CONTROL SYSTEM OF CRYOGENIC PLANT FOR SUPERCONDUCTING CYCLOTRON AT VECC

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Abstract

Cryogenic Plant of Variable Energy Cyclotron Centre consists of two Helium refrigerators (250W and 415W @ 4.5K), valve box with sub-cooler and associated sub systems like pure gas storage, helium purifier and impure gas recovery etc. The system also consists of 3.1K liters of liquid Nitrogen (LN_2) storage and delivery system. The plant is designed to cater the cryogenic requirements of the Superconducting Cyclotron. The control system is fully automated and does not require any human intervention once it is started. EPICS (Experimental Physics and Industrial Control System) architecture has been adopted to design the Supervisory control and data acquisition (SCADA) module. The EPICS Input Output Controller (IOC) communicates with four Programmable Logic Controllers (PLCs) over Ethernet based control LAN to control/monitor 618 numbers of field Inputs/ Outputs(I/O). The plant is running very reliably round the clock, however, the historical data trending of important parameters during plant operation has been integrated to the system for plant maintenance and easy diagnosis. The 400 KVA UPS with 10 minutes back up time have been installed to keep the cryogenic system running with one 160KW cycle compressor during utility power interruptions.

PROCESS DESCRIPTION

Superconducting Cyclotron at VECC requires a dedicated Helium Refrigerator for operation of the Superconducting Cyclotron Magnet at a temperature of about 4.2 K. The process diagram is as shown in Figure 1.

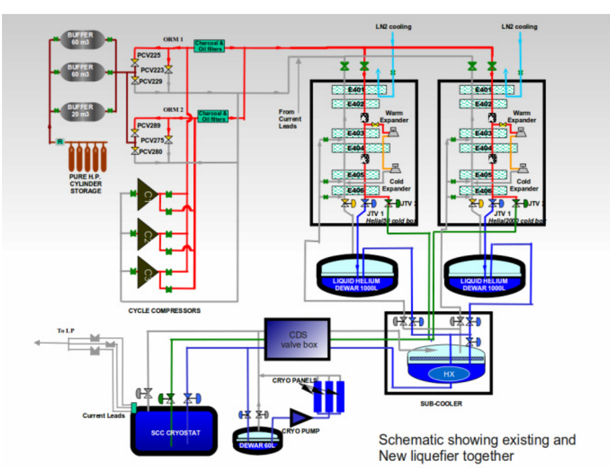

Figure 1: Process Diagram

The heat load of the liquid Helium(He) Cryostat of superconducting cyclotron system is around 160W @ 4.2K. One of the existing two helium liquefiers is connected at a time to the cryostat through a sub-cooler. Each liquefier is having Dewar of 1K litres capacity each. Liquid helium is transferred by keeping a constant pressure of 1.4 bar at Dewar and 1.2 bar at Cryostat. The liquefiers are operating in modified Claude Cycle with two turbo expanders running in series. There are six heat exchangers and two Joule-Thompson expansion valves in the system. The bigger liquefier requires 85 gm/s compressed helium gas at 14 bar pressure and the smaller one requires 50 gm/s. The system is having two Oil Removal Modules (ORM) (100gm/s and 50gm/s capacity) and three numbers of helium screw compressor of 50gm/s capacity each. The high and low pressure lines are common to both the liquefiers and the compressor selection with the ORM has been made flexible so that any compressor can be operated with any liquefier. The higher size liquefier requires two compressors running for its operation cycle. The advantage of such arrangements gives the benefit of compressor isolation for maintenance without stopping the operating liquefier. One 20 m^3 and two 60 m^3 of water capacity helium buffer gas storage tanks at a maximum working pressure of 14 bar are connected to the system.

Four liquid nitrogen storage Dewars of 2x2KL, 1x12.5KL and 1x14.5KL are also operating to receive LN_2 from the supplier tanker and the stored LN_2 is transferred to the Superconducting Cyclotron radiation shield cooling system. LN2 cooled external helium purifier of $20m^3/hr$ @ 140 bar, pneumatic air system for control valve, turbo-expander water cooling system and impure helium gas recovery system are also connected for the proper operation of the plant.

Out of the three, one compressor is powered through 400 KVA UPS. This has been done because in case of normal power failure the liquefier which is connected to the cryostat keeps operating. However, in case the bigger liquefier is in operation, the second compressor is started from the normal power or Diesel Generator (DG) power automatically after 5 minutes. This facility provides the non interruption of the cryogenics operation and also saves the restoration time and pure helium gas loss. Highly skilled manpower need not to be deputed round the clock for restoration job.

CONTROL SYSTEM OVERVIEW

Control architecture of our cryogenic system control is a three layer architecture comprising of device layer, IOC server layer and user Interface layer. The device layer consists of PLCs which controls the automatic process

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sequence operations. The PLCs and the process components are configured to satisfy fail-safe operation. The user interface layer consists of the control computers where the operators issue the set points and the mode of operation commands. The alarm and historical archiver are also running in this layer. Figure 2 represents the overview of the control system.

