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Developing A Process Parameter Based Performance Monitoring and Evaluation System for Power Plant

Mehmet BULUT*[1]

Abstract

Today, there are many electricity production methods. Thermal power plants are still widely used for electricity production from hydrocarbon sources as one of the electricity generation options. Due to their complex structure, thermal power plants are composed of sections that interact with each other, and they are called units. A change in the performance of any unit or equipment affects the operation of the entire plant positively or negatively. Therefore, performance monitoring and evaluation systems are designed to support the measurement and monitoring of the performance of plant and equipment. In order to increase the availability of the plant, equipment-based maintenance plans should be prepared according to the maintenance needs of the equipment. In this study, a power plant performance monitoring and evaluation system has been developed and designed using process parameters approach for the parameters affecting the performance of plant. In order to monitor and evaluate the performance of thermal power plants, the requirements of the system were revealed and the efficiency and performance increases to be achieved by designing and using this system specific to a natural gas power plant were examined and results are given.

Keywords: Performance monitoring, Electricity, Power generation, Evaluation, Thermal power generation

1. INTRODUCTION

It is of utmost importance that electrical energy is obtained continuously and efficiently under the most optimum conditions. Power plants are facilities consisting of equipment combined to convert other forms of energy (thermal, nuclear, hydropower, geothermal, solar, wind, tidal, etc.) into electrical energy. Electricity generating hydraulic and thermal power plants consist of many large industrial equipment. Regardless of the type, most of power plants basically has a moving device, an alternator and a conversion station. The electrical energy obtained in thermal power plants based on hydrocarbon sources is more than half of all electrical energy produced in the world. Power plants based on thermal energy currently meet 65% of global electricity, and in some countries, electricity generation is provided by thermal power plants with higher electricity percentage. In 2018, 38% of the electricity produced in the world was obtained from coal, 23% from natural gas and 4% from oil [1].

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Monitoring performances of thermal power plants, which have a very important place in the production of electrical energy, evaluating the performance by monitoring the efficiency in the power plants, and determining the reasons that lead to inefficiency and how to increase the capacity is much important. There are many parameters which have an impact on the performance of each of plant elements that need to be found out. For maximum power uptake from the plant, the interaction between the plant equipment should be monitored and their negative impact on each other should be minimized. For example, a problem that may occur in the air filters of a natural gas-fired combined cycle power plant does not only affect the compressor, but also changes in the performance of all elements up to the cooling tower and leads to losses in power generation.

In power plants, instantaneous values are taken and transmitted to the control room by data collection systems like supervisory control and data acquisition (SCADA) and distributed control system (DCS) for control purposes. However, when we look at the combined cycle power plant, it is seen that there are much parameters that should be followed for even only a single unit. Automation systems are geared towards power plant operation and aim to facilitate the operation, especially to reduce the workload of the operator and to minimize the human factor. However, by measuring and monitoring the performance of the plant elements and equipment, it is possible to support the preparation of maintenance programs according to the maintenance needs of the equipment and thus to perform the maintenance on-site and on time and increase the availability [2,3]. For this purpose, performance monitoring and evaluation systems are designed. These systems continuously monitor and evaluate the data obtained during operation of the plant, calculate the required performance parameters for the units and equipment and compare them with their actual values[4,5].

There have been several previous studies to analyze the behavior of thermal power plant (TPP) using optimization techniques. Konrad Swirski proposed using statistical data analysis to improve the features of existing performance monitoring systems in their study [6]. Process performance monitoring and evaluation; It is a process that needs to be done to measure, maintain and improve the thermal efficiency, maintenance planning of the power plant [7]. In the study of Özdemir et al., the performance of the plant was examined in four main parameters as thermal efficiency, pipe efficiency, turbine efficiency and boiler efficiency in the light of the data received from the thermal power plant. In the five-year period of a system operating under high temperature and pressure, contamination, wear, fatigue, etc. that occur in the system elements. performance changes due to reasons have been identified [8]. For the variation of each of the operational parameters in a thermal power plant, performance calculations are made to configure the energy variation database. These can then be used as assessment criteria based on detecting deviations from a reference system updated during plant performance tests. Balaram et al, they aimed to identify the operational gaps associated with the operation of operational parameters in the power plant process [9].

