An intellectual fault detection and alarm system based on multitude of tools

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Abstract

Mainly due to the drive to improve safety, reliability and efficiency of process operatios, intellectual fault detection and alarm management has gained significance in the recent years. This paper highlights an inhouse industrial implementation of a multitude of tools used for monitoring, analyzing and reporting alarm and safety system performance at LongLake site of Nexen Energy ULC. These tools mainly used by plant engineers and control room operators in improving the alarm system performance. The efficacy is demonstrated through case studies. A brief overview of the implementation architecture is also presented in this paper.

Keywords: alarm Management, data visualization, event analysis

1 Introduction

The structure of standard paper is presented in Appendix 1. In the process industry, alarm system is an integral part of Control Room Operators' (CROs) toolset to efficiently troubleshoot abnormal events. With the evolving role of CROs in terms of overseeing larger and more complex process facilities, alarm management has become a critical component of efficient process operations. Alarms fall under the second and third out of the eight independent layers of protection according to safety protection layer philosophy [1].

An alarm is defined as an audible and/or visible means of indicating to the operator an equipment malfunction, process deviation, or abnormal condition requiring a response [4]. Alarms are implemented typically as part of the plant design and commissioning stage or very early into the plant operation. Poor rationalization and inefficient alarm design contribute to nuisance alarm generation. Nuisance alarms are alarms that do not tell the operator anything he/she does not already know, or which do not require operator action. Another reason for nuisance alarms is due to changing process and equipment conditions.

During normal operation, the CRO workload is minimal and other supervisory automation systems typically aid them in smoothly performing the operations. However, under abnormal operation, the CROs are prone to a multitude of notifications not just from the breach of operating boundaries but also from advanced process control systems there by overwhelming the CRO and adversely affecting his/her decision making process. Surveys indicate that on an average, during routine operation, many process industries currently have a much higher alarm annunciation rate compared to what standards suggest as maximum manageable for efficient operation [2] & [3].

International Society of Automation (ISA) has published a standard, ISA 18.02 [4] that addresses the development, design, installation, and management of alarm systems in the process industries. The standard [4] recommended a set of key performance indicators for the alarm system and suggests a lifecycle approach to alarm management details of which are not discussed in this paper. Out of the several stages that are part of this lifecycle, Monitoring and Assessment stage is a crucial stage and typically a starting point to make improvements. This stage involves challenges in historical alarm data analysis to identify nuisance alarms that include chattering and related alarms [5]. An alarm is said to be chattering if it repeatedly transitions between alarm state and Return To Normal (RTN) state within a short span of time. As the name suggests RTN is a state when the alarm has cleared. In standards ([4] & [6]), rules of thumb are suggested to identify chattering alarms. For example, in the ISA Standard [4], a threshold of 3 alarms per minute is used to identify worst chattering alarms. Related alarms are a collection of two or more alarms that almost always occur simultaneously or in tandem without a specific order within a short span of time. Consequential alarms are a special case of related alarms where one particular alarm always appears a short duration after another alarm [2]. Redundant alarms are another special case of related alarms that always occur simultaneously or with a specific time delay. Related alarms are usually triggered due to the same root cause and result from poor alarm rationalization. If not identified and acted upon appropriately, related alarms can drastically increase the alarm count during process upsets.

The purpose of this paper is to illustrate an in-house application that automatically and periodically generates a console-wise report with simple but effective tools for performance assessment of alarm system using routinely collected alarm data. Most of the contents of this automated report are a direct application of tools proposed in [5] & [7]. Industrial data with masked tag names for a particular console is used to showcase the tools. In addition to them, the report also show cases several other analysis

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components to assess safety aspects such as safety interlock bypasses, alarm suppressions and standing alarms.

2 Identifying related and chattering alarms

This section provides some background of the indices used in this work to identify chattering and related alarms. In reference [5], alarm events which are usually stored as long strings of text on the historical alarm database are mathematically represented as binary sequences. Each alarm is categorized based on the tag name followed by its identifier (which is typically low, lowlow, high, hihi and so on). Based on the binary sequence representation, a similarity index that measures the extent of correlation between two alarms is proposed in [5] and a chatter index is proposed in [7].

2.1. RELATED ALARMS

The Jaccard similarity index, S (X ,Y) jac between two padded alarm sequences, X and Y is defined in [5].

