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A Case Study of Offshore Production Control Through Advanced Process Automation

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Abstract

The Malampaya Deepwater Gas-to-Power project, the single biggest industrial investment to date in the Philippines, supplies clean, environment-friendly fuel to service 30% of Luzon's power generation requirements. Subsea wells and a manifold gather gas and liquid and control the flow to a shallow water platform. Here, gas and condensate are separated before transporting dry gas through a 504 km long pipeline to an onshore gas plant. A key challenge of the Malampaya offshore facility is to maintain a smooth, continuous operation under varying demands of gas delivery from the onshore gas plant, which often leads to slugging at low flow rates.

This paper focuses on the successful implementation of Halliburton's advanced process automation solutions to improve operation of the offshore platform. The applied solutions include advanced control applications to better control production and the operation of the methanol recovery column and an alarm management system to improve the effectiveness of the alarm system that enables the operators to better respond to abnormal operating conditions.

A core principle of the advanced control application for production control is to maximize the use of topside installed capacity to better handle production rate changes while maintaining the stability of the export gas compressor and the liquid processing equipments, particularly at low production levels.

As part of the implementation of the advanced control applications, some advanced regulatory control improvements to the compressor systems were required to automate speed control for the compressor and to reduce recycling.

The alarm management system allows regular analysis of alarm activity and identifies "bad actors". The project included the execution of a rigorous alarm rationalization procedure, which reduced the number of unnecessary alarms considerably and allowed the operator to focus on the needed areas of action during abnormal operation.

Significant tangible and intangible benefits have been identified as a result of the implemented solutions. These benefits included increases in production, stemming from improved process stability, and reduction of environmental risks from the methanol column operation and better alarm reaction times. This case study highlights the value that advanced process automation can bring to the upstream industry.

Introduction

The Malampaya development includes an offshore facility and an onshore facility. The offshore facility gathers the gas, separates the water and condensate, and sends the gas to the onshore facility. The onshore facility processes the gas and delivers it to a power plant.

The multiphase fluids, including injected methanol to prevent hydrate formation, flow from the Malampaya wells through the subsea flow lines to the high pressure (HP) separator. In the HP separator, the well fluids separate into a gas phase, an aqueous phase, and a condensate phase. Additional liquids are removed from the gas phase in the dew point unit, which includes a cold exchanger and a cold separator. The export gas compressor then compresses the gas phase and sends it to the on-shore facilities. The design capacity of the platform is 508 MMSCFD of gas at delivery point and 32,800 BPD of condensate. The liquid phases from the HP separator are sent to the low pressure (LP) separator. The LP separator produces a gas phase, an aqueous phase, and a condensate phase, with the gas phase feeding the 2nd stage flash gas compressor. The condensate phase feeds the condensate stabilizer, which removes light components from the condensate before it is stored in a concrete gravity substructure (CGS). The aqueous effluent from the LP separator flows to the methanol recovery unit. Methanol is recovered from water via distillation; and the recovered methanol is injected in the wells again, while the wastewater is sent to the drain for disposal.

The offshore facility has a control room with a Process Automation System (PAS) enabling the control of the subsea and topside operations. The offshore PAS is connected to the PAS of the onshore facility via a satellite link; therefore, offshore operation can also be monitored and controlled from the onshore control room.

The Malampaya offshore facility was designed with the objective of minimizing the operations personnel offshore through the implementation of the latest technology in monitoring, automation, and control. Implementation included an advanced process control system to control the critical elements of the topside operation, and an alarm management and monitoring system to assure the effective utilization of the PAS alarm system to reduce operator reaction time to abnormal operating conditions. As discussed below, critical operational challenges existed in the operation of the facility and had to be addressed by the automation and control systems.

The systems were implemented immediately after the offshore facility started operation and have been in operation since then. The operation of the offshore facility is now controlled from the offshore control room during the day and from the onshore control room at night, aided by the implemented systems.

Operational Challenges

Plant Operation Range. The produced gas from the platform is sent through a 504 km long subsea pipeline to an onshore gas plant (OGP), which — after treatment and further processing — is used to generate power to meet 30% of Luzon's requirements through three customer power plants. The Gas Export Pipeline (GEP) both acts as a means of transport and as a storage buffer for the onshore gas plant.

Two full capacity export gas compressors are available to export produced gas, each with a maximum capacity of 509 MMSCFD at 196 bars. The compressors are designed to run in two modes – normal and line pack. In the normal mode, one compressor is running if the conditions are within a compressor's capability. If the demand is less and if the platform is on turndown for a short period, then the operating compressor can run on a partial recycle. In the line pack mode, the onshore gas demand is lower; and the pipeline will be packed without curtailing the platform production rates.

Any prolonged problems in production at the platform will directly result in a pressure decline in the pipeline. Similarly, any downstream constraint at the gas or power plants also requires the platform to adjust its production accordingly. Further, the varying daily onshore gas nominations force the platform to operate in a wide range of operating conditions.

The operations personnel are faced with the challenge of frequently ramping production up or down to meet the varying gas demands. Therefore, it is of utmost importance to transit from one operating condition to another in the most efficient and optimal manner to avoid the formation of slugs and/or other operational problems.

Unstable Flow at Low Production Rates. The topography of the subsea flow lines connecting the wells to the platform result in liquid holdup near the bottom of the risers and at select locations, especially at low production rates. A minimum sweeping velocity of the liquids is required to avoid formation of these slugs. However, the platform production targets often need to be set below this minimum velocity in response to the onshore demand. After prolonged periods of production below these minimum limits, any production ramp-up brings the accumulated liquids to the platform and flood the inlet separators, thus constraining the maximum throughput of the platform.

Due to the presence of liquid water, liquid hold ups pose an additional problem of hydrate formation at low temperatures. Methanol is injected to alleviate this problem. Subsequently, methanol is recovered from the aqueous stream in a methanol separation column.

Because of the conditions described above, the operations personnel often needed to use their expert knowledge to anticipate the occurrence and duration of slugs. This, not only increased manual supervision of the operations at all times, but further constrained the initiative to achieve remote operation of the platform.

Installed Capacity Utilization. During start up and at high production rates, a number of platform resources may be constrained or operate very close to their limits. The inlet separators are flooded during ramp up at low production rates. The platform override mechanism is designed to protect the asset through a fail safe method if the incoming fluids exceed available capacity. Under these circumstances, the inlet choke will automatically close down through a cascade of single loop control mechanisms that considers only the surge capacity of the specific equipment where it was installed. In other words, there were no mechanisms to leverage surge capacity from one equipment to another when needed from the surge of incoming liquids.

The storage capacity of the inlet separators was largely underutilized to mitigate a dynamic condition such as a moderate sized passing slug, which requires manipulating the separator level set points appropriately and consistently to handle the additional fluids. In addition, while the oil phase throughput is typically not constrained by the stabilizer column, the performance of the methanol separation column is limited by its design and throughput capacity, especially while ramping up to high production rates.

