Knowledgebase and Acquisition System for Failure and Accident Analysis of Gas Processing Facilities

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Abstract

This paper presents knowledgebase and acquisition system to support the analysis of faults and accidents for gas plants. The developed solution defines faults in generic class level so that it is easily associated with equipment classes. Once plant process flowsheet is defined, it generates automatically the possible fault propagation scenarios using the dynamic structure of fault semantic network (FSN). Risks are calculated in the fault and equipment class level and aggregated in the fault propagation scenario and process blocks. Accident models are structured using FSN and linked with lessons and controls so that it can support the engineering design and operation of gas production facilities.

Keywords: Fault Semantic Network (FSN); Accident Analysis; Failure Analysis; POOM, Gas Processing Facilities.

1 Introduction

LNG based energy is receiving higher attention for cleaner and efficient energy supply. However, there are high risks associated with LNG production facilities. These risks are revealed in different accidents that occurred in different accidents. There are different techniques used to reduce risks in LNG plant processes. Such as risk analysis, mitigation, reduction, and management. Process monitoring techniques are developed significantly so that it can provide fault forecasting or prediction prior to any serious deviations or process upset. The concept of accident forecasting is discussed by many researchers in the past in different disciplines and views. Predictive maintenance is used to estimate remaining life through condition monitoring of equipment failures [1]. Predictive maintenance is mainly based on understanding of equipment good condition and degradation criteria and use to predict remaining life [2]. This technique is useful when one failure is assumed to contribute to the degradation of process equipment [3]. This will be more complex when more than one failure contributes to process degradation or upset. The understanding of equipment degradation with multiple failures requires developing fault propagation scenarios with the consideration of multiple failures. In order to develop fault models systematically, generic or class level fault models should be considered which can be generalized for equipment level. The integration between generic fault models and plant equipment classes will support the automatic generation of fault propagation scenarios. Typical LNG plant might have large numbers of fault propagation scenarios which require database to be properly managed and searched. The systematic structure of fault database along with accident database will support the analysis and simulation of all possible fault and accident scenarios for LNG plants. And in order to provide accurate and quantitative risk assessment of fault propagation scenarios risk estimates should be conducted for each fault model and for each fault propagation scenario. This paper presents practical models to support the analysis of fault and accident scenarios for LNG plants.

1.1 LNG Process Description

Gas processing facilities receives natural gas and produces LNG, or liquefied natural gas, as a final product. LNG is the strategic source for clean energy supply for different applications. LNG is refrigerated into a cryogenic liquid so that it can be shipped long distances in carriers. Once an LNG carrier reaches a receiving terminal, the LNG is unloaded and stored in large tanks until it is revaporized and piped into the natural gas distribution network. LNG is a hazardous liquid, because it is cryogenic and, as natural gas, it is combustible. The basic block diagram of LNG treatment facility is shown in figure 1.

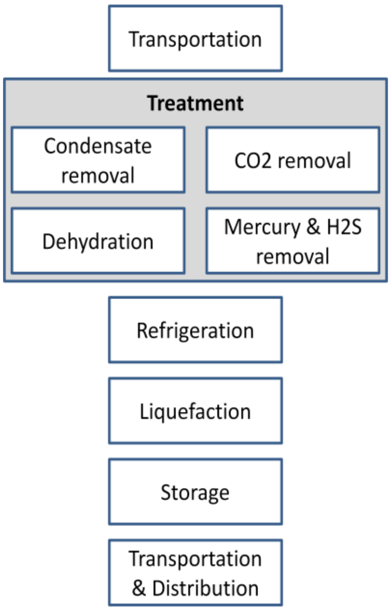

Figure 1. LNG Process Block

1.2 Possible Risks in LNG Production Facilities

There are typical risks associated with LNG production facilities. The main hazards include fire, explosion, as well as health and environmental impacts like asphyxiation. Due to the worldwide increasing interests and expansion for different LNG applications it is required to provide automated solution to identify and evaluate different risks associated with LNG production facilities.

This paper presents design of knowledgebase and advanced acquisition system to capture faults, failures, and accidents related to LNG and use along with the associated risk estimates to support design and operation of LNG production facilities. The following section describes the proposed fault modeling mechanism, followed by accident analysis approach. Finally, the proposed system design is presented.

