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APPLICATION OF MONITORING, DIAGNOSIS, AND PROGNOSIS IN THERMAL PERFORMANCE ANALYSIS FOR NUCLEAR POWER PLANTS

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As condition-based maintenance (CBM) has risen as a new trend, there has been an active movement to apply information technology for effective implementation of CBM in power plants. This motivation is widespread in operations and maintenance, including monitoring, diagnosis, prognosis, and decision-making on asset management. Thermal efficiency analysis in nuclear power plants (NPPs) is a longstanding concern being updated with new methodologies in an advanced IT environment. It is also a prominent way to differentiate competitiveness in terms of operations and maintenance costs.

Although thermal performance tests implemented using industrial codes and standards can provide officially trustworthy results, they are essentially resource-consuming and maybe even a hind-sighted technique rather than a foresighted one, considering their periodicity. Therefore, if more accurate performance monitoring can be achieved using advanced data analysis techniques, we can expect more optimized operations and maintenance. This paper proposes a framework and describes associated methodologies for in-situ thermal performance analysis, which differs from conventional performance monitoring. The methodologies are effective for monitoring, diagnosis, and prognosis in pursuit of CBM. Our enabling techniques cover the intelligent removal of random and systematic errors, deviation detection between a best condition and a currently measured condition, degradation diagnosis using a structured knowledge base, and prognosis for decision-making about maintenance tasks. We also discuss how our new methods can be incorporated with existing performance tests. We provide guidance and directions for developers and end-users interested in in-situ thermal performance management, particularly in NPPs with large steam turbines.

KEYWORDS : Thermal Efficiency, In-situ Analysis, Condition-Based Maintenance, Turbine Cycle, Nuclear Power Plant

1. INTRODUCTION

Integrated information technology (IT) solutions for power plants are being installed not only for administrative purposes but also for plant operations and maintenance decision-making. Such a technical trend is not new or novel. Most power plants already use operator-aid solutions to facilitate operations and maintenance. However, the current trend clearly differs from conventional systems by (1) increasing data availability via massive but low-priced databases, (2) providing convenient data accessibility with advanced wired or wireless networks, and (3) promoting a reappraisal of the value of operator-aid solutions given the new big-data environment.

Given that the primary purpose of power plants is to produce electricity at a competitive price, the most typical operator-aid solutions in nuclear power plants (NPPs) is software to monitor thermal efficiency and diagnose performance degradation. A plant computer system (PCS) uses an algorithm to calculate the efficiency of a heat supply side and a power conversion side, along with performance indices associated with major components such as the reactor, steam generators, turbines, heat exchangers, pumps, and so on. The traditional algorithms embedded in PCSs calculate the performance metrics with measured signals and compare them with reference values. Performance metrics thus identify increasing or decreasing conditions from the reference values in periodic performance monitoring during day-to-day operation. An abnormal condition observed during performance monitoring or maintenance effectiveness, particularly before and after overhauls, needs to be checked using a special performance test conducted under well-ordered conditions with authorized codes and standards. The results of performance monitoring and testing initiate an engineering process to clarify the cause of degradation and find appropriate maintenance activities. In conventional thermal efficiency management, periodic monitoring has focused on the preliminary detection of anomalies, and special tests have essentially determined whether such anomalies are problematic or not. The procedures for both performance monitoring and testing are provided in performance test codes (PTCs) from the American Society of Mechanical Engineers (ASME). Although several PTCs are in accordance with users' purposes, Volumes PM, 6, and 6S are representative for evaluating overall electricity generation. PTC PM [1] addresses performance monitoring, and PTC 6 or PTS 6S [2, 3] are used for performance testing of NPPs with large steam turbines. Table 1 shows their representative features.

As Table 1 shows, performance monitoring and testing are complementary. The results analyzed by PTC 6 or 6S are reliable and officially accepted, but the performance test is a resource-consuming task. Conducting a performance test for a large steam turbine cycle requires meeting tough standards for sensor calibration, flow path isolation, and the stability of operational parameters [2, 3], which is not easy in most NPPs connected to the national grid. Despite such difficulties, performance tests are usually carried out before and after a scheduled overhaul to check the effectiveness of maintenance. While performance tests are necessary; however, strengthened performance monitoring can reduce the frequency of performance tests.

The concept of in-situ thermal performance analysis we are suggesting falls between performance monitoring and testing in terms of its purposes, measurements, and general procedures. The technical convenience and simplicity of conventional performance monitoring are inherited in the in-situ thermal performance analysis. The features of the proposed concept that distinguish it from conventional monitoring are: (1) it covers monitoring, diagnosis, prognosis, and decision-making for asset management, (2) it reduces measurement uncertainties using physical or empirical data validation models, and (3) it uses a plant simulation model in the entire analysis.

The ultimate goal of our in-situ thermal performance analysis is to fully support condition-based maintenance (CBM). CBM, sometimes called predictive maintenance, can save money by reducing time-consuming and unnecessary maintenance or testing activities and can also decrease human errors, which is vitally important for safety-critical systems in NPPs. The proposed methods can facilitate the CBM process for heat conversion cycles because the periodicity is much shorter than the progress of the usual degradation mechanism. Technical limitations in the signals coming from the sensors installed in a plant and the analysis under variable plant configurations are improved using advanced algorithms that use physical and empirical techniques. Because all the processes of in-situ thermal performance analysis should be managed on-line in real-time without an operator's intervention, a high level of automation is required.

Table 1. Comparison between PTC PM and PTC 6 or 6S

	PTC PM	PTC 6, 6S
Objective	Continuous detection of performance degradation	Quantitative identification of degradation as part of performance monitoring
Use	Trend monitoring during day-to-day operation	Significant decision-making such as acceptance tests
Measurement	Use of field instruments Possibly few sensors and low quality	Use of high-quality instruments
Uncertainty of Results	Not specified	Specified upon satisfaction of procedures
Procedures	Data acquisition, Calculation of significant performance metrics, Comparison with reference metrics	Initialization (cycle stability, isolation), Data acquisition Calculation of heat balance (for PTC 6), performance metrics, and corrections Comparison with reference metrics