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Fault detection and diagnostics of a three-phase separator

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ABSTRACT

A high demand of oil products on daily basis requires oil processing plants to work with maximum efficiency. Oil, water and gas separation in a three-phase separator is one of the first operations that are performed after crude oil is extracted from an oil well. Failure of the components of the separator introduces the potential hazard of flammable materials being released into the environment. This can escalate to a fire or explosion. Such failures can also cause downtime for the oil processing plant since the separation process is essential to oil production. Fault detection and diagnostics techniques used in the oil and gas industry are typically threshold based alarm techniques. Observing the sensor readings solely allows only a late detection of faults on the separator which is a big deficiency of such a technique, since it causes the oil and gas processing plants to shut down.

A fault detection and diagnostics methodology for three-phase separators based on Bayesian Belief Networks (BBN) is presented in this paper. The BBN models the propagation of oil, water and gas through the different sections of the separator and the interactions between component failure modes and process variables, such as level or flow monitored by sensors installed on the separator. The paper will report on the results of the study, when the BBNs are used to detect single and multiple failures, using sensor readings from a simulation model. The results indicated that the fault detection and diagnostics model was able to detect inconsistencies in sensor readings and link them to corresponding failure modes when single or multiple failures were present in the separator.

1. Introduction

According to the U.S. Energy Information Administration (U.S. Energy Information Administration, 2013) approximately 93 million barrels per day of oil products were produced every day around the world in 2014. An increasing demand of oil products requires the oil and gas processing facilities to work at maximum efficiency and every second spent without producing oil results in economic losses. The biggest losses are experienced when the offshore oil and gas plants need to be shut down unexpectedly due to a failure of its equipment. Three-phase separators (TPS) are one of the key components of offshore processing facilities. A failure in the TPS can cause the whole oil processing plant to be stopped. Thus, a timely detection of failing components in the TPS is necessary.

Faults in the TPS and other processing units in the oil and gas industry are commonly detected by using either thresholds of the process variables (Chan, 2005) (e.g. oil level, water level and etc.), statistical analysis of the process variables (Roverso, 2002; Omana and Taylor, 2007; Taylor and Omana, 2008; Gao et al., 2009) or precise mathematical models (Dias et al., 1993; Afonso et al., 1998; Kinnaert et al., 2000; Al-Hajri and Rossiter, 2010) simulating the operation of the TPS and then comparing its outputs with the readings obtained from the actual separator. The first approach usually detects failures when their effect is already critical and prevention of the separator shut down is unavoidable. Moreover, observing the readings from individual sensors and comparing them to threshold values might hide certain failure modes (level transmitters stuck on the last reading) unless comparison between several sensors is not performed. The second approach needs historical data of the process variables under fault free and faulty operation, which might not always be available in practice, especially for the hazardous failure modes. Finally, the detailed mathematical model approach needs a very good understanding of the process conditions and usually requires extensive modifications if operating conditions change.

A novel fault detection and diagnostic methodology for TPS is

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proposed in this study. It can give an early warning of a failure in the system and has an ability to be easily adapted for the specific system. The methodology was built using the Bayesian Belief Network (BBN) technique. Such an approach was chosen due to several reasons, including the graphical representation of the modelled system, inclusion of expert knowledge about failure modes of the system, ability to model uncertainties in a probabilistic way, ability to build the model in a structured and modular way and update the prior knowledge about occurrence of certain failure modes without altering the structure of the model.

2. Three-phase separator

The three-phase separator is one of the main components in the oil production plant. This unit is responsible for separating gas, water and solid impurities from oil. The operation of the TPS is based on the laws of gravity, allowing a liquid with a higher density, such as water, to settle on the bottom of the separator, and a liquid with a lower density, such as oil, as well as gas, to flow to the top of the separator. Different types of separators can be used in industry, the most common ones being horizontal, vertical and spherical. A horizontal separator is most commonly used due to the ease of maintenance, good separation quality and low initial set-up costs. In this study, a horizontal TPS with a weir is considered. However, the proposed methodology is generic and with some minor adjustments it could be applied to other types of separator.

