MICROPROCESSOR-BASED MULTI-LOOP CONTROLLER FOR CRUDE OIL LOADING

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ABSTRACT. Saudi Aramco operates several Crude Oil Terminals in Saudi Arabia. Achieving smooth flow control of the crude oil flow rates was always difficult in the past. The conventional controllers had fixed set points and were not adequate because they did not offer full protection and control since the suction pressure is a function of flow rates and speed of the loading pumps. The instrumentation enhancements, through the use of intelligent microprocessor based multiloop controllers offered a solution for a smooth operation and to keep loading operation within the desired operating envelope at all times. The state of the art programmable controllers through the dynamic calculations of process constraints, allowed the loading pumps to be used safely and provided a smooth transfer to the higher flow rates when needed.

1. INTRODUCTION

Saudi Aramco operates several Crude Oil Terminals in Saudi Arabia. At one of the Crude Oil Terminals, oil is pumped from the storage tanks via combination of 2000 HP constant speed booster pumps and a 7000 HP variable speed loading pump (LP) to the offshore berths to load the ships. Smooth flow control of the crude oil flow rates was occasionally a problem in the past at this facility. The low flow rates required for starting and topping off operations created cavitation problems that led to pump vibrations and unstable operation.

The constant speed booster pumps delivered 65,000 barrels per hour (BPH) of crude oil and the low flow required for starting and topping off operation was only in the range of 10,000 - 20,000 BPH. This was achieved through throttling the flow control valve (FCV) in the loading line, which produced high differential pressure across anticavitation type flow control valves. The process caused severe pump cavitation leading to induced vibrations in the piping around the area making the operation unstable and the facility unsafe.

In the past, loading pumps were controlled via conventional electronic controllers to provide flow and pressure control. The conventional controllers had constant set points and were not adequate because they did not offer full pump protection and system control since suction pressure is a function of flow rates and speed of the loading pumps. Net positive suction head (NPSH) requirements were not satisfied at all process flow conditions. Also, the controllers were not backed up and failures resulted in the upset of the crude loading process.

One of the major problems of the original controllers was the ability to transfer the control smoothly between the FCV and the Loading Pump when going from low flow rates (FCV control range) to high flow rates (loading Pump control range) and vice versa. In most of these cases the two controllers overlapped each other and the flow rates to the tanker were never steady.
2. ENGINEERING SOLUTIONS
A detailed study of the process was conducted and evaluation of various options from piping modifications to instrumentation enhancements to solve the problem were made. Three possible solutions were reviewed:

1. Reduce cavitation by replacing the existing control valves with anti-cavitation type to compensate for high pressure drops.
2. Provide smooth flow control by means of instrumentation and control enhancements that includes redundancy.
3. Protect the loading pumps inadequate Net Positive Suction Head (NPSH) during crude loading at all times, by means of simultaneous dynamic calculation of both the NPSH and suction pressure set point.

After a thorough evaluation, it was determined all solutions were necessary to overcome the loading flow rate control problems and to operate the loading pumps within their calculated safe operating windows. Actions were taken to implement all of them.

Problem of cavitation was solved by replacing the flow control valves with anti-cavitation type valves, which reduced vibrations (solution 1). The instrumentation enhancements, through the use of a microprocessor based multiloop controller was the solution to the smooth operation to keep the loading operation within the desired operating envelope at all times (solutions 2 and 3). A state of the art selected multiloop controllers allowed the loading pumps to be used safely and provide a smooth transfer to the higher flow rates when needed. Also, the logic for engineering line up was included in the controller software instead of implementing complex and unreliable relay logic as in the previous operating control system.

3. LOADING OPERATIONS
A typical loading system would transfer the crude oil from a storage tank by booster pump(s) to a loading header through the loading pump, the meter skid, the FCVs, and the loading berth to the tanker.

