Development of Easy Maintenance Assistance Solution (EMAS) for Gas Turbine

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ABSTRACT

The solution was developed for the maintenance decision support of combined cycle power plant gas turbine. The developed solution provides the calculated result of optimal overhaul interval through the following modules: Overhaul Interval Prediction, Real Time Performance Monitoring, Model-Based Diagnostics, Performance Trend Analysis, Compressor Washing Period Management, and Blade Path Temperature Analysis. Model-Based Diagnostics module analyzed the differences between the data of MHI501G gas turbine performance model and the online measurement. Gas turbine performance model can be modified by the type of gas turbine of each combined cycle power plant. Compressor washing management module suggests the optimal point of balancing between the compressor performance and the maintenance cost. The predicted results of compressor washing period and overhaul period are able to support the operators in combined cycle power plant to make a proper decision of maintenance task. The developed solution was applied to MHI501G gas turbine and is, in present, on the process of field test at Gunsan combined cycle power plant, South Korea.

1. INTRODUCTION

Along with the recent increase in the interest in after-sales services in the mechanical industry, manufacturers are expanding their services from simple maintenance and parts support to operation and management services during the entire product life cycle. Such service expansion of the industry results from the trend that the increased product life and the enhanced cost competitiveness are recognized as a means for the emerging countries to overcome the decrease in demand for new products.

The expansion of this after-sales service market is getting bigger in the gas turbine industry, and the competition among engine manufacturers is becoming intense. Rolls-Royce, a manufacturer of gas turbines for aircrafts which has supplied more than 4,000 engines operated every day by about 500 airlines, analyzes the engine operation data equivalent to 65 thousand hours of operation a day, to provide the service for determining when to repair engines and/or replace parts. GE recently opened a data analysis software center by investing one billion dollar, and has provided after-sales services like preventive maintenance and remote monitoring to the fields of aircraft engines, power plants, and medical equipment.[1]

Presently, the global market for industrial gas turbines amounts to about 40% of the entire gas turbine market, and it is expected to have the annual average growth of 3.8% by 2018. The gas turbines for generation accounts for the biggest portion of the entire gas turbine maintenance (service) market as approximately 78%.[1] The considerable portion of the gas turbine after-sales service market is concentrated on the manufacturers. For this reason, the operation companies have neglected managing the data for maintenance and operation of gas turbines and the data, if any, does not reflect a systematic operation and management environment. The increase in the power generation cost due to recent depletion of fossil fuel has caused the gas-turbine operating generation companies to invest a huge amount of manpower and resources in order to reduce the operating cost and ensure an efficient operation of generation systems.

Easy Maintenance Assistance Solution (EMAS), developed as part of this investment, includes modules for monitoring the gas turbine engine status online, analyzing the performance decrease rate and performance trend, and estimating the optimum compressor washing cycle and optimum overhaul cycle. Currently, it is under pilot operation at Gunsan Combined Cycle Power Plant under Korea Western Power Co., Ltd. This paper describes the development of EMAS and its application cases.

2. EMAS(EASY MAINTENANCE ASSISTANCE SOLUTION)

Easy Maintenance Assistance Solution (EMAS) consists of six modules as shown in Fig. 1. Data measured at the gas turbine is entered into EMAS through the data server, and

