The INGAA Foundation, Inc.

Rupture Monitoring on Natural Gas Pipelines Using SCADA Rate of Change Combination

Prepared by Schneider Electric for

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RUPTURE MONITORING USING SCADA RATE OF CHANGE COMBINATION

Research Report

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Executive Summary

Rate of Change alarms are used in modern SCADA systems to notify a gas controller of sudden changes in pipeline operating characteristics such as pressure and flow rate. This study evaluates the feasibility for using SCADA "pattern of alarms" techniques to identify ruptures in gas systems, similar to the SCADA "Rate of Change Combination (ROCC)" methodology used by the hazardous liquids pipeline industry. The concept of ROCC analysis studied here shows promise, based on the results of gas pipeline rupture monitoring under the conditions tested. It has the potential to be developed into an effective rupture monitoring tool, but more testing under real-world, complex-system configurations, in cooperation with suitable SCADA modeling experts, is needed to better understand the true viability of this adaptation of SCADA technology.

Since gases and liquids exhibit different physical behaviors under changing pressure and flow conditions (gas being compressible, liquids generally being non-compressible and affected by hydraulics) a direct correlation between the effectiveness in gas versus liquids systems cannot be correctly assumed.

This study addressed a very basic proof of concept, under known, controlled, very defined and limited conditions not typical of a real, complex gas pipeline system. Conditions from snapshots of known rupture data were taken from member operating companies to test the feasibility of applying the general theory to gas models. More effort is necessary to establish key sensor location requirements, normal operating parameters at each location, impact of system changes for weather, outages, no-notice customer load changes, reversal of flows, configuration changes such as by-passing and back-feeding, and numerous other system specific conditions requiring customized solutions.

Natural gas pipeline SCADA systems, under as-tested conditions and with further development, could address the NTSB recommendation stating that "*providing automatic SCADA system trend data alarms of this type would improve controller recognition of abnormal conditions*" (such as pipeline ruptures), and notify the controller to examine the condition and take the appropriate action to respond to it.

The ROCC methodology could also address the NTSB recommendation in NTSB Pipeline Accident Report NTSB/PAR-14-01 PB2014-103977 (Columbia Gas Transmission Corporation Pipeline Rupture Sissonville, West Virginia December 11, 2012) for a "*simple yet effective way to reduce the burden on the controller to remember or analyze <u>a series of data outputs</u>*".

1. Introduction

The main focus of this study is to review historical rupture data from gas transmission operators to determine the effectiveness and feasibility of this application for natural gas pipelines and make recommendations based on the findings. In addition, this effort demonstrates the industry's eagerness to collaborate to find a practical solution for natural gas rupture detection that works well and can be effectively managed and maintained with reasonable effort and cost.

Rapid detection of a leak or rupture on natural gas pipelines is difficult, because of the compressible nature of natural gas and how it is transported. Existing techniques such as Real Time Transient Models (RTTM) are capable of providing internal-based leak detection on natural gas pipelines. However, due to the engineering effort to configure and maintain these systems, along with the continuous changes that are common for interconnected natural gas transmissions networks, RTTMs may not be practical for all operations. Typical volume-balance Computational Pipeline Monitoring (CPM) systems used commonly on liquid pipelines are ineffective and prone to false alarms due to the physical nature of natural gas under pressure.

These applications are SCADA based (i.e. not requiring a hydraulic model), use existing pipeline instrumentation, and only require small enhancements to traditional SCADA to provide the logic needed for the monitoring of gas transmission pipelines for ruptures. Therefore, there is a higher likelihood that the methodology would be adopted by the industry. This could help to ensure ruptures are reliably recognized and responded to as quickly as possible.

SCADA systems often use a Rate of Change (ROC) alarm to notify controllers of sudden changes in pressures and flows. By extending ROC alarm functionality to include a "pattern of alarms" concept, the resulting composite alarm can be used to identify leak events and ruptures while reducing false or nuisance alarms caused by normal operational activities.

Advanced alarm management best practices encourage the use of "pattern of alarms" techniques to reduce nuisance alarms and replace them with a more meaningful alarm that better relates to the variables being evaluated. The application being studied in this research project uses a pattern of rate of change alarms, and is referred to as "Rate of Change Combination (ROCC)."

This combination of alarms works well with a classic pattern of measurement responses for a liquids pipeline rupture. This study will evaluate whether this combination of alarms application is equally useful in detecting natural gas pipeline ruptures. In a liquids pipeline rupture, the upstream pressure drops, the upstream flow increases while the downstream flow rate drops. Using each of these values as inputs to a simple alarm, or combinations of any two of these inputs as a composite alarm can result in an alarm in normal operations. When all three of them happen within a short time period of each other they represent the signature of a rupture.

2. Research Overview

Data from actual pipeline ruptures was provided confidentially by INGAA members. As the application being evaluated allows for four inputs that can be used collectively to identify a rupture signature while reducing or eliminating false alarms, the request for data was to analyze real world pipeline data, that when used in combination, can confidently recognize the rupture condition. A single pressure point is of limited value, so we asked for “related” pipeline inputs, ideally upstream and downstream pressures and flow rates where possible.

In cases where flow rate data was not available, we used multiple related pressure data points monitored as a group.

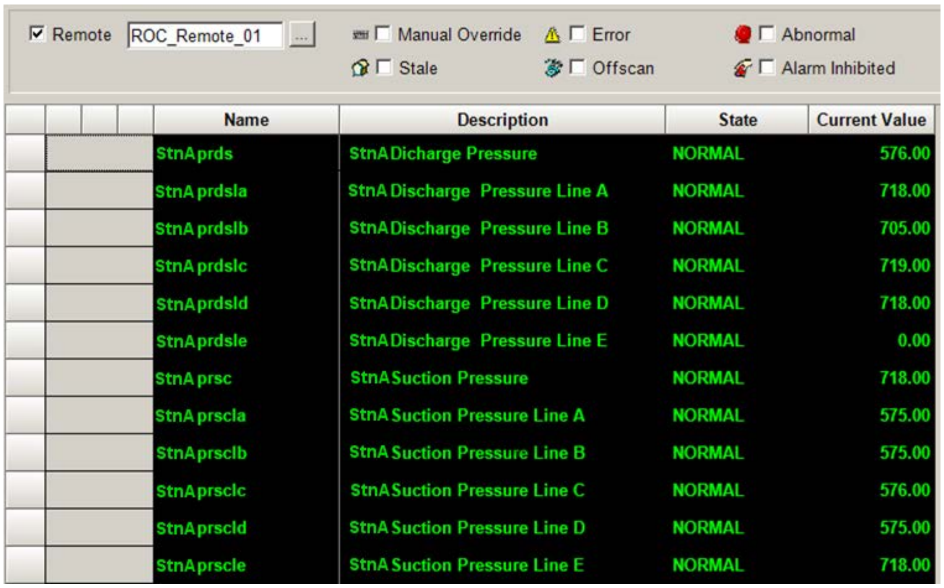
Data provided included a brief description of the pipeline layout, such as where the inputs were relative to the rupture location. (i.e. P1 is located approximately x miles upstream of rupture/leak location etc.) Additional pipeline information requested included fundamental details such as pipe alignment, nominal operating pressure and how the leak/rupture was determined.

