MIGRATION OF REFRIGERATION COMPRESSOR CONTROL SYSTEM

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ABSTRACT

To improve the production performance and efficiency of process plants through migration of control system has become an important strategic initiative. The typical drivers for migration projects include the impact of downtime of existing control system, the ever-increasing cost of maintaining obsolete equipment and inadequate spares and service support.

A well-executed migration into latest redundant control system provides significant operational and maintenance benefits through seamless integration of new and existing control systems. In this paper various issues and challenges during migration of Refrigeration Compressor Control System from PLC to DCS in Ammonia-2 plant at IFFCO phulpur unit are discussed.

KEYWORDS

Surge Control, Programmable Logic Control, Distributed Control System, Redundancy, Scan Time, Voting Logic, Communication, Governor, Vibration Monitoring System.

INTRODUCTION

The Refrigeration Compressor (K-3451) is a multi-stage centrifugal type compressor with inter stage cooling and separation. It is driven by a condensing Steam Turbine (TK-3451). Refrigeration Compressor is used for cooling & separation of Ammonia from synthesis gas from ammonia convertor outlet of Ammonia-2 plant at IFFCO Phulpur unit.

This compressor train consists of M/s Bharat Heavy Electrical Limited (BHEL) make injection Steam Turbine to drive M/s Kobelco, Japan make HP & LP stages of compressors train.

The M/s Dresser-Rand make Local Control Panel (LCP) provides instrumentation for the monitoring and control of a steam turbine driven compressor train. This control system was having GE-Fanuc 90-70 series Programmable Logic Control (PLC), supplied and commissioned by M/s Dresser-Rand in the year 1997. Following control functions were performed by the control system.

1. Monitoring of all field process variables
2. PID control function for all closed loop control
3. Safety logical operation (Shutdown, Ready to Start & Start Permissive Logics)
4. All Pumps (Lubrication Oil, Condensate, Turning Gear & Centrifuge)
5. Valves & Motor Operated Valves (MOV)'s control logic
6. Zener type Intrinsic safety barriers of MTL make to meet hazardous area operation as per Zone-2 Group-IIC T4
7. All three stages compressor surge control (Surge control function was configured in same PLC)
8. Two Operator Interface Stations (One mounted on the control panel & other is desktop type having engineering facility) are installed for operation and monitoring.

For controlling the speed & injection steam of the steam turbine, a separate Woodward make 505 governor old model was installed on the front panel. To monitor the radial vibration & axial displacement of the machine (Turbine & Compressor), Bently Nevada make 3300 Series vibration rack was installed since commissioning of the system.

Why Up-gradation of Existing Control System (PLC)?

A decision was made to upgrade the control system due to following reasons.

1. Poor Reliability: Control System was around 21 years old & control components were failing leads to tripping.
2. Poor Redundancy: Only PLC rack was dual redundant & all I/O's were simplex having no fault tolerance capability.
3. Poor Service Support: Control system was so old & having no service support from the vendor.
4. Poor Spares Support: Difficult to arrange the spares & problem rectification during emergency.
5. Obsolescence of Control System: Control system had become obsolete.

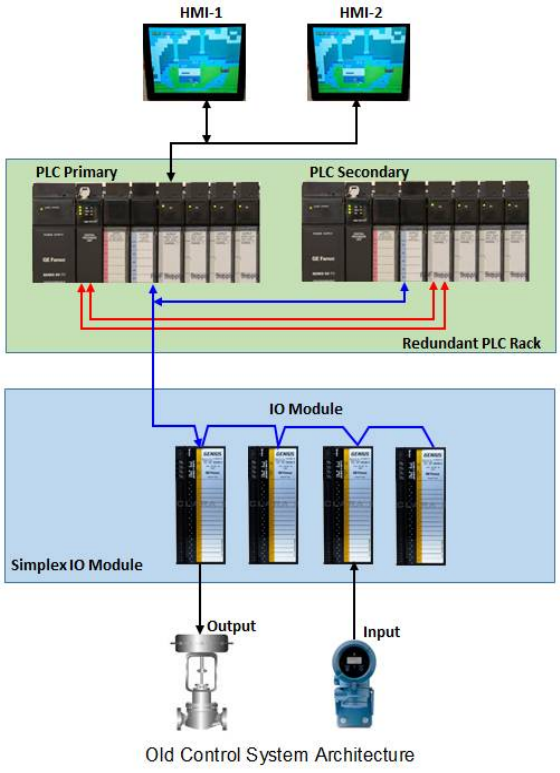


Figure-1

To improve the reliability, looking at all the above problems & limitations of the existing control system, enquiry was issued to OEM for up-gradation of existing control system with fully redundant latest control system.

