Up gradation of LHCD system for rf power level up to 2MW for SST1

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Abstract. To operate superconducting steadystate tokamak (SST1) for 1000 seconds, lower hybrid current drive (LHCD) system has been designed at a frequency of 3.7 GHz., which would couple 1.0 MW CW of microwave power to the shaped plasma. The system consists of various rf passive components and transmission line, employing which the rf power from the source is transported to the antenna. During calibration of transmission line, it was observed that the losses in the transmission line is substantial and eventually would lead to less coupled power to the plasma. Further it is anticipated that more LH power would be required for advanced operation of SST1 machine. Thus it is decided to upgrade the existing LHCD system to 2 MW CW power level.

The proposed up gradation would demand several infra structural changes and needs to be addressed. Due to lack of space, we have proposed a scheme in which additional two klystrons, along with existing two klystrons would be accommodated in the existing space. The low rf power requirements have also been increased to cater the new needs. Accordingly additional cooling requirements have been proposed to accommodate the two new klystrons. The DAC and auxiliary power supplies have been also designed.

The new up graded LHCD system would address several key technological issues. Firstly it would establish the operation of four klystrons at rated power in parallel employing single RHVPS (80kV, 70A). Secondly it would establish the operation of two high power klystrons operation at rated power when their collectors are cooled in series.

In this paper we would present the various requirements for up-gradation of LHCD system to 2MW. The main requirements like high power rf source, along with modified support structure, low power rf systems to drive the high power rf source, auxiliary power supplies required for high power rf source, DAC system improvement, cooling improvements, etc. would be discussed.

1. Introduction
The LHCD system [1] is one of the most important RF system in SST1 [2] used mainly for driving and sustaining plasma current non-inductively for steadystate operation. Presently the LHCD system is configured to provide the rf power of 1 MW at 3.7 GHz to the shaped plasma for 1000 second operation. The system employs two high power (500 kW CW) klystrons to generate 1 MW of rf power. The LHCD system employs waveguide-based components and transmission lines to deliver RF power into the plasma. Many of the critical components have been successfully designed, fabricated, tested and integrated with the system. During the calibration of transmission line, it was observed that the losses in the transmission line are significant due to larger number of physical joints and long
transmission line. Further more LH power is foreseen for sustaining the plasma in advanced operation of SST1 machine. Thus it is decided to upgrade the existing LHCD system to 2 MW CW power level by installing two more high power CW klystrons in the existing system.

In this paper, the up-gradation scheme along with various requirements like rf power driver stage, auxiliary power supplies, DAC, cooling, etc. on the source side are discussed and presented in section-2. As the transmission line components like waveguides, E & H bends, direction couplers, phase shifters, transformers, narrow vessel module, window, grill etc. are capable to handle the improved rf power, hence no modification is made in this part of the LHCD system. Conclusions are drawn in the last section.

2. Up-gradation Scheme

![Figure 1. Schematic of high power source side for the proposed LHCD up-gradation.](image)

It is proposed to upgrade the existing LHCD system to 2 MW CW power level without having large impact on the main LHCD system. Since the provision for up-gradation was kept in our earlier design, therefore all the transmission line components with higher rated power were installed in the transmission line. Thus in this phase only source side is upgraded and the transmission line is kept
intact. In the existing system, the rf power from the output of each klystron (each klystron having two outputs) is fed to each of the four layers of the LHCD system. To include two more klystrons in the existing system, it is decided to employ recombiner, so that rf power from each of the klystron is converted into single output. The output from each klystron is then fed to each of the layer of the transmission line keeping the transmission line section intact. Due to space constraint a new scheme is followed to include two more klystrons. The layout of the new scheme along with the four klystrons is shown in the figure 1.

In this scheme, a platform structure having size of 6.5m x 3m x 2m is proposed to mount microwave components like circulators, DC breaks, wave-guides etc. Since the size of the platform is too large it is made in two parts for easy transportation and assembly at site. The network of cooling lines, required for components cooling, is laid beneath this platform. The klystron base structure is placed on one side of the platform to house four klystrons as shown in figure 1. It is proposed to mount four high power klystron amplifiers at approx. 1m heights from ground level and would carry a uniformly distributed load of eight tones. Below this base structure, the header cooling lines for collector of the klystrons would be laid. A removable table structure is proposed near the klystron base to facilitate for working at height. The area where high voltage power supply and its components are placed is surrounded by a fence structure for security and protection reasons.

The rf drive capability is also upgraded to cater the requirements for all the four klystrons. Each klystron typically needs an rf drive of ~10W. A PLO followed by four individual solid-state amplifiers provides the necessary input to all the klystrons. Another fall back option is also available in which one single source, with in-built PLO and amplifiers, having four outputs would feed the four klystrons.

To operate the klystrons in parallel employing a single 80kV, 70A regulated high voltage power supply (RHVPS) and with minimum anode modulator power supply, identical klystrons to the existing ones, are being procured. The typical parameters of klystron TH2103D are shown in table 1.