It should be emphasized here that the research focused on finding out if the SCADA application had the capability to detect the rupture condition and not on the robustness of the application with respect to generating false positive alarms under certain operating conditions. As a result, the data collected from INGAA members were associated with specific rupture incidents and not special operating conditions that potentially could have triggered a false positive.

3. Testing Set-Up

Research and analysis was conducted in conjunction with Schneider Electric's new Oil and Gas Competency Center in Houston, specifically with the Midstream StruxureLab, using the industry's most widely used pipeline SCADA system, O&G OASyS DNA. Pressure and flow rate points (tags) were created to match data supplied, then connected to a simulated remote telemetry unit (RTU) that read in the test values accurately, reflecting the way the data would be polled on the live SCADA system.

Figure-1 shows the defined pressure points for one of the tests performed. Similar real-time points were created for each process variable provided in the sample rupture datasets provided.



Name	Description	State	Current Value
StnAprds	StnA Dicharge Pressure	NORMAL	576.00
StnA prdsla	StnA Discharge Pressure Line A	NORMAL	718.00
StnA prdslb	StnA Discharge Pressure Line B	NORMAL	705.00
StnA prdslc	StnA Discharge Pressure Line C	NORMAL	719.00
StnAprdsld	StnA Discharge Pressure Line D	NORMAL	718.00
StnAprdsle	StnA Discharge Pressure Line E	NORMAL	0.00
StnA prsc	StnA Suction Pressure	NORMAL	718.00
StnA prscla	StnA Suction Pressure Line A	NORMAL	575.00
StnAprsclb	StnA Suction Pressure Line B	NORMAL	575.00
StnAprsclc	StnA Suction Pressure Line C	NORMAL	576.00
StnAprscld	StnA Suction Pressure Line D	NORMAL	575.00
StnAprscle	StnA Suction Pressure Line E	NORMAL	718.00

Figure-1 - Pressure Points defined in SCADA

3.1. ROCC Application Configuration

The first step was to identify and configure a robust "rate of change" monitor for each of the inputs. Rate of change in SCADA has traditionally been "noisy," causing many false alarms due to the uncertainties of poll times, fast or interrogate scanning, and latency of the data.

The ROCC application provides a more reliable rate of change evaluation by using a configurable number of samples versus a fixed time to evaluate the rate of change. The inputs are intended for pressure and flow, but the same algorithm could be used for any input: control valve position, compressor rpm, etc.

A typical rate of change (ROC) configuration dialog is shown in Figure-2 below, and it is important to note the following definitions:

- **ROC violation limit** is the value that the rate of change has to exceed in either negative or positive direction to create an ROC violation. The value needs to reflect the point chosen to use for ROC.
- **ROC suppression limit** is the value that the rate of change has to exceed in either negative or positive direction to suppress the ROC calculation.
- **Sample Count** is the number of samples that are used for the ROC calculation.
- **Exceed limit time duration** is the amount of time an ROC stays in violation or suppression once it enters that state.

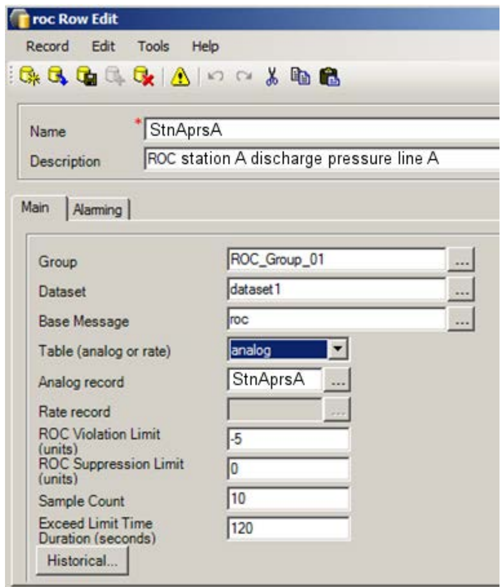


Figure-2 - Rate of Change (ROC) Configuration

With potentially several inputs now configured for individual rate of change monitoring, the next step is to assign them to a specific pipe segment or region, so that when the rate of change conditions matches the defined logic, the application generates a higher priority alarm to indicate that all the defined conditions that may indicate a leak or rupture have been met. This is done using the ROCC row edit screen seen below in Figure-3.

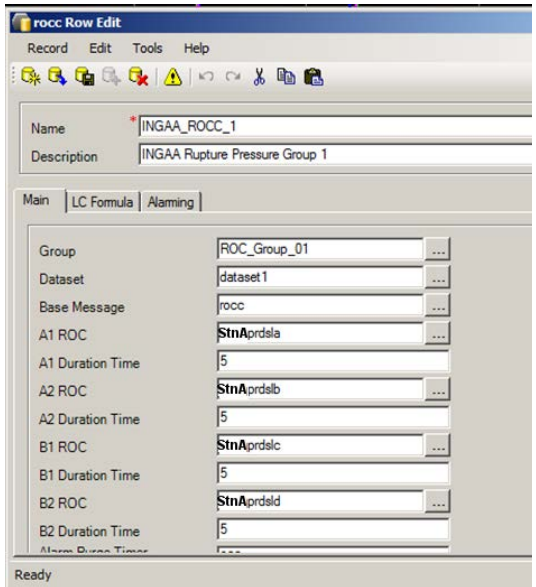


Figure-3 - Rate of Change Combination (ROCC) Configuration

As can be seen in Figure-3, the main screen allows the user to select up to four input ROC-enabled analogs or rates that should be used for each group of rate of change combination. By definition two adjacent ROCC evaluations should be able to use the same ROC evaluation.