Compressor Operation. The export gas compression system consists of a common discharge header to handle flow through two parallel compressor trains (one operational at any time). The primary control of the compressor in the PAS is by the export gas flow rate controller, which cascaded to the gas turbine speed controller to maintain the export gas flow. In the event that the compressor went into surge, the compressor's safety control system would take over completely to protect the equipment, which otherwise could result in a major platform trip. In order to maintain the compressor operating point conservatively far from surge, it was common to operate the compressor on manual with high recycle rates. This practice was not only highly energy inefficient, but it also over-worked the compressors during normal operation.

PAS Alarm System. The control system of the platform has been designed as an interacting set of several systems (e.g. Fuel Gas System (FGS), Emergency Shut Down (ESD), SOLAR compressors, COOPER ROLLS etc.), with the PAS system as an interface to all these systems. Therefore, there were a wide variety of alarms being sent to the operator making it difficult for him/her to identify the emergency and its urgency, and determine the type of corrective action to take.[1] In most instances, the operators would not be able to use the information from the alarm system due to the excessive number of alarms received.

Overall Plant Stability. The combination of all the above factors affected the overall plant stability which, in turn, resulted in inefficient asset performance and partial or complete platform shutdowns. Clearly, there was a need for a supervisory system to automate the frequent production ramp up/down operations, while optimizing the utilization of the available platform resources. Simultaneously, the alarm management system needed to be rationalized and redefined to increase the effective utilization of the operations personnel.

Project Objectives and Scope

In light of the above requirements, the main objectives of the project were as follows:

- Increase asset deliverability through better utilization of platform installed production capacity
- Improve stability through the automation of operations work processes such as production ramp up and ramp down
- Improve operation of the methanol recovery column to maximize processing capacity through better control while also minimizing environmental risks
- Automate the compressor operations to increase the stability and reduce recycle
- Rationalize and manage the number of process alarms to improve operator productivity and response time to abnormal conditions according to the standards of the EEMUA Guidelines[2].

Based on the operational needs of the Malampaya platform and the stated objectives as discussed above, a solution was envisaged consisting of four major applications – Production Control, Methanol Recovery Column Control, Compressor Control, and Alarm Rationalization and Management.

Production Control. The main objectives of the Production Control application are to improve the operability of the platform and to manage the ramp up or down of export gas to the desired production target in a stable and expedient manner, while observing process operating constraints. The strategy for achieving the control objectives is to allow the application to control the export gas flow rate as well as the liquid flows through the unit. The application manages the condensate and aqueous levels in the HP separator, taking advantage of the vessel's surge capacity to handle temporary downstream constraints and/or transient liquid slugs from the wells.

The Production Control application was implemented using Halliburton's hybrid multivariable, Model Predictive Control (MPC) technology. Several process variables were simultaneously controlled within specified limits and close to their targets. Control was achieved by manipulating a pre-configured set of decision variables, using a predictive technique over a moving horizon[3,4,5,6] based on an empirical model. The application was designed to optimize the transition from one production target to another (ramp up and down). The transitions were done considering downstream constraints such as the limits on the inlet separators and methanol recovery column, as well as the export gas compressor and pipeline (see Fig. 1).

A short-term, predictive modeling approach was chosen specifically to control production ramping due to the nature of the slugging problem. This was further justified by the lack of mature and reliable, online tools for the long term prediction of multiphase flows in subsea pipelines and production risers[7].

To ensure maximum liquid slug handling capability, controlled variables (CV's) were included for the separator levels. This allows the production control application to drive both the HP separator levels to a low target value specified by the operator when possible, thus maximizing the available surge capacity of the platform at any given time.

The application is designed to operate in two main modes – start-up mode and production mode. Each mode is further sub-divided into two phases to capture the various regimes of flow based on expert knowledge. The Production Control application doesn't preclude the platform control overrides in place. Rather, it acts before the overrides are triggered to efficiently handle the liquids entering the platform with the available resources.

The native control system (PAS) interface is used to operate the Production Control application, which benefits from the operator familiarity standpoint. The PAS screens provide information related to the operation of the application including:

- Real time values of measured variables and targets

- Active constraint indications for all application variables
- Command controls for activating and deactivating the application
- Health status of the Production Control application

A snapshot of the operator interface screens for the Production Control application is shown in Fig. 2 and Fig. 3.

Methanol Recovery Column Control. The objective of the Methanol Column Control application is to maintain stable, automatic control of the methanol recovery column at full rates and during production ramp-up or ramp-down conditions. The overall strategy for achieving the stated control objectives is to use a Model Predictive Controller (MPC)[3,6] to control the methanol recovery column operation. The Methanol Column control application (see Fig. 4) manipulates the major column parameters (feed rate and split, reboil, pressure, and reflux) and predicts the maximum achievable methanol recovery feed rate subject to the column operating constraints and product quality requirements. The key operating constraints considered in the application include column pressure drop (upper and lower) as potential indicators of flooding, feed drum level, methanol to storage temperature, and manipulated variables controller outputs. The product quality parameters considered are the methanol purity (measured as % methanol) and the wastewater methanol content, inferred from the bottoms temperature. A snapshot of the operator interface screens for the Methanol Recovery Column Control application is shown in Fig. 5.

Compressor Control. The compressor has an anti-surge controller to prevent the export compressor from going into surge at low throughput/high head conditions. The anti-surge controller works by sensing the approach of surge conditions and opening the anti surge valve to the required extent to enable recycling of export gas from discharge back to the suction, thus moving away from the surge condition.

The primary or regulatory control of the compressor is by a flow controller in the line leading to the export gas pipeline. The output from the flow controller resets the gas turbine speed controller to maintain the export gas flow. If the discharge pressure upstream of the flow controller is higher than set point, the signal from a pressure controller will override the signal from the flow controller and reduce the turbine speed. Similarly, another pressure controller at the suction scrubber outlet will override the signal from both flow and pressure controllers to reduce the gas turbine speed in the event of an excessively low suction pressure. A distance-from-surge controller was built in the PAS system to safely operate the compressor without encroaching safety margins before the anti-surge controller can take over. This further reduced the amount of recycle, which results in direct energy savings and more robust compression system.

For the two compressors operating in parallel (one operational at any given time except during online changeover), a master controller will communicate to each compressor's load sharing and anti-surge controller to control the total load and capacity of the compressors. Gas flows from the Export Gas Compressor Discharge Coolers through check valves and an outlet shutdown valve into the compressor discharge common header. Flow from each compressor is combined into the header.

The compressor is started and stopped automatically or manually from the remote control room and is configured for safe, unattended operation. Each compressor is equipped with inlet/outlet shut-down valves to allow isolation of individual compressors.

