Overview of Fault Detection Methods for Power Plant Control Systems Purposes

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Abstract— **The main objective of this paper is to review of fault detection and isolation (FDI) methods and applications on various power plants. Due to the focus of the topic, on model and model-free FDI methods, technical details were kept in the references. We will overview the methods in terms of model-based, data driven and signal based methods further in the paper. Principles of three FDI methods are explained and characteristics of number of some popular techniques are described. It also summarizes data-driven methods and applications related to power generation plants. Parts of control system applications of FDI in TPPs with possible faults are shown in the Table I. Some popular techniques for the various faults in TPPs are discussed also.**

Keywords— power energy generation; fault detection and isolation; fault diagnosis; fault-tolerant system; thermal power plant; FDI method.

I. Introduction

The electrification of Ukraine historically was based on the use of three main sources of energy: coal, oil and gas. The country's energy industry is dominated by nuclear and thermal energy. Nearly 36% of the electricity produced in Ukraine in 2018 is given by TPPs [1]. They have several advantages over other types of stations. The plants can be located near the consumer and evenly distributed throughout the country. TPPs operate on virtually all types of organic fuel: coal, shale, liquid fuel. But combustion products of TPPs are the main pollutants of the environment: carbon oxides, nitrogen oxides, which turn into harmful nitrogen dioxide in the atmosphere, sulfuric acid is formed.

Therefore, it would be highly advisable to consider at this stage the Resolution of the Cabinet of Ministers of Ukraine [2] dated 06 June 2018 No. 497-p On Approval of the Plan of measures for the implementation of the stage "Energy Sector Reform (2020)" Energy Strategy of Ukraine until 2035 "Safety, energy efficiency, competitiveness". This is an active document, which has the general objective of building an efficient energy sector of Ukraine with the possibility of sustainable development, reduction of hazardous and harmful emissions and, undoubtedly, integration into the European energy space. We are going to consider the key features of the Energy Strategy further.

Types of generation used by modern thermal and nuclear power plants will remain effective, in terms of the possibilities for reconstruction of TPPs, taking into account the environmental requirements and prolongation of NPPs' lifetime. To ensure the demand for electricity by 2025 it would be sufficient to extend the life of 6 GW of NPPs and 9 GW of TPPs.

Thus, the development of fault-tolerant control systems for various types of power plants is an important scientific and practical task. Its solution is based on various methods of detecting and preventing faults of process equipment.

II. Overview of FDI methods

Complex modernization and retrofit of instrumentation and automation systems are required for power generation plants (PGPs) of Ukraine to produce more electricity with higher efficiency and less operating expenses, regardless of threats in performance degradation. This is where the role of Fault Detection and Isolation (in some literature also called Fault Detection and Diagnosis [2]) algorithms became very important. Afterwards, FDI can be further divided into data-driven methods (multivariable, artificial intelligence based) and signal-based methods (single variable, pattern recognition) in general. In model-based methods, a mathematical model is used to represent the ideal or normal behavior of the system. Fault in a system can be detected by checking consistency between predicted output and observed output of the model. The limitation of model-based method is the difference to find out an accurate model, that is always hard for any system in practice.

Data-driven methods rely on correlated measurements of normal/healthy conditions and faulty conditions. Hence the relationship can be formulated by the implicit way by training an empirical model through analysis of fault free training data obtained during normal conditions. The empirical model is used to find out new measurements for faulty conditions, and the fault is detected, and fault diagnosis is done by evaluating the residual values statistically. A signal is monitored and exerted (e.g., spectrum) from the measured value with respect to the desired limit in signal-based methods. FDI decision can be made from the actual signal with standard baseline values then. Signal-based and data-driven methods are extensively used for various industries [3].

In model-based FDI [4] methods normal behavior of the system is represented by a mathematical model of the physical system. Sensor measurements are estimated analytically by other correlated measurements using the model that describes their relationship. The difference between analytical estimated value and actual measured values are labeled as residuals (fig. 1). Any non-zero values of the residuals identify the faults in the system. By analyzing the residual values statistically, faults can be determined [2]. Fault diagnosis methods vary by model structure. The model-based FDI methods are classified into three following categories: model-based online data driven methods, signal-based methods and knowledge-based history data driven methods [5].

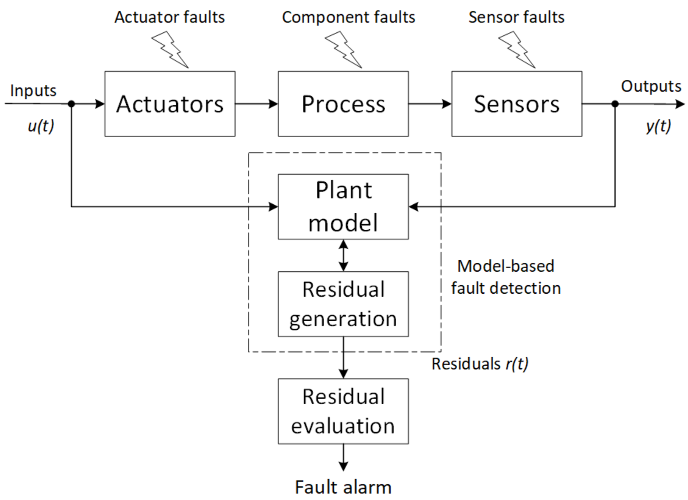

Figure 1. Model-based fault detection scheme

The model-based FDI methods are capable and designed to detect multiple faults and diagnoses simultaneously. However, an accurate model is required for the physical system, which can be difficult to obtain for complex systems. All faults are not considered at the modeling stage and may not be detected at all. This is the challenge. Further, robustness required against model uncertainty and disturbances [6].