The naming convention of A1, A2, B1 and B2 is indicative of grouping of ROCs, where the As are upstream of a specific pipeline segment and the Bs are downstream of the same specific pipeline segment. This allows for logical combinations between groups of points to be generated, but it should be emphasized that these points can be any related points, such as pressures for interconnected pipelines.

With the more reliable rate of change combination (ROCC) group configured, the next step is to establish in SCADA the pattern of ROC alarms required to trigger the rupture alarm. This is done in the Logical Condition (LC) Formula tab in the ROCC record and includes the related inputs and the logical pattern occurrence used to identify the rupture event.

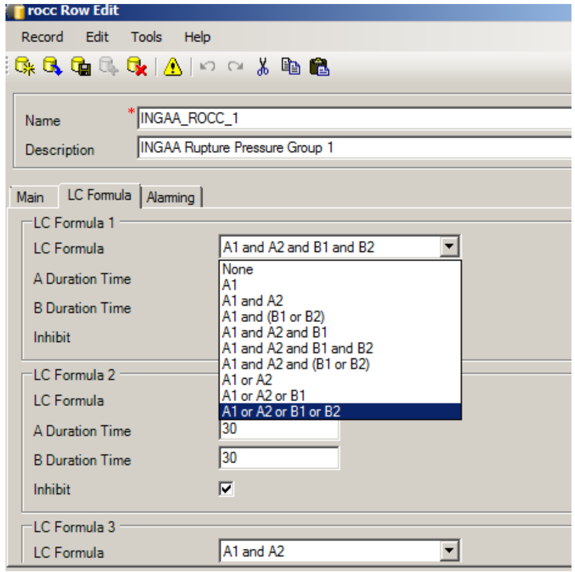


Figure-4 – ROCC Logical Conditions

As can be seen in Figure-4 above the four ROC points correspond with the related inputs configured earlier as part of Figure-3 and are identified as A1, A2, B1 and B2. A total number of three logical condition formulas can be created for each ROCC group. Each of the logical condition formulas could be either enabled or inhibited, allowing the controller in the control room the ability to inhibit a ROCC group that is not behaving correctly.

Each of the logical condition formulas allows the controller in the control room to specify duration time for both A points and B points. These duration times are provided to filter out noise and to accommodate the distances that may separate the upstream (As) from the downstream (Bs) inputs (if so configured).

3.2. Polling the Test Data

With the Rate of Change Combination record fully configured, we start the SCADA polling of the points through a simulated remote telemetry unit (RTU) that reads the data provided as time-series data in real time. This enables us to represent live data in the SCADA application as it occurred in the rupture event and evaluate the effectiveness of the application.

With the data being polled, each of the configured ROC points are monitored by comparing the value of the first sample against the last value and dividing by the time span between them to calculate the rate of change of the process. These ROC points are normally not seen, nor alarms generated, when alarm violations occur because the goal of the application is to eliminate the individual alarms and look for alarms that occur in the predetermined combination. However, ROC records can be called up from the ROCC Control Panel to review the data being processed and the current state of the evaluation as seen in Figure-5 below.

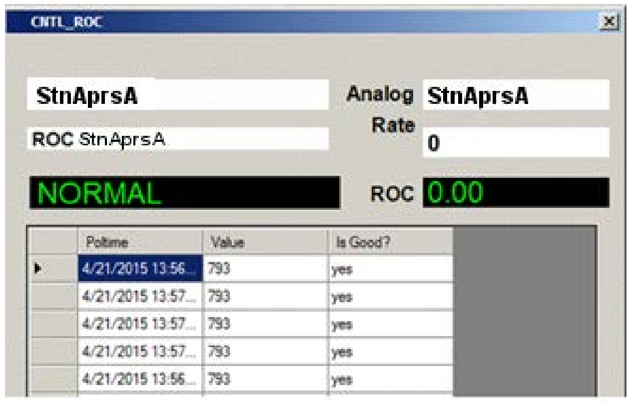


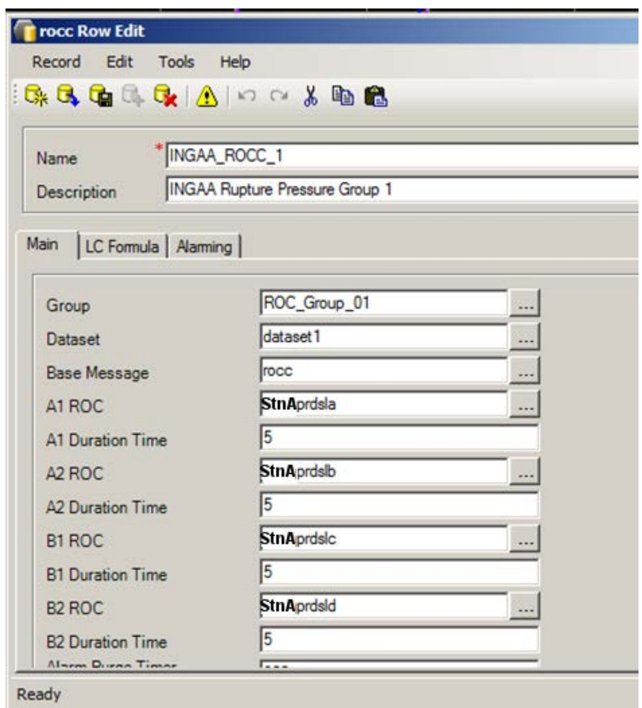
Figure-5 – ROC Control Panel (launched from ROCC Control Panel

4. Application Validation

4.1. Setup of Dataset #1

The first data set consists of 12 pressure inputs that cover a thirty-minute time span, updated once a minute. The dataset represents normal operations for seven minutes before the rupture and 23 minutes after the rupture. The pressure data supplied represents five interconnected main lines. <u>Note:</u> In reality, this rupture was recognized when the difference between the pressures between two of the interconnected lines exceeded a configurable alarm threshold using conventional SCADA functionality.

Test configuration for dataset #1 consisted of the setup of four selected pressure inputs to be configured as the ROC records to be used in combination. (The application uses analog or pulse inputs as input to the ROC calculation).



