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IFAC-PapersOnLine 49-28 (2016) 280–285

System Failures of Offshore Gas Turbine Engines in Maintenance Perspective

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Abstract: Several system failure events of a selected gas turbine engine with respective to its maintenance actions are considered in this study. These system failure events are derived from condition monitoring (CM) data of a selected gas turbine engine and modeled into a nonhomogeneous Poisson process (NHPP) under maximum likelihood estimation. Various erroneous data intervals are noted in the CM data of the gas turbine engine and removed from the respective analysis. The CM data set is divided into several intervals due to the erroneous data intervals and the modified data set is used to estimate the parameters of the respective models of system reliability. These models represent the failure intensity levels of the gas turbine engine during various sectors of its life cycle. These failure intensity levels consist of increasing and decreasing reliability trends and those variations are compared with system faults and maintenance periods to observe the respective reasons. Finally, the reasons among these system faults and maintenance periods by considering the inputs from the maintenance crew are also summarized in the conclusion of this study.

Keywords: Gas Turbine Engines, System Failures, Failure Intensity, Condition Monitoring, Condition based Maintenance, Offshore Power Plants.

1. INTRODUCTION

System failures and maintenance actions of an offshore power plant with several gas turbine engines to satisfy the power requirements of an oil and gas field are considered in this study. The industrial power plant is facilitated with four gas turbine engines/generators in a floating production, storage and offloading (FPSO) unit located in Campos Basin, Rio de Jeneiro (Machado *et al.,* 2014). These gas turbine engines are equipped with condition monitoring (CM) facilities to monitor the system health under harsh ocean environmental conditions with appropriate maintenance actions and that process is categorized as condition based maintenance (CBM). Therefore, the system degradation (i.e. health condition) of each gas turbine engine is monitored with various sensors under CM. Catastrophic failure situations in the entire power plant can be avoided by monitoring each engine degradation condition and executing appropriate maintenance actions. One should note that CBM is enabled by CM activities, where appropriate maintenance decisions/actions are taken by the crew to improve the power plant availability. It is also believed that appropriate diagnostic and prognostic tools should be developed to identify the present and future health conditions of gas turbine engines under CMB approaches.

The environmental effects can degrade the system performance of offshore gas turbine engines as discussed previously. Therefore, appropriate maintenance actions under the required system integrity and safety levels with essential component upgrades should be initiated to improve the availability of the power plant. However, the ageing effects of offshore gas turbine engines may require additional maintenance actions to cope with fatigue and corrosion issues of the components. Furthermore, old system components should be replaced with new ones to improve operational availability of offshore gas turbine engines in some situations. That process is associated with not only respective maintenance costs but also health, safety and environment (HSE) and service quality (SQ) considerations. The respective maintenance costs can have a direct relationship to the respective system reliability in such situations. These maintenance actions are a part of the overall maintenance strategy of the respective oil and gas operator. In general, system reliability in the oil and gas industry is categorized under three main divisions: availability, safety and maintainability. Since the present economic downturns, the oil and gas industry focuses to identify the most critical requirements for these oil and gas platforms, where various cost-effective maintenance actions are introduced under the required availability, safety and maintainability considerations.

System maintenance is often done after complete system failures (i.e. run-to-failure maintenance) in various industries, where the respective HSE and SQ considerations are neglected in some situations. However, this approach can be improved by considering planned system maintenance (i.e. preventive maintenance) in some situations. That consists of implementing periodic time maintenance intervals regardless

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.11.048

of the system health condition and improves the system availability in a majority of industrial systems. However, such preventive maintenance actions can be expensive for some industries with complex machineries (i.e. systems with a large number of subsystems and components) such as gas turbine engines. Therefore, CBM as a cost effective solution is adopted by such industries, where actual health conditions of respective systems are monitored, continuously and appropriate maintenance actions can be chosen and executed appropriately.