It is of great importance to define the operational gaps associated with the operational parameters in the power plant process [10] and calculate key performance indicators for the management of power plants [11]. Blanco in their study, aims to identify and monitor the semi-stable conditions associated with measurements in the time series of the power plant process [12]. The models are then used for performance monitoring by comparing the calculated measured value with the reference value. The data-based migration plant system modeling method ensures that the model, which can provide a higher accuracy in performance monitoring, is constantly updated. By using the real-time operating data of the plant, the system monitoring study can be done by creating the mathematical models of the plant components [13]. The maintenance priorities [14] required for the power plant can be made by performing performance modeling [15] of a thermal power plant or by using the simulation and parametric optimization of thermal power [16]. Similarly, it can be evaluated as a decision support system [17] about the plant as a tool for safer operation in the plant. In recent years, many studies have been done in the literature to improve both the operating conditions of thermal power plants and to reveal their performances. In this sense, the approach proposal for temperature distribution control in thermal power plant boilers [18], using of modern information technologies to increase energy efficiency of thermal power plant operation [19], quality assessment of fuel preparation production process in thermal power plants [20] and fault detection and diagnosis in power plants methods in Indian electricity generation sector [21] studies were conducted.

Most facility performance evaluation systems monitor the data obtained during the operation of the facility and evaluate the data obtained according to the design model during the first installation of the facilities. However, due to the aging of the equipment over the years, etc., the capacity decrease is considered normal. In this study, the performance of the facility, the current operating curves of the enterprise are extracted and a performance evaluation is made according to the parameter changes that occur accordingly. In other words, the model curves for the unit and equipment are extracted and compared with the real performance by calculating the new data according to the changing conditions, not the performance parameters that should be in the first installation.

In this study, it is aimed to continuously monitor the current performances and performance losses of units and equipment in order to determine operational problems of power plant operators and managers, to improve unit performance, to accomplish maintenance plans and to make economic decisions in all these studies by developing system-specific performance monitoring and evaluation system. In order for a performance monitoring and evaluation system to be successful and efficient, it should indicate the amount of change in unit and equipment performances and the share of equipment in total performance loss. In this way, power plant operators can estimate the amount, location and economic losses resulting from this loss. In addition to providing an economic enterprise with continuous monitoring of performance, it will also improve future operational conditions and increase safety via helping to predict future problems.

2. PERFORMANCE MONITORING SYSTEMS

One of the most important factors affecting efficiency in thermal power plants is the issue of maintenance and revisions. If a modern monitoring system is used in a plant, maintenance and revision costs and times will be reduced since the plant will be kept under nominal operating conditions and the equipment forming the system will be operated without difficulty, so the effects of improvements in control systems on efficiency can be clearly monitored. The heat cycle should be kept under constant control in the thermal power plants. The correct operation of all measurement and control systems and measuring instruments, their correct value, and the healthy operation of automation systems are vital for power plant efficiency as well as the safety of the power plant.

Steam and water losses in the cycle should be eliminated as soon as possible, the boiler and steam turbine should be operated at nominal loads, keeping the temperature, pressure, flow, level and other measurements and percentage rates as close as possible to the operating conditions in which the unit's efficiency tests are performed. There are many difficulties in determining the most appropriate one from the existing performance monitoring and evaluation systems of which with different aims and abilities, to the needs of the plants. The practices show that these generic software programs do not provide the expected benefits in general. Therefore, designing performance monitoring and evaluation systems according to the structure and needs of the plants will provide much more benefits than using a package program.

As mentioned earlier, coal, natural gas and oil are mostly used as fuel in thermal power plants. In many thermal power plants for electricity generation, there is no Plant performance monitoring system for monitoring and evaluating the performance as a complete system, on the basis of the unit or on the equipment forming the units, but only some parameters (temperature, flow, pressure, etc.) is measured. These parameters, measured by the plant control system, can be used to determine the performance of a part of the plant and its elements, but they do not represent the current situation. In thermal based power generation plants that have only control system and do not have performance monitoring system, the change and decrease in the performance of the facilities and units in the power plant are evaluated by the power plant operators and plant operation personnel. Even if they are very experienced, it is very difficult for the operators to fully evaluate the performance results due to the excess of parameters in the power plant and its elements and the lack of reference performance values in different operational and environmental conditions. However, due to the changing power demands and falls of the turbine and other plants in the power plant, power plants should always operate under non-design or partial load conditions, which in time leads to a loss of performance of the equipment [22].

The fact that each plant has a separate design and technology makes it difficult to make human-based assessments healthy. Aside from the personnel knowledge and experience, an additional system that can evaluate the power plant performance is needed. Therefore, performance monitoring and evaluation systems that compare the actual value with the reference performance value and determine the economic size of it contribute to achieving healthier results for the power plants.