<u>Figure-6 - Dataset #1 ROCC Inputs and Durations</u>

As mentioned, the applications can group the four points into “A” ROCs and “B” ROCs to help designate upstream inputs (A) from downstream (B). However, this designation may not be relevant depending on the pipeline layout and input locations. Timed alarm durations help to ensure that the alarm condition persists for longer than the duration window to help filter out normal operational transients and spikes.

In this case the duration time was selected to be five seconds for each individual ROC, which means that if one ROC would detect a violation it would be active for five seconds. Other ROCs that violate their limits in that same time period (five seconds) would then potentially create an ROCC alarm.

With the four inputs determined, the next step is to select the logical combinations that would generate the more meaningful rupture alarm. Each of the three Logical Condition formulas have nine possible combinations to select the most relevant combination for the points involved. For this dataset, three Logical Condition Formulas where generated as follows using the display seen in Figure-7 below:

1. Logical Condition Formula 1 - all four inputs have to violate their ROC threshold to trigger the ROCC alarm (A1 and A2 and B1 and B2).
2. Logical Condition Formula 2 –three violations of the ROC threshold to trigger the ROCC alarm (A1 and A2 and B1).
3. Logical Condition Formula 3 – required two violations of the ROC threshold to trigger the ROCC alarm (A1 and A2).

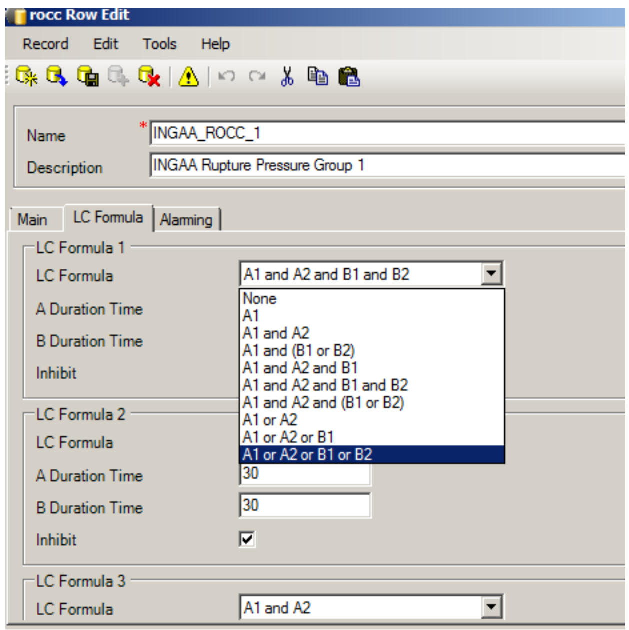


Figure-7 - Logical Conditions configuration for Dataset #1

During normal operation, the ROCC control display gives a snapshot of current setting and current rates of change. Individual ROCs can be viewed as indicated in Figure-8 below by selecting "ROC Control" in the ROCC control display. The ROCC control display also shows the snapshot of the Logical Condition Formula evaluation as seen in Figure-8 below.

ROC Control Panel
(see Figure-2)

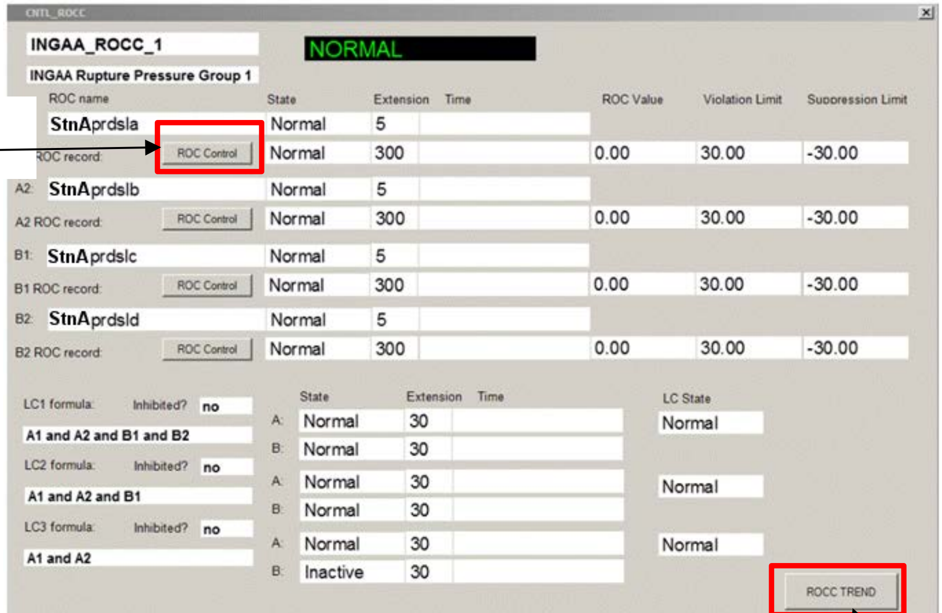


Figure-8 - Dataset #1 ROC Current Conditions

Trends are manually pre-configured with the ROCC inputs, see Figure-9

The runtime data in Dataset #1 and ROCC test record "INGAA_ROCC_1" is shown in the trend below in Figure-9. As can been seen from the trend, all four pressure inputs dropped at a similar rate.