A schematic diagram of a typical horizontal three-phase gravity separator with a weir can be seen in Fig. 1. The whole vessel can be roughly divided into three sections:

1. The gravity settling section (or the liquid separation section), where the separation of water and oil takes place (the section to the left of the weir).
2. The separated oil section, where the separated oil flows from the liquid separation section (the section to the right of the weir).
3. The remaining space of the vessel is left for the gas phase (separated gas section).

The main components to monitor and control the horizontal three-phase separator given in Fig. 1 are summarised in Table 1.

2.1. Simulation model of a three-phase separator

When developing a fault detection and diagnostic technique for an industrial system, it is essential to test the technique in as close to the real operating conditions as possible. This can be done in several ways: having a scaled version of the real operating system or modelling the system and its operation using specialised software tools (Taylor and Omana, 2008; Dias et al., 1993). The first option is more desirable, since a scaled system can have operating conditions similar to those of the real system. However, this option is rarely used in practice, since building a test system can be costly. Moreover, testing using such a system usually takes more time, since all the effects of failures have to be removed from the system before another failure can be induced in the system. It might even be unsafe to induce certain failure modes, which might lead to the damage of the system.

The second option – system models – are favoured, since they can capture the main operating conditions of real systems and are cheap to implement. Furthermore, the data from the models is easily obtainable and even hazardous failure modes can be easily tested. The cost of developing models, the time taken to get the data and the ease of modelling different failures are the most important factors making the system models a preferred option for testing and validating fault detection and diagnostic techniques. The latter approach was also used in the study performed.

Software with a graphical user interface for modelling the operation of a TPS under both normal operating conditions and those affected by faults was written in C++. A simplified model of a TPS was considered. If necessary, the complexity of the simulation model can be increased by modifying the model assumptions. The assumptions used for the TPS modelling are as follows:

1) The separation process is assumed to be perfect. All of the incoming mixture is completely separated into three different phases, i.e. water, oil and gas, and the separation occurs instantly.
2) The layers of the different phases are formed on top of each other and do not mix, just separate.
3) There are no leaks in the separator.
4) The volume of internal components (e.g. inlet diverter, weir) is not considered.
5) The maximum inflow is twice as high as the average inflow. Control valves are designed to allow the same maximum outflow rates as those of the maximum inflows, when the valves are fully open. When outlet valves are half opened, an amount corresponding to an average inflow is released from the vessel.
6) The precision of level transmitters is 1 cm, the precision of the flow rate transmitters is 0.001 m^3 (1 L) and the precision of the pressure transmitter is 1 kPa.
7) Control valves can be opened with a 5% precision ranging from being fully closed (opened 0%) to fully opened (opened 100%).
8) A control command sent from the controller to a control valve is recalculated every 5 s, while levels of water, oil and gas are monitored every second.
9) There is no dead time between time points when the level of each phase is measured and sent from the transmitter to the controller; and then the control command is sent from the controller to the control valve.
10) Selected PI control parameters CO_b (controller bias value), K_C (controller gain) and T_i (integral time) are such that they do not cause a disruption to the operation of the TPS when all of the control components are working.
11) Physical design parameters of the separator (e.g. weir height, separator radius and etc.) and normal operating conditions (e.g. water–oil interface set point, oil level set point), given in Table 3 are assumed to be chosen appropriately.

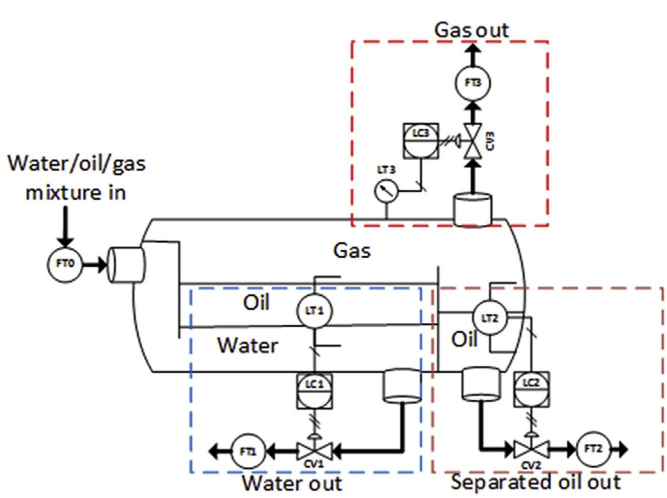

Fig. 1. Horizontal three-phase separator schematic of configuration with weir.