In [10], a Gaussian kernel method is applied to convert binary alarm data into pseudo continuous time series and the time lagged correlation is considered to calculate similarity between alarms.

2.2 CHATTERING ALARMS

Chattering alarms are identified in [7], if the chatter index defined by the following expression (1) crosses a threshold (0.05 as per ISA standards).

$$\Psi = \sum_{r \in N} P_r \frac{1}{r} \quad (2)$$

Where r is the run length defined as the time difference between two consecutive alarms on the same tag and identifier and r ,P is the probability corresponding to run length, r. Reference [11] shows a method to estimate the chattering index based on statistical properties of the process variable as well as alarm parameters. To incorporate the length of collected alarm samples, a revised chattering index was proposed in reference [8].

3 Format Alarm report components

This section provides some details on each of the components of the alarm report. It describes a little about its contents, purpose and how the details can be analysed and interpreted. The plots used in this section are based on one weeks' worth of alarm data for a particular unit console. All the tag names are masked due to confidentiality.

A. Alarm Summary: Alarm summary report as shown in Fig.1 mainly shows the top 10 alarms that occurred during the time period under consideration (weekly). The contribution column in the figure gives an idea of what abnormal events during that week kept the CRO occupied. The top alarms typically provide obvious causes for abnormal events during the plant operation. Analyzing and acting on the top bad actors seems to be the first course of action to improve the alarm system performance however, in reality it is barely sufficient to bring out much other inefficiency [14].

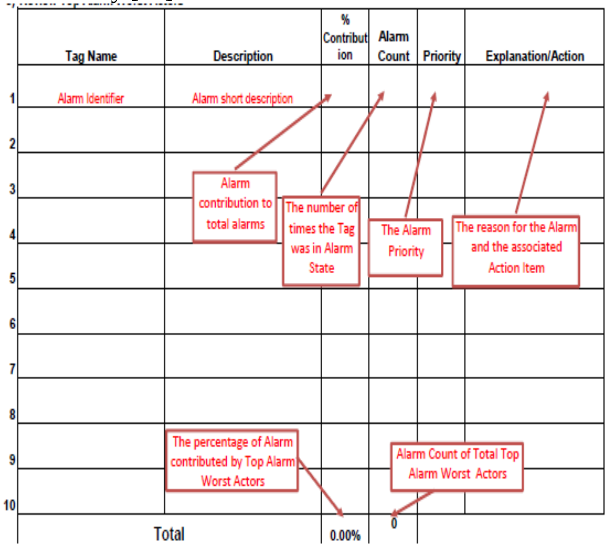

FIGURE 1 Alarm Summary page showing brief description of each of its components

B. High Density Alarm Plot: Using the High Density Alarm Plot (HDAP) proposed in [5], historical alarm data of an alarm system can be charted in an easily interpretable form. Fig. 2 shows the HDAP of a console using the alarm data for one week. Following are the features of the HDAP.

1)Each row corresponds to an alarm

2) Alarm count in each 10 minute interval is color coded. The color legend is shown to the extreme right in Fig. 2

3)The alarms are rank ordered. It means that the top row contains maximum number of alarms during the time period

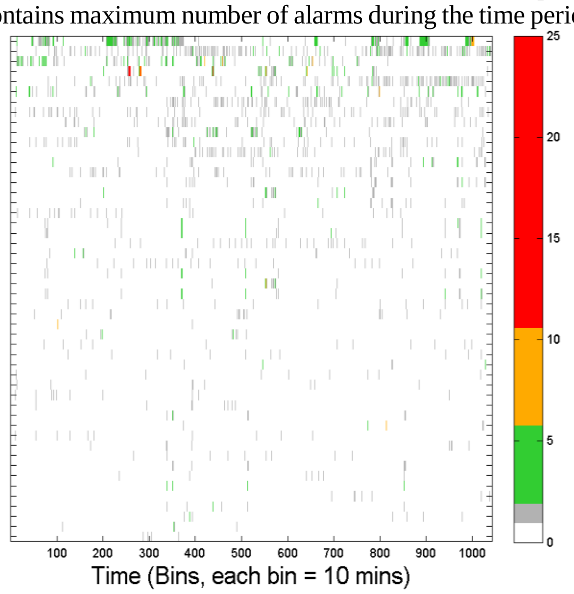

FIGURE 2 High Density Alarm Plot showing color coded alarm annunciation over one week's period for top 50 alarms

HDAP shows not only the progression of top alarms with time but also highlights apparently related and chattering alarms. Alarms occurring due to process upsets can be conveniently visualized and attributed in time domain. Figure.2 shows instances of apparently chattering and related alarms.

