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Optimization the Efficiency of Gas Turbines for Air Pollution Reduction

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Abstract

Increasing concerns about energy and emissions from fuel consumption in gas turbines has attracted many researchers to protect the environment and reduce pollutants in the world. The main objective of this paper is to investigate the increasing efficiency of three-stroke gas turbine operation based on the technical analysis of the operation of three-axis gas turbine cycles with non-design conditions in partial loads, taking into account environmental criteria and sustainable development. Three-axial gas turbine has been studied and thermodynamic modeling and the database has been formed and completed for all constant and variable parameters. Then, the objective function (increased efficiency and gas turbine power) is defined and the objective function is optimized by connecting the databases and using the genetic algorithm. After thermodynamic modeling for different values of the position of the input guide blades and the position of the three-stroke gas turbine drainage positions, the efficiency of the gas turbine and the efficiency of genetic algorithm increased. Based on the results, NOx emissions were compared to the various partial gas loads of the gas turbine. It was observed that with the help of this optimization, NOx emissions were reduced. In this sense, using this optimization has been instrumental in environmental protection. The application of this research in the country's power industry and gas turbine power plants is used to increase the efficiency and power and hence reduce air pollution.

Key words: Pollutants, Nitrogen Oxides, Gas Turbines, Functional Efficiency, Air Pollution.

Introduction

Today, air pollution in cities is a major problem in the world, with particular attention to protecting the environment and reducing pollutants in the world. Increasing population, creating big cities and developing communications led to a large number of electricity use and as a result, increased gas turbines in order to generate electricity. Gas turbines are one of the most important subjects in engineering sciences and are widely used in various industries including air, power plants, oil, gas and marine transportation. So that the pollution caused by gas turbines is known

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as one of the factors of air pollution. Due to the burning of fossil fuels and organic fuels or any other combustion, substances in combustion products such as SO2, NO2, NO, CO, CO2, etc are often produced from environmental pollutants. Nitrogen oxides are one of the major pollutants of gas turbines. Hence, with the growth of gas and combined power plants in the country, according to new global standards, environmental concerns about the production and release of this pollutant are increasing. For the past twenty years, the average level of nitrogen oxides has grown steeply.

Available results from various airspace surveys from industrialized cities indicate that the average amount of these materials has been exceeded. The release of NOx, in addition to the formation of acid rain and the destruction of the ozone layer causes the formation of ozone in the lower layers of the atmosphere, which is itself the primary source of air pollution in cities. Considering the destructive effects of NOx release on human health and other organisms, consideration of different methods for reducing NOx has been considered by the experts. Given that the gas turbines used at the gas pressure booster stations and also the power plants should be in different climatic conditions and in different loads, therefore, considering that the engine efficiency in the partial loads beyond the design point it decreases and therefore its fuel consumption per unit of power output increases. An important part of this research is the optimization of gas turbine efficiency and power in partial loads. The thermodynamic modeling of gas turbine processes provides tools that can be used to investigate and better understand the performance of the components and thereby reduce the emissions from the combustion system (Environmental Protection Agency, 1999). The main issue of this research is to optimize the efficiency and power of three-axis gas turbines in partial loads, taking into account environmental criteria.