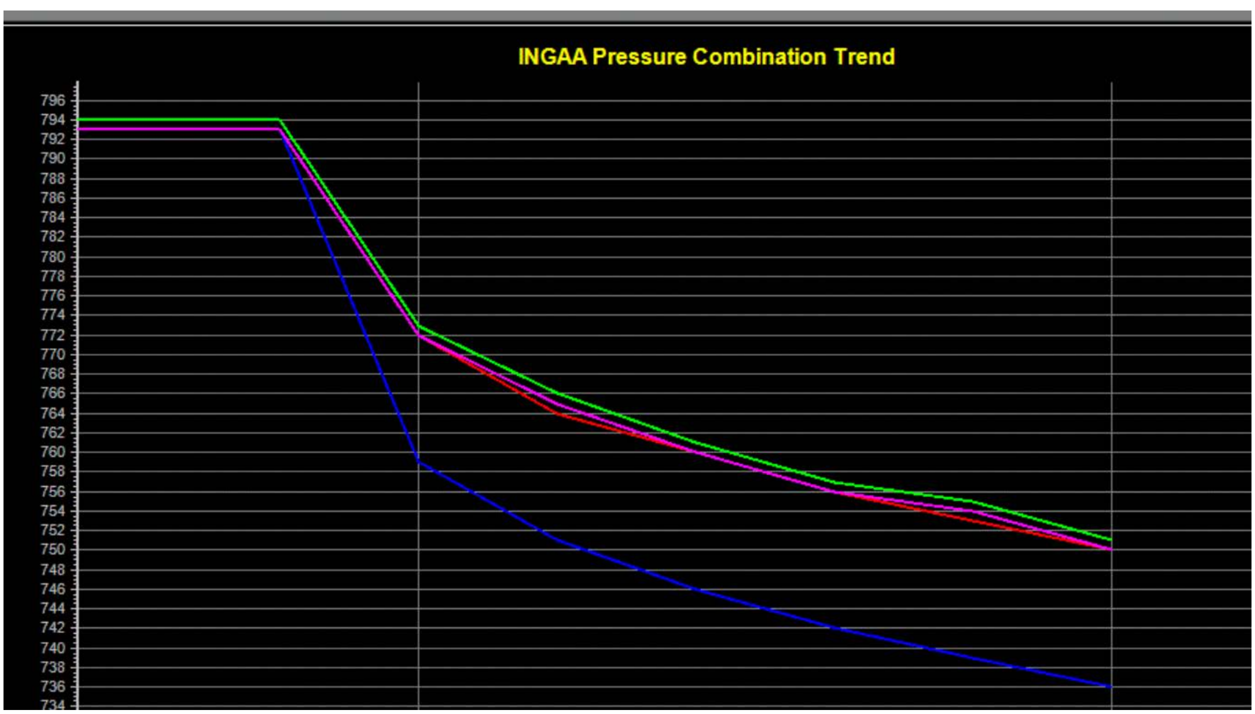


Figure-9 - Pressure Trend from Dataset #1 used for ROCC evaluation

4.2. Results for Dataset #1

In this test, all four inputs violated together within the timeframe configured resulting in the ROCC application triggering the rupture alarm as the highest priority alarm in the system. OASyS DNA message sets are used to define the alarm severity and the “Rupture?” message and can be modified as required.

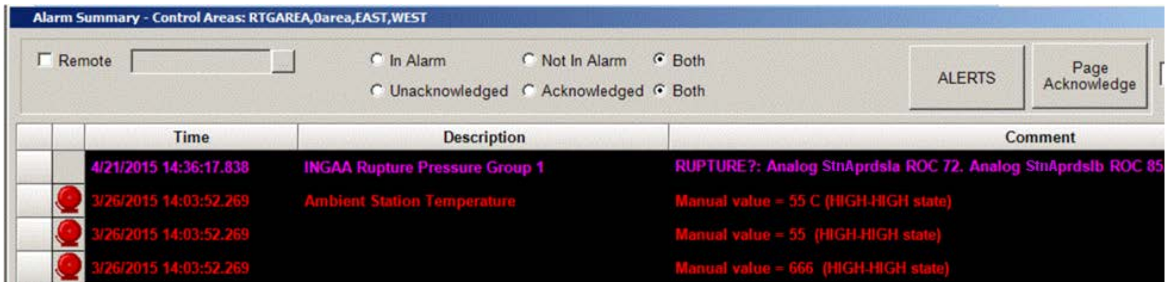


Figure-10 – Dataset #1 ROCC SCADA Alarm

Using the ROCC application, the normal condition display, seen in Figure-8, is updated to reflect that each parameter on the display e.g. ROCs, ROC limits and current values, durations and logical conditions being evaluated, has changed as a result of the input data for Dataset #1. This is seen in Figure-11.

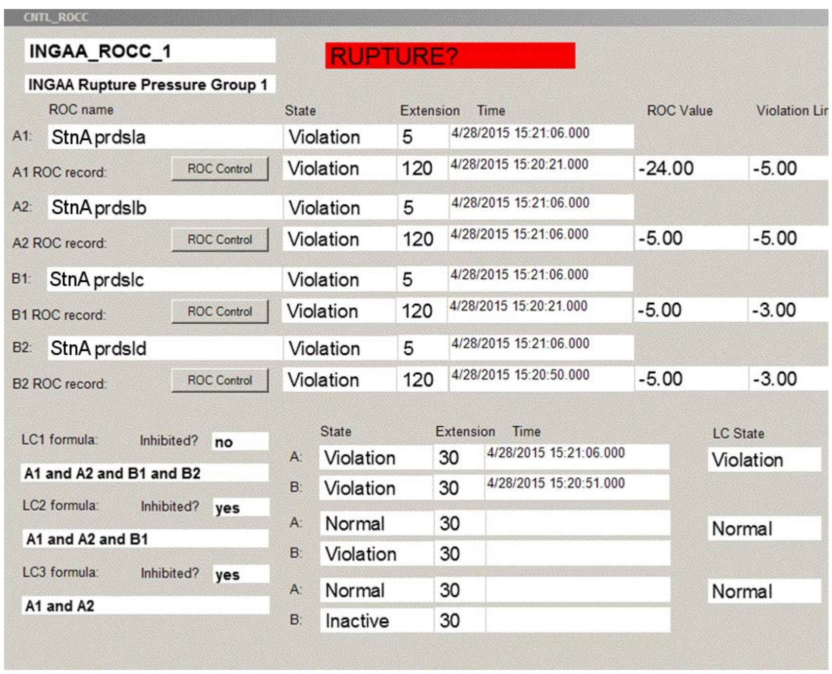


Figure-11 – ROCC Control Display for rupture event found in Dataset #1

As can be seen in Figure-11, both Logical Condition Formula 2 and 3 were inhibited during the testing of dataset #1. Figure-11 also shows that one of the pressure measurement (ROC points) significantly exceeded the violation limit, while the other three ROC points were close to the limit.

All the individual ROC alarms triggered at roughly the same time as seen in Figure-11. Similarly, the ROCC alarm was triggered 45 seconds after the first indication at a pressure measurement (single ROC violation) was detected. This is understandable from looking at the pressure trend for the same four ROC points in Figure-9.

Dataset #1 analysis indicates that the application would have generated the ROCC alarm for the rupture event. This dataset does not exercise the full capabilities of the application, as the simultaneous pressure drop off all inputs would be obvious to the gas controller using standard ROC alarm generation; however, the application does ensure it will not be missed, and provides additional confirmation of the rupture event.

