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Fault diagnosis based on Petri Nets: the case study of a hydropower plant

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Abstract: Identification and fault diagnosis of industrial discrete event system has been used Petri Nets models in classical Place/Transition approach or even high level nets. A very important issue in this approach is the system monitoring and the integration of structural and behavioral models observed while the system is working, which is captured in the net system. In 2004 a ISO/IEC Petri Nets standard was launched where classic and high level net could be synthesized by folding/unfolding processes. The new standard approximated Petri Nets formal representation to both requirements and fault diagnosis methods. On the other hand, in what concerns the risk analysis of hazardous operations, some new methods appear that approximate diagnostic to the design process or to functional analysis, all requiring discrete process representation. In this paper a fault diagnosis method is proposed, where a HAZOP model is used as input requirement that is transformed in a Goal Oriented Requirements Engineering(GORE) representation called KAOS, which are further analyzed in Petri Nets. KAOS diagrams are translated to Petri Nets, using the classic P/T (place/transition) approach. Such approach is scalable and suitable to be applied to large and critical systems as hydroelectric plants. A case study is presented just to this to show applicability to this kind of application.

Keywords: Fault diagnosis, Petri nets, hydropower plant, formal modeling, intelligent maintenance.

1. INTRODUCTION

Hydropower is already one of the cleanest and most efficient forms of electricity generation available. However, improvements still could be made at a hydroelectric plant in order to make the process even more efficient. One of the main sources of power loss in the generator string can be traced to the thrust bearing used to support the rotating assemblage. Energy dissipated as a result of fluid shear, friction and increased temperatures within the bearing and lubricant have the combined effect of reducing efficiency and limiting generation capacity.

The loss of the lubricating film in the bearings can induce extreme localized rises in temperature, and stress, which consequently contribute to material damage, increased rates and volumes of wear and a general reduction in system operating efficiency and can also cause the unavailability of hydropower.

As well as any fluid-film bearing, temperature is arguably the most important factor in determining the limits of performance. This applies to both the bearing itself as well as the lubricating fluid. Temperature influences lubricant viscosity which in turn has an effect on pressure within the oil film. This pressure affects bearing load carrying capacity. Therefore, in order to develop a full picture of bearing and lubricant performance, all these factors must be monitored.

The cooling and lubrication system of thrust bearing is responsible for formation of fluid-film and it is essential for the hydropower plant operations, so it becomes necessary the development of not only a good maintenance plan, but a failure diagnostic system as well. Fault diagnosis, according to Papadopoulos (2001), is the process of identifying the origin of a fault by analyzing a series of effects that it causes in the system to which it belongs. Moreover, a fault diagnosis system can, through modeling techniques, predict or at least indicate the causes of certain failure (Lampis, 2010).

Hence, by pinpointing one or more root causes of a given system failure, fault diagnosis allows both operations and maintenance teams to take corrective actions. Moreover, a fault diagnosis system can also be used to identify critical components, enabling the development of an appropriate preventive maintenance plan.

To develop a fault diagnosis program, a broad overview of the subject matter is needed. Risk analysis techniques such as Hazard and Operability Study (HAZOP) are important tools for the complete understanding of the functioning of a particular system as well as a broad understanding of causes and risks of possible failures it presents.

Hu et. al. (2015) developed an intelligent fault diagnosis system for process plant using a functional HAZOP alongside with Dynamic Bayesian Networks (DBN). In this study, HAZOP was used in order to acquire knowledge about the system in a structured way. According to (Cheng et al., 2015), Petri nets have attracted much attention in fault diagnosis because, besides having rigorous math-

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ematical definitions, they also have intuitive reasoning processes that are consistent with the occurrence of faults. Cavalheiro (2013) applied the HAZOP technique alongside with Bayesian Networks and Petri Nets in order to develop a control and diagnosis system for a ventricle assist device.

Mansour et. al. (2013) showed that Petri nets can be applied for fault diagnosis of large power generation station using information acquired by SCADA system. Rueda et. al. (2015), Liu et. al. (2013) and Fanti et. al. (2015) also applied Petri nets for diagnostics purposes.

The development of a fault diagnosis methodology using the HAZOP technique and Petri nets in case of thrust bearings contributes to greater safety in operations of a hydraulic turbine. Additionally, fault diagnosis method will allow the hydropower plant operations team to quickly mitigate a failure, reducing downtime of the system.

