उच्च तीव्रता प्रोटोन त्वरक

3

त्वरकों के लिए आरएफ प्रोटेक्शन इंटरलॉक एवं मॉनिटरिंग प्रणालियां

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चार वीएमई मॉड्यूल युक्त आरएफपीआई प्रणाली

सारांश

त्वरक नियंत्रण प्रभाग, भाभा परमाणु अनुसंधान केंद्र (भा.प.अ.कें.), ने वीएमई 64x आधारित रेडियो आवृत्ति सुरक्षा इंटरलॉक (आरएफपीआई) और निगरानी प्रणाली विकसित की है, जो वर्तमान में कार्यरत है। यह प्रणाली भा.प.अ.कें में निम्न-ऊर्जा उच्च-तीव्रता वाले प्रोटॉन त्वरक (एलईएचआईपीए), आरआरकेट में क्षैतिज परीक्षण स्टैंड (एचटीएस), और फर्मीलैब में पीआईपी2आईटी सहित विभिन्न त्वरक केंद्र में स्थापित की गई है। आरएफपीआई प्रणालियाँ त्वरक केंद्रों में स्थापित विभिन्न संवेदकों, जैसे कि दिशात्मक युग्मक, फोटो गुणक ट्यूब (पी. एम. टी.), क्षेत्र उत्सर्जन जांच, रेडियो आवृत्ति एंटीना, तापमान संवेदक आदि की निगरानी करता है, और यदि निगरानी किया गया कोई भी सिग्नल निर्धारित सीमा से अधिक है, तो 1-2 माइक्रोसेकंड के भीतर कैविटी में रेडियो आवृत्ति तरंगों को बंद कर देता हैं। इन संकेतों को डिजिटल रूप में मेमोरी में संग्रहीत किया जाता है, जो बाद में दोष विश्लेषण के लिए उपयोगी होता है। भारतीय संस्थानों फर्मीलाब के बीच विज्ञान और प्रौद्योगिकी सहयोग के तहत विकसित 325 मेगाहट्र्ज, 7 किलोवाट रेडियो आवृत्ति पावर एम्प्लीफायरों की सुरक्षा के लिए इंटरलॉक सुरक्षा और निगरानी प्रणाली को साकार करने के लिए आरएफपीआई की डिजाइन संरचना का विस्तार किया गया है।

High Intensity Proton Accelerator

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RF Protection Interlock and Monitoring Systems for Accelerators

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One RFPI system with four VME modules

ABSTRACT

Accelerator Control Division, Bhabha Atomic Research Centre has developed VME64x based RF Protection Interlock (RFPI) and monitoring systems presently functional and installed at different accelerator facilities including Low Energy High Intensity Proton Accelerator (LEHIPA) at BARC, Horizontal Test Stand (HTS) at RRCAT and PIP2IT at Fermilab. RFPI systems monitor different outputs of different sensors such as Directional Couplers, Photo Multiplier Tube (PMT), Field Emission Probes, RF antenna, Temperature Sensors etc. installed in an accelerator facility and if any of the monitored signals exceeds the set limit, switches OFF RF power to the RF cavity within 1-2us. All the monitored signals are digitised and stored in memory, which is available for post fault analysis. The design architecture followed for RFPI has been extended to realize Interlock Protection and Monitoring system for protection of 325 MHz,7 KW RF power amplifiers developed under IIFC.

KEYWORDS: *Accelerator, EPICS, fast protection and interlock, RF, VME64X*

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Introduction

ACnD has designed, developed and installed RF Protection and Interlock system which protects high power RF components, such as, RF windows, Couplers, RF power sources, waveguide, RF cavity etc. of an accelerator facility. RFPI system monitors sensor outputs installed in these sub-systems as well as status signals from other sub-systems, such as vaccum and cooling in an accelerator. Upon detecting a fault, it switches OFF RF input to the RF power source within 1-2us. RFPI system has been installed at LEHIPA, BARC and at HTS, RRCAT. Two RFPI systems have been delivered to Fermilab, USA under IIFC.

RFPI Architecture

The RFPI system has been designed based on VME protocol and is modular and scalable in nature. 6U, single width modules have been fabricated and the system is easily expandable depending on the number of signals to be monitored. Each module has a VME carrier board and a rear carrier board which are same for all the modules and function specific mezzanine cards have been placed on the carrier boards.

Each mezzanine card (Fig.1) on the front carrier card can monitor four input signals on SMA connectors. RF signals, PMT signals, Field Emission Probe signals can be interfaced on the front mezzanine cards. Analog/digital/contact signals can be processed by RFPI system in the mezzanine cards placed on the rear carrier card. Analog and TTL outputs are available from these cards.