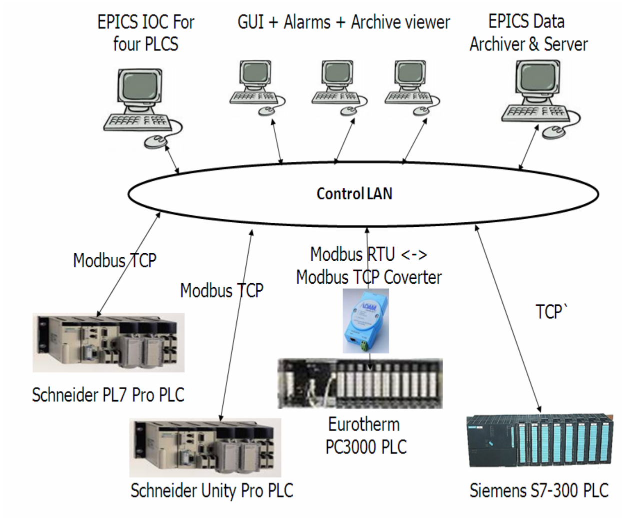

Figure 2: Control system overview

The smaller helium liquefier is controlled by means of Eurotherm PC3000 PLC which is handling 130 field I/Os. The bigger liquefier and the sub-cooler valve box are controlled by Siemens S7-300 PLC having 144 field I/Os. Both liquefiers are designed in such a manner that there is only few initial commands is required to be issued by the operations [1],[2]. For example, to operate with the cryostat in cooled down condition the operator gives only the commands of start liquefier and connection to cryostat. Liquid helium level to be maintained in the 1KL Dewar and the maximum allowed turbine speed are set in the set point and can be modified in certain range by the operator. The plant automatically adjusts the refrigeration power according to the demand by varying the turbine speeds to keep a constant level in the Dewar. Once the liquefier is operating in steady state there is no human intervention is required for the operation of the plant.

The impure gas handling, turbine cooling, buffer tanks, liquid nitrogen Dewars and transfer system and turbine water cooling system are controlled by Schneider PL7 PLC which is having 292 field I/Os. [3]. All the systems related to Schneider PL7 PLC are operated based on mode of operation commands from the operator. All sequence, set points and safety features are programmed in the PLC logic.

The external helium purifier operating at 140 bar, 77K and 20 m^3/hr is controlled by Schneider Unity Pro PLC having 52 field I/Os. Operators have to select and issue command of the Purification or Regeneration mode and rest sequences are automatic. Sequential Flow Chart (SFC) language is used for all PLC programming.

SUPERVISORY CONTROL

Supervisory control is the user interface layer part. In this layer four different PLCs of three different manufacturers are being monitored and controlled through Ethernet based control LAN. We felt a requirement of a SCADA which can give user interface at a common platform as well as exchange data between systems. Also the user interface computers were required to be put at different locations spread over two buildings.

After evaluation of requirements, we selected Experimental Physics Industrial Control System (EPICS) [4] as suitable system which fulfil our need.

We first tested EPICS IOCs (Input-Output Controllers) on simulator software for Modbus TCP protocol for communicating with Schneider and Eurotherm PLC. After testing successfully we implemented this in a linux PC in our network to run the IOC to communicate with Eurotherm and Schneider PLCs. We also used IOC for Siemens PLC with TCP communication. There was no Ethernet port in Eurotherm PLC. So we have put a Modbus RTU to Modbus TCP converter module of Advantech make. Watch dog program is also implemented to generate alarm to operator when there is a communication failure for more than 5 seconds.

The Graphical User Interface (GUI) is made by using EPICS Motif Editor and Display Manger (MEDM) tool. All the process parameters of all the systems are displayed here for monitoring with a proper navigation buttons. Same GUIs are running in three different PCs so that different systems can be monitored together. Process line colour change occurs according to the process so that the process can be viewed at a glance. Figure 3 shows the GUI of liquid helium system overview.

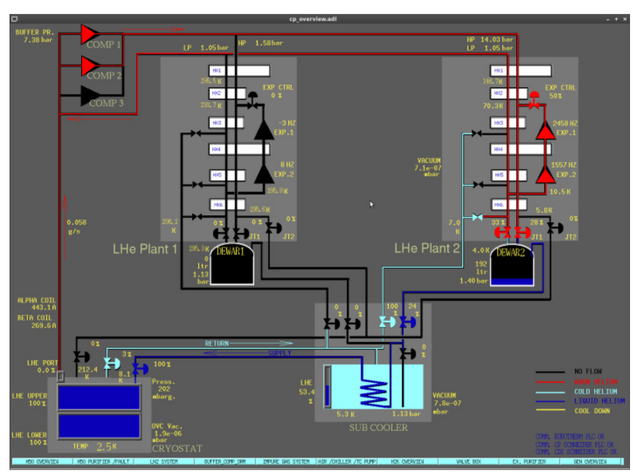

Figure 3: GUI of liquid helium system overview

EPICS Alarm Handler is used to handle the Alarms of the channels observed from all four IOCs to sound an alarm to the operator to take preventative action. For example if the water level in the turbine cooling system tank then the alarm handler sounds an alarm with red coloured indication against the particular alarm. The operator then acknowledges it and takes necessary action to fill up water or change the pump or repair the gland packing leakage etc. Screenshot of alarm handler is shown in Figure 4.