Thermal power plants should be operated at maximum efficiency and profitability due to their high production income and economic size. In this sense, great importance is given to performance monitoring systems and studies show that these systems increase energy efficiency. Depending on the development of automation and computer systems and the increasing importance of efficiency as much as production with energy crises in the world, it has come to the fore that the operation of the power plants is not sufficient and the performance should be monitored also. Therefore, plant equipment manufacturers have developed plant monitoring systems with or after the plant. Diagnosis procedures are often tested on data obtained through simulators [23,24].

A schematic diagram of a plant efficiency under different operating conditions can be shown as in the figure 1. The graph reveals the efficiency of the facility in terms of the combination of uncontrollable and controllable losses depending on time. The upper curve shows the achievable efficiency of a power plant in design values before aging or deterioration occurs. The lower curve shows its true efficiency due to the degradation and aging of materials in a power plant. The status of the plant at a specific point in the lower curve can be captured by performance testing or monitoring. To move from a point in the real efficiency curve to a point in the achievable efficiency curve with the same working condition, uncontrollable losses can be avoided by changing or maintaining the components [25,26].

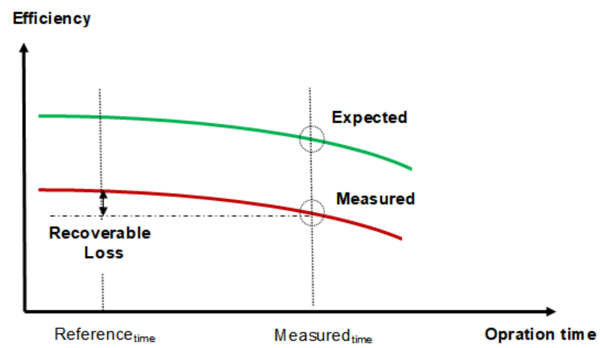


Figure 1 A schematic diagram of a plant efficiency under different operating conditions

2.1. Establishing a Data Management System

The Plant Information (PI) system was established to form the infrastructure of the evaluation and monitoring system in the a combined cycle power plant. PI is used to describe all the information (data) generated by a process consisting of electrical or mechanical equipment. In general, the PI system is used to collect, save and manage data in a process or business. The PI system is capable of gathering processes and enterprises from multiple points (established in different geographical locations) in one place. In this way, all systems can be observed in one place and all data required for analysis can be collected. The operation of the system is simply as follows: Data received from a data source comes to the PI system via an interface, which can be reported by the user in any desired format [27].

The information generated by the PI system for an industrial enterprise can be low in availability and large in capacity. For this reason, there are several commercial programs called “PI Management Systems" which are developed to make this information usable and meaningful, and to convert it into data that can be saved and stored. The PI system is basically a computer-based system and is capable of communicating with the interfaces of open platform communication (OPC) with other industrial devices that collect sensor data and status messages from intelligent machines is shown in Figure 2.

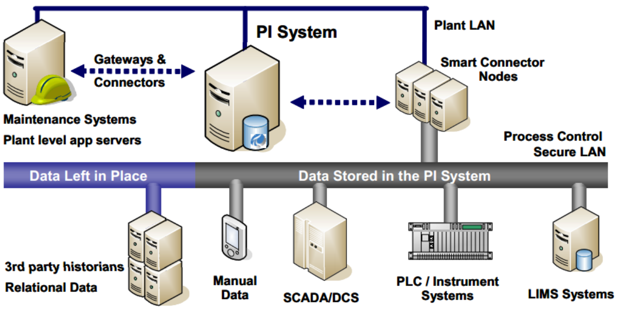


Figure 2 Typical PI system network connection and basic structure (OSIsoft)

2.2. Data Processing and Filtering

The PI system is capable of receiving all parameter data from the OPC machine at regular intervals. Raw state of these data may be too bulk for a healthy observation of the process. It is also possible that unnecessary data is saved and stored for years. In order to prevent this, some of the observed data in the PI system can be compressed with the name Exception and archived data with the name Compression. In this way, unnecessary data is not stored and system performance can be kept high, resources can be used more efficiently. In PI data processing stage; All data from the OPC server connected to the SCADA system is observed and recorded depending on a particular algorithm to be meaningful and give an idea. The collected parameters are stored in archive files, all data between each start and end time.

