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Energy Efficient Strategy Development of Steam Turbine through Vibration Reduction Using ANN and SVM Approaches †

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Abstract: The energy efficiency of a power plant is largely determined by the vibrations of bearings that hold the shaft rotating at high speed which need to be critically controlled. This study presents the relative vibration modeling of a shaft bearing that is installed in a 660 MW supercritical steam turbine system. The operational data in raw form after being cleaned using machine learning based visualization and extensive data processing helped in training and validation of SVM and ANN models which are then compared by external validation tests. The model with best results is then used for the simulations of constructed operating scenarios. The ANN has been further tested for the complete operational load range (353 MW to 662 MW) which predicted the reduction in relative vibrations. Moreover, the validated ANN model has been used to develop many strategies of vibration reduction which helped in achieving more than 4% reduction in relative vibrations. Subsequently, an operational strategy that predicts a significant reduction in the bearing vibration levels is selected. For confirmation of the accuracy of prediction by ANN process model, the selected strategy has been used with the actual power plant. This assures the significant reduction of bearing vibration less than the alarm limit.

Keywords: energy efficiency; steam turbine efficiency; power plant; ANN; SVM; vibration analysis; vibration reduction techniques

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1. Introduction

The most important part of rotating machines is bearing, which ensures smooth operation [1]. For this purpose, the types of maintenance employed are corrective and preventive, predictive, and condition-based maintenance. The large-scale systems are more subjected to threats like high level of vibrations which need to be overcome through proper analysis [2]. Conventional techniques of mathematics don't help much in such complex analysis. To solve such problems Artificial Intelligence (AI) Based Models are used [3]. These models show promising potential to deal with such complex problems with ease, and specifically for achieving the vibration reduction in our case, two methods have been used; artificial neural network (ANN) and support vector machine (SVM) [4]. ANN is a widely used technique because it has great potential for formulating the data-driven characteristics, whereas SVM is a technique based on machine learning that is frequently used in science and engineering [4].

This study focuses on using AI based techniques in achieving the vibration reduction in the shaft of a steam turbine system operating at supercritical level having an output of 660 MW. The measurement of relative vibration is done in micrometers. Eight total bearings are assembled along the length of the running shaft of the turbine and one of the bearings with vibrations higher than the alarm limit has been considered for the study. The vibrations have been consequently reduced by optimizing the operational parameters. Afterward, the methods have been implemented physically on the power plant, and reduction of vibrations has been observed.

2. Methodology

The methodology of this work is shown in Figure 1. After extracting the operational data, data processing and visualization has been done through different tests in order to prepare the cleaned dataset. Subsequently, the data is fed for developing the advanced state-of-the-art models, i.e., Artificial neural network (ANN) and Support vector Machine (SVM). The comparative prediction capacity of the models is evaluated by external validation test. Subsequently AI model is employed to simulate the operating scenarios which are helpful in understanding the system's response and learning the insight. Moreover, the AI driven strategy is tested on the actual operation of the power plant.

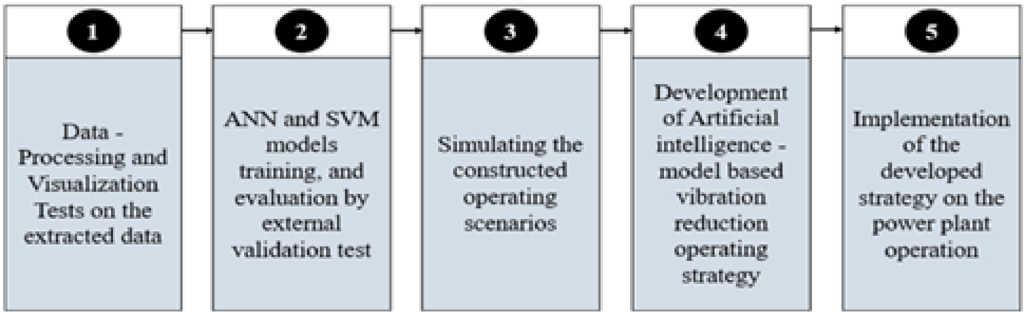

Figure 1. Methodology adopted to proceed the scheme of study.

