Process Control Migration of 50 LPH Helium Liquefier

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Abstract. Two helium liquefier/refrigerators are operational at VECC while one is dedicated for the Superconducting Cyclotron. The first helium liquefier of 50 LPH capacity from Air Liquide has already completed fifteen years of operation without any major trouble. This liquefier is being controlled by Eurotherm PC3000 make PLC. This PLC has become obsolete since last seven years or so. Though we can still manage to run the PLC system with existing spares, risk of discontinuation of the operation is always there due to unavailability of spare. In order to eliminate the risk, an equivalent PLC control system based on Siemens S7-300 was thought of. For smooth migration, total programming was done keeping the same field input and output interface, nomenclature and graphset. New program is a mix of S7-300 Graph, STL and LAD languages. One to one program verification of the entire process graph was done manually. The total program was run in simulation mode. Matlab mathematical model was also used for plant control simulations. EPICS based SCADA was used for process monitoring. As of now the entire hardware and software is ready for direct replacement with minimum required set up time.

1. Introduction
One helium liquefier (capacity 250W @ 4.5K or 50 lit/hr w/o pre-cooling) is operational in VECC since 2001. The main application of this liquefier was to cater the cryogenic loads of the superconducting cyclotron in the form of superconducting magnet and cryo-panels situated in main beam chamber for acceleration. Another liquefier (capacity 415W @ 4.5K or 80 lit/hr w/o pre-cooling) was commissioned in 2010 in order to add redundancy and enhanced refrigeration power. Helium liquefiers are running in parallel [1], one in refrigeration mode for superconducting cyclotron and other in liquefaction mode for supplying liquid helium to other users.

The first liquefier has already completed fifteen years of operation. This liquefier uses Eurotherm PC3000 PLC based process controller. Based on Modbus TCP/IP protocol this system is also hooked up to EPICS based supervisory control system. This PLC system has become obsolete [2] since last seven years or so. We have sufficient spares based on which we are still able to run this system. However this system is under risk of stopping the operation in case of malfunctioning of the system and lack of spare.

This paper describes how we have prepared for smooth migration of control system to Siemens based PLC based control system which has a long term support and backward compatibility.

2. Selection of the new process controller system
All leading manufacturers in the world are using Siemens PLC for helium liquefier process control. The new liquefier we have also has Siemens PLC as controller. To have common spare and with
available knowhow we decided to replace the existing PC3000 process controller with Siemens S-7 300 PLC system. Siemens PLC has also has good backward compatibility.

3. Description of PLC hardware and program

The selection of PLC and its hardware is done first. We selected the Siemens S-7 300 PLC [3] and its input and output according to existing wiring so that the control wiring can be modified with very minimum rerouting and without changing the wire ferrule markings. Existing PLC and new PLC input output cards details are shown in Figure 1.

Methodology for PLC programming was finalised after hardware selection. We have the documentation of the entire logic in printed format in Sequential Flow Charting (SFC) Format. This documentation is also updated and verified from latest operating program. Siemens PLC supports all five IEC standard languages [4]. We selected GRAPH language for programming in SFC language. Input and output block processing is programmed using LAD language, Structured DB and Functions. Input, output and variables are named identically using the same pneumonic.

For example discrete input (bit input) for existing Eurotherm PLC “PRIM_VAC.VAL” is for “primary vacuum OK signal”. In Siemens discrete input processing also we have programmed it such that in data block DB1 is named as “DI”. There is a structure named as “PRIM_VAC” inside the DI db and value field as VAL inside this structure. Hence while accessing this input in program we keep the same pneumonic “DI”.PRIM_VAC.VAL for the ease of programming. Representation of old and new DI function block program is shown in Figure 2.

The total sequence was programmed in two GRAPH blocks as each block has a step and transition limitation of 250 blocks. The faults and safety graph block has 67 steps and 75 transition. The main sequence program has 159 steps and 215 transitions. A total of 226 steps and 290 transitions were programmed in two GRAPH blocks. All these program blocks are processed in main sequence (OB1).

The PID logics is put in one block called “Control” written in Instruction Listing language (STL) and processed in time scheduled instance (OB35) of 100ms time interval. There are also some ramp functions, filter functions and PID function blocks associated inside the control DB.

The fault messages generated in the program are stored in fault message DB. The command instructions received from software user interface like EPICS (Experimental Physics and Industrial Control System [5]) are put in command DB. There is also a variable DB which stores the set-points and can accept changes by the software user interface. Old and new SFC program is shown below in Figure 3 and 4 respectively.
Figure 2: Representation of old and new DI function block

Figure 3: Representation of old sequential flow chart for turbine control

Figure 4: Representation of new sequential flow chart for turbine control
4. Description of the EPICS user interface developed

We are presently using EPICS as our supervisory control and data access (SCADA). In this system all variables are named according to their original PLC pneumonic. We have put “CP_” as a prefix to the pneumonic or tag names to represent the data is from cryogenic plant. These data are also having both way real time communications with our superconducting cyclotron EPICS control system. Presently we use Modbus TCP device support [6] as communication protocol for communication of Eurotherm PLC with EPICS input output controller (IOC).

With the replacement of PLC with Siemens S7-300 we initially planned to implement Modbus TCP communication inside the Siemens PLC program and keep the EPICS IOC side unchanged. We successfully tested. But block data copy is the limitation which is to be taken care inside the PLC programming and is error prone.

The S7-300 EPICS IOC code used at Paul Scherrer Institute (PSI) Germany [7] is used at VECC is time tested and reliable one. We could have used it. But in this method also block copy to be managed inside PLC program is the limitation.

Finally we tested the EPICS IOC code for Siemens developed at Aquenos Baden Germany [8] which is found to be very much flexible and allow direct data access without any requirement of block copy. Entire EPICS IOC based on this code has been re-written keeping all process variable names identical to the existing IOC being used.

5. Simulation and testing of the developed program and user interface

After completion of the program one to one verification of the entire code was carried according to the document available with us. Then the program was compiled for error checking. After compiling successfully the entire code the program was run in PLC simulator. Control loops were tested using simulation mode and variable tables. Program and variable table for pressure control loop is shown in Figure 5.

We have procured the required Siemens S-300 PLC hardware and made a test setup. The compiled program was downloaded in the PLC and the PLC was put in run mode. All the input and outputs were tested by external switches and sources. The outputs were measured. After confirming the hardware integrity the control loops were simulated again with the code running in PLC.

Finally EPICS IOC was run which communicated successfully with the PLC. Few errors in the EPICS IOC data base were corrected. The new IOC is handling 1150 records in total for the user interface. The existing user interface screen was tested for process animation. The newly developed
IOC and functioning with the existing GUI is shown in Figure 6. Functioning of alarm handling and data archive were also tested and found to be OK.

![Figure 6: The newly developed IOC and functioning with the existing GUI](image)

**Conclusion**

As long as we are managing the exiting liquefier control with PC3000 PLC and with the available spares we will continue to use it. When there will be crisis we will have a shut down for replacement of the PLC and the user interface. Field input and outputs integrity will be tested first. Then all sequence except the turbine will be tested for proper functioning. The turbine control logic will be again re-verified using variable tables. Then final operation of the turbine will be carried out with close observation.

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