3. DETERMINATION OF POWER PLANT PERFORMANCE PARAMETERS

Dynamic behavior of power plants is predominantly; it depends on inlet and outlet distortions and changes in set points. This is especially the case in large coal-fired power plants. It is expected from the power plant to keep up with fast operating conditions in case of sudden and sudden load changes, switching in and out. In terms of control engineering, it is very difficult to control a switchboard representing a time-varying and non-linear multivariable process or a system with multiple inputs / outputs (MIMO, multi input multi output).

Increasing competition and fuel costs in the electricity generation sector have led power plant operators to focus on efficiency, availability and reliability. For this purpose, power plant managers should be able to assess the status of their power plants. As a result of these evaluations, it is necessary to understand how much of the targeted performance is realized in the plant operation. For this purpose, long-term monitoring of all the values obtained during the operation of a power plant, performance analysis and comparison with past performance values is very important in detecting the degradation of the unit or equipment. All these reasons reveal the need for performance monitoring and evaluation systems. There are many novel on-line monitoring performance methods of thermal power unit [28-30].

However, since performance losses due to operating and environmental conditions are not within the scope of degradation, the calculation should not take this into account. In order to make the necessary comparisons in order to evaluate the actual performance, the design and off-design performance values of the unit where the performance monitoring and evaluation system will be installed are needed. Design and off-design values are often used in acceptance tests of the unit and are therefore given to managers by manufacturers. However, in cases where these curves cannot be obtained from manufacturers, design and off-design performance values that can be obtained through performance analysis with appropriate physical modeling software are used in performance monitoring and evaluation systems. In many of the SCADA or other monitoring systems used in today's power plants, especially in Turkey, performance analysis either cannot be accomplished or intended to. Therefore, it is difficult to interpret the changes in the performance of the units in a power plant where measurements are made only for control purposes.

In this study, it is aimed to design and implement a thermal power plant performance monitoring and evaluation system that will monitor and measure the parameters affecting the power plant's performance. With this system to be installed, the operator can be informed about the performance levels of the equipment.

Table 1 Parameters and performance indicators affecting the performance of the plant

Model Name	Parameter Affecting Performance	Performance Outputs
Gas Turbine	Outdoor Temperature Air pressure Relative humidity GT Filter Pressure Loss GT Drop Pressure Loss IGV Angle Fuel Lower Heating Value	Net Power Heat Rate GT Exhaust Flow GT Exhaust Temperature
HRSG	GT Exhaust Flow GT Exhaust Temperature	HP Steam Flow HP Steam Temperature LP Steam Flow LP Steam Temperature
Steam Turbine and Water Cycle	HP Steam Flow HP Steam Temperatu re LP Steam Flow LP Steam Temperature Coolant (Water) Temperature	Net Power Condenser Pressure
All Cycle	Outdoor Temperature Coolant(Water) Temperature	Net Power Heat Rate

GT : Gas turbine
IGV : Inlet guide vane
HRSG : Head Recovery Steam Generator
LP : Low pressure
HP : High pressure

In addition, by providing the operator with flexibility of movement to determine the parameters that cause performance failure and to identify and solve the problem, to contribute to the solution of the problem quickly, easily and as independently of the human factor as possible. Within the scope of the study, natural gas combined cycle power plant (CCPP) was selected as the application area of the project. When monitoring the performance of a unit, the performance degradation of both the unit and the equipment must be determined separately. Total degradation indicates the current state of the unit, while equipment degradation indicates where the total degradation stems from. Once the equipment-based degradations are identified, it is also possible to plan the work required for performance recovery [31]. Therefore, first of all, CCPP Power Plant was divided into 3 main sections and the parameters and performance indicators affecting the performance of these sections were determined in Table 1.

In general, there are two different methods used to evaluate the performance parameters determined by the performance monitoring system and to reveal the performance status of the plant. These methods are;

1- Curve-based method (Performance and correction curves method)
2- Model based method

The curve-based method used to determine the level of performance uses correction factors derived from correction curves prepared by the manufacturer for parameters affecting performance or made as a result of simulations and analyzes. The expected power calculation for the gas turbine made using correction factors is given in (1) as an example. Another method is the model based method. In this method, computer simulation including physical models of the equipment is operated with data measured from the plant and expected performance values are obtained.

$$\mathrm{N_{expected}} = \mathrm{N_{measured}} \prod_{i=0}^{n} \mathrm{DF_i} \qquad (1)$$

The curve based method was used in the application to be made at selected a CCPP Plant. For this reason, performance curves supplied by the producer at the plant were investigated and correction curves were obtained with the help of the curves found. However, as a result of the evaluations, it was seen that the number of performance curves obtained from the units of selected CCPP Plant was insufficient to calculate many of the performance indicators.