3. Development of AI models

The generic steam turbine system schematic is presented in Figure 2. Steam is administered in the high pressure (HP) turbine through governing valve (GV) and turbine valve (TV), where it is expanded and leaves for reheater for reheating purpose. The reheat steam expands in intermediate turbine (IP) from where it is directed toward slow pressure (LP) turbines. Steam expands in LPA and LPB turbines and enters condenser. The expansion of steam in the series of turbines helps rotate the steam turbine shaft which is coupled with generator for electrical power production. Total of eight bearings are mounted along the shaft to hold the shaft.

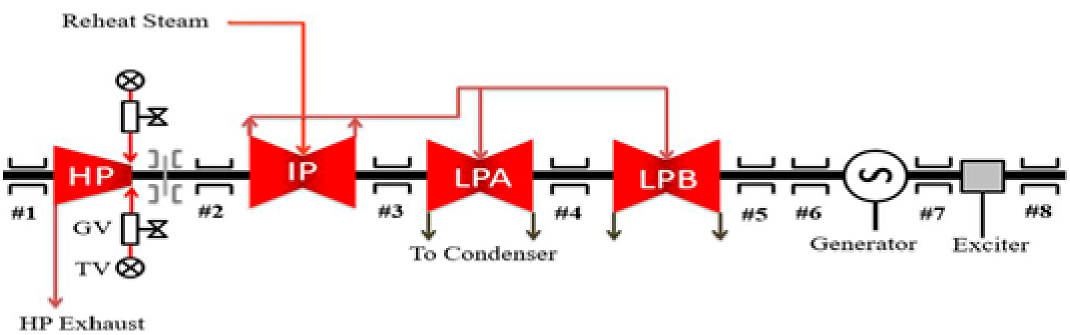

Figure 2. Steam turbine system of the coal fired power plant.

The operational data is taken from the operating parameters of HP turbine and #1 bearing relative vibration values are modeled against them. The data is processed and visulaized through advanced machine learning algorithms to prepare the cleaned dataset. Subsequently, the data is fed for constructing the advanced AI models like ANN and SVM.

The development of ANN requires tuning the number of neurons in the hidden layer of the ANN model. A large number of neurons in the hidden layer are tried. It turns out that ANN with seven neurons in the hidden layer has well performed during training.

Subsequently, it is retained for comparing its prediction performance with other models. The structure of the developed ANN model is shown in Figure 3.

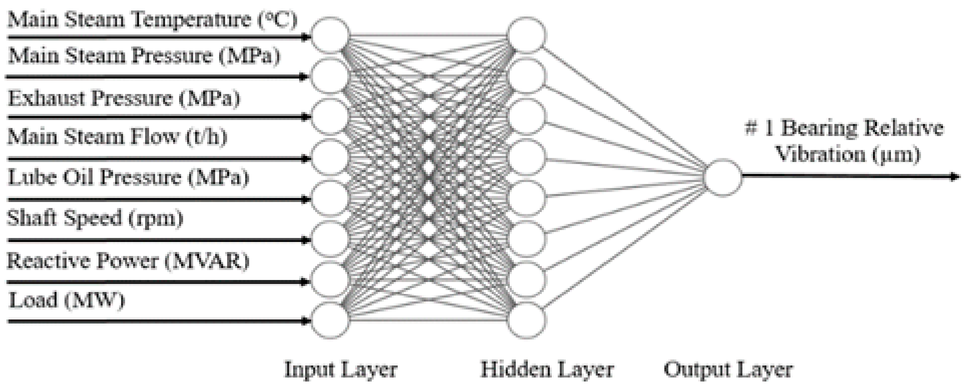

Figure 3. The multilayer perceptron structure of ANN.