The RF signals have a dynamic range of 70 dB and the maximum RF input signal to the module is configured to be 0 dBm so that the sensor is in linear region of operation. Analog input/output signal level and digital input/output levels from the field are 5V to the module. The system is configurable for a particular accelerator facility depending on parameters and number of sensors to be monitored. The modules are connected to the master module through Inter Card Communication Bus and it is the master module which takes decision of switching off of the RF signal, by operating the RF switch, based on the firmware logic programmed. Four TTL output signals are available on the rear carrier card at LEMO connectors which can be interfaced to other sub-systems and also to control the RF switch which will control the RF power input to the high power RF system.

The RFPI system has been developed and realized using in-house expertise in hardware, firmware and software and have undergone significant quality assurance stages.

Function and Interfaces of RFPI system

As shown in Fig.2, RFPI system can be interfaced with signals from cavity, other subsystems such as Low Level RF

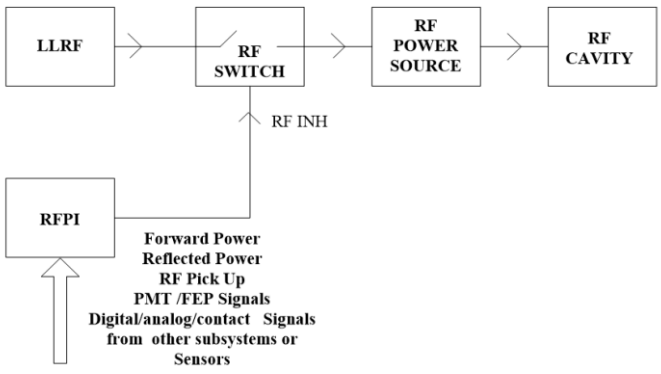

Fig.2: Interfaces of RFPI system to other systems.

Fig.1: One RFPI module with four mezzanine cards.

(LLRF), RF power source, cryogenics, vaccum system, machine protection system etc. and also with sensors such as thermocouples, Resistance Temperature Detectors, water flow/airflow meters etc.

If any of the monitored parameter develops a fault condition exceeding the set limit, RF switch placed at the output of LLRF is switched OFF within 1-2us, which inhibits RF signal from LLRF output to RF power source, thus protecting high power RF components (Fig.3). High isolation, absorptive type RF switch with response time better than 25ns has been selected for this purpose.

All the signals being monitored are digitised and are available for on-line monitoring at a rate of 10kS/s. All the interfaced signals are digitised at a frequency of 6.25MHz and the digitised values are continuously stored in a circular DDR3 memory. Each signal data is available for pre and post fault analysis for a duration of 1ms (Fig.4)

RFPI GUI

The operator of RFPI system has been provided with in-house developed Human Machine Interface (HMI) as shown in Fig.5. EPICS IOC is responsible for all the functionalities supported by the RFPI system including control, monitoring, data display and data collection for diagnostics. The RFPI EPICS IOC is deployed on the VME platform and interfaces to the FPGA. CSS based GUI has been developed, which provides different tabs for control, calibration and waveform data display.

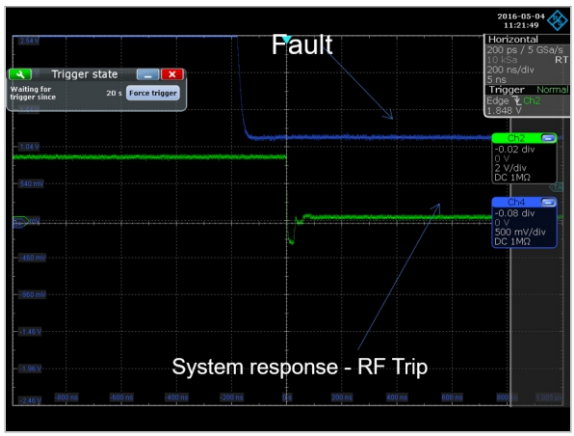

Fig.3: Time response of RFPI system < 200ns.