For this reason, in order to obtain the required performance curves, the three main sections forming the power plant were simulated with the GateCycle ™ program and performance curves were obtained and the results obtained were reported in the relevant sections of the report. In addition, the simulation model of the whole cycle was created by combining these sections validated with the design values, and the effects of the parameters affecting the whole cycle were examined and the results were presented. With the GateCycle ™ program, the heat-equilibrium and mass-equilibrium equations of the equipment that can be found in the thermal power plant can be established. The configuration of a steam power plant on Gate Cycle is shown in Figure 3.

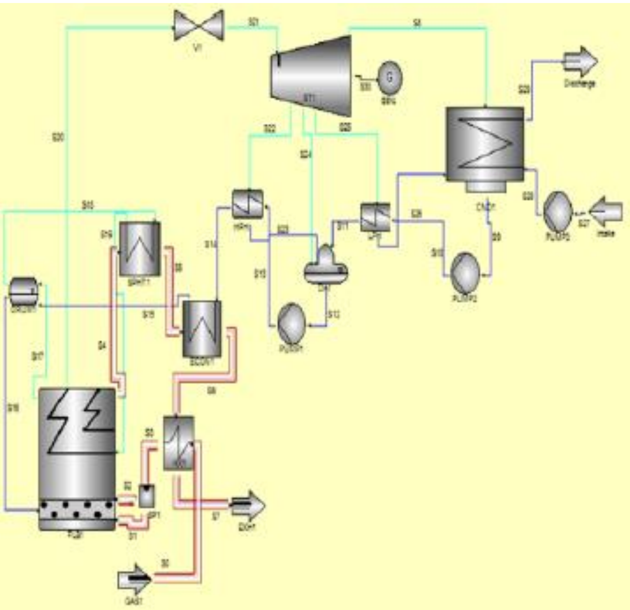


Figure 3 The configuration of a steam power plant on Gate Cycle [32]

Off design simulation models are used to examine the operation of the equipment that is dimensioned according to design values with the design mode under different operating conditions. Thus, with the parametric studies, the effects of various operating values on power plant performance can be seen. It is possible to obtain designs close to the actual design by entering the known design information into the program in the current system. In addition, the obtained design sizes can be verified by comparing them with the actual design information. In addition, the effect of equipment-based degradation on the power plant can be examined in the prepared models. In the studies, it is determined that some additional measurements are needed besides the measured data in the plant to calculate the performance indicators of selected CCPP.

4. COMBINED CYCLE POWER PLANT PERFORMANCE ANALYSIS

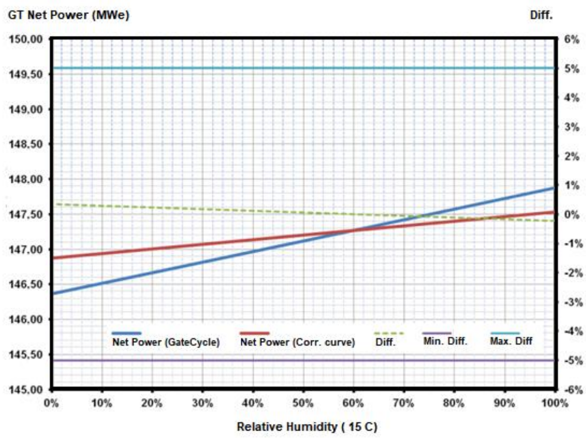
Performance parameters on the basis of unit and equipment, degradation, degradation costs and trends in a given time period will be followed and an important historical database will be created for the plant in the future. Necessary measurements and performance parameters of the power plant have been determined on the basis of equipment and total power in order to perform performance calculations. The PI system, which forms the infrastructure of the evaluation and monitoring system, was established at the power plant where the project will be implemented.

Thirdly, the necessary measurements and performance parameters of the plant for performance calculation are determined on the basis of equipment and total plant. In order to calculate the determined performance parameters, the necessary additional measurements (pressure, temperature, flow rate, etc.) and measurement locations were determined by the project and power plant team. Fourthly, the actual working situation is simulated in computer environment and the design working conditions are verified and correction curves are obtained for the equipment (pump, gas turbine, waste heat boiler, etc.).