2 Fault Modeling

Fault is process deviation or abnormal condition that might be associated with different failures. Fault can be thought as a symptom for a given failure like pump failure might be associated with degradation in output pressure. Also, fault might be thought as a cause or consequence for failure. Fault is described as a deviation in one or more state variables. State variable could be one of the following: (a) process variable, such as temperature or pressure; (b) control variable, such as valve angle or pump speed; (c) environmental variable, such as surface temperature or gas concentration / radiation level; (d) human variable, such as stress level or injury level; or (e) equipment variable, such as wall thickness, diameter, etc. On the other side, failure is a termination of a function of a physical system. For example, pump failure indicates that the pump is not working or terminated. Similarly, failure is associated with the following process elements: equipment, human, material, controllers, or environment. The proposed fault model includes both fault and failures along with their association with causes and consequences. Fault is represented as combination of process variable and deviation. Deviations are modeled using guidewords like "High", "Low", etc.

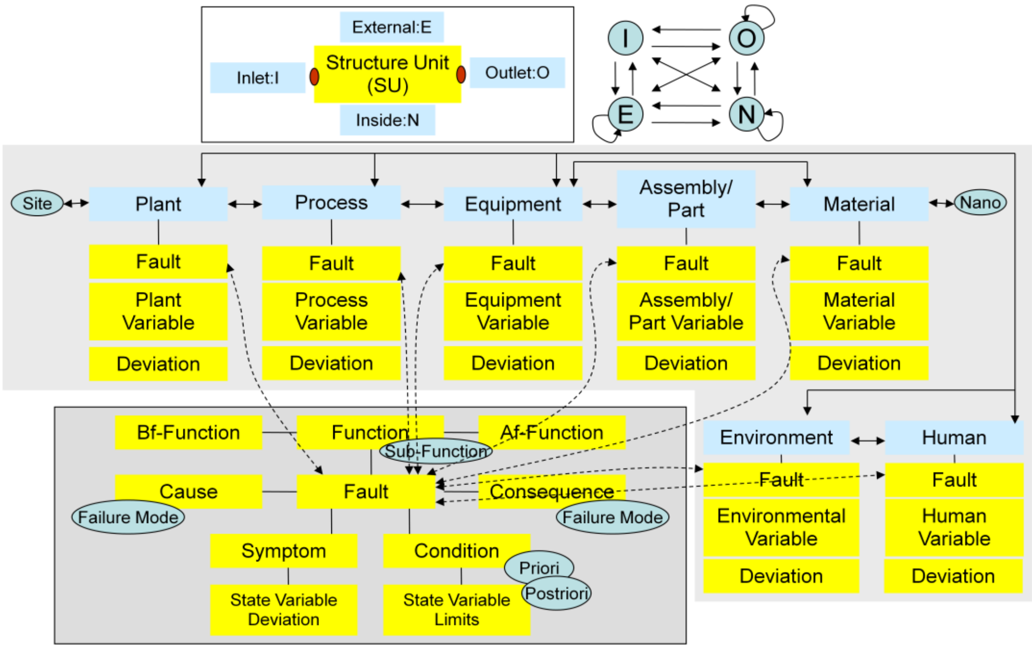

Figure 2. Fault Model Using FSN

For example, high temperature is modeled as association of process variable = "Temperature" and deviation is "High". For simplicity, fault is used to denote both fault and failure. Fault is represented in generic or class level where it is defined for any plant process. Causes and consequences are defined for the class level to represent all possible causes and consequences for a given fault. The second level of fault model is the association between fault model and equipment class. Faults along with their causes and consequences are replicated for equipment class level. For example, leak is defined in generic form and associated with all possible causes and consequences. Leak is associated with equipment class such as pipe and all causes and consequences are replicated from the leak class level into pipe class level. User is allowed to further tune and enhance the fault models for equipment class, e.g. pipe-leak. The last stage of fault model is related to plant equipment, which is associated with equipment tag or ID. Such as pump-1. Similarly, faults, causes, and consequences are copied from equipment class level into plant equipment level, e.g. pump-1. Figure 2 shows the proposed fault model where fault classes are created for plant, process, equipment, assembly, Material, environment, and human. Each fault is associated with fault location which could be: I-inlet; O-outlet; N-Inside; and E-External.

3 Accident Modeling

In addition to fault modeling, accident / incident modeling is important where it is possible to link accident scenarios to fault propagation scenarios for better accident analysis and prediction. Accidents are typically modeled as set of events where faults are escalated till top events. Top events might be escalated to disaster or accident.