Data-driven methods have been studied for different applications like instrumentation calibration, equipment monitoring, reactor core monitoring, transient identification, and furnace monitoring in various power plants (e.g., NPPs, TPPs, and SPPs). PCA is the most appropriate and used method amongst the data-driven methods, due to the fact of its simplicity and adjustability. There are two methods widely used for applications in NPPs: MSET and ANN. A technique-based on MSET and ANN is used for the smart signal system and process evaluation and analysis by neural operators (PEANO) system [7] developed for OLM in NPPs. ANN has also been studied in power generation plants for transients' identification and to estimate important parameters for reactor core monitoring. Features of PCA, MSET and ANN methods are overviewed in the Table V. Recently, kernel-based machine learning techniques have been used for pattern-recognition and fault detection in various industries. Their applications in different power generation plants have not yet been fully explored.

Signal-based FDI methods work by comparing two signals. One signal is feature extraction from measured signal, and the second one for base line characteristics, that are considered to be normal operation. Signal-based methods do not rely on the analytical relationship between measured variables.

Spectrum analysis is the most used method in signal-based FDI. The spectrum of the measured signal can be obtained using Fast Fourier Transform (FFT). Spectrum analysis is used for NPP instrumentation, equipment, and processes. Time-frequency Analysis (TFA) and Wavelet Transform (WT) are extensions of spectrum analysis.

Process information using tools such as if-then rules are also used in FDI methods. These qualitative methods can process incomplete information to make FDI decision. Two popular techniques are fuzzy logic [8] and expert systems. Fuzzy logic, expert systems, genetic algorithms and ANN are the most used techniques in computer systems.

Application of the computational intelligence methods in various power generation plants include sensor validation, equipment monitoring and core or furnace surveillance. Such applications are reviewed in many books about nuclear and thermal power plants. Other qualitative methods studied in the literature include qualitative reasoning, signed directed graph and case-based reasoning. However, applications of such methods in power generation plants are relatively limited at present.

III. Fault Detection and Isolation for Power Generation Plants (PGPs)

Safety is of major importance in critical objects, such as PGPs, and their control systems. To improve safety, reliability and capacity in PGPs even preventive actions are desirable. Generally, fault is defined as unpermitted deviation or change in characteristics from the desired ones in the system. A failure is a permanent interruption of a system ability to maintain desired performance [9]. Different faults and failures can occur in instruments, equipment, and systems of PGPs, which can have significant impact on plant performance and productivity. For example, drift in steam generator (SG) can reduce power up to 3% in NPPs. To enhance efficiency certain PGPs establish heat recovery steam generator (HRSG) to capture energy from the hot combustion gases exhausted from the turbine. Therefore, efficiency of HSRG plays very vital role in improving the efficiency of PGPs. The design in the thermal measurement system for fault detection within a power generation system improves SPPs productivity. Measuring yields by automatic supervision, analyzing the losses, and faults in the present system using automatic fault detection in grid connected PV systems will improve maximum efficiency Power

Various FDI methods have been applied during the last decades in different power generation plants. Especially discussed above data-driven and signal-based methods are extensively used in their control systems. The Table I below shows possible errors and their consequences at thermal power plants. Another types of power plants also can be observed with their special characteristics.

TABLE I. IMPACT OF POTENTIAL ERRORS ON THERMAL POWER PLANTS.

Error description	Classification of faults	System influence
Bearing temperature sensor fault; leak fault in lube oil system and turbine shaft axial position proximity switch fault.	Steam Turbine Health Monitoring and Control Design fault.	Reduce efficiency of the steam turbine hence decreasing the overall efficiency of the TPPs. The hazardous situation may occur.
Actuator or leak faults occur in pipe line which carries the coal and air to the boiler.	Combustion Control Mechanism and Flue Gas Heat Recovery Fault.	Combustion efficiency reduces and thereafter the insufficient amount of superheated stem to the turbine.
Fuel quality for TPPs.	Change in calorific value of the fuel.	Reduce efficiency of the power plant.
During the load variation actuator fault which carries water in boiler and sensor transients.	Faults in boiler feedwater control.	Affects the boiler safety and efficiency.
Leakage in pipes containing water, steam or fuel.	System (Leak) fault.	Potentially affect safety functions also trip the turbine system due to the leak of superheated steam.

From the plant economics viewpoint, benefits of FDI in various power plants, among other things are as follows:

1) Optimize the maintenance schedule: the correct method and time for maintenance are the major limitation for power generation plants [10]. Condition or OLM based maintenance of instruments and equipment can be accepted.

2) Improves plant reliability: FDI can improve plant reliability for various reasons. First, FDI can do early detection and diagnose incipient faults and avoid unexpected breakdown. Second, it helps to schedule correct plant down-time efficiently and manage the maintenance time. And finally, FDI application helps to improve plant performance by reduction in various system or plant and sensor faults.

3) Escape from converging a minor problem to major problem: FDI is an advance application which can detect and diagnose the faults early before any dangerous situation happens. FDI is prevents faults from developing into the more critical situation.

5) Power production and system life extension: using better plant performance monitoring and aging management, production of power is increased, and plant life is increased through application of FDI.

IV. CONCLUSIONS AND PROSPECTIVE

Various strategies for fault detection in power plant's equipment are considered. Causes of faults and their impact on the system in total are described and classified.

Application of FDI in TPPs will become more beneficial due to instrumentation and control technologies and FDI methods theory progress. Application of model-based FDI methods is essential because of complex plants like NPPs. Signal-based FDI methods have proven practicality for instrumentation channel dynamics performance monitoring and equipment vibration monitoring. Various faults are considered and appropriate FDI methods are discussed now for TPPs. However, the most promising method for future researches is artificial neural network (ANN). It allows to predict several kinds of faults associated with the main part (the turbine) of thermal power plant or with the boiler house.

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