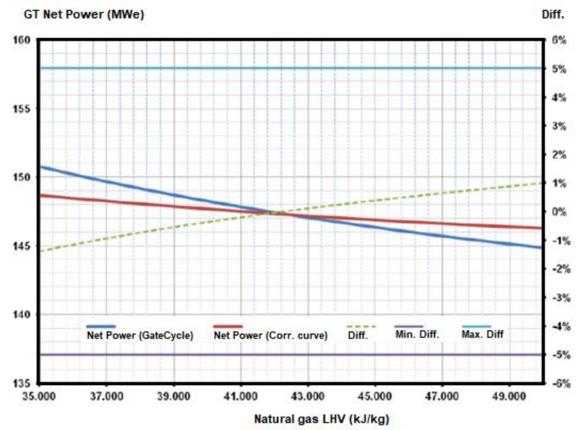
While the plant was simulated, it was examined as 3 main sections, and finally the entire cycle was simulated by combining these 3 main sections and parametric analyzes were completed. After this process, parametric analyzes were performed on verified simulation models, and performance correction curves were obtained on the basis of equipment. The three main sections that make up the CCPP cycle are: gas turbine, waste heat boiler and steam turbine and water cycle. Parametric analyzes for the gas turbine group are listed below:

- Change in GT net power according to outdoor temperature
- Change in GT net power according to outdoor air pressure
- Change in GT net power relative to relative humidity
- Change of GT net power according to GT inlet filter pressure loss
- Change in GT net power according to GT output pressure loss
- Change in GT net power according to natural gas lower heat value
- Change in GT net power relative to change in Inlet Guide Vane (IGV) angle

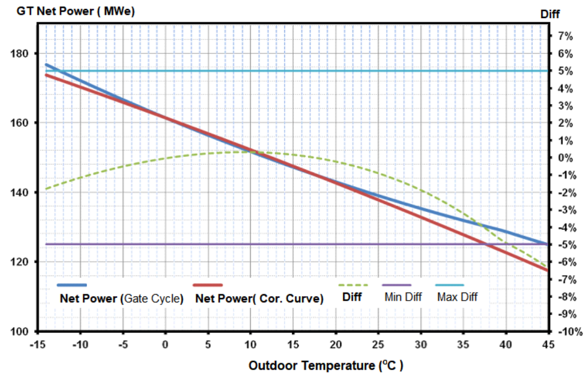
The parameters affecting the gas turbine performance are the parameters affecting the compressor inlet air and the values (pressure, temperature and flow) affecting these weather conditions and fuel properties (LHV- lower heating value). According to the changes in these parameters, the efficiency of the gas turbine (power, outlet temperature and pressure) varies. The parametric analyzes were performed to verify the off-design simulation model and the results are as example in Figure 3.



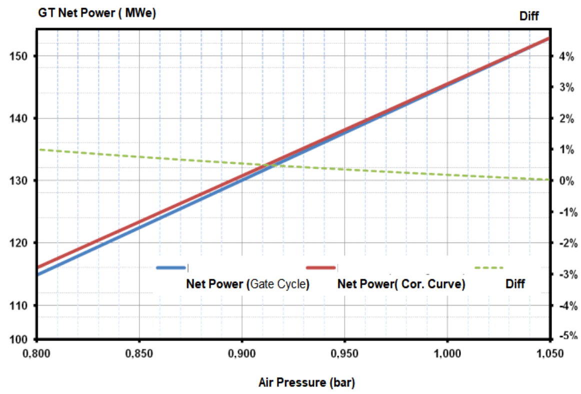
(a) change in relative humidity (15 ° C)



(b) change in natural gas lower heat value (LHV)



(c) change outdoor temperature



(d) change in air pressure

Figure 3 Change in GT net power relative to a) change in relative humidity (15 ° C), b) change in natural gas lower heat value (LHV) c) change outdoor temperature and d) change in air pressure

By using the correction factors obtained from the correction curves obtained from the measurements based on the parameters determined in the power plant, the status of the total unit and equipment (pump, gas turbine, waste heat boiler, steam turbine etc.) can be monitored. For selected Natural Gas Combined

Cycle Power Plant, a special software has been developed that includes performance parameters of the unit and equipment, degradations, the share of equipment in total degradation, hourly cost of equipment degradation and impact and solution analysis.