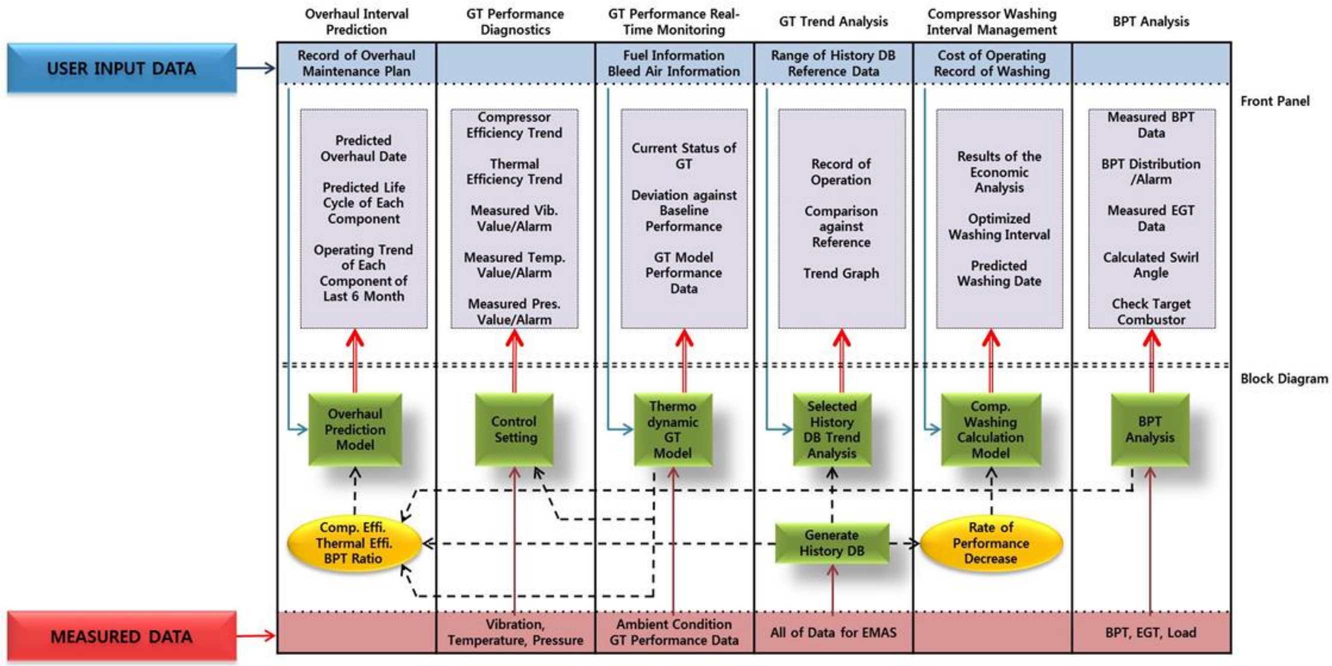

Figure 1 Configuration of 6 Modules and Data Flow

data directly entered by the user is entered through each module. The data server was designed to allow easy modification and reuse depending on the power plant where the target engine and EMAS system are installed.

The system consists of six modules specifically designed for certain uses, and each module is designed to have sub modules if necessary. Data measured directly at the gas turbine in real time is saved in the data sever in the form of database and is accessible by all modules. Each module performs independent or complementary functions as needed, and the interface between the modules has the optimum design in consideration of program computation and data load management.

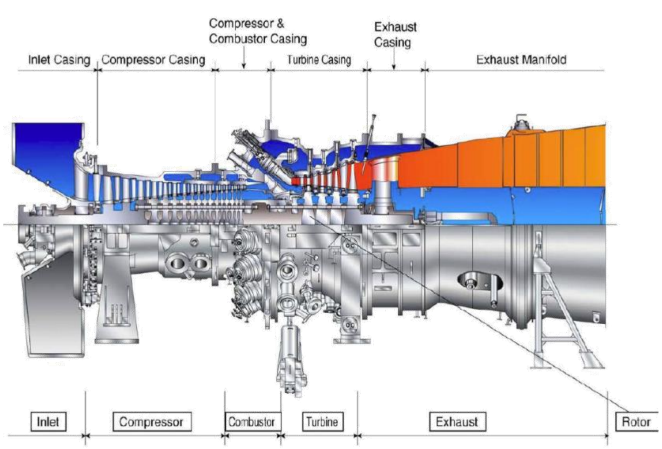

Figure 2 MHI 501G Gas Turbine Engine

2.1. Application Gas Turbine

The gas turbine, being the object of EMAS under pilot operation, is MHI501G developed by Mitsubishi (MHI). This state-of-the-art engine raises the turbine inlet temperature up to 1500℃ and, in Korea, Gunsan Combined Cycle Power Plant was the first one to introduce it and has operated it so far. MHI501G is one-spool type, which is configured with a 17 stage axial compressor, a can-annular combustor comprised of 16 combustion chambers, and a 4 stage axial turbine. Its rated output is 258MW. The configuration of MHI501G is shown in Fig. 2 and its major performance listed in the interval is shown in Table 1.[2]

2.2. Verification of Based Engine Model

EMAS is a model-based solution. Therefore, an accurate modeling of the performance of the turbine is important for accurate diagnosis and estimation. EGT Co., Ltd developed engine model. For develop engine model, acceptance test data and design point data from MHI were used. Reference [3] was used for engine model development process and expressions for the performance of each component. Static model was used because most industrial gas turbines operate in the static load unlike for aircraft.