Note: With the four pressure inputs, we effectively configured a methodology that addresses the National Transportation Safety Board (NTSB) recommendation from Sissonville, West Virginia report[1], for a "simple yet effective way to reduce the burden on the controller to remember or analyze a series of data outputs." By monitoring a combined rate of change in a group of related pressure points this application can create "A trend that is indicating an abnormal or unsafe condition could be programmed to trigger an alarm condition that would notify the controller to examine the condition and take corrective action to resolve it."

The NTSB concluded and recommended that providing automatic SCADA system trend data alerts would improve controller recognition of abnormal conditions. Further details of the recommendations P-14-2 and P-14-3 can be found in Appendix A, and the full NTSB report can be found at the following link:
https://www.ntsb.gov/investigations/AccidentReports/Reports/PAR1401.pdf

4.3. Setup of Dataset #2

Dataset 2 (shown as INGAA_DS_3) consists of a combination of pressure and flow inputs that allow us to better evaluate the design of the ROCC applications to monitor related pressure and flows relative to a rupture event. Dataset #1 only provided multiple pressure variables, while the configuration of Dataset #2 consists of the setting of three selected pressure inputs and one flow input, as seen in Figure-12 below.

[1] NTSB Pipeline Accident Report NTSB/PAR-14-01 PB2014-103977 (Columbia Gas Transmission Corporation Pipeline Rupture Sissonville, West Virginia December 11, 2012)

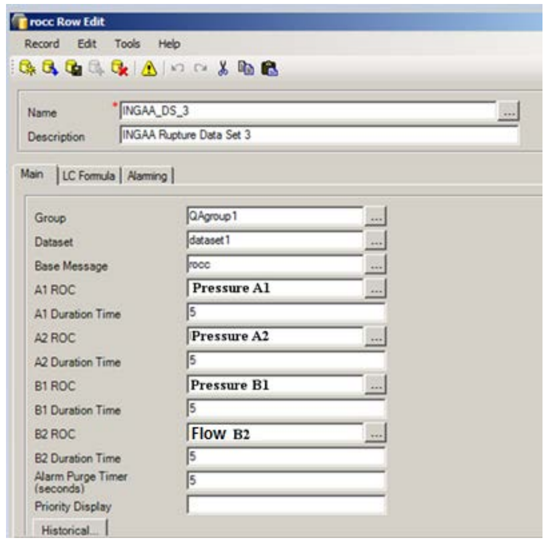


Figure-12- Dataset #2 Inputs and Durations

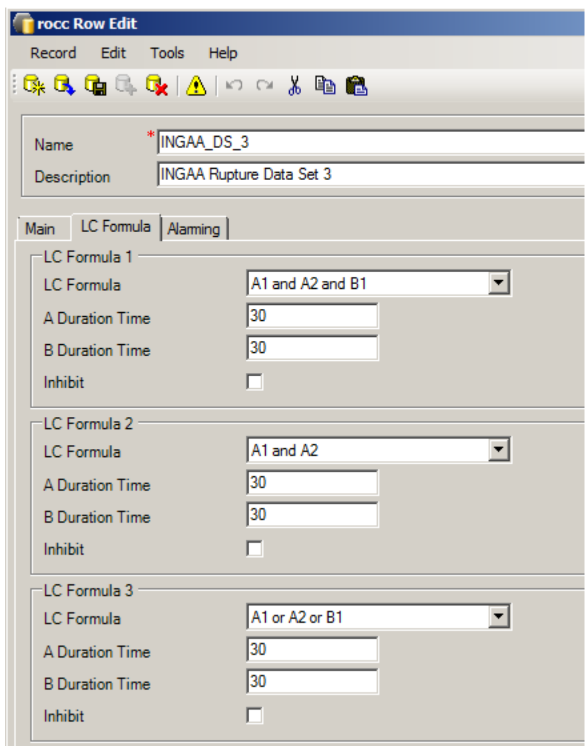


Figure-13 - Logical Conditions configuration for Dataset #2

Figure-13 shows the logical condition formulas chosen for Dataset #2. As can be seen the following three conditions were identified:

1. Logical Condition Formula 1 – required three violations of the ROC threshold to trigger the ROCC alarm (A1 and A2 and B1).
2. Logical Condition Formula 2 – required two violations of the ROC threshold to trigger the ROCC alarm (A1 and A2).
3. Logical Condition Formula 3 – any one of three inputs have to violate their ROC threshold to trigger the ROCC alarm (A1 or A2 or B1).

4.4. Results for Dataset #2

The collected data found in Dataset #2 demonstrated a much more erratic behavior, compared with the data seen in Dataset #1, indicating that it would be more difficult for a pipeline controller in the control room to understand that a rupture took place purely by observing the measurements. This is illustrated by looking at the trends of the relevant data associated with Dataset #2 in Figure-14 below.

Figure-14 - Trends from Dataset #2 used for ROCC evaluation

Figure-14 shows that the pressure trends were all dropping while the flow (yellow pen) was increasing, followed by dramatic spikes in both directions. Flow typically increases upstream of the rupture and drops downstream of the rupture. However, if flow control regulation is in effect or interconnected lines are nearby, the flow will be further affected.

As can be seen from the trends in Figure-14, there was some time between the start of the data and the actual rupture incident. During this time period the ROC for the flow measurement (Flow B2) exceeded the violation limit and generated an internal alarm as seen in Figure-15. It should be noted that when such incidents occur the pipeline controller in the control room will not be disturbed because the ROCC requires more than one ROC violation limit to be exceeded at the same time. This is a benefit of ROCC and is clearly seen in Figure-15 below.