Alarm Rationalization and Management. The goals of the Alarm Rationalization and Management (ARM) effort were essentially encapsulated in the EEMUA guide[2] "Alarm systems, a guide to design, management and procurement No. 191 Engineering Equipment and Materials Users Association 1999". The main criteria within this guide for alarm management[1] are that:

- The long term average alarm rate during normal and stable operation should be no more than one every ten minutes (six alarms per hour), although twelve alarms per hour is deemed manageable (Reference: EEMUA Guidelines Section 11.5, Fig 42). The EEMUA Guidelines indicate that the industry average, in a Health and Executive survey, was one alarm per two minutes- thirty alarms per hour (long term average alarm rate in steady operation).
- Following a major plant upset, no more than ten alarms shall be displayed in the first ten minutes.

The two main objectives of the ARM effort were those listed above under the standards of the EEMUA Guidelines. Certainly, the project made considerable effort to reduce the number of alarms (particularly critical alarms) that were presented to the operator during a plant disturbance. Reduction was achieved by focusing on eliminating alarms that do not give the operator meaningful information. For instance, at the project start, many of the ESD trip output functions were classified as critical alarms. These functions have now been reclassified as either advisory or simply logged alarms dependent upon functionality. Critical alarms are now reserved for high priority fire and gas alarms (e.g., confirmed high level gas) and process alarms leading to a high Safety Integrity Level (SIL) rated trip. The total number of critical alarms is now approximately 11% of the total.

The Alarm Rationalization project consisted of two phases. Phase I reviewed the existing system and provided limited solutions in a short time horizon.

Phase II focused on the development of applications and solutions resulting from the Phase I review. Phase II concluded with implementation of alarm rationalization software changes at the Malampaya facility.

The PAS alarms were reviewed in relation to:

- Service description
- Alarm parameters (names)
- Priorities considering alarm type, process, instrument, system
- Standing alarms
- Static alarm suppression
- Dynamic alarm suppression

In addition, a customized application was developed. This application uses the PAS alarm and event log file as source data to allow analysis of the number of alarms and events for the chosen period.

The Alarm Management Philosophy document classifies PAS alarms into two groups:

- EVENTS defined as ALARMS
- EVENTS

The events defined as alarms are given three possible alarm priority levels: Critical, Warning and Advisory. Events not requiring immediate Operator attention or knowledge are given a category defined as “Log” and therefore not immediately presented to the Operator.

After identifying the “bad actors” and developing the process to remove them from the system, other types of alarms were considered. After reviewing the complete set of alarms and reclassifying them according to the guides in the philosophy document, the team worked on the resolution of other alarms.

A “Standing Alarm” is defined as an alarm that has been active for long time periods. These alarms have typically been acknowledged by the operator and may be associated with non-running equipment. Fig. 6 shows a sample screen.

A solution was developed via an application in PAS dedicated to the suppression and reactivation of these alarms dependent upon equipment status. Some process alarms are only of operational significance when a plant item is running but not when it is out of service. For example, a low flow or pressure alarm at a pump discharge is not relevant when the pump is not running. Logic was used to suppress such alarms. This concept of suppression and reactivation, as appropriate, was referred to as “Static and Dynamic suppression.”

Static Alarm Suppression describes the suppression of expected alarms when packaged equipment is shutdown during normal operation. In general these were associated with low pressure and flow alarms that remain active until the equipment is brought back on line.

Dynamic Suppression of alarms offered the operator a handle to control and minimize alarms that were expected as a result of, for example, a process upset. The facility provided the operator a window of opportunity to solve an ongoing issue without being hampered by associated alarms. For Dynamic Suppression, the logic was engaged automatically based upon an initiator tag, but it could be disengaged manually. It is also possible to use logic to disengage the suppression automatically.

A new series of graphics were developed that allow operators to place a bulk quantity of alarms in “suppression” mode. Once suppressed, the alarms are removed from the current PAS Alarms list but are included in the “suppressed” list.

For the Static Suppression the logic required the operator to manually engage the logic. Once engaged the operator can disengage the suppression manually or allow the logic to disengage the suppression automatically. The following platform facilities were considered for static suppression – Flash Gas Compressors, Export Gas Compressors, Main Power Generators, and Emergency Generators.

Fig. 7 shows a snapshot of the PAS screen developed for the Dynamic Suppression application.

Results and Discussion

The Production Control application has demonstrated significant improvements in operations by providing consistency in production target ramp-up, establishing smoother overall operation of the process, maximizing utilization of resources, and assuring proper handling of the incoming liquids.

Similarly, the Methanol Recovery Column Control application has demonstrated significant improvement in stability of the column operation, reducing the methanol in the water overboard by over 80%. This improvement has a substantial environmental impact in addition to the obvious savings of methanol.

The Compressor Control application automated the compressor speed control and allowed a drastic reduction in the amount of recycle used, while continuing to keep the machines well within the safe approach to surge margin. The economic benefits of these improved compressor controls are in addition to the potential increase in overall production stemming from the greater degree of overall process stability of a steadier gas compression system.

In the preliminary assessment of the alarm system, based on data collected during a 4-week sample time, the average number of alarms calculated per hour was 202 (see Fig. 8). Additionally, seventy-two modules were identified as the "bad actors" of the system.

After all the modifications and developments as part of the ARM work were implemented, the number of alarms was reduced to a value of 25 per hour on the topside only, during a new period of sample days. The number of process alarms per hour and the number of alarms per day are shown in Fig. 9 and Fig. 10, respectively.

Conclusions

The automation and control applications that were described above improved the stability and deliverability of the Malampaya asset. In addition, these applications delivered environmental and safety benefits stemming from improved operations consistency and reliability.

As a result of the solutions that were implemented, the operations personnel can focus now on analysis of problems of larger concern rather than on routine operations. Moreover, the increased level of stability and automation enabled remote control of platform operations from onshore facilities.