Before the developed model was applied, verification of the performance reliability was conducted. Performance analysis was carried out for the standard ambient condition which was the design point and the average ambient condition of January and August in Gunsan where the target engine was installed, and the results were compared with the data in the cycle contract provided by the manufacturer. According to the results shown in Fig. 3, 4, the developed model has considerably accurate thermodynamic performance.

Table 1 Performance of Target Engine

Parameters		Unit	Value
Ambient	Temperature	℃	15
	Barometric Pressure	kPa	101.3
	Relative Humidity	%	60
Compressor	Inlet Air Flow Rate	kg/s	586.1
	Inlet Air Pressure Drop	kPa	1.226
	Inlet Air Pressure	kPa	100.1
	Outlet Temperature	℃	451
	Outlet Air Pressure	kPa	2,059.4
	Pressure Ratio		20.57
Combustor	Fuel Gas Flow	kg/s	13.456
	High Heat Value	kJ/kg	54,709
Turbine	Inlet Gas Temperature	℃	1,500
	Inlet Gas Pressure	kPa	1,961.3
	Exhaust Gas Temperature	℃	609.7
	Exhaust Gas Pressure	kPa	105.03
Gross Power Output		MW	258.1
Thermal Efficiency		%	35.06

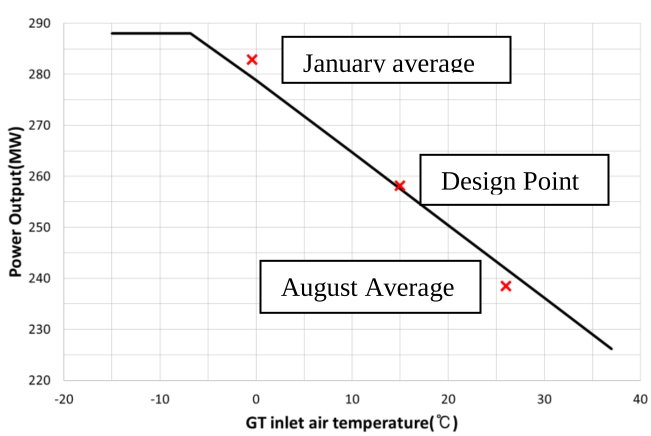

Figure 3 Verification of Based Engine Model (Power)

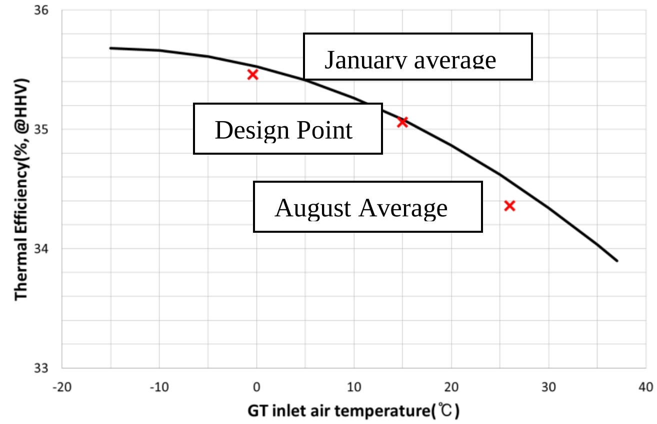

Figure 4 Verification of Based Engine Model (Thermal Efficiency)

3. DESCRIPTION OF EACH MODULE

The purpose of developing EMAS was to assist the user for intuitively determining the performance of gas turbines. For this, the main window displays the current atmospheric conditions, the change in the current performance compared to the reference performance, overhauls plan and estimated date, major performance monitoring variable alarms, Blade Path Temperature (BPT) distribution, compressor efficiency trend analysis, and estimated washing interval/date, by summarizing the results of computations in each module. Fig. 5 shows the main window of EMAS.

Through this window, the operator can have a comprehensive understanding of the current performance status and maintenance information of the gas turbine, to make decisions about maintenance. The following sections describe the purposes and functions of each module, and how to use each module..