Finally, OEM submitted the technical & commercial bid for new control system GE Fanuc RX3i model fully redundant PLC.

It was also decided to upgrade the existing obsolete Woodward 505 Governor and 3300 Series Bently Vibration Rack with latest models for integration through MODBUS communication with DCS.

Why migration to other control system DCS?

Even though offered model of new PLC GE Fanuc-RX3i by OEM was technically suitable but due to following reasons, decision was made to migrate from PLC to DCS Control System.

- Better Connectivity: It was better to have same (DCS) control system, which is already being used for controlling total Ammonia plant.
- Better Expansion Ability: DCS has better scope of expansion ability than PLC.
- Easy Engineering: DCS has better scope of online changes during running of the plant than PLC.
- Reduced Service & Maintenance Cost: Customer has to maintain common emergency spares for all system.
- Higher PLC Cost: On behalf of implementation of compressor anti-surge control in PLC, OEM had quoted very high cost for the offered PLC & engineering.
- Lower DCS Cost: It is much cheaper to implement anti-surge control in DCS system with similar scan time.

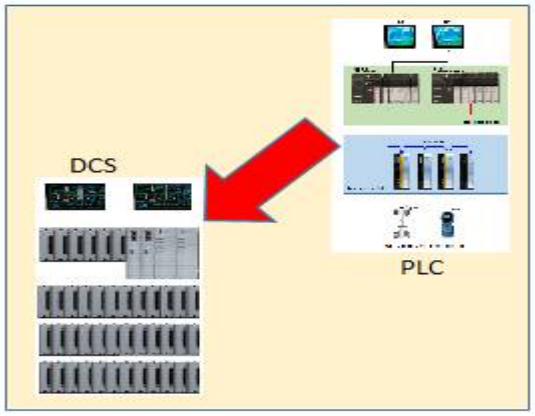


Figure-2 PLC to DCS

Challenges for migration to DCS

1. The biggest challenge for migration to DCS was design, develop & implementation of compressor anti-surge control algorithm in the DCS system as none of the vendor was agreed to provide details & incorporate their surge control philosophy in DCS. Even compressor OEM also denied to provide compressor's surge control details. All vendors were agreed to provide anti-surge control software only along with their own dedicated control system.

2. DCS OEM M/s Yokogawa India Ltd had no experience of compressor surge control & had never been implemented such type of critical control philosophy in any other plant in past.

3. Only compressor performance curves were available in OEM Operation & Maintenance manual.

Setting a milestone by designing anti-surge algorithm

Finally, after detailed discussions, it was decided to design, develop, test and to implement our own in-house anti-surge control algorithm & incorporate in Yokogawa make Centum-VP DCS. A proposal document having complete surge control philosophy was prepared and functional simulation test was done in DCS. Main feature & control philosophy of the proposed surge control are as below.

New control philosophy is equally or more safe than existing system.

- Scan time for all anti-surge control loops are 50 millisecond.
- There are three separate anti-surge control loops for three stages of the compressor (Ist/IInd Stage, IIIrd Stage & IVth Stage).
- Action of all recycle valves are air/signal fail to open & remain unchanged.
- Individual stage suction flow is used for respective stage control loop.
- Individual stage suction & discharge pressure are used for respective stage control loop.
- Speed range for anti-surge control is 9256-11435 (85-105%) RPM for all stages of compressor as existing.
- Anti-surge control remains disabled & recycle control valve remains full open for compressor speed below 9256 RPM. Recycle

valve can not be closed by the operator even on manual mode of controller.

- Discharge& suction absolute pressure are used to calculate the pressure ratio Pd/Ps.
- Mass flow of the compressor shall be compensated with pressure, temperature, molecular weight & compressibility of the gas as in existing scheme.
- Control system shall issue a “Disable” command if surge control conditions are not fulfilled.
- On issue of surge control “Disable” command by the control system, FIC surge controller output shall fall to 0% & recycle valve get full open.
- Once the surge control is disabled by the surge control loop due to either failure of field input or failure of control loop & recycle valve will open 100%, it can be loaded automatically again after recovery of the “Disable” conditions.
- To improve the reliability, all field instruments connected to anti-surge control for individual process variable is triplex (03 Nos.) & there is voting logic to select median among three for control. Failure of any single input will not affect the operation of machine & control shall continue with healthy value of remaining two inputs.
- Two additional control actions (Boost action & Solenoid De-energize) are introduced for additional safety of the machine.