4. LOADING FACILITIES
For a flow rate less than 85,000 BPH, the loading pump is normally bypassed since a single tank booster can pump up to 65,000 BPH. Two booster pumps can pump up to 85000 BPH. For a flow rate more than 85,000 BPH, the loading pumps are brought on-line to achieve the requested flow rate. The meter systems are dedicated to the loading berth, but the pumps are not. Four (4) loading systems and four (4) loading pumps can be lined up in a manner that any loading pump can direct crude oil into any meter system. This flexibility is achieved via software pairing logic in the controller. The loading pump Suction pressure, discharge pressure and the flow rate control the speed of the loading pumps via programmed instructions in the controllers, to achieve the desired flow rate within the operating constraints.

5. PREVIOUS LOADING CONTROL
Previously, loading pumps were controlled via conventional electronic controllers to provide flow and pressure control. Each loading pump had three separate controllers, suction pressure, discharge pressure and flow rate controller. Output of these controllers were connected to a low select relay and its output was sent to the field to throttle the flow control valve and the speed controller to vary the speed of the loading pump simultaneously.
In the event of low suction pressure or high discharge pressure the respective controller could override the flow control to provide the speed control for the pump. This brought the loading pump back within the safe suction or discharge pressures parameter in case of low suction or high discharge pressure. However, the problem was having a fixed set point on these conventional controllers. The fixed set point was not adequate because it did not offer compensation, for full protection, since the suction pressure is a function of speed and flow rates. This was more noticeable at low flow rates. The hardwired suction pressure override switch was the ultimate protection, but did not allow the full range of the loading pump rates.

6. THE NEW LOADING CONTROL
The flow control of any loading operation is accomplished by controlling the flow control valve opening and the loading pump speed. This process is accomplished through the following three stages:

Stage 1. Equipment Assignment and Pairing Logic
The four loading pumps and the four meter skids (FCVs) have the flexibility to operate in any combination through the meter system manifold valves. And since each FCV and each loading pump is controlled by a stand-alone multiloop controller, a pairing logic is implemented in each loading pump controller to create a logical link between the loading pump controller and its partner FCV controller, so that both controllers can share the common control input data (flow rate setpoint, actual flow rate, and the FCV bypass Motor Operated Valve (MOV) status) and form a single control system that controls the loading flow rate.

The pairing logic is utilizing the controllers’ Lateral Communication Network (LCN), and the controller virtual discrete (VD; internal software switches which can be viewed and manipulated remotely or locally from the controller front panel). The flow rate setpoint, actual flow rate, and FCV bypass MOV status of each meter skid are transmitted over the LCN and stored in each loading pump controller in sequential memory locations.

Because of the absolute one-to-one assignment between the loading pumps and meter skids, the pairing logic is also providing an interlock logic to protect against wrong equipment assignment by allowing only one VD to be set within the loading pump controller. If a certain VD is set in one of the loading pump controllers, the other loading pump controller will not be able to set that VD.

Stage 2. Control Philosophy
The FCV’s controller runs a simple PID (Proportional, Integral, Derivative) loop to control the opening of the FCVs by tracking the flow through the FCV to match the desired flow rate setpoint by applying direct control logic;

- If the setpoint is greater than the actual flow rate, the output will increase. (open the FCVs more).
- If the setpoint is less than the actual flow rate, the output will decrease. (close the FCVs more).
The loading pump controller runs three PID loops. The first loop controls the speed of the loading pump based on the flow rate setpoint versus the actual flow rate. The second loop controls the speed based on the minimum allowable operating suction pressure (suction pressure override) versus the loading pump actual suction pressure; to protect the pump from cavitation. The third loop controls the speed based on the maximum allowable operating discharge pressure (discharge pressure override) versus the actual discharge pressure. The output to the loading pump variable speed drive (VSD) is the lowest of these three loops. (figure 1).

Stage 3. Control Transfer and Surge Protection

To achieve smooth control transfer between the FCV and the loading pump controllers, and prevent control overlapping of the controllers, a number of conditions were introduced to manage the flow control process.