3.1. Gas Turbine Condition Monitoring

This module monitors whether the system performance is degraded or the system is damaged by comparing the performance simulated by the thermodynamic model of the gas turbine and the actual measured system performance. It analyzes the difference between the design performance provided by the manufacturer or the user-designated performance and the actual operation data(Fig. 6). Its main functions are the following:

- To display the performance of major components, measured in real time;
- To calculate the reference performance under the current operating condition;
- To analyze the difference between the expected performance and the actual operation performance;

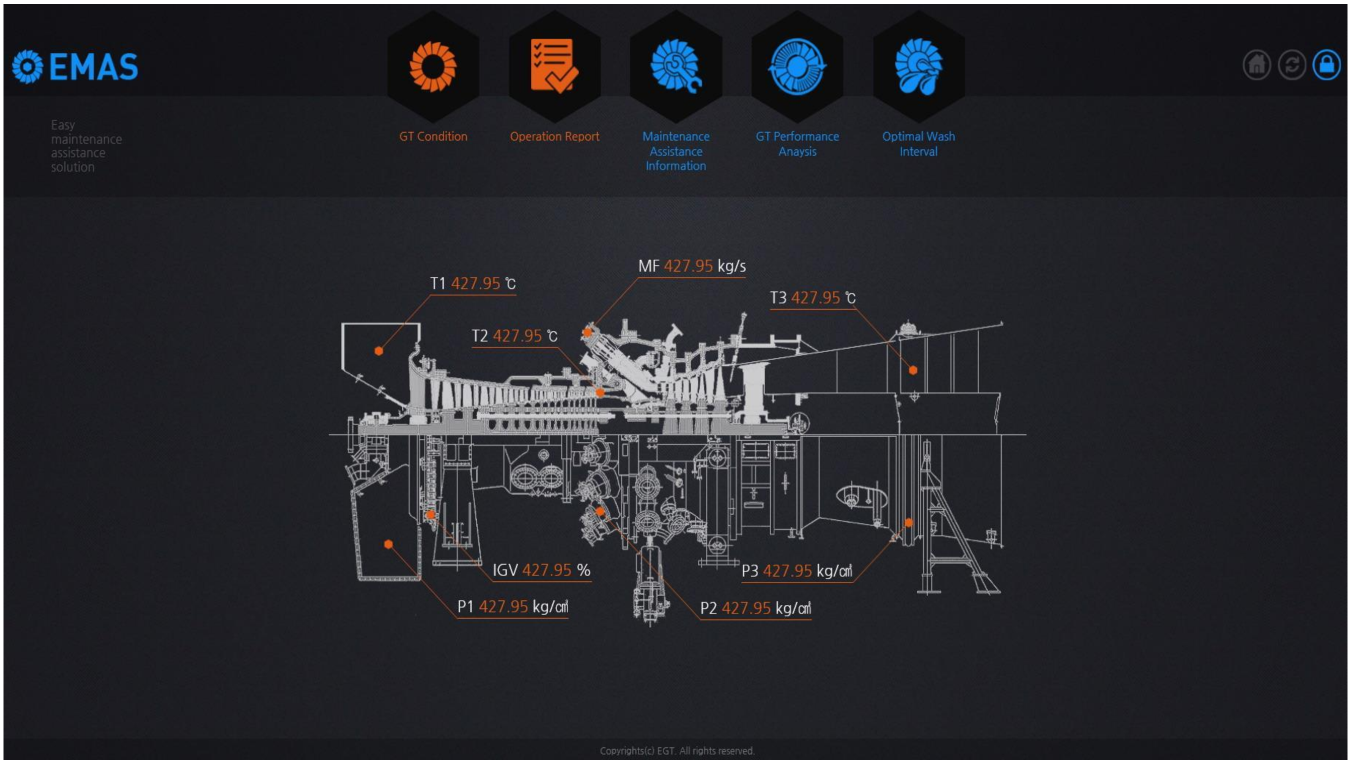

Figure 5 EMAS Main Display

- To estimate the performance under certain operating conditions (atmosphere, fuel composition, load, secondary flow path performance, etc.)