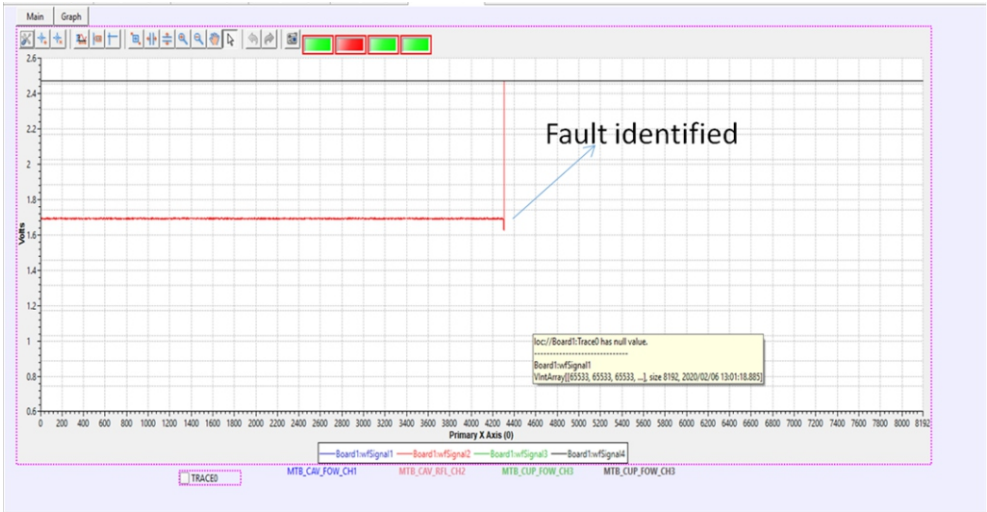

Fig.4: Pulsed RF signal data stored in DDR3 (x- axis gives number of data samples).

GUI features setting of control limit of each parameters monitored by RFPI system. The set limit can be controlled locally or remotely. The value of each parameter monitored is indicated on GUI in appropriate units. A provision has been kept in GUI to set cavity fill time which enables handling high reflected power during transient ON time in pulse mode of cavity operation. Digital inputs to RFPI are monitored and outputs under its control are also displayed. A calibration table has been provided for each monitored parameter so as to incorporate insertion loss or coupling factor of RF signals. Display of all parameters on same GUI panel eases fault diagnosis and arriving at quick conclusions in event of fault/trip. Provision to exclude a particular signal from being monitored and /or not to affect the output signal of RFPI has been implemented. The signal causing trip is also be indicated on the GUI.

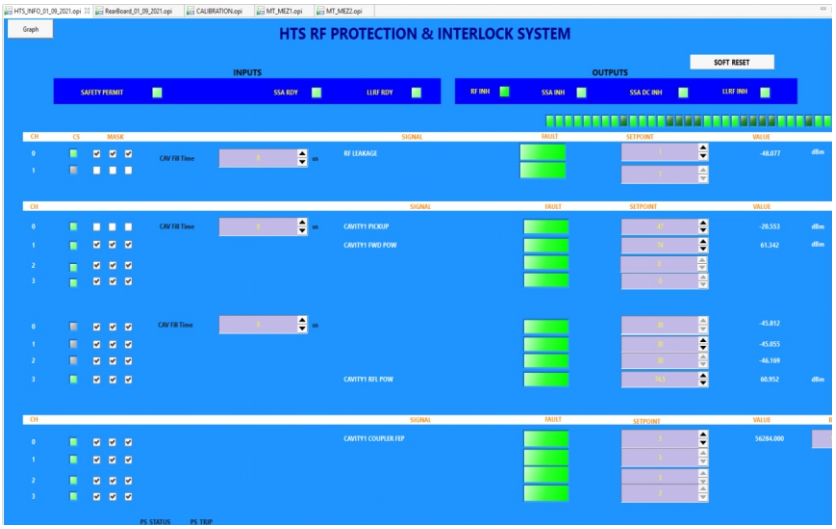

Fig.5: GUI of RFPI system.

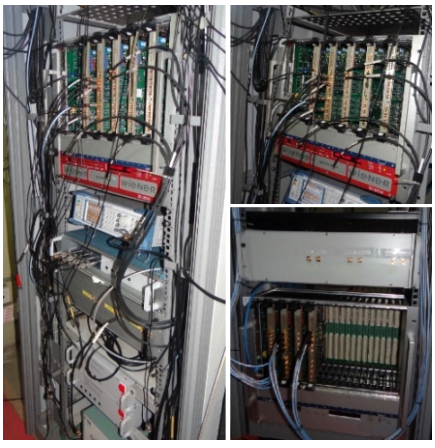

Fig.6: RFPI system for protection of RFQ, buncher and 10 MeV DTL.

