INTEGRATED SYSTEM ELECTRONICS AND INSTRUMENTATION ;
OPERATION AND DIAGNOSTIC FOR ADITYA-U TOKAMAK

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Abstract

The first phase operations of Aditya-U successfully performed various plasma experiments with repeatable plasma discharges of maximum plasma current of ~160 kA and discharge duration ~250 ms. The electronics and instrumentation requirement for these experiments are mainly of signal conditioning, embedded digital signal processing and automation. The signal conditioning electronics is developed to measure signal through sensors of different plasma diagnostics. To measure accurately and precisely the signals of various strengths, keeping all the embedded information intact in a wide frequency domain in a highly radiating (electric and magnetic field) environment of Tokamak, special care has been taken in terms of design, component selection, signal transmission and EMC/EMI shielding. The signal conditioning design incorporates amplification, attenuation, isolation, filtering, self-test and offset calibration. At present Electronic system caters around the need of hundreds of channels from different diagnostics of Aditya-U. These channels include electronics for Electromagnetic, Spectroscopy, Bolometer, Soft-x-ray, Microwave and ECE radiometer diagnostic to name a few.

Furthermore, FPGA and microcontroller based electronics are designed and developed for plasma operation and control applications. Microcontroller based few real-time feedback control applications were successfully carried out in the last campaigns and these experiments are plasma disruption control using Electrode-Bias and ICR pulse, Radial position control, density feedback control and real-time control of gas-feeds pulses to reduce wall loading of fuel gas. FPGA based timing system is developed which generate various triggers to operate different subsystems and archive data during plasma discharge of Aditya-U.

The Automation & Instrumentation system is developed for baking of vacuum vessel and pumping lines, TF coil temperature measurement and data logging for Aditya-U. The LabVIEW based SCADA application monitors and control the temperature of PLC based baking system.

The paper will describe electronics for plasma diagnostics, Instrumentation, embedded control and timing system for plasma operation.

KEYWORDS: DAQ (Data Acquisition system), SBC (Single board computer), FPGA (Field programmable gate arrays), SCU (signal conditioning unit), DSP (Digital signal processing), CPLD (Complex Programmable Logic Device)

1. INTRODUCTION

Aditya-U [1] diagnostic electronics consists of SCU (Signal Conditioning Unit) for Magnetic probes, Spectroscopy, Bolometer, Soft-x-ray, Microwave and Langmuir Probes. For Aditya-U, Magnetic Probe SCU design is upgraded using CPLD. Electronics for the Soft-x-ray array detector is developed and most of the diagnostics SCU are integrated with in-house developed SBC DAQ system in same RACK. The integration of SCU with DAQ system has improved the signal to noise ratio and eliminated long ground loops among channels which earlier needed additional electronics. At present four nos. of SBC based DAQ system (SBC1, SBC2, SBC3, SBC4) each with 64 Analog Inputs are installed in Aditya. The description of diagnostics, sensors and SBC based DAQ for Aditya-U is shown in Table 1. The DAQ system is triggered by in-house developed FPGA based Timing control system. The timing system provide trigger to different subsystems for synchronized operation in Aditya Tokamak. The timing system receives trigger through fibre optic cables from Toroidal field power supply system and transmit to different subsystems like Gas Pre-Fill System, data acquisition system, radio frequency pre-ionization and heating system, plasma position control etc. The GUI based software is developed using LabVIEW, through which user defined delay can be selected for each trigger prior to plasma discharge. The physical layout and connections among Diagnostics, SCU, SBC DAQ and Trigger system is shown in Figure 1.

For operation of Aditya, Microcontroller and DSP based circuits are developed to control gas feed system in real time and Radial position plasma control respectively. A real-time microcontroller based circuit is developed which stops gas puffing in real time when plasma current falls below pre-set threshold.
For Aditya-U, PLC based Control system are installed for baking and conditioning of vacuum vessel. Baking is one of the most effective method of removing water, volatile hydrocarbons and hydrogen from the vessel walls. This is required to produce impurity free Plasma. The vessel walls are heated at various temperatures in controlled manner for baking [3]. Earlier baking was performed using auto transformer and individual PID controller making system large in size, distributed and disintegrated, requiring tedious wiring loops that involves manual setting. This PLC based system is rugged, reliable, small form factor and automated.

