Automatic impedance matching network for ICRH-RF experiments on SST-1

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Abstract. Ion Cyclotron Resonance Heating (ICRH) is a promising heating method for a fusion device due to its localized power deposition profile, a direct ion heating at high density, and established technology for high power RF generation and transmission low cost. For the same reason 1.5-Megawatt ICRH system is developed indigenously for steady state super-conducting tokamak (SST-1).

Since plasma-loading impedance is generally small as compared to the characteristic impedance of the transmission system, a significant amount of power will be reflected from the antenna back towards the generator giving very high reflections to SWR which can damage the high power RF tube. Hence matching network is used to match the total transmission line system to the antenna impedance so that the RF generator sees a matched load and can operate at high efficiency. In the ICRH system, coarse matching network and the on-line automatic matching network designed for the impedance matching of the system to transfer maximum power to the tokamak plasma during 1000 seconds operation. The plasma impedance varies in time on milliseconds scale and hence on-line impedance matching has to match the impedance on a faster scale to avoid the reflections as well as to transfer maximum power to the plasma for heating.

There are two transmission lines connected with Hybrid coupler sourced by RF Generator (RF Power) 45.6 MHz frequency. Automatic matching network is connected with each transmission line, which offers on-line fine matching along with coarse matching system connected with transmission line. The matching system includes stubs, phase shifters and the automatic matching system consists of motorized vacuum variable capacitors connected to 9” transmission line.

The method includes the detection of reflected power in transmission line with the help of probes, give a right signal to VME based data acquisition and control system to do calculations and generate the signal to vary the capacitance of motorized vacuum variable capacitors within few milliseconds with the help of the controller of the motor of the variable capacitor.

Initially automatic matching system was tested with individual transmission lines and then both the lines were matched simultaneously. In order to deliver power to both the lines from a single RF generator, hybrid coupler was used which also protects RF generator from reflections.

Here we present the details of the on-line matching system and its testing results. The significant result is that we could match the variable load impedance with the generator impedance within 40-50 milliseconds with d1600 count of motor controller program.
1. ICRH System overview

The block diagram of the ICRH system as shown in the figure 1 having following sub-systems.

**Probe section:** From this section 22 voltages probe signals are taken out for VSWR plot. Two signals are used for error signal calculation of AMN & hence for matching. The distance between two probe positions is 210 mm.

**Direction Coupler:** From direction coupler forward & reflected power signals are taken out for error signal calculations of the AMN.

![Figure 1: ICRH System](image)

(1.a) **Coarse Matching Network:**
Slow on-line impedance matching (say in order of second) would be achieved with the coarse-matching network. It consists of following components.

**Coarse Stub:** Mechanical shunt tuners are added at appropriate positions on the main transmission line. The reactance of such shorted stub is varied by varying length of the stub.

**Coarse Phase-shifter:** Mechanical phase shifters are added to the transmission line. The reactance of such shorted stub is varied by varying length of the phase shifter. As it involves mechanical movement, matching is expected to achieve in few seconds.

(1.b) **Automatic Matching Network (AMN):**

Automatic matching network would match on-line impedance within milliseconds order of time according to the variation of various plasma parameters like plasma density, plasma position etc. AMN consists of two motorized 0.5-meter stubs & two motorized vacuum variable capacitors (VVC) connected in parallel to each other. This network is located between the generator & the coarse matching network. In the beginning of any plasma shot operation AMN systems are kept in NULL position. At Null position of the system, inductive reactance (XL) provided by the stub movement is equal in magnitude but opposite in direction of capacitive reactance (XC) provided by the VVC, thus net reactance in the system cancels out each other’s effect.
24 probe signals are taken out from the probe section of the ICRH-transmission line. These signals are acquired, digitized in high speed analog board at the rate of 1ms. Software programming written in VME system does the calculation from these signals as per the RF error signal equations & generates the directional signal to motor-controller for the movement of the VVC motor in case of mismatched load.

![Diagram of Real time feedback controlled ICRH – AMN System for SST-1](image)

Figure 2: Real time feedback controlled ICRH – AMN System for SST-1

Magnitudes of the probe signals change because of the new VVC movement & again new error signal calculations are performed which causes new directional signal to be generated to the motor-controller for the VVC movement. This keeps continuing till the error signal becomes zero (it ensures that load is matched).

So AMN is feedback control system as shown in figure 2, which is controlled by the real time VME system and its response time is expected to be in milliseconds.
2. Integrated System with the DAC

Figure 3 shows the block diagram of the DAC system integrated with both ICRH-Transmission line sections.

Coarse matching network can match any load starting from milliohms range to few ohms range obtained from the variable load.

As shown in fig -4 first plot of reflection coefficient curve shows it starts downing from value of 0.9 to 0.15 as AMN Start-Stop Signal generated by the VME (hence VVC motor-1 controller received CW pulse & VVC Motor-2 controller received CW/CCW Pulse). Same as second plot showing error signal window margin added in the VME programming & error signal not crossing the set window limit, so motor driver didn’t get any direction signal from VME system for the same load

Fig 4 third plot shows that after adjusting the response time it starts reducing immediately after receiving the AMN Start/Stop signal. It means VVC motor –1 start moving in CCW direction as soon as its controller gets CCW direction signal from the VME. That time is to ~ 300 msecond. after adjusting the step size of count from d400 to d1200 in VVC motor controller, the matching time reduces to ~90msecond(fourth plot).
Conclusion

The design, development & testing of the AMN is very important aspect for the ICRH experiments in tokamak, where plasma impedance changes dynamically. Following are the important conclusions.

- If time scale or magnitude of plasma impedance variation is known then count value can be optimized further to minimize the matching time.
- Set count (distance) into motor controller from the VME system is not possible, because controller has its own programming (compu-motor S/W) which can be uploaded/downloaded from serial communications only.
- Total matching time is 135 ms with d400 count of motor controller program & vme response time for feedback loop is 2 ms.
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