Literature Review

Major optimizations are related to systems in which the gas turbine is one of its components, taking into account the behavior of different components of the gas turbine and the ratio of pressures, the effect of each component on the final performance of the turbocharging and calculates the efficiency (Chen et al, 2004). Ehyaei et al (2011) examined the effect of the inflow of turbines in three aspects, economic and environmental in a one-year period. Momen et al (2013) using an economic analysis at the design point, compared the simple turbocharging and turbocharging with the converters. Chaquet et al (2012) optimized the number of airfoils and gas turbine compressor classes using a genetic algorithm and using an approximate method to predict the gas turbine efficiency. Sanaye and Tahani (2010) using thermodynamic modeling, investigated the effect of input air at the operating point on the compressor compression curve page. Ahmadi and Dincer (2011) conducted a thermodynamic, economic and environmental analysis on turbine shafts. Then they performed a multi-objective optimization using the analysis. Objective functions are defined in two-objective optimization, exergy efficiency and economic costs. The input variables of optimization also include the pressure ratio, the high turbine input temperature, the isentropic compressor efficiency and the outlet temperature of the compressor. The optimization has been carried out in the form of boundary that can be considered from the constraints, taking into account the minimum temperature at the outlet of the turbine for the production of sulfuric acid, technology level constraints. Except for the use of isentropic efficiency as the level of technology (the polytropical efficiency represents the level of technology of turbo machinery components), the operation of the gas turbine has not been shown in terms of outside conditions. Turner et al (2004) modeled the GE90-94B in NASA. To do this, they first developed a one-dimensional modeling of characteristic curves with a limited area of activity and then they used the subsequent zero-model modeling and performed the 3D simulation using the resulting boundary conditions. The complete simulation of the engine took place in less time. Pachidis and Nikolaidis (2006) modeled the CFM56-5B2 engine using the Zoom method. In this work, they performed the next zero modeling with Petya software and obtained the resulting boundary conditions in 3D modeling with computational fluid dynamics and obtained the flow details. Gaudet (2007) designed a control system to model a gas turbine. His model was able to simulate the performance of the start-up conditions and the design point was permanent and transient. Haglind and Elmegaard (2009) simulated the LM2500 + turbine in two simple and complex ways and Haglind (2010) examined the effect of input lead blades on turbines LM2500 + and V64.3. Gobran (2013) modeled the Solar Centaur 40 gas turbine using the Simulink under off-plan conditions. He obtained the characteristic curves from a scale method and modeling the Turbine Repetition Loops method. Visser and Buijtenen (2015) examined the general methods for gas turbine analysis to develop a gas turbine simulation program at the University of Delft. This program is capable of modeling a one-dimensional gas turbine in steady-state conditions. Song et al (2015) presented a model of three-shaft micro turbine. In their work, they considered the blade cooling relations as a combination of experimental and analytic relations. They also performed modeling for different angles of conduction valves. Tahan et al (2017) modeled a double gas turbine. To do this, they first performed calculations on the design point and obtained the necessary data at this point. Then using these data, the characteristic curves were obtained from a scalar method. Finally, using the obtained curves and matching the components of the gas turbine efficiency for a state outside the design point. In this model, they assumed constant cooling current and used empirical relationships to consider the effects of the inductive blades. For research on NOx, Bakali et al (2004) in another study investigated the production of NOx in hydrogen fuels by a finite volume solution for three types of fuel and finally concluded that NOx emissions in hydrogen combustion. The reason is that the temperature will be much higher than methane gas combustion and the mixing of hydrogen and methane will result in significant reductions in NOx. Frassoldati et al (2005) also used fluent software to model NOx in flames.

Case Study

One of the gas turbines active in the gas industry of country is 25 MW gas turbine DU80 Zuria. In order to develop, a complete model of gas turbine with the possibility of analyzing its functional parameters is carried out; its technical specifications are presented in (Table 1).

Table 1. Characteristics of Turbine DU80 (19)

Characteristic	Explanation
Input guiding blades	3 first floors
Compressor	9 floors down pressure and 9 floors high pressure
combustion chamber	Reverse flow cylinder -16 liner
Turbine	1 high pressure floor and 1 floor down pressure
Dimensions	3/6 * / 3/2 * 3/3 cubic meters
Weight	14 tons

Gas turbine design is initially based on ISO conditions. The inlet air temperature is 15 ° C and the pressure is 1.3225 1 bar and the relative humidity is 60%. But usually the conditions for entering the gas turbine will be completely different from these values. Due to the fact that industrial and air gas turbines operate in different environmental conditions and loads, changing the temperature and pressure of the environment and the functional characteristics of each component of the gas turbine will change, resulting in the amount of power and efficiency Gas turbine changes. Therefore, it is important to know the gas turbine behavior in conditions beyond the design point. Also, with this knowledge, we can analyze the ways to increase the power and efficiency of gas turbines. For this purpose, the equations of mass and energy survival (Equations 1 and 2) are written for the single component.