In general, industrial maintenance actions can be divided into three categories of corrective, preventive, and predictive. Those actions are also executed under various maintenance strategies of run to failure maintenance (RTFM), on condition maintenance (OCM) and condition based maintenance (CBM) as discussed previously. As a summary, RTFM approaches focus on corrective measures, OCM approaches focus on corrective and preventive measures, and CBM approach focuses on all corrective, preventive and predictive measures. Therefore, CBM is considered as the most suitable approach to overcome respective diagnostic and prognostic challenges in the oil and gas industry. This study focuses on understanding system reliability of a selected gas turbine engine with respect to its maintenance actions. System reliability is quantified with respect to the failure events of the selected gas turbine engine. It is also expected that these failure events also relate to age related system degradations and that should be reflected in the respective failure intensity levels of the gas turbine engine. Hence, the respective failure intensity levels of the gas turbine engine are calculated from the CM data.

The health conditions of gas turbine engines are observed under two different industrial levels. The first level consists of the top-down concept: the engine degradation with respect to its current usage level is identified and compared to the average engine performance throughout its life cycle. The second level consists of the bottom-up concept: the component health conditions and maintenance information are used to determine probable effects of the engine degradation. This study overlaps both concepts, where engine health conditions with respect to the failure intensity levels are estimated for various sectors of the system life and that information is compared with its maintenance actions. Furthermore, the respective maintenance actions and recorded information are discussed with the crew to derive the conclusions at the end of this study.

CM and CBM have often been a part of engine health management approaches. A summary of such engine health management approaches of gas turbines is presented Perera *et al.* (2015a). These approaches are often based on real-time measurements (i.e. physical parameters), event data (i.e. system failures and shutdowns) and maintenance records (i.e. overhauls and repairs). Hence, engine health management approaches can predict various system failures of gas turbine engines and prevent overall offshore power plant failures. Various mathematical models are developed under these health management approaches and divided into two sections: gas path analysis (GPA) and performance seeking control (PSC). These approaches develop mathematical models for gas turbine engines consisting various parameters that relate to the health conditions of the respective components. The parameters of such mathematical models are estimated by various algorithms with sensor measurements (i.e. pressure, temperature and rotational speed values of the respective components).

Several engine health management applications that relate to GPA are presented in the respective studies of (Simon and Simon (2005), Pu *et al.,* (2013)). Similarly, additional engine health management applications that relate to PSC are presented in the respective studies of (Espana (1994), Gilyard and Orme (1993), Orme and Schkolnim (1995), and Simon and Garg, (2009)). However, GPA and PSC based engine health management approaches in gas turbine engines encounter various industrial challenges and that are summarized as: 1) sensor noise (i.e. bias and variance values in the measurements) can degrade the parameter estimation process, 2) system parameters can have various nonlinear relationships and the respective models and sensor measurements are inadequate to identify those relationships and 3) a large number of sensors are required to estimate the total number of health parameters in gas turbine engines. Even though some solutions to such challenges are proposed in the recent literature (Simon and Garg (2009) and Xuewu *et al.,* (2009)), the complex nonlinearities among the system parameters can still degrade GPA and PSC based health management approaches in gas turbine engines. Therefore, a system failure events based health management approach for gas turbine engines is considered in this study, where the respective failures are categorized as stochastic events. The failure intensity of a selected gas turbine engine is modeled as a nonhomogeneous Poisson process (NHPP) (Perera *et al.* 2015a, b) under such situations. These types of models (i.e. stochastic process) are used in many reliability studies for predicting the failures of various systems and components (Rausand and Hoyland, 2004).

A similar concept is adopted in this study to calculate the system failure intensity levels of a selected gas turbine engine. Hence, this is a simplified approach with compared to GPA and PSC based health management approaches of gas turbine engines and that can also be used to evaluate the respective maintenance actions. The failure intensity levels of a selected gas turbine engine are captured with a nonhomogeneous Poisson process (NHPP). One should note that the parameters of the NHPP model represent the respective component health conditions of the gas turbine engine. These component health conditions also relate to various failure intensity levels of the gas turbine engine in different system age intervals. Therefore, the respective future system failures and failure transitions can also be predicted by using these models and such information can also be used to overcome diagnostic and prognostic challenges in gas turbine engines.

2. SYSTEM FAILURES

The respective system failure events of the selected gas turbine engine are presented in Figure 1. One should note that the failure events are presented with respect to the system