The training of SVM involves the selection of optimum values of hyper parameters like epsilon and box constraint. Various combinations of these two parameters were tried in order to develop a best SVM model. Subsequently the two models' prediction performance in simulating the unseen operating conditions is assessed by validation dataset. It is confirmed that ANN has well predicted the validation dataset and therefore, it is deployed for conducting the value-creating analytics.

4. Result and Discussion

This study focuses on developing ANN model that has been validated for the simulation of different operational scenarios. The developed model also enables us to check the behavior of the system under combined as well as individual impact of all the operational constraints. The robust response of the model is estimated by defining Lower Control Limit (LCL) as well as Upper Control Limit (UCL) lines at 95% interval.

Figure 4 shows the variation in #1 bearing relative vibration with the load. The relative vibration is found decreasing while the load increases from 353 to 662 MW. The relative vibration is more than 118 µm at 353 MW that is much higher than 80 µm computed corresponding to 662 MW.

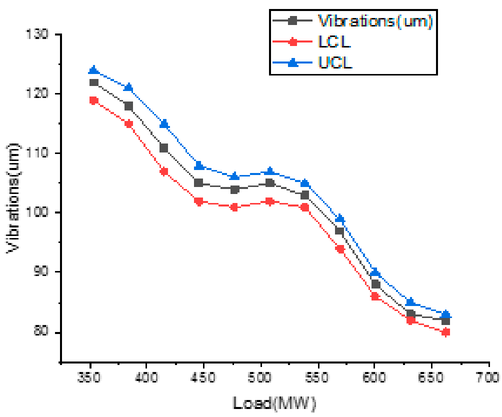

Figure 4. Effect of load on the #1 bearing relative vibration.

The strategy is to set the main steam temperature to the lower limit of 550 °C and lowering the main steam pressure by 0.2–0.5 MPa. The operational value of reactive power on the power plant is from 20–125 MW which has also been lowered by 10–12 MW. The main steam flow is increased by 3–5 Ton. Subsequently, operating values of the parameters for the scenarios are adjusted and simulated by ANN model and a strategy to lower the vibrations during operation has been developed.

The developed operational strategy is tested on the power plant operation as well. The operating conditions of the parameters are carefully controlled under the developed strategy and their impact on the bearing vibration is observed. It is found that the developed strategy has reasonably helped reduce the vibration of the bearing with the value lower than the alarm limit as shown in Figure 5.

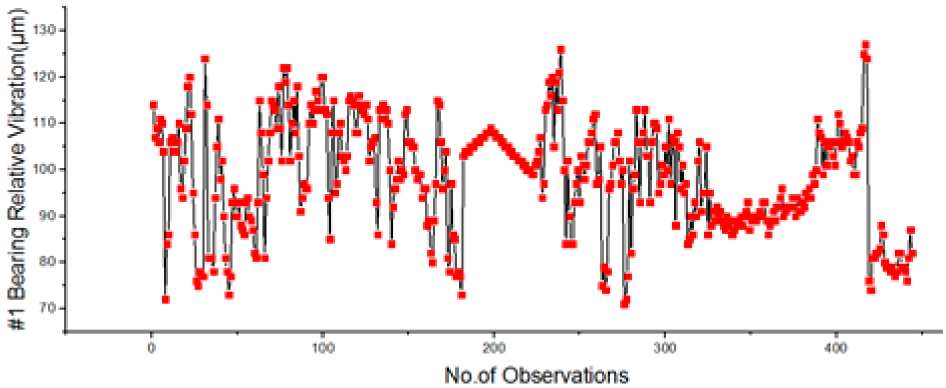

Figure 5. Vibration response against the developed operational strategy.

5. Conclusions

This study focuses on development of AI models for reduction in the relative vibrations in the shaft bearing that is installed on a supercritical steam turbine system. The models developed are ANN and SVM, and with the implementation of ANN model for the operating strategy, there is a significant reduction in vibrations of a bearing. The average reduction in the relative vibrations of bearing is recorded to be more than 4%. This ensures the smoother operation of the shaft, which also increases its operational life and durability. Figure 5 shows the variation in the relative vibration of the bearing with number of observations made during the operation of supercritical steam power plant.

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