Available online at www.sciencedirect.com

ScienceDirect

Nuclear Energy and Technology 2 (2016) 81–84

www.elsevier.com/locate/nucet

Turbine generator status diagnostic system based on petri nets

S.A. Kachur*, N.V. Shakhova

Institute of Nuclear Power and Industry, 7 Kurchatov Str., 299015 Sevastopol, Russia

Available online 24 May 2016

Abstract

The objective of the study is to build an automated system to monitor and control the turbine generator (TG) processes, based on acoustic analysis of the stator failures, for the purpose of improving the operating efficiency of the nuclear power plant (NPP) as a whole. This requires the development of an information and measurement system (IMS) which receives information on the status of the TG stator windings from the noise detectors installed on the TG surface. Acoustic analysis of the TG "hot" spots is used to identify the TG status.

Petri nets were used to build a stochastic model of the automated TG monitoring and control system. The model in question allows local changes in the status of the TG stator windings to be detected and makes it possible to reduce the problem dimensionality through the selection of a subset of conditions leading to a risk of the stator failure. The model is simple and features a high speed of response. The use of the IMS structure under consideration enables the TG condition to be detected at the initial failure stage and the measurement process rate to be increased tenfold.

Keywords: Automated monitoring system; Stator winding condition; Turbine generator; Diagnostic system; Acoustic method; Emergency; Petri nets; Identification of failures; "Hot" spot analysis; Probabilistic model; stochastic model.

Introduction

Integrated instruments and controls (IIC) are used for the acquisition and processing of data in the existing automated NPP monitoring systems. The IIC major performance characteristics are measurement error and data processing time. The NPP unit diagnostic systems are required to be highly responsive and sufficiently accurate in identifying the equipment status [1].

Despite the fact that control and analysis of noise is currently one of the most efficient tools of detecting abnormal drifts in the physical processes in components [2], the operation of a turbine generator suggests that it is only periodically heard at a given distance from the external circuit and the average noise level is compared against that permitted.

This makes it vital to improve automated TG monitoring and control systems based on the so-called noise analysis.

Presently, noise analysis is used to develop various information and measurement systems (IMS) [2]. A standard noise-based testing and diagnostic procedure involves the following major stages: preparation of reference noise signal spectra for a variety of the circuits' operating modes; online noise testing and comparison of test results against reference data; analysis of and identification of variations in noise signals; comparison of analysis results against the equipment structure for the identification of the condition; and decision-making on if equipment can be further used [3, 4]. Acoustic methods offer a number of advantages, including high information capacity, selectivity, simplicity of facilities, absence of specific requirements to the circuit design, extensive functionality, and capability to predict through inspections for the equipment metal cracking. Acoustic oscillations are known to propagate well through metals and can be detected at the point of the circuit convenient for measurements. These os-

* Corresponding author.

E-mail addresses: kachur_62@mail.ru (S.A. Kachur), nata.shakhova.73@mail.ru (N.V. Shakhova).

Peer-review under responsibility of National Research Nuclear University MEPhI (Moscow Engineering Physics Institute).

Russian text published: Izvestia Visshikh Uchebnikh Zavedeniy. Yadernaya Energetika (ISSN 0204-3327), 2016, n.1, pp. 13-20.

http://dx.doi.org/10.1016/j.nucet.2016.05.002

cillations have frequencies ranging from hundreds of Hz to hundreds of kHz.

However, noise testing procedure requires the responses of the reference spectrum to be plotted and compared at given intervals against similar responses obtained based on an analysis of covariance matrices in the process of the component operation. The number of test points (a set of noise detectors installed on the TG surface) specifies the dimensionality of the covariance matrix and the accuracy of the component status detection. With such an approach, covariance analysis fails to satisfy to the speed requirements currently placed on automated nuclear plant monitoring systems [1]. Besides, such system is required to operate continuously, as a normal process monitoring system, to have the maximum efficiency, while not causing plant malfunctions throughout the time of operation. Presently, there are no monitoring systems and on-load contact loss identification techniques, this leading to fires on end coils after which the turbine stator windings require to be fully or partially replaced [5].

