Development of 70kV, 22A DC Power Supply for High Power RF and Microwave Tubes

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Abstract. Our institute (IPR) is involved in the development of High Power RF and Microwave sources for various fusion related heating and current drive applications. All the high power RF and microwave tubes e.g. Klystron, Gyrotron tetrode etc need a high voltage DC power supply to deliver the required high power with necessary protections. To cater to the initial testing and commissioning requirements, the development of 70kV, 22A power supply is initiated. The supply ratings are chosen to meet general tube requirements i.e. Klystron, Gyrotron and Tetrode used in RF group. The supply would be a part of test facility, rather than a regular supply for use in an experiment. Hence some ripple and regulation requirements are relaxed to optimize the cost. However all protections including crowbar protection are accommodated. This supply when ready enables continuous full power testing of TH 2103D Klystron, GLGD-82.6/0.2 Gyrotron and short time (3Sec-"ON", 120Sec-"OFF") full power testing of 1.5MW Tetrode. This paper presents analysis of requirements of various tubes, power supply rating optimization, topology selection, protection requirements and other facilities required. Remote monitoring through DAC and remote control requirement from various locations, are highlighted. Present status of development is mentioned.

1. Introduction
High power Tetrodes, Klystrons and Gyrotrons are the main tubes used by RF group. The typical power ratings of existing microwave tubes are given in Table1. Tetrodes require positive polarity while Klystron and Gyrotron operate with negative polarity. As can be seen the existing power supply of 60kV, 10Amp is not sufficient to test the tubes for full parameters. Hence a test facility is being developed to cater the needs of commissioning and initial testing of the microwave tubes. However for the final use they would be fed by high end Regulated High Voltage Power Supplies that are being developed at our institute.

| Sl. | Tube                  | Power supply requirement | Sl. | Tube                  | Power supply requirement |
|-----|-----------------------|--------------------------|-----|-----------------------|--------------------------|
| 1   | 500kW, Klystrons      | -65kV, ~20A              | 4   | 20 to 40 MHz Tetrode  | +24kV, ~150A             |
|     | TH2103D               |                          |     | 1.5MW                 |                          |
| 2   | 200kW Gyrotron 28GHz  | -85kV, ~10A              | 5   | 91.2MHz Tetrode 1.5MW | +24kV, ~150A             |
| 3   | 82.6GHz Gyrotron 200kW| -42kV, ~9A               |     |                       |                          |

Table 1: The typical power ratings of existing microwave tubes
To meet varying voltage and current requirements, the power supply ratings are to be flexible. Protections must be adequate and must act with adjustable ranges according to the load. Typical existing microwave tubes and their power supply ratings are given in Table1. The list covers most of the existing requirements. However due to development of technologies and varying experimental requirements, ratings other than mentioned may have to be met in future.

2. Topology Selection
A conventional 12-pulse topology is selected with motorized regulator controls. The design accommodates variation of output DC voltage by (i) 0 to 11kV On-line voltage variation system (V.V.S.), (ii) Series and parallel configuration of star and delta bridges and (iii) Off line taps (60%, 80%, 100%). Schematic diagram of the On-line 11kV V.V.S. is given in Fig1. The output of the V.V.S. is fed to the transformer rectifier unit. The schematic diagram of the transformer rectifier unit (TRU) is given in Fig2. The output of TRU (70kV DC) is connected to the Filter panel (RCP). RCP has provisions to vary the polarity, series parallel bridge connections, filter (R/L/C) as per experimental requirements. Series bridge combination is used for operating voltages of ≥35kV and Parallel combination for ≤35kV (Tetrodes). HVDC cables are laid from RCP located in the switchyard to three separate experimental locations namely RF lab, Aditya Tokamak, SST1 Tokamak. The power supply is located in switchyard and is remote controlled. The output voltage is varied with the help of motorized variation system. The power supply’s control and monitoring mechanism can be connected to any of the three experimental locations by changeover panels. When control panel of one location is connected, panels in other areas are automatically disabled. The Data Acquisition and Control (DAC) system of that particular experiment would have the access to control and monitor the power supply.