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Nomenclature

EEMUA	Engineering Equipment and Materials Users Association

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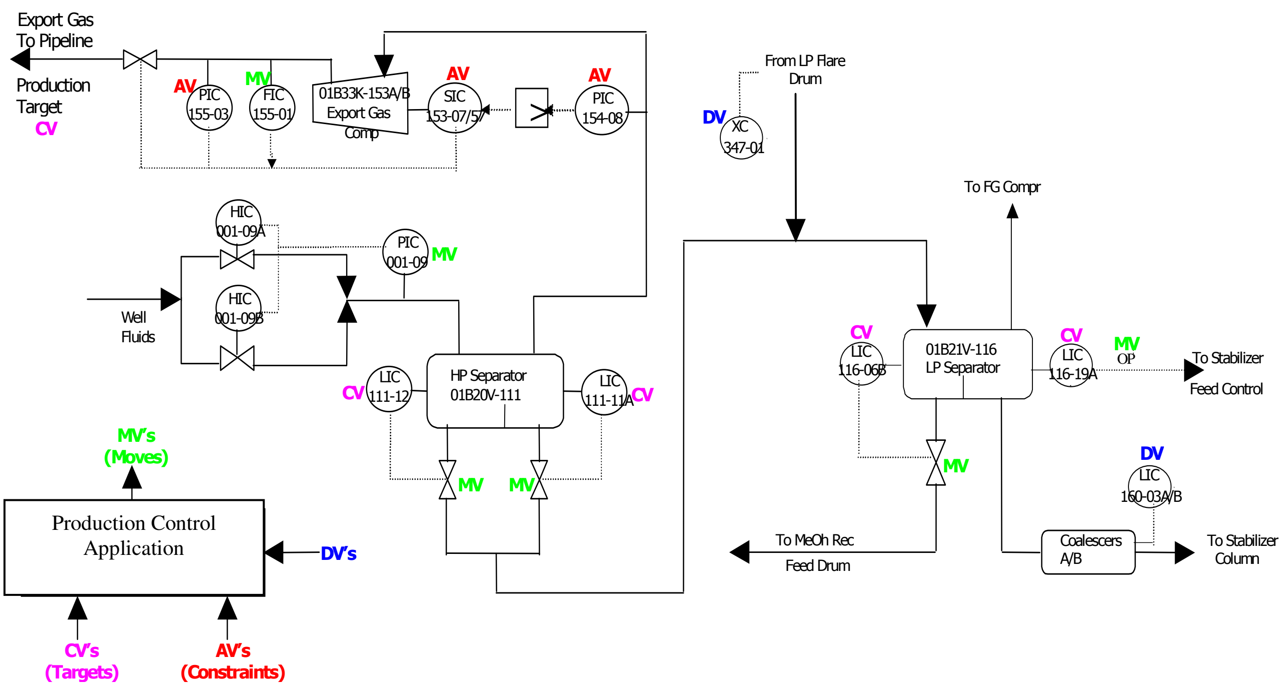


Fig. 1. Production control application configuration

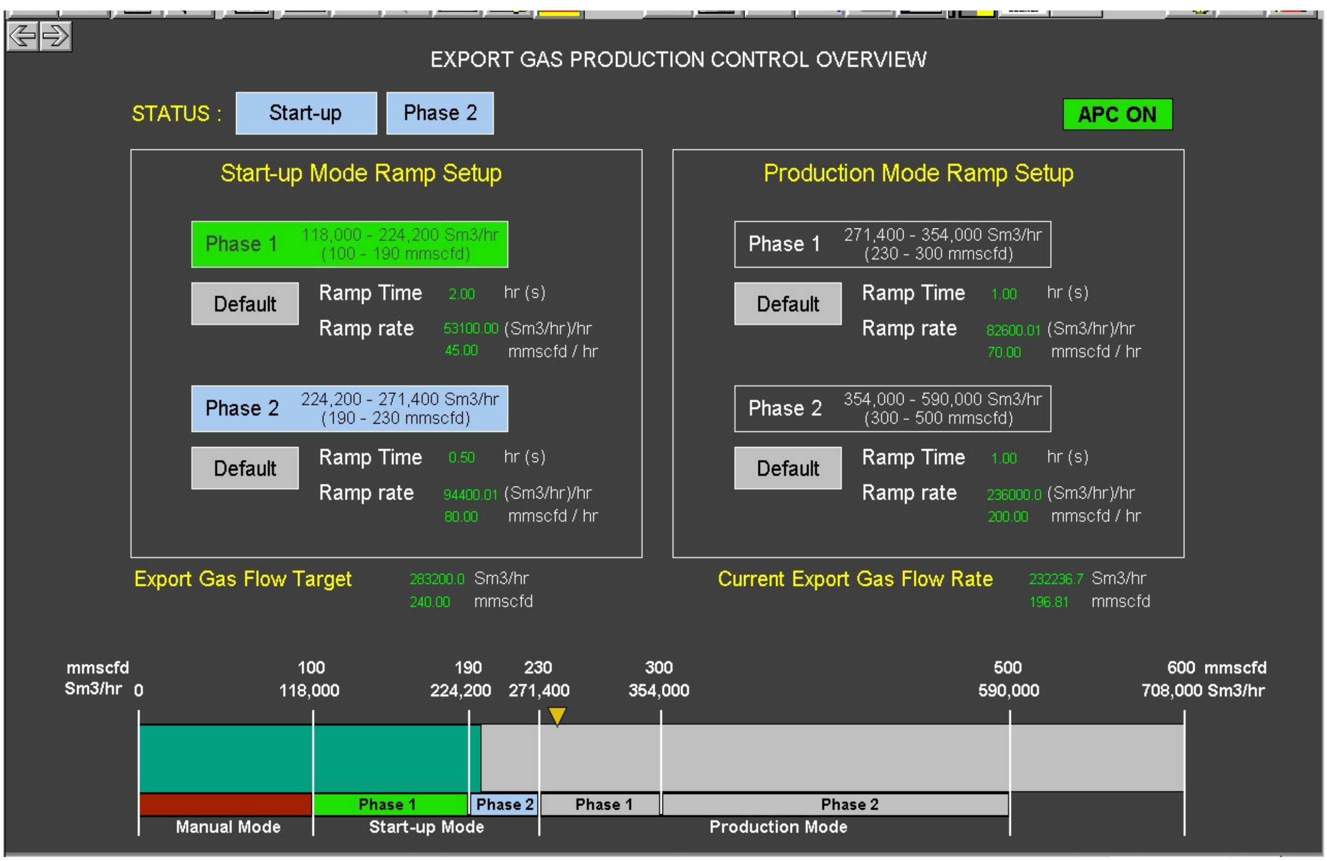


Fig. 2. Production control application operator interface – Production target overview