$$\sum \dot{m}_{in} - \sum \dot{m}_{out} = 0 \tag{1}$$

$$\sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out} + \dot{Q} + \dot{W} = 0 \tag{2}$$

Equations obtained for a single component are dominant in all states. The main difference in design and out-of-design calculations is the input and output of the calculations. For example, in calculations of compressor efficiency, the compressor efficiency (polytopic efficiency) is considered in calculation of the point of design as input. But off-scale calculations comprise the efficiency of the compressor with the help of performance curve. In fact, returns are not considered directly as inputs in calculations outside the design. The same applies to the parameters of the efficiency of other components and the pressure drop. Further, the thermodynamic equations for each individual component are written. Figure (1) schematically shows the three-component gas turbine component. In some cases, there is a need for empirical relationships extracted from references. In order to model components in non-design conditions, it is necessary to somehow predict their behavior outside the design so that calculations can be made in conditions beyond the design. This is done for the combustion chambers through the empirical relationship. For a compressor and a turbine, a scale method is produced using a performance mapping curve for their performance map. By generating a performance map, it is possible to predict performance. In the following, thermodynamic modeling of turbine blade cooling is used. With the help of this modeling, the turbine temperature can be estimated with respect to cooling efficiency and cooling flux. The model is used to model the cooling of turbine blades. Then, by defining different target functions and choosing the main thermodynamic parameters of the Turbo Shaft cycle, optimization input variables (decision variables) and the definition of logical constraints are optimized. Genetic algorithm is used for optimization.

The Stages of Research

Thermodynamic Modeling of Gas Turbine at Design Point

Accreditation of the model developed at the design point with the main data of the main gas turbine manufacturer: In this section, according to the data available at the design point provided by Zuria, the accuracy level of the model was examined, which results in the high accuracy of modeling At design point, the maximum modeling error was less than 1%. *Development the model of gas turbine in terms of out-of-design:* Based on the developed algorithm to solve the gas turbine in a stable condition, the development of the model was carried out. In this model, the complete integration between all components of the engine, including inlet and outlet ports, compressor, combustion chamber and turbine, was established. error in this section was calculated less than 2%.

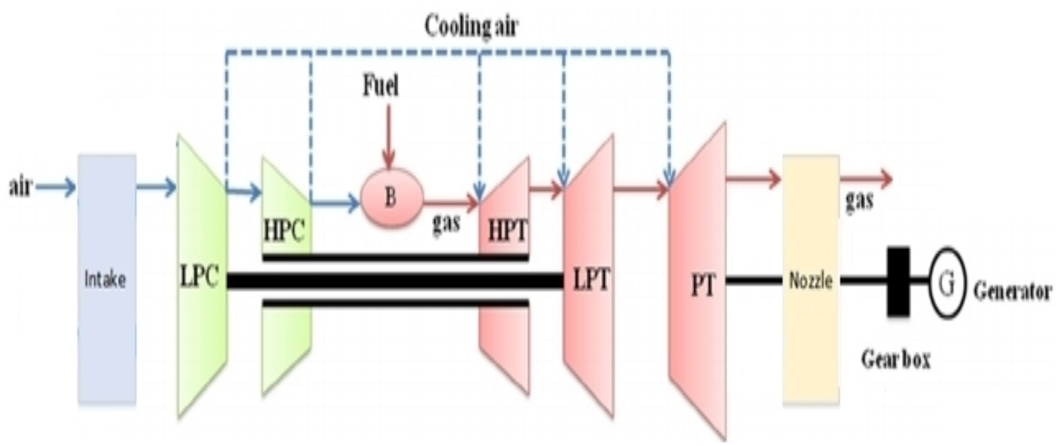

Figure 1. Three-axis gas turbine schematic

Validation of Extended Model: After the development of the model, the validation process was carried out to ensure the model results and the level of modeling accuracy. This process was carried out in two different sections (validation with test data and Zuria correction curves). Modeling