3.1 Causation Modeling

In order to understand the dynamic of each accident / failure, causation model is developed starting from root causes of any accident / upset / or deviation, till the final accident or disaster. Each causation model goes through several escalation steps where control and barriers are incorporated to prevent or mitigate each escalation step. The causation model is formulated as shown in figure 1. The proposed model will enable the identification of the elements at each stage and link them through process model, as described above.

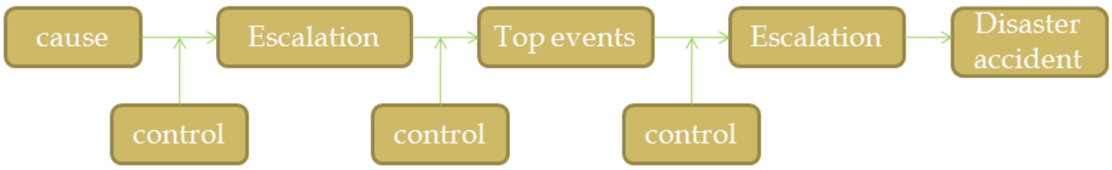

Figure 3. Typical Causation Model shows possible causes and consequences for a given top event, where escalation factors are used to show possible propagation. This includes controls / barriers for each propagation step.

3.2 Lessons Learned from Previous Accidents of LNG Plants

The main reason to capture and analyze previous accidents is to extract learning lessons for proactive applications in day-to-day operation. In order to extract practical lessons, appropriate knowledge structure is essential to map lessons to accident steps, corresponding controls, and suggested actions. Lessons are used to predict, mitigate, control, or prevent accidents by providing appropriate risk treatment at each set in accident escalation.

4 System Design

Based on the proposed fault and accident model described above, an automated acquisition system is developed. The developed knowledge structure is based on POOM and FSN where fault is structured in class level, called CL-FM. Each fault model is associated with causes and consequences, which are called CL-FM-CAUSE and CL-FM-CONS. Accordingly, equipment based fault models are defined, which are called PL-EQ-FM, PL-EQ-FM-CAUSE, and

PL-EQ-FM-CONS.

4.1 System Implementation

The proposed steps to system implementation are shown in table 1.

Table 1. Proposed Fault and Accident Data Acquisition Process

Define Equipment Class
Define Failure Class – Causes / Consequences
Define Equipment & Process Variable List
Define Equipment Class – Failure
Define Equipment Class – Failure – Causes / Consequences
Define Plant Process Equipment / Connections
Define Plant Topology Nodes
Define Plant Process Material
Define Plant Equipment – Failure – Causes / Consequences
Define Fault Propagation Scenarios as FSN
Define Equipment Failure Probability / Impact / Risk
Define Risk Aggregation in Fault Propagation Scenarios
Define Accident Header Information
Define Accident Detailed Information
Define Controls For Accident Steps
Define Lessons Learned From Accidents

4.2 Fault Model Generation Algorithms

The proposed fault model generation algorithm is described in table 2.

Plant Equipment Fault Model Generation [Pl-eq-fm]

1. Select the first equipment id from plant topology and the corresponding equipment class id
2. Searches all related faults for the selected equipment class and equipment fault class
3. Add all the selected values into plant equipment fault model table
4. Repeat for all plant equipment id's

Plant Equipment Fault Model Causes [Pl-eq-fm-cause]

1. Select first plant equipment id and related fault model from plant equipment fault model using plant id, equipment id, and fault model id
2. Search plant equipment to find related equipment class id for the selected plant equipment id
3. For selected equipment class id and fault model, search for equipment class fault model and their causes
4. Select all the causes from equipment class fault causes for the selected equipment class fault model and fault model id using key cause fault model id, cause fault model location, and fault model location
5. For each cause, identify corresponding cause equipment
    a. If the fault model location and cause fault model location are same, then cause equipment is the same as equipment id
    b. Continue to next equipment
    c. Find all equipment connected to the selected equipment id by searching plant

nodes

d. Check if equipment has consequences where consequence-id = fault model id and fault model id = cause id from equipment class fault model consequence

e. Record each value

4.3 Knowledge Structure

The proposed FSN knowledge is implemented within MS Access where classes are represented in different tables. The relationships among tables as represented within MS Access are shown in figure 4.