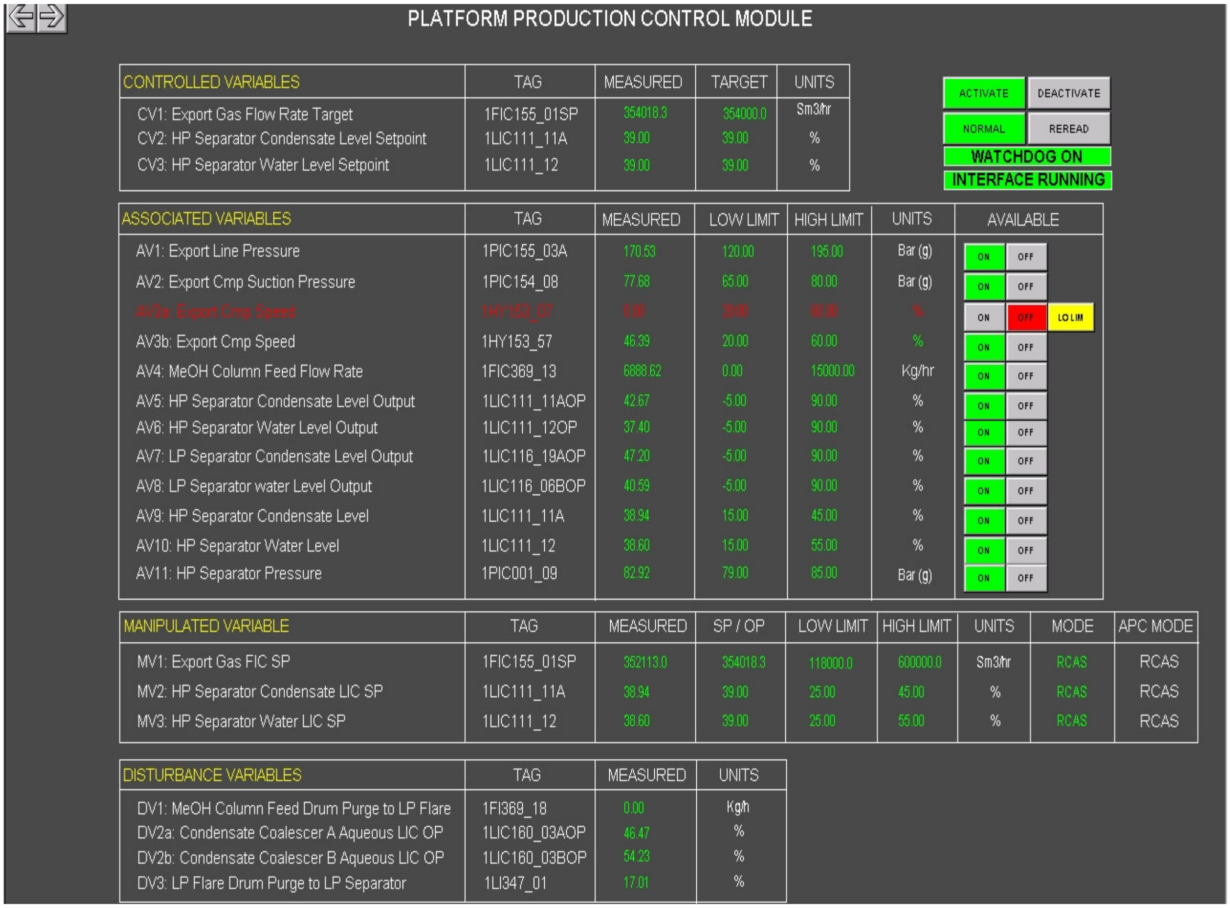


Fig. 3. Production control application operator interface – Control panel

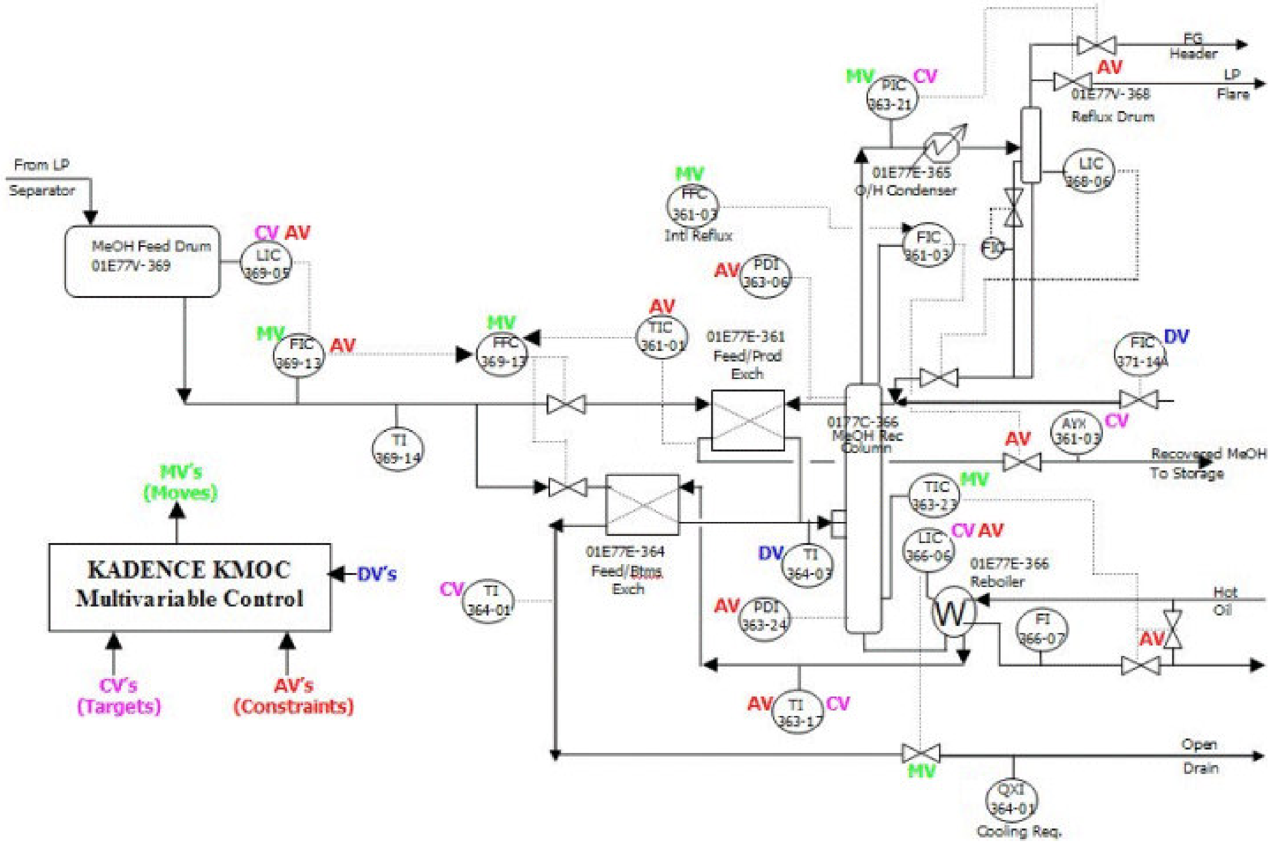
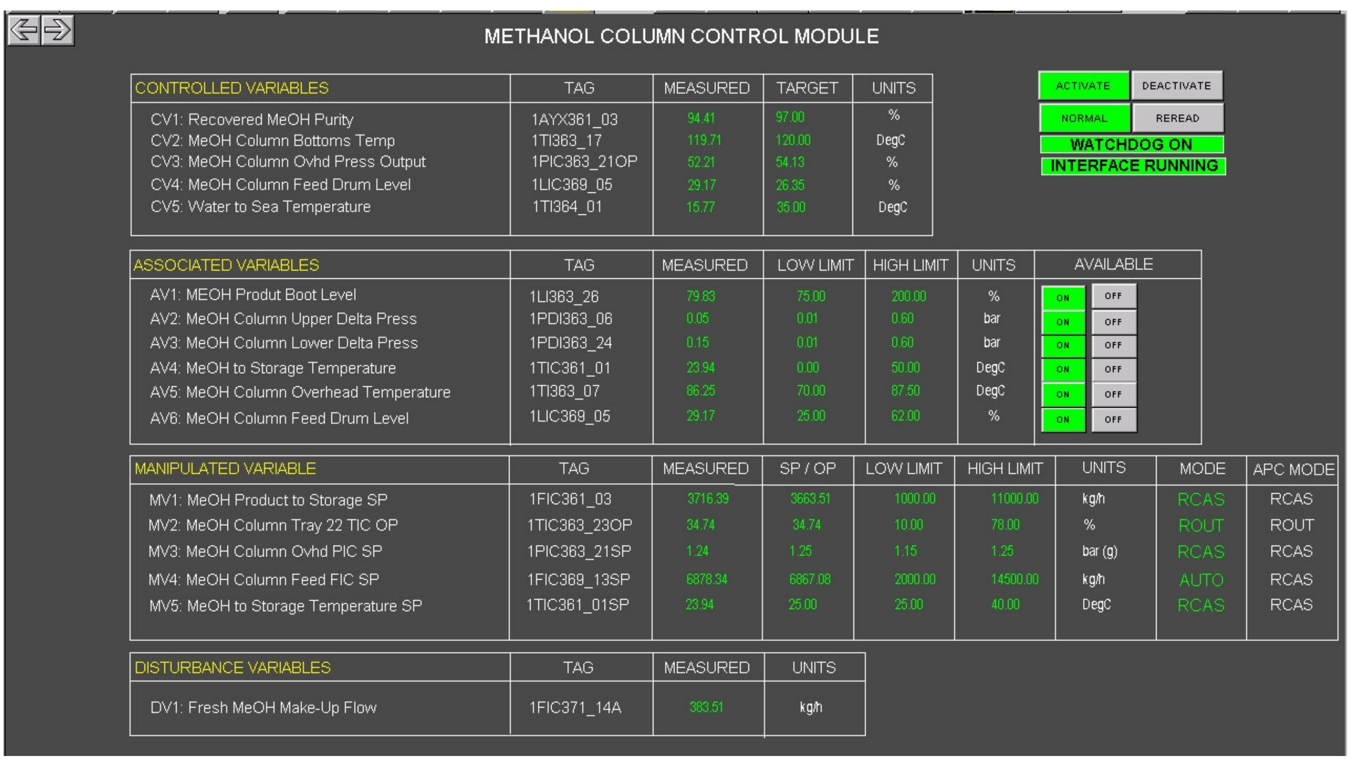