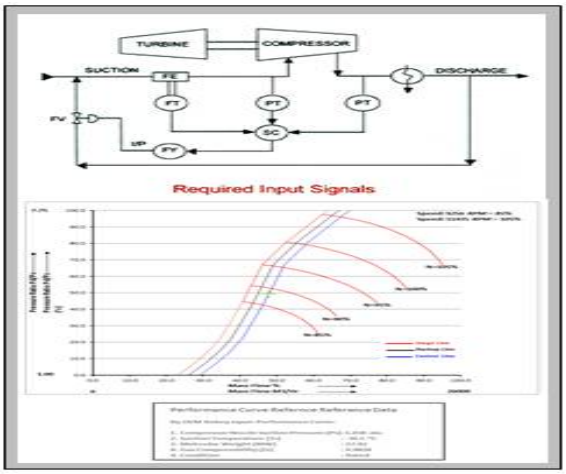


Figure-3 Surge Control Scheme

Refrigeration compressor having three stages (Two stage in LP & one stage in HP). Process flow diagram with surge control loops are shown below. Each surge control loop having three inputs namely suction pressure, discharge pressure & suction flow of individual stage of compressor. The surge controller is basically a flow controller which operates the recycle valve to maintain the sufficient suction flow as per the operating conditions of the machine.

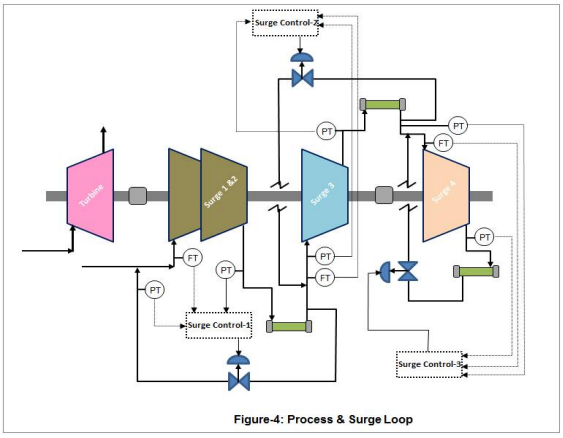


Figure-4 Process & all stages Surge Loop

Surge curves of the different stages of the compressor are extracted from the performance curve of the machine given in OEM O & M manual. Surge curves are basically a representation of minimum recommended suction mass flow with respect to discharge & suction pressure ratio of the compressor at different speed. Surge control curve consists of Control Line, Backup Line & Surge Line. The Backup Line is in between 3% apart from Control line & Surge Line. During normal operating condition, control line flow considered as control set point of the surge controller which is indicated by "+" mark in green colour & actual suction flow is indicated with "O" mark in blue colour.

Three stages of surge curve are shown in the following figures.