C. Alarm Similarity Color Map (ASCM): ASCM strategically captures the time domain similarity of occurrence between each pair of alarms as defined by equation (1). Figure 3 shows the ASCM for top 50 alarms that occurred over a one week's period using the same data used to generate the HDAP. ASCM is basically a color coded symmetric matrix with each column representing an alarm tag with identifier. The first column tag is same as the last row. The second column tag is same as the last but second row and so on. Shades of blue are used to represent the extent of similarity between the alarms. Fig. 3 shows a set of four alarms that showed significant similarity of occurrence. This type of plot can be used to further troubleshoot by questioning the existence of each of the alarm and rationalizing them. Questions like: Does these alarms occur in the same sequence all the time? Are there any abnormal events that a These must be set to 0 cm. In addition, please make sure the Mirror Margins option is not selected.

D. Run length distributions: Run Length Distribution (RLD) that shows the alarm count corresponding to each run length is very helpful in identifying chattering alarms and aid in designing an appropriate delay timer once Return To Normal (RTN) information is incorporated [13]. Fig. 4 shows the RLD for a particular alarm tag that has a significant number of alarms separated by as low as 50 seconds. It is unreasonable to expect a response for all the alarms that occur within that short span of time. RLDs also highlight alarms that occur due to oscillations in underlying variable. In this application, all the alarms that occur with less than 120 seconds run length are charted in the alarm report.

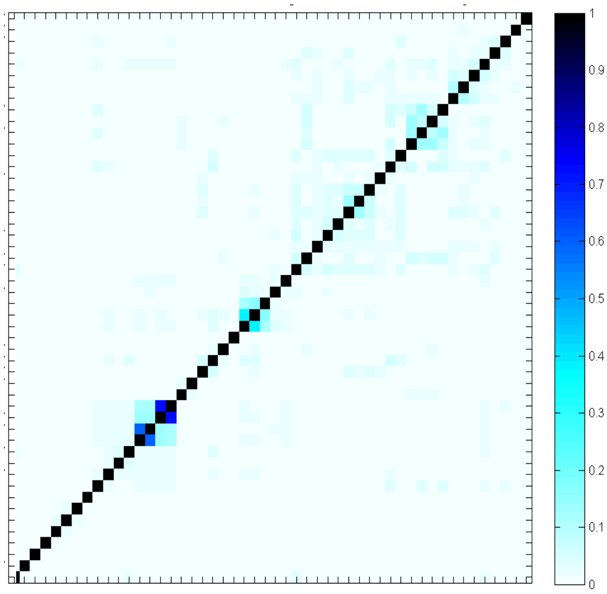

FIGURE 3 Alarm Similarity Color Map showing color coded alarm similarity index [5] over one week's period for top 50 alarms

