25 μsec on-off switching time with the maximum cut-off current of 200 A. A new gate driver circuit with isolated pulse transformer is also cost-effective compared with other switch circuits. The tests carried out up to now have shown a good behavior of the whole system under the limited operational conditions until now.

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