Fig. 4. Methanol recovery column control application configuration



METHANOL COLUMN CONTROL MODULE

ACTIVATE | DEACTIVATE | NORMAL | REREAD | WATCHDOG ON | INTERFACE RUNNING

CONTROLLED VARIABLES	TAG	MEASURED	TARGET	UNITS
CV1: Recovered MeOH Purity	1AYX361_03	94.41	97.00	%
CV2: MeOH Column Bottoms Temp	1TI363_17	119.71	120.00	DegC
CV3: MeOH Column Ovhd Press Output	1PIC363_21OP	52.21	54.13	%
CV4: MeOH Column Feed Drum Level	1LIC369_05	29.17	26.35	%
CV5: Water to Sea Temperature	1TI364_01	15.77	35.00	DegC

ASSOCIATED VARIABLES	TAG	MEASURED	LOW LIMIT	HIGH LIMIT	UNITS	AVAILABLE
AV1: MEOH Produt Boot Level	1LI363_26	79.83	75.00	200.00	%	ON OFF
AV2: MeOH Column Upper Delta Press	1PDI363_06	0.05	0.01	0.60	bar	ON OFF
AV3: MeOH Column Lower Delta Press	1PDI363_24	0.15	0.01	0.60	bar	ON OFF
AV4: MeOH to Storage Temperature	1TIC361_01	23.94	0.00	50.00	DegC	ON OFF
AV5: MeOH Column Overhead Temperature	1TI363_07	86.25	70.00	87.50	DegC	ON OFF
AV6: MeOH Column Feed Drum Level	1LIC369_05	29.17	25.00	62.00	%	ON OFF

MANIPULATED VARIABLE	TAG	MEASURED	SP / OP	LOW LIMIT	HIGH LIMIT	UNITS	MODE	APC MODE
MV1: MeOH Product to Storage SP	1FIC361_03	3716.39	3663.51	1000.00	11000.00	kg/h	RCAS	RCAS
MV2: MeOH Column Tray 22 TIC OP	1TIC363_23OP	34.74	34.74	10.00	78.00	%	ROUT	ROUT
MV3: MeOH Column Ovhd PIC SP	1PIC363_21SP	1.24	1.25	1.15	1.25	bar (g)	RCAS	RCAS
MV4: MeOH Column Feed FIC SP	1FIC369_13SP	6878.34	6867.08	2000.00	14500.00	kg/h	AUTO	RCAS
MV5: MeOH to Storage Temperature SP	1TIC361_01SP	23.94	25.00	25.00	40.00	DegC	RCAS	RCAS

DISTURBANCE VARIABLES	TAG	MEASURED	UNITS
DV1: Fresh MeOH Make-Up Flow	1FIC371_14A	383.51	kg/h

Fig. 5. Methanol recovery column control application operator interface – Control panel