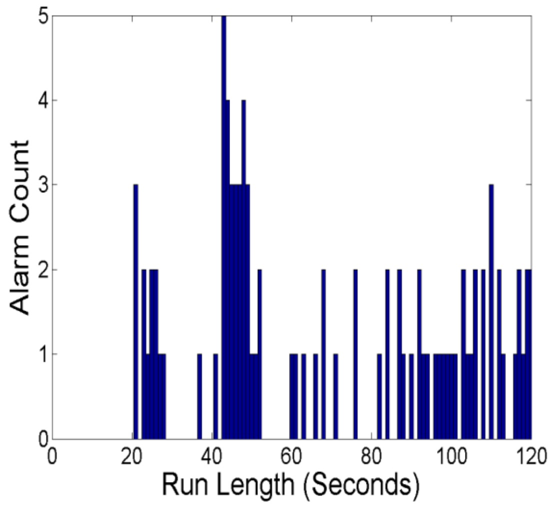

FIGURE 4 Sample run length distribution for an alarm tag

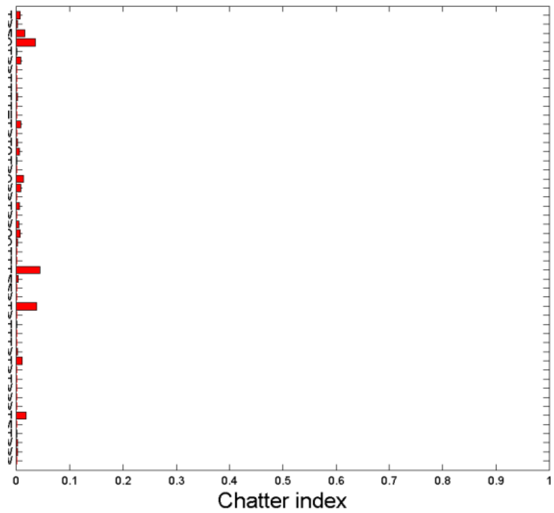

FIGURE 5 Chatter Index plot over one week's period for top 50 alarms

E. Top chattering tags: For the top 50 alarms that appearedmin the HDAP, the chatter Index defined by equation (2) is calculated and plotted as shown in Figure 5. A rule of thumb to identify worst chattering alarms as per [7] is to find the ones with $\psi > 0.05$.

F. Suppressed alarm/Standing alarms/Safety Bypasses

2. SUPPRESSED ALARMS

Console	
Total no. of suppressed alarms	
Average age of sup. alarms (days)	
No. of suppressions < 1 day old	
No. of suppressions < 1 week old	
No. of suppressions < 1 month old	

Recently suppressed Alarms/Alerts

	Tag Name	Description	Time in	Explanation/Action
1				
2				
3				
4				
5				

FIGURE 6 Suppressed alarms summary report

Figure 6 shows the alarm suppressions section of the report. The report has some statistics at the top followed by a complete list which shows the time stamp when the alarm is suppressed. In the statistics part, all the categories indicate items that are less than a certain time period old. The categories indicate how many items came up in the last one day/week/month. For comparing reports from two different time periods with similar number of items, a reduction in average age typically indicates removal of older items from the list. The following scenarios give an indication of addressed issues:

1) Total number increases, average age increases – Typically indicates No/Less work done on older items

2) Total number increases, average age decreases – Typically indicates work done on older items

3) Total number decreases, average age decreases – Typically indicates work may have been done on older items

4) Total number decreases, average age increases – Typically indicates No/Less work done on older items

A similar section of the report is generated for standing alarms and safety system interlock bypasses. The section for standing alarms is also separated based on alarm priority. Additionally, a separate section is provided and can be manually maintained as part of the report for alarms that are caused exclusively due to instrument related issues.

4 Typical case studies

This section highlights a few case studies where tools in this application helped engineers and CROs in identifying operational issues.

A. Detection of oscillations due to poor tuning: There are several instances where ASCM highlighted strong correlation between high and low limit alarm occurrences. On a particular flow control loop, it triggered the engineers to monitor the control loop performance. It was found that the change in operating envelope made the control loop tuning obsolete and deteriorated the control loop performance. The process interactions were re modeled and control loop tuning was changed to improve the performance.

B. Simultaneous occurrence of alarms on steam reboiler condensate pot level and rich amine feed to the Amine regeneration column. Rich amine is the feed. Revealed that steam injection was aggressively tuned under ratio control to the rich amine feed flow to the column. ASCM successfully highlighted the correlation between root cause and the process issue (level oscillations). The issue was resolved by detuning the steam flow control loop with appropriate use of set point filters. This stabilized the steam flow and reduced oscillations in condensate pot level.

C. Reliability of vortex flow meters: Reliability is critical in high pressure steam service at Long Lake facility. Early detection of an impending failure on these important flow meters help us prevent down times. Vortex flow meters show high variance in flow reading and lead to a chattering scenario: Both high and low alarms ring in. Even though the number of alarms is low on these flow meters, the tags appear in the chattering alarm list.

D. Condition based alarming: ASCM and Standing alarms list plays a key role in identifying opportunities for condition based alarming whether the condition is based on equipment run status or a unique process condition. A good example would be the run status of Electrical Submersible Pump (ESP) for Steam Assisted Gravity Drainage (SAGD) wells. Low discharge flow and low producer sub cool temperature are factors that can adversely affect life of ESPs. However, the alarms are relevant only when the ESP is operational and must be disabled otherwise.

E. Identifying root cause using HDAP: HDAP is used mainly to visualize the progression of alarms with time. Due to this feature, plant upset conditions stand out in the HDAP clearly indicating the time of occurrence.