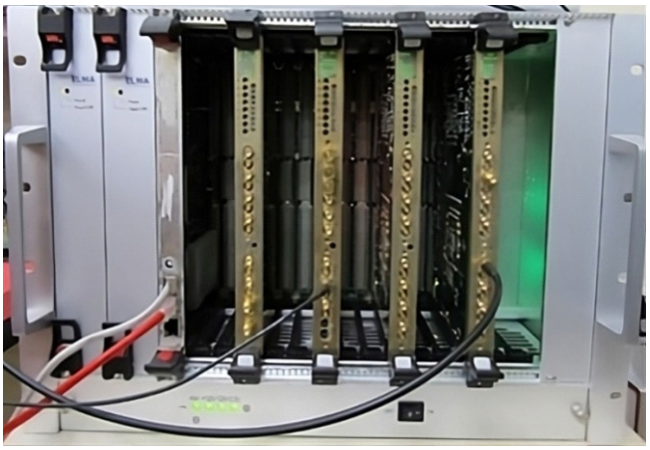

Fig.7: One RFPI system with four VME modules.

RFPI Systems at LEHIPA

RFPI system for LEHIPA has been designed such that each RF cavity is protected by one RFPI system. As LEHIPA has multiple cavities viz. Radio Frequency Quadrapole (RFQ), buncher, 10 MeV and 20MeV Drift Tube Linac (DTL)s, cascading of multiple RFPIS for multi-cavity protection is implemented. Hence, any fault arising in DTL system ceases RF input not only to DTL but also to buncher & RFQ thus avoiding possibility of damage due to beam from RFQ output to DTL.

At LEHIPA, RF signals (forward and reflected power) from directional couplers (placed at Magic Tee input and output), pick up signals from cavity, signals from PMTs mounted at RF windows, and RF load, water flow status etc. are interfaced with RFPI system. RFPI also has the capability to monitor Field Emission Probe signals, RF antenna signals, Digital input signals from other subsystems. Fig.6 shows the RFPI systems installed at LEHIPA. Identical scheme has been followed for RFQ, buncher and DTL cavities of LEHIPA.

More recent developments include addition of linear detection card which has better resolution to monitor RF signals compared to earlier versions. This card has been augmented into RFPI system for protection of 10 MeV DTL section of LEHIPA. Fig.7 shows one RFPI system housing four VME64X based modules. A fast protection action needed optimization of hardware design and firmware development for multiple modules. Modular architecture enables easy scalability to large number of different types of signals from multiple cavities in an accelerator.

Interlock Protection and Monitoring System (IPMS)

A 325 MHz, 7 kW solid state RF power amplifier has been developed and delivered by ACnD under IIFC [5] by combining power output of eight 1 kW RF power modules. An IPMS system [6] has been developed for the protection of the solid state RF amplifier, against any fault conditions. This involves monitoring RF, analog and digital signals from each 1 kW module of the amplifier. External signals such as water flow rate, ambient temperature and safety status signals are also being monitored. Logic interlocks [7] have been incorporated in the system for initialization of RF power amplifier depending on status signals from different subsystems like RFPI and

Fig.8: IPMS with controller.

personal protection system. If any of the parameter monitored exceeds or goes below the set limit, suitable protective actions are taken depending on the signal. All these objectives are achieved by integrating the high speed IPMS with RF power amplifier. IPMS is a VME64X based system which includes seven functional modules and monitors more than eighty parameters from the RF power amplifier.

Forward power, reflected power, drain current and voltage, gate voltage, status of DC power supplies, and temperature of each 1 kW module are monitored and displayed by IPMS. 14 bit ADCs are used to digitize the signals monitored, which are placed on mezzanine cards. The monitored signals are displayed continuously on a local display and also on a remote PC. If any of these parameters, deviates from the set value, corresponding power module is switched off. If more than one RF power modules deviates from set value, all the RF power modules and RF input signal to the driver amplifier are made OFF. The reasons for switching off of the power amplifier are indicated on the GUI, whereas the data acquisition continues for a pre-determined time. If the temperature of any RF module exceeds the set value, all the DC

Fig.9: In house developed GUI for IPMS.

power supplies and RF input to the driver amplifier are switched OFF. Ambient temperature, cooling water temp. and driver amplifier temp. are continuously monitored. Fig. 8 shows the IPMS system with VME controller in a 19" crate and Fig.9 shows in-house developed GUI.

Careful design, layout and component selection has been done so that the IPMS passed the qualification tests [8] such as conducted /radiated emissions and EM field immunity test (IEC 61000-4-6 & 4.3 and 6.3 &6.4), electrical fast transient/burst immunity and surge immunity (IEC 61000-4-4 and 4-5). Voltage dips, short interruptions & voltage variations as per IEC 61000-4-11, and vibration and drop tests IEC-60068-2-64 also were conducted. Industrial grade components have been selected for all the modules of IPMS so that ESS tests are passed as per standard IEC 60068-2-1, IEC 60068-2-2 and IEC 60068-2-14. Burn- in test was done at 40^{0}C for 48 hours integrated with RF power amplifier.

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