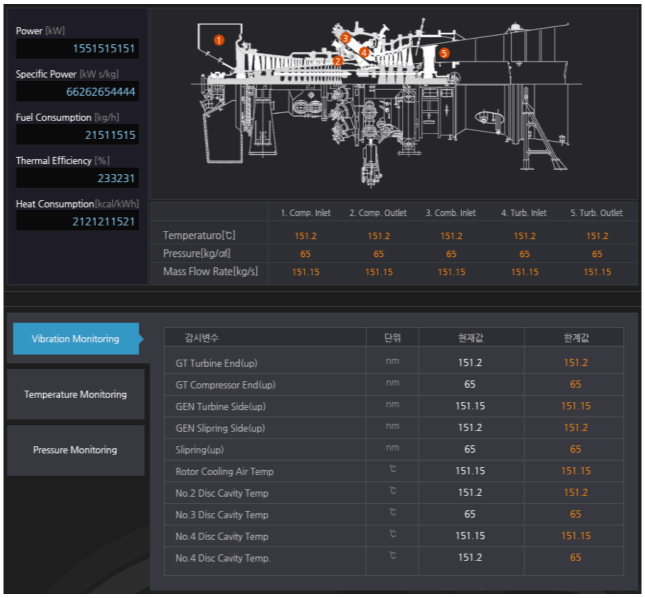

Figure 6 GT Condition Monitoring Display

These functions are useful for monitoring the system performance in real time, simulating the performance of MHI1501G under various operating conditions, calculating the reference performance for model-based performance diagnosis, and analyzing the difference between the reference performance and the actual system performance.

3.2. Gas Turbine Performance Diagnostics

This module monitors the real-time operation performance and monitors the stability of system operation through alarm when the operation performance deviates from the normal range(Fig. 6). Operation system for target engine is using more variables then EMAS, but EMAS is monitoring some variables operators are mainly interested in. Most thresholds recommended by MHI were used, and some thresholds were adjusted by the experience of the operator was also. Its main functions are the following:

- To analyze the trends of compressor efficiency and thermal efficiency;
- To monitor in real time the vibration, temperature, and pressure of major components and parts;
- To notify the deviation from the normal operation range using alarms.

These functions are used for detecting monitoring the compressor performance drop through analysis of the trend of compressor efficiency, the gas turbine system performance drop through analysis of the trend of thermal efficiency, the mechanical defects through the monitoring of vibration of major parts of the propulsion system, and over-temperature/overload and compressor surge and/or faults through monitoring of temperature and pressure of major parts of the system.

3.3. Gas Turbine Trend Analysis

The purpose of developing this module is to analyze the trend of changes in performance using the operation history database and analyze the change in performance of the gas turbine under the user-defined conditions user such as season, period, and before and after maintenance(Fig. 7). Its main functions are the following:

- To display the change in major performance during the specified operation period;
- To save data for comparing the performance between the specified periods;

With these function, it is possible to analyze the changes in performance from the past to the present and use it for estimating the future performance, and to analyze the trend of changes in system performance through the comparison of performance by period.

Figure 7 Performance Trend Analysis Display

3.4. Blade Path Temperature (BPT) Analysis

The BPT analysis module monitors the burner performance by analyzing the temperature of combustion gas from the burner and provides the alarm for deviation from the normal operation range. Based on normal range of BPT and swirl angle calculation expression were referred to operation manual [6]. 16 sensors for measuring BPT are installed at the last stage of the turbine. Its main functions are the following:

To display in real time the result of BPT analysis;

To calculate Swirl Angle compared to output;

To display the temperature measured for each blade and its distribution;

To monitor in real time the temperature of exhaust gas.

These function are used for determining the burner performance through real-time BPT monitoring, identifying the location of a damaged burner through calculation of the swirl angle from output, and monitoring the over-temperature/over-loaded operating status through measurement of the exhaust gas temperature.

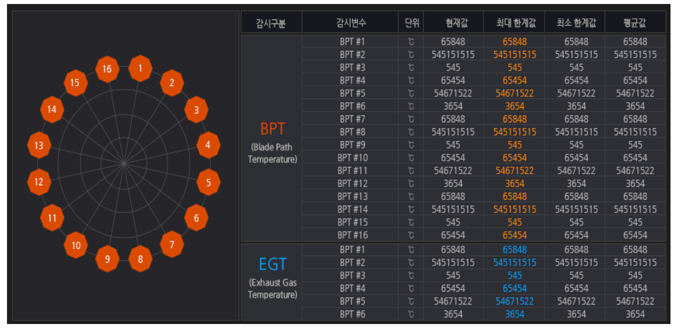

Figure 8 BPT Monitoring Display

3.5. Compressor Washing Interval Management

This module calculates the most economic washing interval based on system operation cost, compressor washing expense, losses from the reduced efficiency, and profits from the raised efficiency after washing. Its main functions are the following:

- To monitor the change in performance of the compressor during system operation;
- To estimate the compressor on-/off-line cleaning intervals, taking into consideration variables like power production cost and profit;
- To display in real time the change in performance of the compressor.