### Table 1. Typical parameters of Klystron TH2103D

| Parameter            | Value                                             |
|----------------------|---------------------------------------------------|
| Frequency            | 3.7GHz ± 3 MHz                                    |
| Input power          | 10W max                                           |
| Output power         | ~ 500kW (1000s)                                   |
| Gain                 | ~45dB min                                         |
| Efficiency           | 40% typical                                       |
| Cathode voltage      | -65kV max                                         |
| Beam current         | 20A max                                           |
| Allowable load VSWR  | ≤ 1.35:1                                          |
| Output type          | WR284 waveguide with CPR284F flange, single output after TH20319 recombiner |

Additions of two more klystrons have doubled the requirements of the auxiliary power supplies. The auxiliary power supply includes the magnet power supply (three for each klystron), filament power supply and ion pump power supply (two for each klystron). All these power supplies are in fabrication stage and would be soon ready for testing. The typical specification of each power supply is depicted in table 2.
Table 2. Typical specifications of Magnet, Filament and Ion pump power supply

| (a) Magnet Power Supply |
|-------------------------|
| Current for three sets of magnet | 30A |
| Voltages | 69V, 69V and 35V |

| (b) Filament Power Supply |
|---------------------------|
| Voltage | 12V |
| Voltage stability | +/- 1% |
| Current | 40A |
| Start up surge current | 50A |
| Pre-heating time | 15 minutes |

| (c) Ion pump Power Supply |
|---------------------------|
| Voltage | 5.5kV |
| Power | 50W |

The upgraded LHCD system would be operated remotely. Also its control would be transferred to central data acquisition and control (DAC) system during operation with SST1 machine. Thus our DAC system, which takes care of data monitoring, data acquisition and interlocking for the fail-safe operation of the system, has to be upgraded also. A huge increase in the signal requirements is anticipated for the 4 klystrons and is listed in table 3.

Table 3. Signal requirement of 4-Klystron

| Signal Type | Fast\(^a\) | Slow\(^b\) | Total |
|-------------|------------|------------|-------|
| Analog Input | 18 | 215 | 233 |
| Analog Output | 06 | 44 | 50 |
| Digital Input | 108 | 69 | 177 |
| Digital Output | 02 | 99 | 101 |

\(^a\) Fast signal is the signal having frequency >1kHz for analog and less than 10µs pulse width for digital

\(^b\) Slow signal is the signal having frequency <1kHz for analog and greater than 10µs pulse width for digital

In the up-gradation, four options for the DAC are being considered. The first option proposes to extend the present configuration (VME + front end electronic). In this scheme all the field signals are routed to front end rack where the signals are conditioned. The signals then go to VME through connector panel and buffer card. This option requires simply the duplication of existing system, i.e duplication of electronics cards and VME cards. It needs more racks to accommodate the numbers of card and requires more cabling. Also the connector panel has to be modified. The schematic of this scheme is shown in the figure 2.
The second option would be to reduce the load on VME. Here all the digital signals can be transferred to VME and incorporate the PLC I/O modules near each subsystem and then run the system through single CPU. This will substantially reduce the cabling inside the shield room and no modification in connector panel is required. The schematic is shown in figure 3. The third option requires combination of micro-controller and VME. This option also reduces the load on VME. The efficient local control can be developed using the micro-controller. Less cabling is required and no modification in the connector panel is proposed. The schematic is shown in figure 4.

The last option proposes to employ a fiber optic cable instead of coaxial or twisted pair cables. In this case the fiber optic cards (Tx/Rx) would replace the present electronics cards. Fiber optic configuration has advantage that it is immune to electromagnetic interference and no ground loop occurs. In this case the Front End Racks can be removed. This scheme is expensive and requires expertise for developing fiber optic cards and cables. The schematic is shown in figure 5. Though the last scheme offers the best solution but the optimized solution would be to follow the second scheme now and later upgrade to last scheme, which calls for involved technological challenges, in a phased manner.
As mentioned earlier, addition of two more klystrons have large impact on thermal management scheme. The cooling system is enhanced to take care of additional klystrons need. The main cooling parameters for the klystron system are shown in the table 4. Normally when klystron operates at rated value (500kW CW), it dissipates ~700kW CW in collector which increases the output water temperature by~10 °C with a flow rate of 1000 lpm. Putting two klystrons in series would increase the output temperature by 20 °C. The input temperature of water is 35 – 45 °C for the first klystron and subsequently, the input temperature for the second klystron would be 45 – 55 °C. The final output temperature from the second klystron would be 55 – 65 °C. The pressure drop across each klystron is ~2 bar and pressure drop for two klystrons in series can be accommodated with an inlet pressure head of 8 bar at the first klystron. These data are in accordance with the klystron data specification sheet.

| System                  | Cooling requirements |
|-------------------------|----------------------|
| Collector               | ~ 1000 lpm           |
| Magnet                  | ~ 15 lpm             |
| Upper body-Lower body   | ~ 12 lpm             |
| Klystron tank           | ~ 15 lpm             |
| Recombiner              | ~ 15 lpm             |
| Recombiner load         | ~ 15 lpm             |

The up-gradation work is in progress. Most of the infrastructure is developed and the cooling work is near to completion. Procurement of high power source, low power rf drive system and auxiliary power supply is in progress.

The upgraded system will address basically two big issues. The first being the operation of four klystrons using a single RHVPS, along with efficient thermal management, DAC system, etc. and secondly it will address the issue of handling 2 MW CW rf power to couple to SST1 machine.

3. Conclusion
In this paper, the up-gradation of LHCD system to 2MW (CW) is discussed. The layout scheme for the upgraded source is presented. Its impact on various auxiliary systems like high power rf source, low power rf driver, auxiliary power supplies, DAC system and cooling are discussed. Once it is implemented, it will address main issues like operation of four klystrons using a single RHVPS handling and coupling of 2 MW CW LHCD power to SST1 machine.

References
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