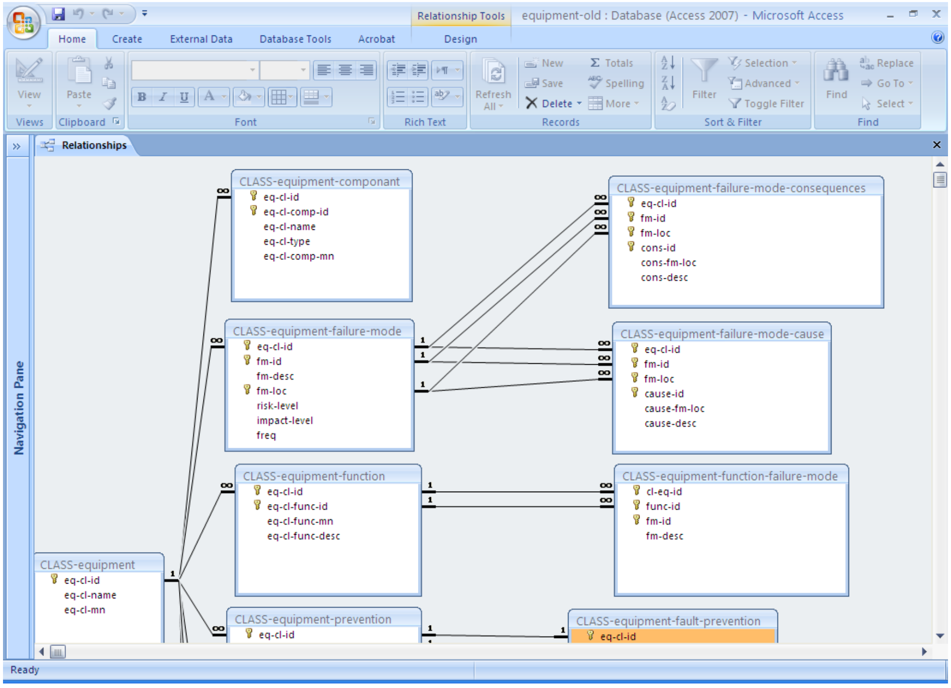

Figure 4. Knowledge Structure in FSN Database

One example of equipment class fault model is shown in figure 5. The first column is eq-cl-id which is the equipment class id that includes pumps, tanks, valves, etc. The second column includes fault model classes, such as leak, fatigue, etc. The third column is fault model description. The fourth column is fault location, or fm-loc. The fifth column is risk level, which is a qualitative measure for risk level for each fault model class. Risk level is the multiplication of frequency of fault and the impact level. Quantitative measures are used for impact level, frequency, and risk level.