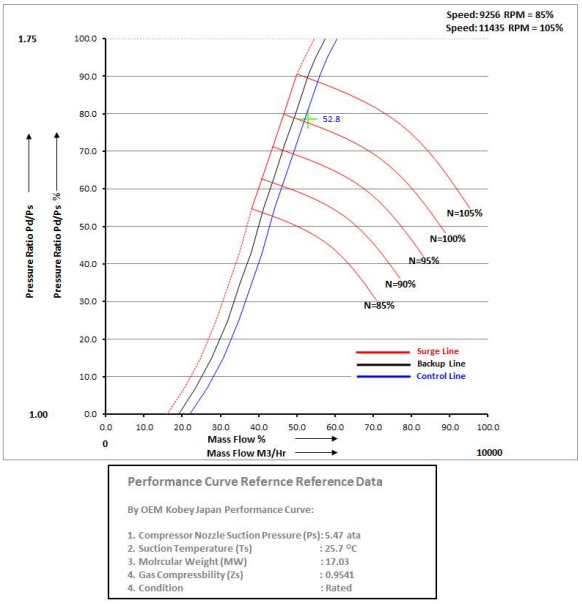


Figure-6 III[rd] Stage Surge Curve

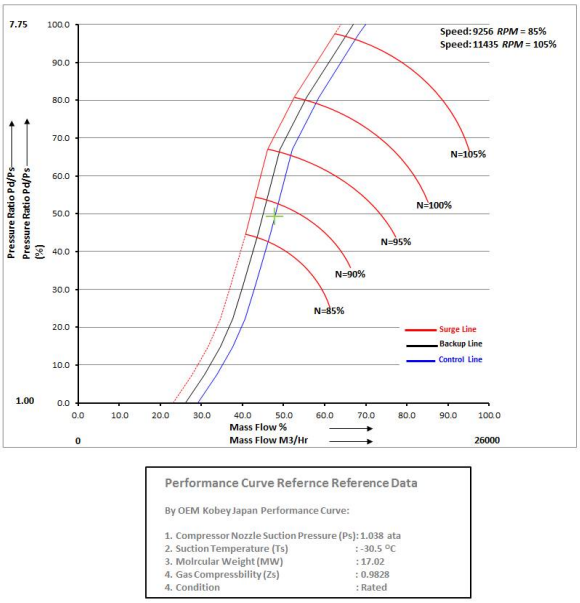


Figure-5 I[st]/II[nd] Stage Surge Curve

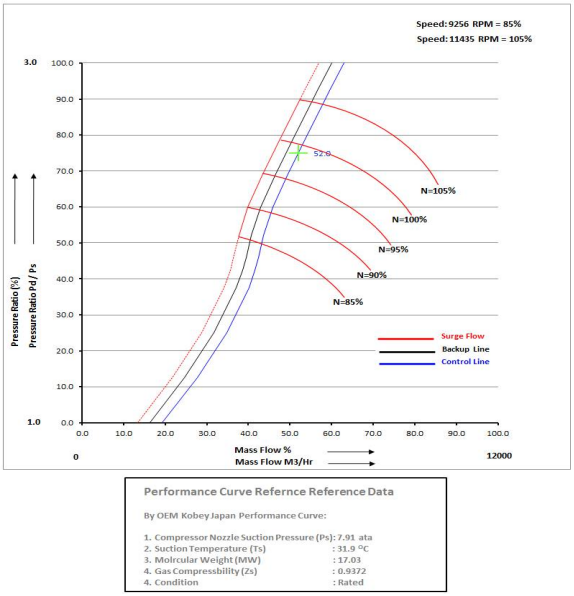


Figure-7 IV[th] Stage Surge Curve

Main Control Actions in Surge Control Algorithm

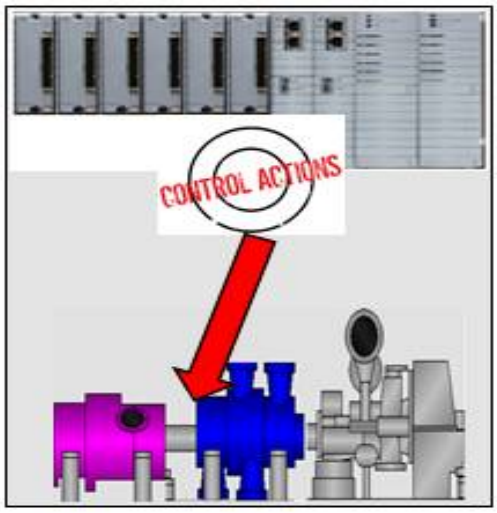


Figure-8 Control Actions in DCS

There are following control actions configured in surge control philosophy. Some of the following actions are used to run the compressor efficiently & some are used for safety of the machine. These control action may be activated one by one or simultaneously depending on the process conditions.

All data for surge control are extracted from performance curves of the compressor provided by OEM manual.

- PI Control Action: During control while process is operating normal, only PI (Proportional+Integral) control action remains active.
- Variable Proportional Gain & Derivative: In case suction mass flow reduces with higher rate, then control system introduces variable proportional gain & derivative action.
- Variable Proportional Gain & Integral Action: If suction mass flow goes below control set point then this control action shall be introduced.
- Set Point Shift Action: This control action shall be introduced in case compressor is stuck in surge cycle.
- Step Ramp Control Action: This is additional control action to support PID control action. It opens the recycle valve in steps.
- Boost Open Action: Control action introduces another safety control action while suction flow reaches the surge line. In this case, control system will open recycle valve 10% immediately.
- Solenoid Valve De-energize: This control action become active when suction mass flow goes below surge line does not recover within 5 second.
- Control Disable Action: Activated while either operating conditions are not normal or trip of the machine.
- Manual Override Action: Controller has feature to switch over to Auto mode while suction flow goes below control set point & controller is running in manual mode.
- Auto Loading Feature: Controller has capability to auto loading of the compressor while abnormality is recovered.
- Variable Ramp Rate: Recycle valve variable ramp rate for loading during auto or manual mode.