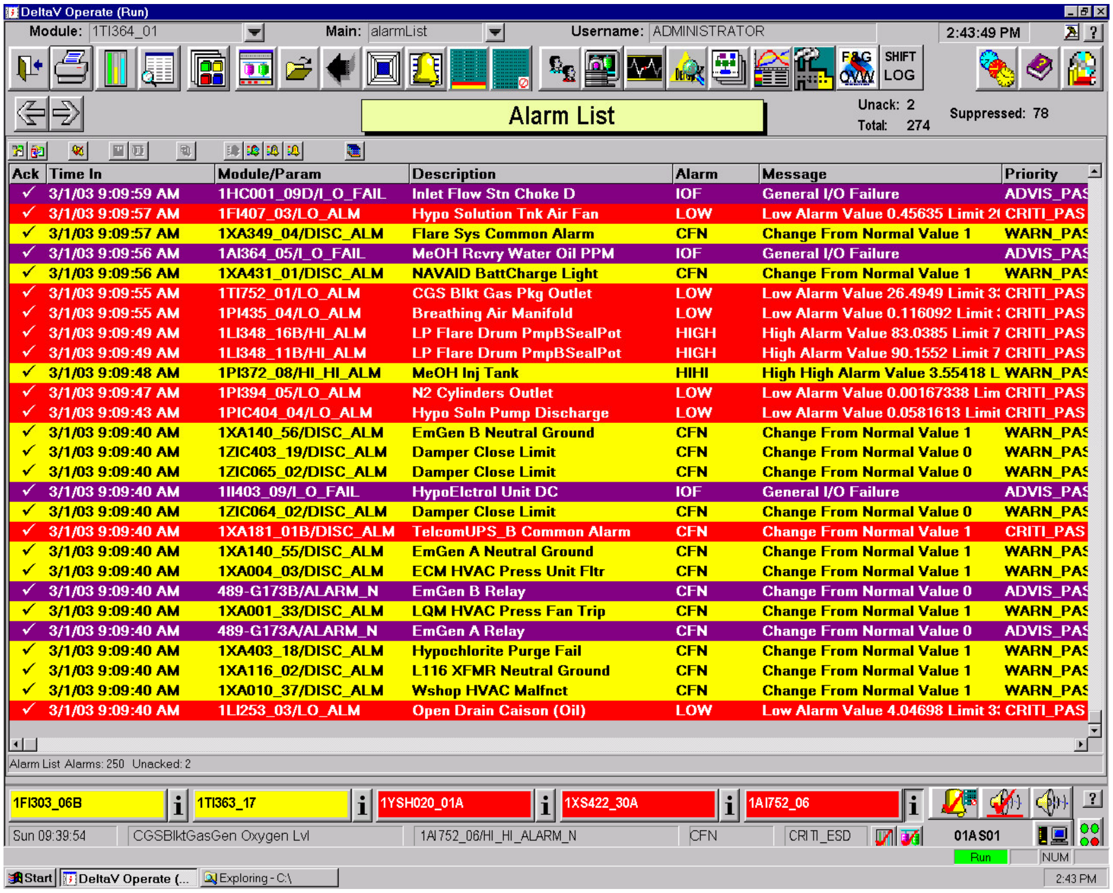


Fig. 6. Standing Alarms Screen

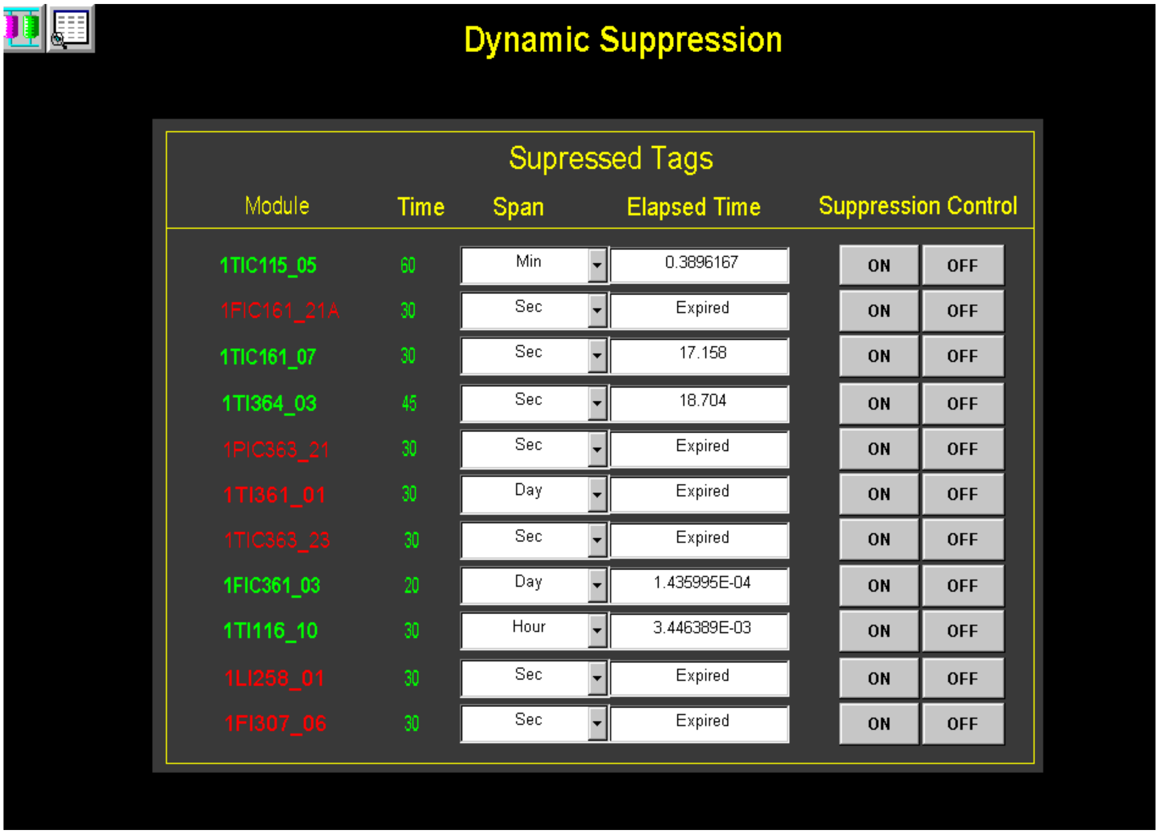


Fig. 7. Dynamic Suppression Screen

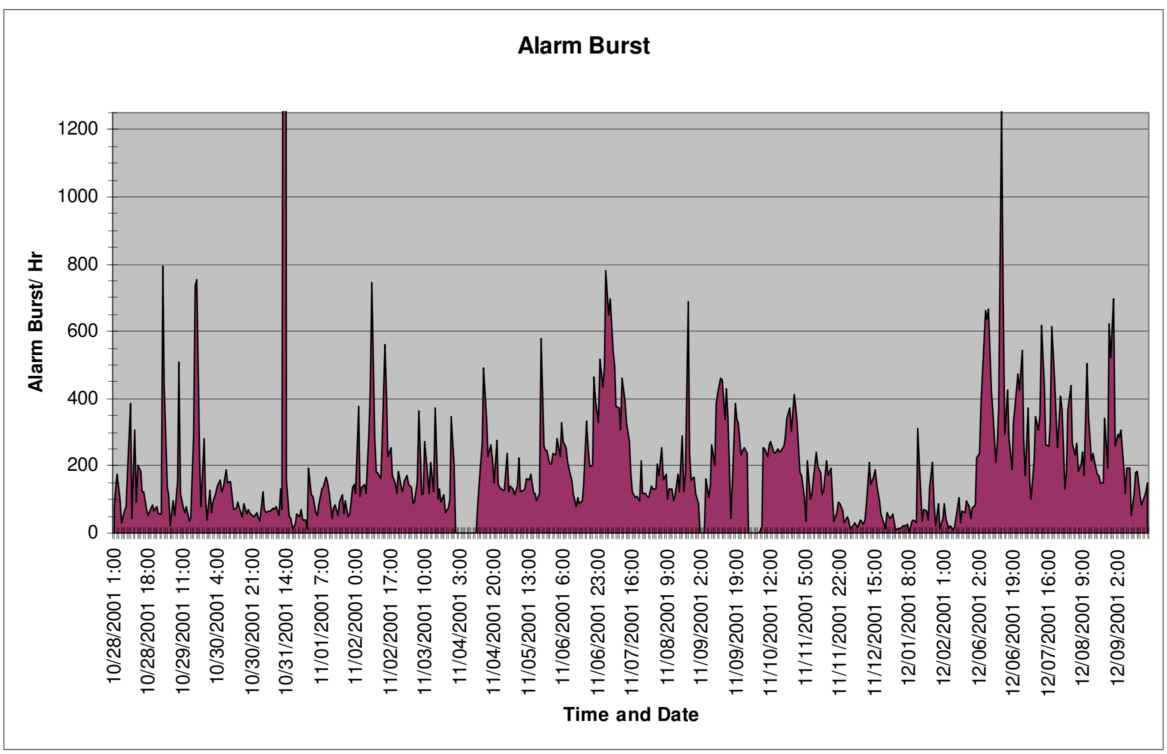


Fig. 8. Alarm burst per hour of system at project start