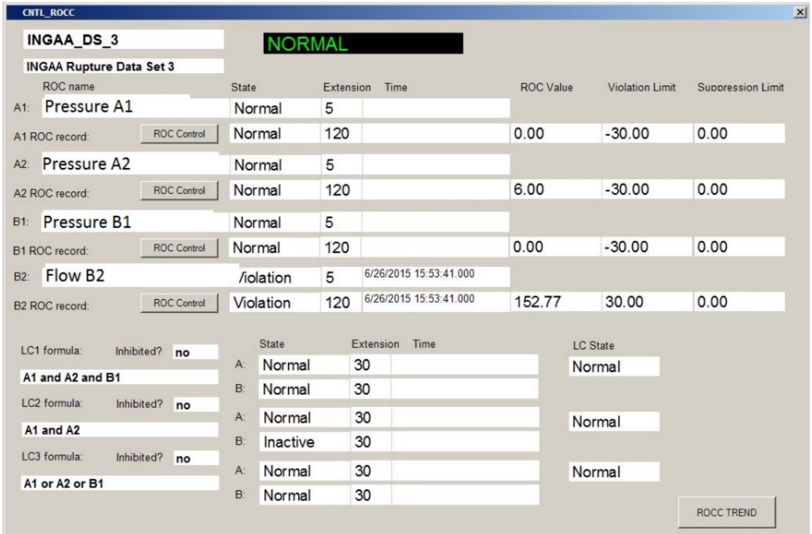


Figure-15 – ROC violated with ROCC status still Normal

ROCC did create an alarm when the rupture incident occurred as seen in Figure-16 below.

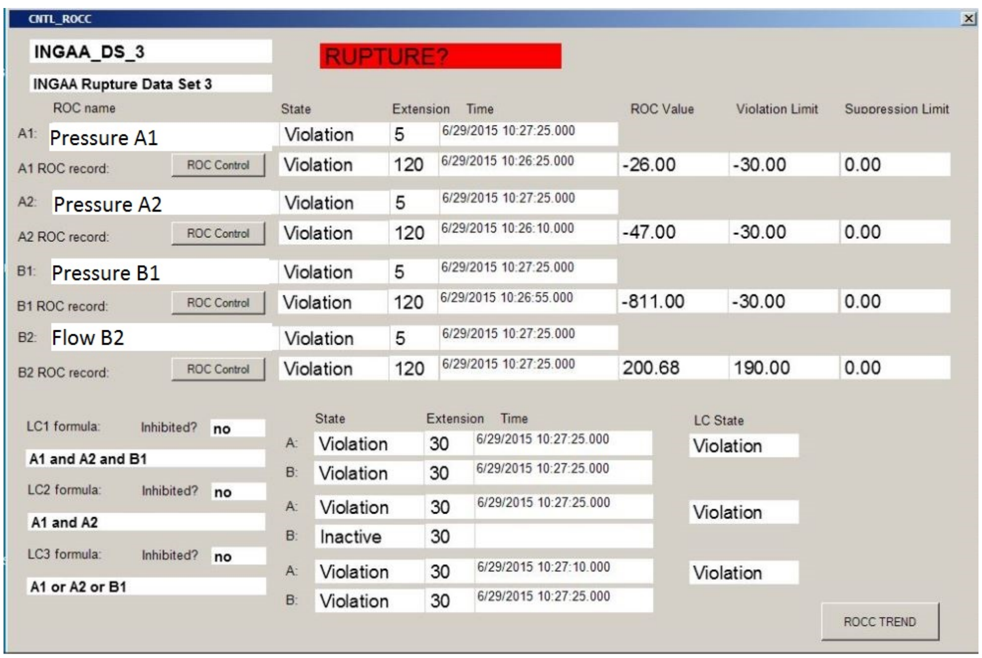


Figure 16 - ROCC Control Display for rupture event found in Dataset #2

As can be seen in Figure-16 above, the individual ROCs where all violated at approximately the same time (within 5 seconds of each other) at around 10:27:25. All three Logical Condition Formulas detected the rupture violation at the same time and created a rupture alarm in SCADA accordingly.

Similar to the results associated with Dataset 1, the analysis associated with Dataset #2 indicates that the ROCC application would have generated the rupture alarm for this rupture event.

4.5. Additional Datasets

By analyzing results of the two rupture datasets that were simulated through the ROCC application and reviewing the trends provided with the other datasets, we can predict that the application would trigger an alarm on the rupture events for the data provided, as pressure and flow changes were significant. As such, we made a decision to limit the effort of fully configuring and inputting data to two data sets at this time.

In hindsight, it is clear that the ROCC application can detect ruptures, which is not surprising since the industry has been using rate of change (ROC) methodology to detect ruptures for a long time. The ROCC application has the added benefit of eliminating many of the ROC nuisance alarms by using such methodology. Other datasets could have been investigated to prove this hypothesis further; however, at the time, it was not considered a priority for the study.

5. Conclusions

After analyzing sample rupture data provided by INGAA members, we are able to conclude that the ROCC application, with further development, may have the potential to recognize ruptures on natural gas pipelines, as well as address the NTSB recommendation that suggests *providing automatic SCADA system trend data alarms of this type would improve controller recognition of abnormal conditions* (such as pipeline ruptures), notify the controller to examine the condition and take the appropriate action to respond to it.

The ROCC methodology seems configurable enough that it could also be developed to address the NTSB recommendation in NTSB Pipeline Accident Report NTSB/PAR-14/01 PB2014-103977 (Columbia Gas Transmission Corporation Pipeline Rupture Sissonville, West Virginia December 11, 2012) for a *simple yet effective way to reduce the burden on the controller to remember or analyze* <u>*a series of data outputs*</u>.

Advantages: This provides a “simple to implement” rupture monitoring application that uses common SCADA data, pressures, flows and rate of change. As the program logic is designed for multiple SCADA point input to alarm generation, a single instrument failure or data anomaly is unlikely to result in a false-positive alarm.

Disadvantages: The administrator setting up the ROCC application needs to be knowledgeable about the relationship of the inputs used for each logical formula and how they might respond to a rupture. Configuration parameters, excursion thresholds and violation durations all affect the capability of the ROCC application and if set incorrectly, might create false positive alarms.

Limitations: Leak rate or leak location cannot be determined by the ROCC application, although the results obtained from ROCC should be a better starting point than those obtained using standard ROC. Interconnects, loops and complexity of the grid will make the selection of inputs and thresholds more important and more complicated.

Suggested Improvements to make this application more beneficial for rupture monitoring include:

- Automating the trend data so that the user does not need to manually configure the trends for each ROC input. The application should automatically configure trends for the points in the ROCC record.
- Creating a warning alarm, so that when part of the ROCC record is in violation, the pipeline controller would get a rupture *warning*. The controller would then use the ROCC trend to watch the changes in the segment, potentially recognizing a rupture before all the logical conditions in the ROCC evaluations have been met. This is useful when there is a long distance between the upstream and downstream inputs
- Currently the ROCC application has its own configuration rather than reusing standard ROC configuration for each point found in SCADA. This means that points are duplicated within SCADA. This should be eliminated going forward so that the standard ROC configuration for each point in SCADA is also used by the ROCC application.