2. SIGNAL CONDITIONING ELECTRONICS & DAQ

The electronics design is customized for each diagnostics which depends on factors such as type and characteristics of sensors, signal magnitude and bandwidth of signals, location and space available at vacuum vessel port.

The design of magnetic probes electronics provide galvanic isolation up to 1kV to protect electronics and data acquisition system from high common mode voltage in case of machine faults. The Isolation Amplifier AD 215 which has built in power supply and buffered input and output is used for the purpose. The isolated signal is adjusted for attenuation or gain with programmable gain amplifier, filtered and differentially transmitted to data acquisition system. Differential transmission improves signal integrity by removing inductive and capacitive coupled noise to signal. The electronic boards, each with four channels are designed for rack mountable Chassis of 3U-sizes. All boards are equipped with features of self-test mode, on board selection for gain, filter bandwidth. For this CPLD is used for implementing the digital logic.
The Bolometer, soft x-ray and spectroscopy diagnostics electronics is required to measure current which are in range of nA-uA. Since the minimum range for measurement is quite low, the selection of first stage operational amplifier in design is crucial to measure signal of weak strength accurately. The ultra-low bias current (fA) IC OPA 129 is used which converts current to voltage at the first stage in design. To avoid loss of amplitude in transmission of low strength signal from sensor, the preamplifier is mounted close to diagnostic port. Double shielded 32 core cable is used between feed-through and front-end electronics of Soft-x-ray detector. The soft-x-ray AXUV array is configured in photoconductive mode and biased with variable voltage provided by electronics while Bolometer AXUV array is configured in photo voltaic mode with no bias. The design includes preamp, amplifier, filter, isolator and driver. For high channel density bolometer, a compact 10 layer PCB is designed.

Since the Signal conditioning electronics is required to function properly in highly noisy environment of Tokamak, it has undergone testing with various IEC-61000-4xx EMC/EMI standards. The Electronics has been tested for Electrostatic discharge immunity test, Radiated, radiofrequency electromagnetic field immunity test, Electrical fast transient/burst immunity test, Surge immunity test, Immunity to conducted disturbances induced by RF fields, Power frequency magnetic field immunity test, Pulse magnetic field immunity test and Voltage dips short interruptions and voltage variations immunity tests. These tests are carried out at local EQDC test lab which has all the necessary equipment and also anechoic chamber for measurement of radiated emission and radiation susceptibility tests All the Diagnostic electronics has been tested at this facility and they all passed these tests successfully for Test Level-2 Class-A.

The in-house developed Data Acquisition system [2] is built using PC/104 bus based single board computer. The system is designed for 64-channel Analog Inputs and simultaneous sampling of 200kS/sec/channel with 16 bit resolution. The system acquires data with defined pre trigger samples as it receives trigger from the timing system. The on-board memory of 4M which is shared among 64 channels presently acquires diagnostic data of duration 640 ms per shot.

<table>
<thead>
<tr>
<th>Diagnostic</th>
<th>Sensor Description</th>
<th>Signal Gain/Attenuation</th>
<th>DAQ System</th>
<th>No. of Analog I/Ps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic Probes</td>
<td>Rogowaski, Mirnov coils, Loop Voltage</td>
<td>Attenuation: 1/10, Gain: 40 Max</td>
<td>SBC1, SBC2</td>
<td>28, 20</td>
</tr>
<tr>
<td>Soft x ray diode array</td>
<td>AXUV diode array</td>
<td>$10^7 \times 50$</td>
<td>SBC3</td>
<td>32</td>
</tr>
<tr>
<td>Spectroscopy</td>
<td>PMT/Photo Diode</td>
<td>$10^5$</td>
<td>SBC4</td>
<td>16</td>
</tr>
<tr>
<td>ECE Radiometer</td>
<td>Schottky diodes (65 to 74 GHz)</td>
<td>1</td>
<td>SBC3</td>
<td>8</td>
</tr>
<tr>
<td>Bolometer</td>
<td>AXUV diode array</td>
<td>$10^4$</td>
<td>SBC4</td>
<td>32</td>
</tr>
</tbody>
</table>