eq-cl-id	fm-id	fm-desc	fm-loc	risk-level	impact-leve	freq	Add New Field
AGITATOR	FATIGUE	Fatigue in agitator	N	2	0.5	0.1	
AGITATOR	MECHANIC-FAIL	Mechanic failure in agitator	N	2	0.5	0.1	
AIR-COMP	FAIL-FUNCTION	Air compressor fails to function on de	A	2	0.5	0.1	
AIR-COMP	FAIL-TO-START	Air compressor fails to start on demar	A	2	0.5	0.1	
AIR-COMP	LEAKING	Air compressor leaks	N	2	0.5	0.1	
ANGLE-VALVE	FAIL-TO-CLOSE	Angel valve fails to close on demand	A	2	0.1	0.5	
ANGLE-VALVE	FAIL-TO-OPEN	Angel valve fails to open on demand	A	2	0.1	0.5	
ANGLE-VALVE	LEAKING	ANGLE-VALVE leaks	A	2	0.5	0.5	
AXIAL-PUMP	CAVITATION	Axial pump is cavitated	N	1	0.1	0.1	
AXIAL-PUMP	FAIL-TO-FUNCTION	Axial pump can not be functioned pro	A	1	0.1	0.1	
AXIAL-PUMP	FAIL-TO-START	Axial pump fails to start on demand	A	1	0.1	0.1	
AXIAL-PUMP	HIGH-OUTPUT	Axial pump drives high output flow	O	1	0.1	0.1	
AXIAL-PUMP	LOW-OUTPUT	Axial pump drives low output flow	O	1	0.1	0.1	
AXIAL-PUMP	OVERFLOW	Axial pump drives material in overflo	N	1	0.1	0.1	
Ball mill	LEAKING	Ball mill leaks	A	2	0.5	0.5	
BALL-VALVE	FAIL-TO-CLOSE	Ball valve fails to close	A	2	0.1	0.5	
BALL-VALVE	FAIL-TO-OPEN	Ball valve fails to open	A	2	0.1	0.5	
BALL-VALVE	LEAKING	Ball valve leaks	N	2	0.1	0.5	
Blender	LEAKING	Blender leaks	A	2	0.5	0.5	
BOILER	CONTAMINATION	Boiler is contamined by undesired ma	N	3	0.7	0.1	
BOILER	LEAKING	Boiler leaks	N	3	0.7	0.1	
Breaker	LEAKING	Breaker leaks	A	2	0.5	0.5	
BUTTER-VALVE	FAIL-TO-CLOSE	Butter valve fails to close	A	2	0.1	0.5	
BUTTER-VALVE	FAIL-TO-OPEN	Butter valve fails to open	A	2	0.1	0.5	
BUTTER-VALVE	LEAKING	Butter valve leaks	N	2	0.1	0.5	
CECCHI-VALVE	FAIL-TO-CLOSE	Checchi valve fails to close	A	2	0.1	0.5	
CECCHI-VALVE	FAIL-TO-OPEN	Checchi valve fails to open	A	2	0.1	0.5	
CECCHI-VALVE	LEAKING	Checchi valve leaks	N	2	0.1	0.5	
CENT-COMP	FAIL-TO-FUNCTION	Centrifugal compressor fails to functi	A	2	0.5	0.1	
CENT-COMP	FAIL-TO-START	Centrifugal compressor fails to start	A	2	0.5	0.1	
CENT-COMP	LEAKING	Centrifugal compressor leaks	N	2	0.5	0.1	
Centrifugal fan	LEAKING	Centrifugal fan leaks	A	2	0.5	0.5	
CENTRI-PUMP	CAVITATION	Cent pump is cavitated	N	1	0.1	0.1	
CENTRI-PUMP	FAIL-TO-FUNCTION	Cent pump can not be functioned pro	A	1	0.1	0.1	
CENTRI-PUMP	FAIL-TO-START	Cent pump fails to start on demand	A	1	0.1	0.1	
CENTRI-PUMP	HIGH-OUPUT	Cent pump drives high output flow	O	1	0.1	0.1	
CENTRI-PUMP	LOW-OUTPUT	Centrifugal pump drives low output fl	O	1	0.1	0.1	

Figure 5. Data Set of Equipment Class Fault Model

4.4 Fault / Accident Acquisition System

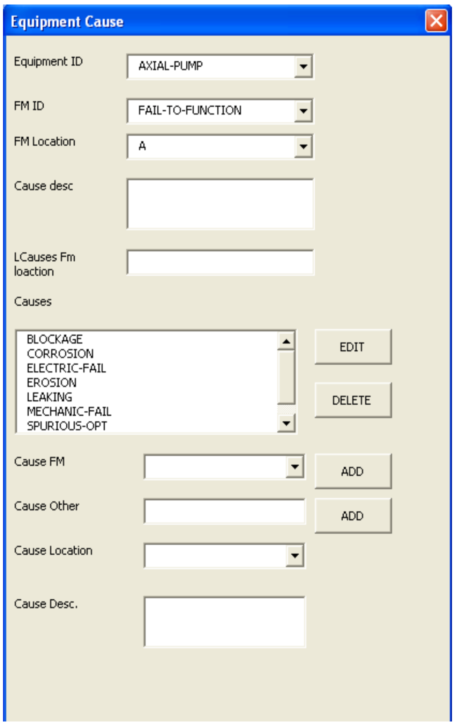

Figure 6. Equipment Failure Cause Data Acquisition

At the beginning, engineer will define fault models in generic way for each equipment class. For each fault model, causes, consequences, and the fault locations are assigned, as shown in figure 6.

5 Conclusion

The worldwide needs for gas processing facilities for cleaner energy supply are increasing. This requires providing robust safety systems based on accurate risk analysis. This research focuses on fault and accident analysis of LNG or liquefied natural gas as one potential gas processing facilities. In order to provide accurate risk analysis for possible fault and accident scenarios it is important to systematically analyze possible fault propagation scenarios qualitatively using fault semantic network (FSN). This will allow the dynamic learning and tuning of fault propagation scenarios based on equipment fault libraries. Risks are calculated for each fault propagation scenario and aggregated for each equipment, process, and scenario. Faults are modeled in class level and classified for each equipment type and fault location. Systematic generation of fault models are developed to associate fault model with each equipment so that it is possible to generate fault propagation scenarios for any given process model. The analysis of failures will provide strong foundations to predict and prevent risks during design and operational activities.

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