6. Other SCADA Based Applications for Gas Rupture Recognition

In addition to the ROCC application that is being analyzed as part of this study, other SCADA techniques have been developed that may be worth evaluating for natural gas leak detection. One simple approach that may prove useful is an “alarm bracketing” or clamping method that allows the gas controllers to activate an alarm bracket for a pipeline (group of hydraulically related pressure inputs). These read the current pressures for all the points in the bracket group, and creates an operating envelope that matches the operating conditions, and provide an alarm when pressures deviate from this envelope without any operational reason.

As the controller makes the decision when to apply these clamped alarm limits, much of the operational transients that occur from normal operations can be eliminated. Intelligent suppression can be leveraged to automatically suspend the clamping based on operational triggers, (compressor starts, valve changes etc.) as well as manual re-bracketing to adjust the pressure envelope as needed.

Although the ROCC application has some benefits, it also has some limitations associated with the rate of change (ROC) functionality. Because of these limitations, Schneider Electric will continue to research and improve our rupture detection methodologies for both liquid and gas pipelines in cooperation with existing customers.

7. Definitions

Alarm - an audible or visible means of indicating to the controller that equipment or processes are outside operator-defined, safety-related parameters.

Leak – An unintended release of pipeline product that may or may not be immediately catastrophic and may be a high or a low energy release.

ROC – Rate Of Change – A parameter-based type of alarm used to notify controllers when there has been a sudden change in system operating characteristics.

ROCC – Rate Of Change Combination – A SCADA “pattern of alarms” technique used to identify major leaks and ruptures in pipeline systems.

RTU – Remote Telemetry Unit.

Rupture – A high-energy, immediately catastrophic, unintentional release of pipeline product.

Supervisory Control and Data Acquisition (SCADA) system - a computer-based system or systems used by a controller in a control room that collects and displays information about a pipeline facility and may have the ability to send commands back to the pipeline facility.

Appendix A

Excerpts From NTSB Pipeline Accident Report PAR-14-01

Columbia Gas Transmission Corporation Pipeline Rupture Sissonville, West Virginia
December 11, 2012

Columbia Gas Transmission Corporation Pipeline Rupture
Sissonville, West Virginia
December 11, 2012

Accident Report

NTSB/PAR-14/01
PB2014-103977

National Transportation Safety Board

2. Conclusions

2.1 Findings

1. Third-party direct pipeline impact damage was not a factor in this accident.

2. The controller was experienced and qualified, fit for duty, not physically fatigued, and not under the influence of illicit drugs or alcohol on the day of the accident.

3. Line SM-80 ruptured at 12:41 p.m.

4. Despite the many pressure deviation alerts occurring on the system over more than 12 minutes, the Columbia Gas Transmission Corporation controller did not recognize the significance of the situation or begin to shut down the system until after the Cabot controller called him.

5. The Columbia Gas Transmission Corporation supervisory control and data acquisition system alerts did not provide useful, meaningful information to the controller to assist him in determining the operating condition of the pipeline.

6. Providing automatic supervisory control and data acquisition system trend data alerts will improve controller recognition of abnormal conditions.

7. Strategically placed automatic shutoff values or remote controlled valves would have isolated the three pipelines and shortened the duration of the intense fire.

8. The coarse rock backfill most likely damaged the external coating on the pipe and shielded the pipe from the cathodic protection current in the vicinity of the rupture.

9. Line SM-80 failed because of severe wall thinning caused by external corrosion.

10. The corrosion damage discovered in 2009 during the in-line inspections of the other two pipelines in the SM-80 system was not adequately considered by Columbia Gas Transmission Corporation when it evaluated corrosion mitigation approaches for Line SM-80.

11. Had Line SM-80 been inspected using in-line inspection or pressure tested after in-line inspection data for Line SM-86 and Line SM-86 Loop were evaluated, the inspection results likely would have revealed the severe wall loss at the rupture location, and the in-service rupture of Line SM-80 could have been prevented.

12. If pipelines in proximity to highways had been included in the high consequence area classification, the ruptured area of Line SM-80 would have been covered by the integrity management regulation and would have been evaluated.

13. The consequences of a pipeline rupture in proximity to an arterial roadway are similar to the consequences of a pipeline rupture near structures for human occupancy, as currently addressed in a high consequence area.

2.2. Probable Cause

The National Transportation Safety Board determines that the probable cause of the pipeline rupture was (1) external corrosion of the pipe wall due to deteriorated coating and ineffective cathodic protection and (2) the failure to detect the corrosion because the pipeline was not inspected or tested after 1988. Contributing to the poor condition of the corrosion protection systems was the rocky backfill used around the buried pipe. Contributing to the delay in the controller's recognition of the rupture was Columbia Gas Transmission Corporation management's inadequate configuration of the alerts in the supervisory control and data acquisition system. Contributing to the delay in isolating the rupture was the lack of automatic shutoff or remote control valves.

3. Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations:

To the Pipeline and Hazardous Materials Safety Administration:

> Revise Title 49 *Code of Federal Regulations* Section 903, Subpart O, *Gas Transmission Pipeline Integrity Management*, to add principal arterial roadways including interstates, other freeways and expressways, and other principal arterial roadways as defined in the Federal Highway Administration's *Highway Functional Classification Concepts, Criteria and Procedures* to the list of "identified sites" that establish a high consequence area. (P-14-1)

To Columbia Gas Transmission Corporation:

> Implement a process for selecting alert setpoints, and provide guidance to pipeline controllers on the expected alert response time, ways to evaluate the significance of alerts, and actions the controller must take in response to those alerts. (P-14-2)

> Modify your supervisory control and data acquisition system to (1) provide the controller with operating parameter trend data that can be used to evaluate the significance of a system change and (2) assign an alarm function to trends that are likely significant system malfunctions and therefore require immediate action by the controller. (P-14-3)

> Establish a procedure to ensure that all integrity-related information gathered for pipelines located in high consequence areas is considered in the risk assessments and integrity management of other pipelines not located in high consequence areas. (P-14-4)