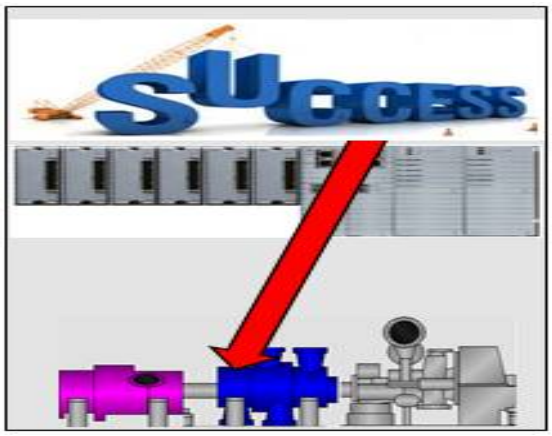
Story of Success

Finally, proposed surge control philosophy is implemented in M/s Yokogawa make Centum-VP add on DCS control system successfully in September-2018 during annual shutdown. Functionality of all control action were checked on full load & partial load of the compressor. All tuneable parameters & control constants are tuned & fixed during running condition of the machine.

Following are the operational & maintenance benefits of the implementation in DCS for the compressor control system.

- Improved reliability with complete redundancy at each level.
- All safety trip logics are made 2OO3 in place of 1OO1 to improve the safety level of the machine.
- All field instruments connected to surge control loop are made triplex (03 Nos.) for individual process variable with median voting to improve RAM (Reliability, Availability & Maintainability).
- Improving availability by installing additional field instruments in critical service.
- Local pneumatic field instruments are also upgraded with SMART instruments & configured in DCS to improve the operator effectiveness.
- Being same add on DCS control system & seamless integration with existing DCS, all information related to the machine are available at all operator stations.
- Graphical representation of safety interlocks (Trip, Start Permissive, Pump Start / Stop & Valves logic) for ease of operators.
- Alert alarms are provided for the different critical condition of the machine.
- Improved trending & data logging of reports.
- Easy engineering for addition & configuration of new tags.
- Easy diagnostics & troubleshooting.
- Lower maintenance cost because of same DCS system having common inventory spares & service support.

After migration from PLC to DCS control system, Refrigeration Compressor overall performance of the surge control loops is found functioning well & highly satisfactory.



HP High Pressure

LP Low Pressure

RAM Reliability, Availability & Maintainability

SMART Single Module & Auto Ranging Transmitter

RPM Revolution Per Minute

Total migration cost of add on DCS control system is substantially low in comparison to PLC cost which was offered by OEM.

This is matter of pride and setting a milestone in design, development, testing & implementation of surge control for centrifugal compressor.

ACRONYMS

PLC Program Logic Control

DCS Distributed Control System

HMI Human Machine Interface

OEM Original Equipment Manufacturer

I/O Input/Output

PI Proportional, Integral

PID Proportional, Integral, Derivative

LCP Local Control Panel

MOV Motor Operated Valve

REFERENCES

1. OEM Operation & Maintenance Manual.
2. Operating Experiences of the Machine.
3. Text Book References of Surge Control phenomena in Centrifugal Compressors.

BIOGRAPHIES

Shri A.P.Rajendran was born in Dharmapuri, Tamil Nadu, India in the year 1965. He graduated in Instrumentation Engineering from Madras Institute of Technology (Anna University). He joined IFFCO Ltd in 1989. At present he is working as Dy. General Manager (Instrumentation) at Phulpur Unit of IFFCO Plants

Shri Animesh Singh was born in Varanasi, Uttar Pradesh, India in the year 1967. He graduated in Electrical & Electronics Engineering from Birla Institute of Technology, Ranchi. He joined IFFCO Ltd in 1989. At present he is working as Sr. Manager (Instrumentation) at Phulpur Unit of IFFCO Plants.