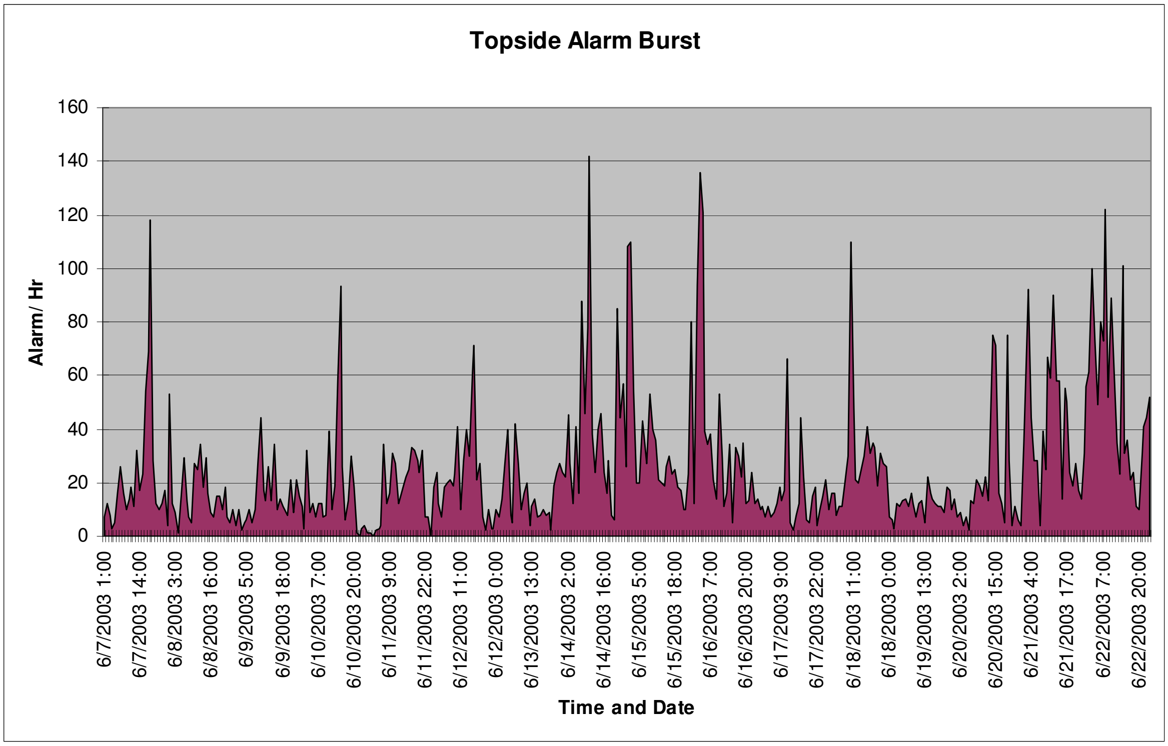


Fig. 9. Alarm burst per hour of system by project end. Note change in vertical scale compared to Fig. 8.

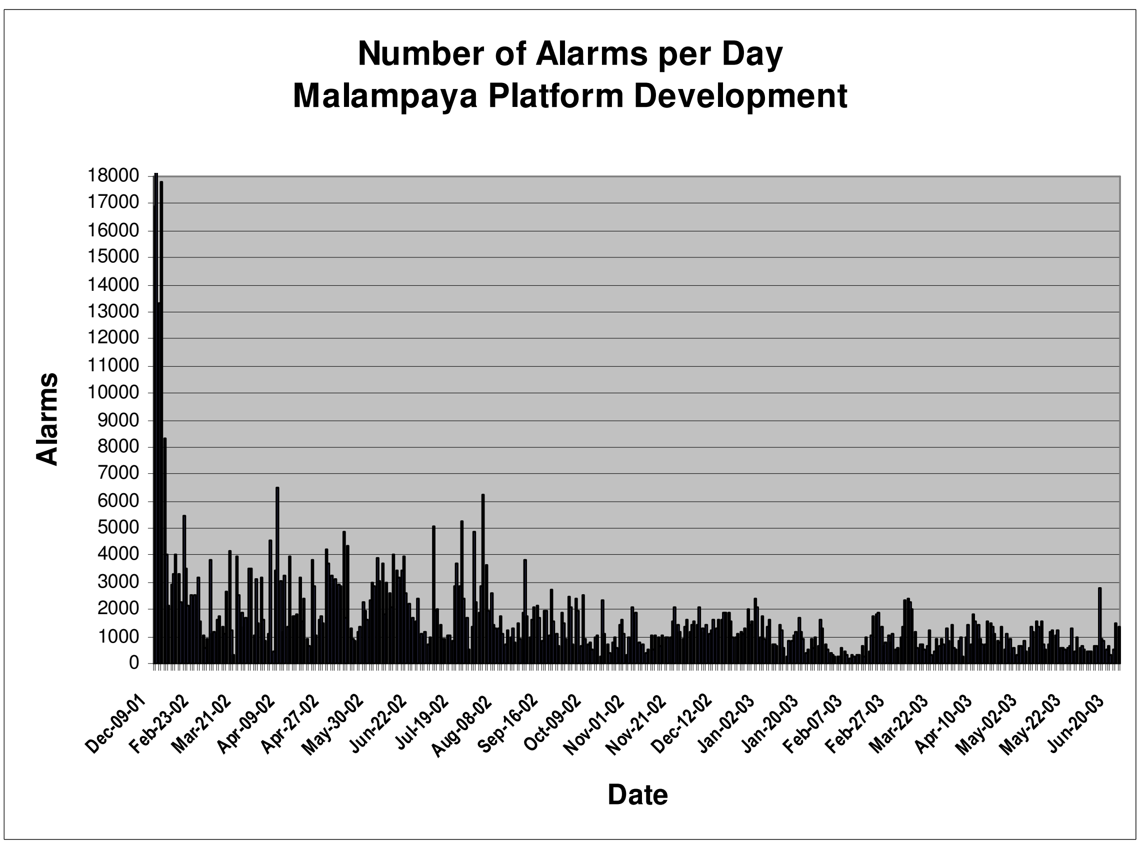


Fig. 10. Number of Alarms per day during project