When graphs in Figure 3 are examined, the highest difference between the power calculated according to the reference correction curves and the simulation model was calculated as -6% in the outdoor temperature change curve. This difference occurs in sections where the outdoor temperature is 45 ° C. The difference between -15 ° C and 30 ° C is the highest -2%, which is within the acceptable limits for simulation studies. Considering the weather conditions in Istanbul, it is a very rare event that the air temperature reaches 45 ° C. Therefore, the simulations made were verified by comparison with the design and non-design values taken from the plant.

5. CONCLUSION

In order to increase the performance of thermal power plants, this system has been designed to design and implement a power plant performance monitoring and evaluation system that will measure all the parameters affecting the performance by measuring them on a unit basis and compare them with the required reference performances. Outputs targeted from the performance monitoring and evaluation system; It is aimed to monitor the performance of the plant with easy-to-understand graphics depending on time, to provide the operator with the opportunity to monitor performance on the basis of units and equipment, to compare the performances of the equipment with the current performance values, to diagnose the problem before the problem occurs, and to provide solutions to the root of the problem and to provide solutions. All modules (performance indicators, distortions, decay costs, trends, etc.) in the software were followed for a certain period of time and the detected errors were corrected. With this software, performance parameters, distortions, decay costs and trends in a certain period of time can be tracked on a unit and equipment basis, and an important historical database for the plant can be created in the future. In addition, these data will assist the switchboard team both in operating the switchboard well and in predictive maintenance of the switchboard. Thus, the condition of the units and equipment in the power plant can be evaluated more efficiently and possible performance losses can be minimized.

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The Declaration of Conflict of Interest/ Common Interest
No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

M.B. 1- Organized the data collection/processing, analysis and interpretation. 2- Supported conceptual approach and design of the study. 3- Made conceptual arrangements during preparation. 4-prepared content of the article draft. 5- Wrote the manuscript.

The Declaration of Ethics Committee Approval
The authors declare that this document does not require an ethics committee approval or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

REFERENCES

[1] World Bank Group, “Electricity production from oil, gas and coal sources”, 2020. https://data.worldbank.org/indicator/ Accesed 25 Sep 2020.

[2] K. Kawai, Y. Takizawa, S. Watanabe, “Advanced automation for power-generation plants - past, present and future,” Control Engineering Practice 7, 1405-1411, 1999.

[3] S. Cafaro, L. Napoli, A. Traverso, A.F. Massardo, “Monitoring of the thermoeconomic performance in an actual combined cycle power plant bottoming cycle,” Energy, 35, 902–910, 2010.

[4] J. Cai, X. Ma, Q. Li, “On-line monitoring the performance of coal-fired power unit: A method based on support vector machine,” Applied Thermal Engineering, 29, 2308–2319, 2009.

[5] A. Valero, MA Lozano, JL Bartolome, “On-line monitoring of power-plant performance, using exergetic cost techniques,” Appl Therm Eng, 16:933–48, 1996.

[6] K. Swirski_, Power Plant Performance Monitoring Using Statistical Methodology Approach, Journal of Power Technologies, 91(2) pp. 63–76, 2011.

[7] L. Li, “Process Performance Monitoring and Degradation Analysis, In Thermal Power Plants,” Ed. Mohammad Rasul, IntechOpen, 2012. Doi: 10.5772/27335

[8] M.B. Özdemir, T. Menlik, H.İ Variyenli, and L. Sevi, “Performance analysis and rehabilitation methods of a thermal power plant”, J. of Polytechnic , 20 (4): 971-978, 2017.

[9] B. Saha, V. Patel and K. Chaterjee, "Assessment of process parameter to improving power plant performance," 2014 Innovative Applications of Computational Intelligence on Power, Energy and Controls with their impact on Humanity (CIPECH), Ghaziabad, pp. 441-446, 2014. doi: 10.1109/CIPECH.2014.7019125.

[10] T. Sudhakar, B. Anjaneya Prasad, K. Prahlada Rao, “Analysis of Process Parameters to Improve Power Plant Efficiency,” Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 14, Issue 1 Ver. II, pp. 57-64, 2017.

[11] S. Vasilica Oprea and A. Bâra, “Key Technical Performance Indicators for Power Plants,” In Recent Improvements of Power Plants Management and Technology, Ed. Aleksandar B. Nikolic and Zarko S. Janda, IntechOpen, 2017. DOI: 10.5772/67858.

[12] J. M. Blanco, L. Vazquez, F. Peña, "Investigation on a new methodology for thermal power plant assessment through live diagnosis monitoring of selected process parameters; application to a case study," Energy, Elsevier, vol. 42(1), pp. 170-180, 2012.