First, the FCV maximum operating capacity is 85,000 BPH, therefore, when the FCV exceeds 95% open or the flow rate setpoint is more than 85,000 BPH or the FCV bypass MOV is open, the output control signal to the FCV is forced to its maximum scale (100% open) and the FCV is eliminated from the control process.

Second, the output control signal to the loading pump variable speed drive is enabled only when the FCV bypass MOV is fully open and the flow rate setpoint is greater than 85,000 BPH. Otherwise, the output control signal will be forced to its minimum scale (minimum RPM).
Third, to protect against surging the loading line as a result of sudden high flow change, especially at the beginning of the loading operation where the booster pump is started with a capacity of 65,000 BPH. The FCV controller continuously checks for startup conditions by verifying that the actual flow rate is less than 1,000 BPH and the flow rate setpoint is greater than 10,000 BPH, where it forces the FCV to open 20%, which allows up to 14,000 BPH to flow initially, then the normal control resumes.

7. CONTROLLER MODE OF OPERATION
The multiloop controller operates in two modes, Remote and Local. When operating remotely, the loading flow rate setpoint is entered by the console operator from Supervisory Control and Data Acquisition (SCADA) console. The flow rate setpoint is then transmitted to the meter skid flow computer to open the required meter runs. Ten(10) seconds later the setpoint is transmitted to the FCVs controller through the Programmable Logic Controller (PLC) and the Remote Input/Output (R I/O). This ten(10) second delay is necessary to allow the required number of meter runs to start opening before increasing the flow rate by either opening the FCV or increasing the loading pump speed. Also the loading pumps pairing bits (VD) are set automatically by SCADA application when operating remotely.

When operating in Local mode the flow rate setpoint and the loading pump pairing bits are set from the controller front panel.

8. INSTRUMENTATION SET UP
Total of eighteen (18) Microprocessor based multiloop controllers, compact in nature are housed in a cabinet which resides in the local field control room, and powered by an Uninterruptable Power Supply (UPS) system. A pair of microprocessor controllers (primary and backup) are used for controlling each FCV and each loading pump. In addition, a pair of controllers are common to the system for NPSH dynamic calculation (figure 2).

The communication between SCADA and these multiloop controllers is accomplished through PLC-3 at Central Control House (CCH) and PLC-5 (local at the field R I/O’s). The communication between the controllers themselves is accomplished through the LCN.

![Diagram of Loading Control System Hierarchy](Fig. 2)
9. CONTROLLER CONFIGURATION
The microprocessor based multiloop controller has four high level analog inputs, two analog control outputs, four discrete inputs, four discrete outputs, sixteen virtual discretees, 80 steps for loop configuration (4 loops, 20 steps per loop) and 38 steps for analog and discrete input configurations. Virtual discrete or “soft” switches are used to design a logic which was configured in the controller to include the engineering lineup and a simple path management.

Self diagnostic routines continuously monitor the controller’s “health” and interrupt train of pulses generated by the controller, the so-called “keep alive” signal, in case a malfunction is detected. The self diagnostic routines also generate alarms and error codes very useful in pinpointing hardware problems and rapidly restoring full normal operation.

Reliability and versatility, in conjunction with the complex functions and the number of loops within these controllers made it possible to be used successfully in a relatively complex crude loading applications.

10. CONCLUSIONS
The control system described here was commissioned in July 1993 and is presently working. State of the art microprocessor based multiloop controllers were designed and used in the application to control crude oil loading flow rates. These controllers are reliable in terms of accuracy, speed and redundancy.

The present control has achieved the following two (2) features:

10.1 Provides smooth flow control within the calculated process constraints, i.e. operating within the pump's normal operating windows.
10.2 The calculation of dynamic process constraints, i.e. calculating the actual curve for minimum suction pressure based on flow, speed and temperature parameters rather than entering a set point.

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REFERENCES