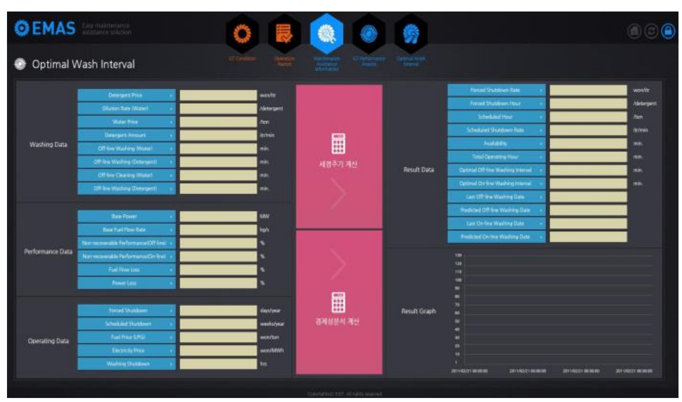

Figure 9 Input/Output Display for Compressor Washing Interval Calculation

Currently, these functions can be used for calculating the optimal washing interval that takes into consideration the gas turbine operation cost (fuel cost, maintenance cost, loss cost, etc.) and the unit sale price, and reviewing the economic feasibility of the compressor washing interval and cost provided by the manufacturer.

3.6. Overhaul Interval Prediction

The overhaul interval Prediction module was developed to predict the optimal overhaul interval through the analysis of performance of components subject to Class A, B and C overhaul(Fig. 10). Its main functions are the following:

- To analyze the recent trend in performance variables of major components subject to overhaul;
- To predict the reduction in life of major components, reflecting the current performance change;
- To compare between the planned overhaul date and the optimal predicted overhaul date
- To display the number of days remaining until the next overhaul;
- To display the planned overhaul dates for the next 3 years.

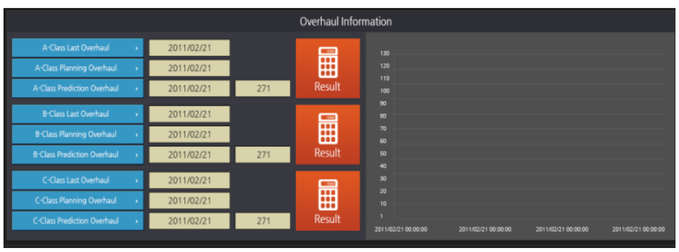

Figure 10 Input/Output Display for Calculation of each Class Overhaul

The numerical model for predicting the performance degradation of each components are shown from Eq.1 to Eq.3. Each equation is developed as an empirical form by applied the actual performance degradation trend data based on the lifetime degradation factor and the application method of degradation coefficients[4]

- Calculation of degradation coefficient for life reduction factor
  - Life reduction of compressor and turbine is calculated with efficiency and mass flow

$$Comp_{factor} = 0.5 \times e^{(0.02 \times Comp_{eff})} + 0.5 \times e^{(0.01 \times Comp_{NDMF})} \quad (1)$$

$$Turb_{factor} = 0.5 \times e^{(0.025 \times Turb_{eff})} + 0.5 \times e^{(0.01 \times Turb_{NDMF})} \quad (2)$$

Where, effi = efficiency, NDMF = Non-dimensional mass flow.

  - Life reduction of combustor is calculated with the imbalance of temperature distribution from combustor

$$Comb_{factor} = e^{(0.3 \times -BPT\ Ratio)} \quad (3)$$

where, BPTRatio = Temperature distribution rate of turbine exit passage; Calculate the date of OH, shorter than OEM's service life if the value of factor is more than 1, Calculate the date of OH, longer than OEM's service life if value of factor is less than 1

Using this module with these functions, it is possible to verify the validity of the overhaul interval provided by the manufacturer through comparison and analysis of the overhaul interval predicted based on the current system status, and to establish the optimum overhaul interval model In addition, this module can be used for maximizing the generation efficiency and operation rate through optimal system maintenance and management.