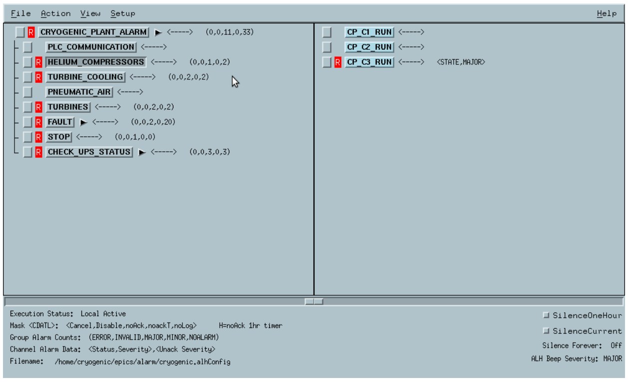

Figure 4: Screen shot of Alarm Handler

EPICS Channel Archiver is used to archive the values of 376 important parameters from all four IOCs. The archive values are stored to hard disk only when the value changes. Standalone archive server is used to host the data for viewing in EPICS Archive Viewer. EPICS Archive Viewer is available at three computers in the network. Process sequence step numbers are also achieved to diagnose the system behaviour for understanding the system dynamics.

Pure gas stock calculation is continuously done by EPICS IOC by monitoring parameters from different systems like pressure and temperature from gas storage tanks, liquid helium level of Dewars, valve box and cryostat etc. The calculated value is the pure gas stock in normal m^3 and archived in the Archiver. The trend gives us the idea of helium gas leak rate from the total installation. Screen shot of Archive Viewer is shown in Figure 5.

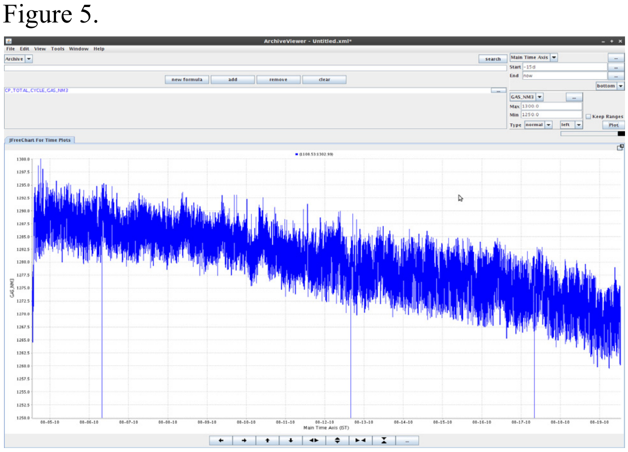

Figure 5: Screen shot of Archive Viewer

All the applications are set in the start up script so that in case the PC got switched off due to UPS power fail or some other problem all the applications get restarted. PCs BIOS are also set such that PC restarts itself after the power failure.

CONCLUSION

We had operated the system continuously for 22 months and 13 months without any interruption with the small liquefier. Presently total control system is running undisturbed and without any human intervention since 19th July 2010 with the new helium liquefier and valve box commissioned. The superconducting magnet of the cyclotron had been cooled down to 4.2K, and filled up with liquid helium and plant is operating in refrigeration mode. The required current is applied in the superconducting magnet and Ne3+ beam tuning in progress. The cryogenic control system is integrated with the main cyclotron control system through EPICS so that cyclotron operator can also monitor cryogenic system status from the central control room.

REFERENCE

[1] U. Panda et al, "Modifications For Optimum Operation Of Helium Liquefier – Refrigerator at VECC, Kolkata", Indian Cryogenics Journal Vol 33 No 1 2008.

[2] R Dey et al, "Operational Experience of Helium Liquefier-Refrigerator after interfacing with K-500 Superconducting Cyclotron", Indian Particle Accelerator Conference, VECC, Kolkata, March 1-5, (2005).

[3] Sandip Pal et al, "PLC-based Helium Gas Management and Liquid Nitrogen Delivery Control System for K-500 Superconducting Cyclotron at VECC, Kolkata", DAE BRNS Symposium on Nuclear Physics, December 12-16, (2005).

[4] EPICS website : http://www.aps.anl.gov/epics.