[13] Z. Guo, S. Gu, P. Liu, Z. Li, “Operation dota based modelling and performance monitoring of steam turbine regenerative system under full working conditions,” Chemical Engineering Transactions, 61, 127-132, 2017. DOI:10.3303/CET1761019

[14] S. Malik, P.C. Tewari, “Performance modeling and maintenance priorities decision for the water flow system of a coal-based thermal power plant”, Int. J. Quality Reliab. Management, 35(4), pp. 996-1010, 2018.

[15] R. Kumar, A.K. Sharma , P.C. Tewari, “Performance modeling of furnace draft air cycle in a thermal power plant”, Int. J. Eng. Sci. Technol., 3 (8), pp. 6792-6798, 2011.

[16] P.R. Kumar, V.R. Raju, N.R. Kumar, "Simulation and parametric optimization of thermal power plant cycles", Perspect. Sci., 8, pp. 304-306, 2016.

[17] R. Kumar, "Performance evaluation and decision support system of the water circulation system of a steam thermal power plant", Elixir Mech. Eng., 44, pp. 7551-7557, 2012.

[18] A. Marjanović, Sanja Vujnović, Željko Đurović, "One approach to temperature distribution control in thermal power plant boilers," Automatika, 61:2, 273-283, 2020.

[19] E.K. Arakelyan, A.V. Andryushin, V.R. Sabanin, S.V. Mezin, F.F.Pashchenko "Use of Modern Information Technologies to Improve Energy Efficiency of Thermal Power Plant Operation", 2017 J. Phys.: Conf. Ser. 891-012286, 2017.

[20] R. Patel Himanshukumar, Vipul A. Shah, "Fault Detection And Diagnosis Methods In Power Generation Plants - The Indian Power Generation Sector Perspective: An Introductory Review," PDPU Journal of Energy & Management, pp. 31-49, 2018.

[21] Ya A Tynchenko and I V Kovalev, "Quality assessment of the fuel preparation production process at thermal power plants", J. Phys.: Conf. Ser. 1515-052067, 2020.

[22] S. M. Kim, Y. Jin Joo, Implementation of on-line performance monitoring system at Seoincheon and Sinincheon combined cycle power plant, Energy, 30, 2383–2401, 2005.

[23] V. Verda, R. Borchiellini, "Exergy method for the diagnosis of energy systems using measured data", Energy, Vol.32, pp.490-498., 2007.

[24] A. S. Karakurt, Ü. Güneş, Performance Analysis Of A Steam Turbine Power Plant At Part Load Conditions , Journal of Thermal Engineering, Vol. 3, No. 2, pp. 1121-1128, 2017.

[25] H. Kim, M. Gyun Na, G. Heo, "Application Of Monitoring, Diagnosis, And Prognosis", In Thermal Performance Analysis For Nuclear Power Plants, Nuclear Engineering And Technology, Vol. 46, Issue 6, pp. 737-752, 2014.

[26] M. Bulut, "Designing Performance Monitoring And Evaluation System Of A Thermal Power Plant Using Process Parameters", In Engineering And Architecture Sciences Theory, Current Researches And New Trends, Cetinje, Montenegro: Ivpe Int. Publishing, pp. 160-185, 2020. Doi.10.5281/Zenodo.4101427

[27] H. Hong, W.G. Yang, L. Zhong-Da, "PI database system and its application in power plant SIS", Electric Power Automation Equipment, 11, 2004.

[28] J. Cai, X. Ma, Q. Li, "Online monitoring the performance of coal-fired power unit: A method based on support vector machine", Applied Thermal Engineering, Vol.29, pp.2308-2319, 2009.

[29] L. Pan, D. Flynn, M. Cregan, "Statistical model for power plant performance monitoring and analysis", Universities Power Engineering Conference, UPEC 2007. Vol.4, Issue 6, pp.121-126, 2007.

[30] H.A. Silva Mattos, C. Bringhent, D. F. Cavalca, O.F. Reis Silva, G.B. Campos, J. T. Tomita, "Combined Cycle Performance Evaluation and Dynamic Response Simulation", Journal of Aerospace Techn. and Management. vol.8 no.4, 2016.

[31] Project Report, "Thermal power plant performance monitoring and evaluation system design and implementation", TUBITAK Project No. 110G092, 2013.

[32] F. Vidian, Tomi, "Simulation of 25 MWe Steam Power Plants Using Gate Cycle, Int.

Journal of Engineering and Advanced Technology (IJEAT), Vol. 8 Issue 6, 2019.