The objective of this paper is to develop a model-based fault diagnosis for the cooling and lubrication system of thrust bearing through the use of Petri nets, alongside with risk analysis techniques such as HAZOP, in order to automate the process of identification of the source of a given fault in the system. By analyzing sensor readings, the developed Petri net should identify which system components can be responsible for the failure of the system.

Therefore, the Petri net design must be carefully developed in order to optimize its results. In order to do so, the Petri net will be obtained through the conversion of a previously obtained KAOS (Keep All Objectives Satisfied) model of the diagnostic system. The KAOS model is a goal oriented requirements engineering method which defines, among other things, the goals that the system should meet (Van Lamsweerde, 2001). To validate the method, all possible sensor readings combinations will be introduced in the Petri net and the results will be analyzed.

The main advantage of the proposed method is the systematic way of obtaining the Petri net. In a fault diagnosis expert system, it is very difficult to determine how the inference engine design must be like. So, by using the KAOS model to obtain the Petri net, which is the inference engine (the one which will do the reasoning, the identification of possible faulty components), the process of developing a diagnosis system is partially automated.

2. METHODOLOGY

The objective of this paper is to develop a model-based fault diagnosis for the cooling and lubrication system of thrust bearing. The proposed method is given by five steps, shown in Fig.1.

The first step of the proposed method is defined by a study of the cooling and lubrication system of thrust bearing, in which a description of its operation is made. To carry out operational description, it is necessary to examine the technical characteristics of the components through the study of plans, catalogs, manufacturer manuals, etc. This step may present some difficulties in the industry since this information may not be available.

In the second step, it is developed a Hazard and Operability Study. The purpose of the HAZOP is to investigate how the system can deviate from design intent, creating operability problems or even risk for personnel. So, by using HAZOP, it will be possible to analyze what are the faults that the system can present and, by doing that, it allows an analysis of whether the sensors used are able to identify those faults.

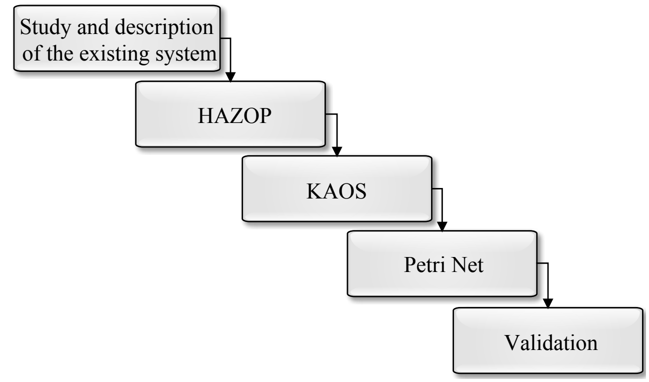

Fig. 1. The proposed method divided in five steps

In the third step, it is developed a goal-driven requirements engineering method called Knowledge Acquisition in Automated Specification (KAOS). The use of this method in this research aims to define the goals of the fault diagnosis process to be developed. The results of HAZOP will be used to improve the development of the KAOS model, since it will help identify the requirements of the fault diagnosis system.

The fourth step is to develop a Petri Net that should indicate which component or components of the system can be the responsible for the fault showed by the system. The Petri net will be developed based on the KAOS goal diagram obtained in the previous step. In order to do so, the KAOS diagram will be translated to a Petri net through a transference algorithm called ReKPlan, proposed by Silva, J.M. and Silva, J.R. (2015). By analyzing sensor readings, the developed Petri net should identify the components that can be responsible for the failure of the system.

The final step is to validate the model and, in order to do so, all possible sensor readings combinations will be introduced in the Petri net and the results will be analyzed.

3. APPLYING THE METHOD TO THE MAINTENANCE OF HYDROELECTRICS PLANTS

The system to be analyzed is the lubricating and cooling systems of hydraulic turbine thrust bearing used in hydroelectric power plant localized in São Paulo state in Brazil. The hydroelectric power plant has a generation capacity of 120 MW.

3.1 Cooling and Lubrication System of Thrust Bearing at a Hydraulic Turbine

The thrust bearing, or hydrodynamic bearing, operates on the principle of hydrodynamic lubrication and is used to carry loads in applications where roller bearings are unsuitable due to dimensional limitations, demands for operational lifespan or high loading requirements. In it,