F. Identifying opportunities for smoother transition in sequence operations: Run length distributions play a key role in identifying repeating alarms that help in identifying equipment and control system issues with processes that involve sequence operation. An example is where steam condensate collecting drum in vapor service is periodically emptied to push the fluid into the main production line. Malfunction of any one of the five valves used in this system can cause the sequence to default. Impending failure of valves is often captured in the alarm summary page or the run-length distribution as this is relatively a high frequency operation.

G. Tracking progress of work list items: Several components of the report deal with longer term issues such as faulty instrumentation, equipment malfunctions, and operation outside design conditions. For example, list of bypasses is closely monitored and minimized by progressing Management of Change (MOC) process.

5 Date flow: network architecture overview

A utility server has been dedicated to run the application that automatically generates the alarm report in the form of an excel work book [15]. The program gathers data from two different sources. First data source is the historical alarm event database that collects important information including process, device and instrumentation alarms along with all the CRO moves on the panel. The program also has access to a terminal server that stores the raw data files that contain snapshot information of safety interlock bypasses, alarm suppressions and standing alarms. These raw files are generated based on snapshot data from the DCS and pushed into terminal server at a specific time of the day (every morning). Matlab [12] software is used to build a package and an executable has been deployed on the utility server that runs the program on a particular schedule.

6 Conclusion

This work showcases an industrial application that automatically and periodically generates a console-wise report with simple but effective tools for performance assessment of alarm system using routinely collected alarm data. The application is greatly assisting the engineers and CROs at Long Lake facility in better understanding the operational issues and subsequently contributing toward sustainable improvement of safety related key performance indicators.

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References

[1] Centre for Chemical Process Safety/American Institute of Chemical Engineers (CCPS/AIChE) 1993 Guidelines for engineering design for process safety Wiley Interscience: New York
[2] D. H. Rothenberg 2009 Alarm management for process control Springfield: New Jersey, Momentum Press
[3] M. Bransby and J. Jenkinson 1998The management of alarm systems: A review of best practice in the procurement, design and management of alarm systems in the chemical and power industries Technical Report CRR 166 Health and Safety Executive
[4] International Society of Automation (ISA) 2009 Management of alarm systems for the process industries Technical Report ANSI/ISA-18.2, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, North Carolina 27709, 2009
[5] S. R. Kondaveeti, I. Izadi, S. L. Shah, T. Black and T. Chen 2012 Graphical tools for routine assessment of industrial alarm systems Computers & Chemical Engineering vol 46 pp 39-47
[6] Engineering Equipment and Materials Users Association (EEMUA)
[7] 2007 Alarm systems: A guide to design, management and procurement, London EEMUA publication No. 191
[8] S. R. Kondaveeti, I. Izadi, S. L. Shah, D. S. Shook, R. Kadali, T. Chen 2013 Quantification of alarm chatter based on run length distributions Chemical Engineering Research and Design vol 91(12) pp 50-58
[9] J. Wang, T. Chen 2013 An online method for detection and reduction of chattering alarms due to scillation Computers & Chemical Engineering vol 54 pp 40-50
[10] Z. Yang, J. Wang and T. Chen 2013 Detection of Correlated Alarms Based on Similarity Coefficients of Binary Data Automation Science and Engineering, IEEE Transactions on
[11] Vol 10
[12] Liu C, Wang F and Shi K 2014 Robust H∞ Control for Satellite Attitude Control System with Uncertainties and Additive Perturbation International Journal of Science Vol 1(2) pp 1-9
[13] F. Yang, S.L. Shah, D. Xiao and T. Chen 2012 Improved correlation analysis and visualization of industrial alarm data ISA Transactions Vol 51(4) pp 499-506
[14] E. Naghoosi, I. Izadi, and T. Chen 2011 Estimation of Alarm Chattering Journal of Process Control vol. 21 pp. 1243-1249
[15] MATLAB version 7.14.0.739 Natick 2012 Massachusetts: The MathWorks Inc
[16] S. R. Kondaveeti, I. Izadi, S. L. Shah and T. Chen 2011 On the use of delay timers and latches for efficient alarm design Control & Automation (MED) 2011 19th Mediterranean Conference on vol 12 pp 20-23
[17] I. Izadi, S. L. Shah and T. Chen 2010 Effective resource utilization for Alarm Management Decision and Control (CDC) 2010 49th IEEE Conference on vol13 pp 15-17

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