It is proposed that the noise testing procedure should be modified and taken as the basis for the "hot" spot acoustic analysis technique [6]. This technique was tested for the first time and proved to be valid under the leadership of Prof. I.A. Popov, Dr. Sc., Eng, using adaptive control of the nuclear reactor boiling process as the example [7]. The method under consideration makes it possible to increase the TG status identification rate and to improve the quality of the TG failure assessment by localizing the stator winding breakdowns during operation. Technically, the effect of this technique is achieved through the development of the IMS noise detector layout and the procedure to calculate, based on the IMS readings, the coordinates of the hot spot projections on the TG surface. Since the data processing rate, with all other conditions being equal, depends on the problem dimensionality, specifically, on the number of the noise detectors considered at a given time, models of the system behavior should be built to enable online acquisition and processing of data in pre-emergencies. The capabilities offered by the mathematical apparatus of Petri nets (PN), with the net elements being interpreted to a certain extent, provide for the best possible solution to the problem as compared to existing models [8].

The objective of the study is to build an automated TG process monitoring system based on acoustic analysis of the stator failures for the purpose of improving the operating efficiency of the NPP as a whole.

The probabilistic model of the stator failures is a set of distributions for impure subsamples of the fluctuation signal amplitudes measured by the noise detectors on the TG surface [9].

The way to achieve this objective is to develop an information and measurement system to receive information on the TG stator winding condition from l noise detectors installed on the TG surface. The noise levels are measured at a time interval of Δt. The TG status is identified by the TG "hot" spot acoustic analysis method (HS AAM) [6].

At the initial measurement stage, the "hot" spot acoustic analysis method uses n primary noise detectors d_i (i=1, ..., n), the layout of which on the TG surface forms a coordinate grid. "Hot" spots are localized more accurately at the second stage, for which purpose secondary detectors d_{xi} (i=1, ..., 8), installed each halfway between two primary detectors, are considered for each d_x detector found being at a "hot" spot.

The analysis of the initial detector layout results in a solution tree. The solution tree leaves match the HS locations on the TG surface in a first approximation. The number of the solution tree levels reflects the risk degree which increases with the level number.

The result of the HS AAM application is the TG stator status vector $S=(s_1, s_2,..., s_n)$. It reflects the stator failure risk degree and matches the maximum number $1s_p$ of the solution tree levels at such points as defined by the vector UX of the HS locations for the heat noise distribution. The vector UX is a controlling action for the TG cooling automatic control and emergency protection system.

When the noise detector activation diagram is plotted, there is a problem of determining the vectors $PU=(pu_1, pu_2,... pu_n)$ and $PUB=(pub_1, pub_2,... pub_m)$ for the probabilities of failures matching the controlling actions for the primary and secondary noise detectors in a class of models with discrete time as the transformation

$$[PU, PUB] = F(S[k], S[k-1], \mathrm{C}, k), \tag{1}$$

where F is the transformation based on the expansion of a stochastic PN; S is the TG status vector that describes the heat noise distribution; $C$is a Petri net; and k is the discrete time point number. The initial probabilities of failures are assumed to be equal to 0.5 for the primary detector installation points and to 0 for the secondary detector installation points.

The general solution to the problem of building an information and measurement system for the TG acoustic noise is based on the search for the maximum stator failure risk.

The failure risk R can be determined as

$$R = \max_i pu_i, \tag{2}$$

$$pu_i = \begin{cases} 1, & \text{if } sp \geq 3 \\ 0,\ 75, & \text{if } sp = 2 \\ 0,\ 5, & \text{if } sp = 1 \\ 0,\ 25, & \text{if } sp = 0 \end{cases}, \tag{3}$$

where pu_i is the probability of a failure at the primary detector locations; and sp is the maximum level of the solution tree for the ith primary detectors at points.

For the secondary noise detectors, the activation (measurement processing) probabilities are found from the following relation:

$$pub_i = \begin{cases} 1, & \text{if } sp \geq 3 \\ 0, & \text{otherwise} \end{cases}. \tag{4}$$

A generalized diagram of the turbine generator automated process control system (TG PCS), shown in Fig. 1, includes the turbine generator information and measurement system (TG IMS) under consideration, the turbine generator automatic control system (TG ACS), IIC and computer system (CS) acquisition and initial processing facilities.