4. REAL APPLICATION CASE

EMAS has been under test operation at Gunsan Combined Cycle Power Plant in Korea since July 2012. Main contents of the test operation include system stability verification, system reliability verification through generation and analysis of database, and materialization of various alarm values proposed by the manufacturer and settings based on the operator's experiences and the operation environment. Currently, a considerable portion of the system has reached the stabilization stage through modification of the network interface with power plant servers. It is deemed that the system reliability has been enhanced through periodic data analysis and update.

4.1. BPT Alarm Standard Change

At present, the normal range of BPT proposed by the manufacturer is -30 ~ 20℃ against average temperature of all BPT sensors. However, the Gunsan Combined Cycle Power Plant in Korea, the operating company, determines the normal operation range for use based on the results of combustor tuning conducted after overhaul. Therefore, in this study, the normal operation range was determined based on the results of analysis of data collected for one week after combustor tuning and the system operator's opinion. As a result, it is expected to perform inspections faster than before.

4.2. Changing the Standard for Estimating the Washing Interval for the Decrease in Compressor Performance

When an incident happened at the end of May 2013, where the output did not increase while the fuel consumption at the gas turbine increased, emergency inspection was conducted. The cause of the incident was found to be the compressor contamination, which resulted in the decrease in overall output and subsequently caused the controller to limit the output. At that time, the EMAS system was operating but did not detect this problem. The results of database analysis showed that the system did not provide alarms due to a slack in the standard even though there was evident performance drop compared to the reference performance, as shown in Fig. 11 and 12. Afterwards, the reference for alarm was changed from 3% performance drop to 2.5% and a preliminary alarm was added to be issued at 2% performance drop.

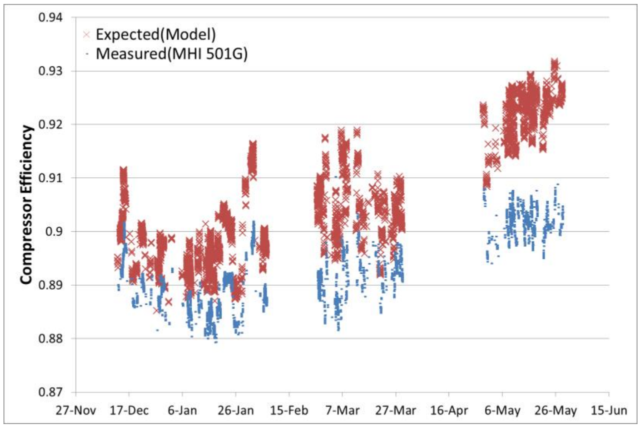

Figure 11 Compressor Efficiency

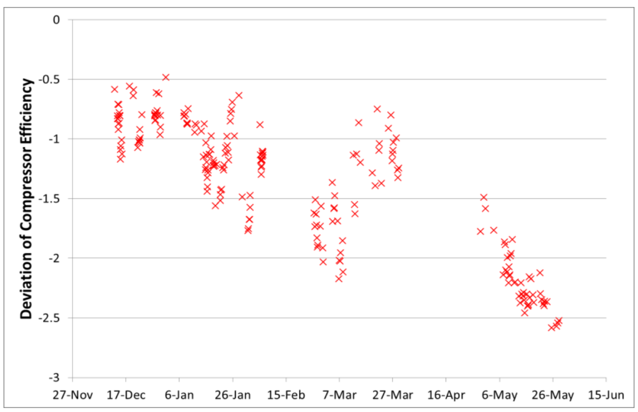

Figure 12 Deviation of Compressor Efficiency

5. CONCLUSION

In this study, a system to assist the decision-making for overhauling the industrial gas turbine was developed. For this, a base model of the target gas turbine was developed and a solution to provide the information necessary for decision-making for overhaul was also developed. The developed EMAS was modularized for each module in consideration of the expandability of its functions and designed to allow easy modification and reuse when the target gas turbine was changed. It is installed in Korea, Gunsan Combined Cycle Power Plant for pilot operation and the compatibility test for additional modules is under way. In addition, database for status diagnosis and prognostics is being built, which will lead to additional development of a module to predict the component life.

ACKNOWLEDGEMENT

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NOMENCLATURE

BPT	Blade Path Temperature
EGT	Exhaust Gas Temperature
EOH	Equivalent Operation Hour
GT	Gas Turbine

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BIOGRAPHIES

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