3. ELECTRONICS FOR OPERATION & CONTROL

At present, three categories of feedback control has been installed for plasma operation in Aditya machine. These are Disruption control, Gas-puffing control interlock, Radial position plasma control. Microcontroller based in-house developed electronics circuits are deployed for these experiments. These different feedback mechanisms are briefly explained in the following sections.

3.1. Disruption control

Tokamak plasma is prone to many random events such as disruptions, production and elimination of high-energy runaway electrons etc., having potential for causing severe damages to the machine. These events can be mitigated by detecting pre-cursor signals leading such events then taking proper action in real time just before it occurs. The disruption can be mitigated by massive gas injection or putting a bias voltage on an electrode placed inside the plasma. The microcontroller based electronic circuit is developed which compares with pre-set values to pre-cursor signal leading to these events and generates feedback trigger in real time. Disruption
control experiments are successfully carried out in the last campaigns of Aditya before up-grade with two different techniques viz., electrode biasing and ICRH pulse techniques [5]. These circuits will be re-installed on demand in the upgraded machine.

3.2. Gas-puffing control interlock

In Aditya-Upgrade Tokamak, gas-feed pulses are pre-fixed prior to the initiation of the discharge. The pre-fill gas feed is applied about 150mS prior to the application of loop voltage. In a typical standard plasma discharge of Aditya Upgrade Tokamak (Plasma current ~ 100 kA; discharge duration ~ 180 ms), this scheme of gas-feed pulses work quite well. However, in the discharges which do not evolve fully or are disrupted in the break-down or current ramp-up phases, hydrogen gas injection through the pre-fixed gas-feed pulses load the vessel wall with hydrogen gas and subsequently hamper the next plasma discharge during break-down as well as in the current ramp up phase. To avoid these occurrences, a microcontroller based circuit is designed and developed to control the gas puffing scheme. The circuit will stop the further gas puffing pulses if the plasma current disrupts early i.e. after about 30 ms which is the typical time to reach the flat top of plasma current [4]. The circuit is being also used as an interlock in every shot for neon gas puffing experiment as well.

3.3 Radial position plasma control

For Aditya-U, to control radial position of plasma, DSC based real time control circuit is developed. The circuit consist of TMS controller module which is integrated with multi-channel 12 bit ADC, 12 bit SPI DAC, Analog Input and Output scaling amplifier and isolated digital I/O. The spectroscopy diagnostic signal (in-board, out-board) are input to board which is the sampled at the rate of 10kS/s. The digitized data is software processed in real time on DSC controller for difference, amplification and offset correction. The processed digital signal after analog conversion with same sampling rate as of ADC is transmitted to PXI based FPGA board for further processing. The processed signal is transmitted through optical fibre cable to Fast Feedback power supply for radial plasma position control. Experiments are successfully carried out in the on-going campaign. PID tuning and reducing of ripple in the plasma position has been progressing.

4. INSTRUMENTATION & AUTOMATION

PLC based Control system are installed in Aditya upgrade for baking of vacuum vessel. The approx. 50 heaters and 80 RTDs are installed in vacuum vessel for controlling and monitoring the temperature. The baking process is tested for 48 hrs. It begins ramp up from room temperature, to constant temperature of 150 degree and ramp down. The various PLC modules AI, AO, DI, DO are programmed in Simatic Step-7 software and SCADA is developed in LabVIEW. The block diagram of system and panel mounted PLC are shown in Figure 2
5. RESULTS

Electronics and in house developed DAQ system is successfully working in Aditya-U Plasma operations. The results of few diagnostic electronics (Plasma current, Loop voltage Mirnov, soft x ray, bolometer and ECE radiometer) and DAQ system are shown in Figure 3.

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REFERENCES