3. Protections
The protections generally needed by microwave tubes are technically very challenging. In addition to over voltage, over current protection, arc fault protection is necessary. Emergency shutdown access is required in the experimental area to take care of any untoward incident. In the event of an arc fault, the supply output voltage must be brought to zero within 10μsec and the energy deposited into the fault must also be limited to 10Joules. As the supply is of conventional type with no solid-state devices it takes approximately 100msec to switch off the input to the power supply by a circuit breaker. To meet the protection requirement a crowbar switch is provided that short-circuits the power supply DC output within 10μsec. The crowbar takes short-circuit current for 100msec till the input circuit breaker opens.

4. Wire-burn test
Crowbar system effectiveness must be tested before using any power supply for testing the microwave tubes. In the wire burn test microwave tube is replaced with a wire that fuses at specified energy dumping. The tube manufacturers mention the wire material and dimensions in their data sheets. The wire dimensions vary for different tubes according to their fault withstanding capacity. For performing the test an arc fault is simulated at maximum operating voltage of the tube, by closing series switch (Fig.3). This allows the power supply short circuit current to flow through the specified soft copper wire. This fault current is sensed by the protection system and crowbar firing is initiated. Simultaneously isolation of input to the power supply is also initiated. The series resistor R2 (Fig.3) prevents fault current from flowing through soft copper wire. Fault current is diverted to crowbar upon successful firing, thereby protecting the wire. Crowbar should withstand the fault current till the input to power supply is isolated. If the fault energy dumped in the wire is greater than recommended energy in the process, wire fuses, which implies failure of the protection system. The wire burn test is considered successful if the wire remains with the crowbar firing and successful fault current diversion. Any change in the system configuration warrants repetition of the wire burn test for new configuration. An ignitron (NL8900) crowbar is used for Tetrode applications where operating voltage is ~25kV.
A series ignitron crowbar system is being developed for applications where operating voltage is \( \geq 35 \text{kV} \). This supply is interconnected with various auxiliary supplies of the microwave tubes while operation e.g. filament supply, magnet supply, control grid supply etc. Several varying requirements of “on”, “off” sequences are taken care by the DAC system. The supply has several status monitoring signals to accommodate such requirements. Over Voltage, over current, safety interlocks act locally on the power supply. Some critical faults from RF generator also can trip the supply within 10\( \mu \)Sec through DAC.

5. Monitoring
Output voltage and current monitoring serves the purpose of status monitoring and protection in the event of fault. The values of output voltage and current are displayed and recorded for further analysis. They are also fed to protection circuits that initiate protection when the values exceed safe values. The limits to initiate protections can be varied over \( \sim 20 \) to 100\% of power supply’s output ratings to take care of several loads. A potential divider is used for output DC Voltage Monitoring. The ratio of the divider used is 10,000:1. The signal from the divider needs to be isolated for \( \sim 100 \text{kV} \) DC. It is accomplished by Voltage to frequency (V to F) conversion at the HV side. The frequency signal is transmitted through optical fiber cable and it is converted to back by a Frequency to Voltage signal (F to V). The optical cable provides the necessary isolation required for protection, monitoring, DAC processing circuits. This signal is recorded in DAC with a sampling rate of 1000 samples/second. Hall effect DC Current Transducer is used for the output DC current monitoring. This signal is an isolated signal. This signal provides continuous current monitoring and protection from sustained over current fault. It may be noted that it is not suitable for arc fault protection. A Pulse current CT used for the detection of arc fault. It may be noted that for continuous DC current monitoring through pulse CT is not possible. This gives output for fast rising/ falling currents indicating arc fault. A comparator checks this signal and initiates crowbar in the event of arc fault.

6. Present Status
After successful completion of factory acceptance tests, Voltage Variation System (VVS), Transformer Rectifier Unit (TRU) and Filter panel (RCP) have been received. Installation work is expected to start soon.
Figure 1. 11kV Voltage Variation System
Figure 2. 70kV, 22A Transformer Rectifier Unit