Extracting the Gas Turbine Functional Analysis Algorithm in Different Working Conditions: In this section the operational analysis of gas turbine algorithm was extracted in non-design conditions. In order to analyze the gas turbine accurately, the constant and variable input conditions have been investigated, as well as different parameters such as the velocity of the axes, the mass flow rate of the fuel, the ratio of the pressure of the compressor groups and the different classes of turbine, the flow rate of the mass of cooling in Different points and pressure drops in the duct were guessed that, after the simultaneous solving of all engine components, complete compatibility between all components was established.

*Extracting Final Modeling Results***:** In this section, the results of modeling were extracted and analyzed in different situations with the general outcomes as follows:

With increasing load, the power and gas turbine efficiency increased, and engine operating points were moving on the characteristic curve of the compressor on the margin of the compressor line. With increasing ambient temperature, the power and thermal efficiency of the gas turbine decreased. In this situation, in accordance with the philosophy of designing the gas turbine, the input temperature to the turbine remained constant at almost all ambient temperature intervals. This is due to the achievement of the highest possible power and the maximum use of energy produced by the gas turbine. As the altitude increased, the gas turbine power decreased. The rate of change in efficiency was much lower than power variation. Also with the change in altitude from the sea level, the input temperature to the turbine remained constant. *Setting goals and optimization algorithms***:** In order to perform the optimization process, initially, the algorithm and optimization goals should be determined. The optimization algorithm is the task of setting the control parameters of model with the goal of optimizing the target parameters (efficiency and power) optimized. Two parameters are optimized. These parameters are related to each other for optimization with the coefficient of weights and the objective function of the optimizer model is defined in Equation 3.

$$Target\ function = W_1 \times \frac{1}{GT\ efficiency} + W_2 \times \frac{1}{w_{net}} + W_3 \times W_{net\ constraint} + constraints\ of\ governor\ limitations \quad (3)$$

The optimization algorithm tries to minimize the target function. In the objective function, all constraints such as the power turbine round, turbine inlet and outlet temperatures are considered. In the above equation, the effect of constraints is described in the objective function. Applying constraints to the target function is possible through consideration of fines.

Preparing the proper database of the model: At this stage all the constant and variable parameters for the optimization process including the position of the input guide blades, the turbine output temperature were extracted and the optimization algorithm was extracted. Fixed Parameters include Environmental conditions including temperature, relative pressure and humidity as well as fuel pressure and fuel temperature of the combustion chamber. Variable parameters include the position of intake guide blades, the position of the discharge valves, the fixed angle of the first floor turbine first floor and the output temperature of the turbine.

Input guide blade position: In order to control the flow of air to the turbine when operating on different loads, the guide inputs are mounted on the air inlet of the air compressor which is defined by changing the angle of the blades to control the turbine temperature within the defined range and prevent Surge phenomena is controlled at different stages of the operation of intake air.

Drainage position: The drainage opening percentage can be changed based on the different periods of the high pressure turbine. Cool air evaporated from the compressor is used to inject and cool the gas turbine blades which prevent supercharging in the compressor while reducing power.

Given that the direct connection of the extended model with the genetic algorithm resulted in many problems, including the very high running time in each of the working conditions. Therefore, in this section, after determining the different working range, the model was implemented in different conditions.

Connecting the Database to the Genetic Algorithm: In this section database linked to the genetic algorithm for optimizing the process. Figure (2) illustrates general optimization flowchart and how this connection is.

Extraction the Optimization Results of DU80 Gas Turbine

At this stage, the results of optimization were carried out in different situations and objectives with the previous steps. The results show that by making different control changes in the gas turbine, it is possible to increase the power and efficiency of the gas turbine. Figure (3) shows the relative power optimization diagram (power at design point) in terms of load percentage and Figure (4) the optimization diagram shows the relative efficiency (efficiency per time for the design point) in terms of load percentages.

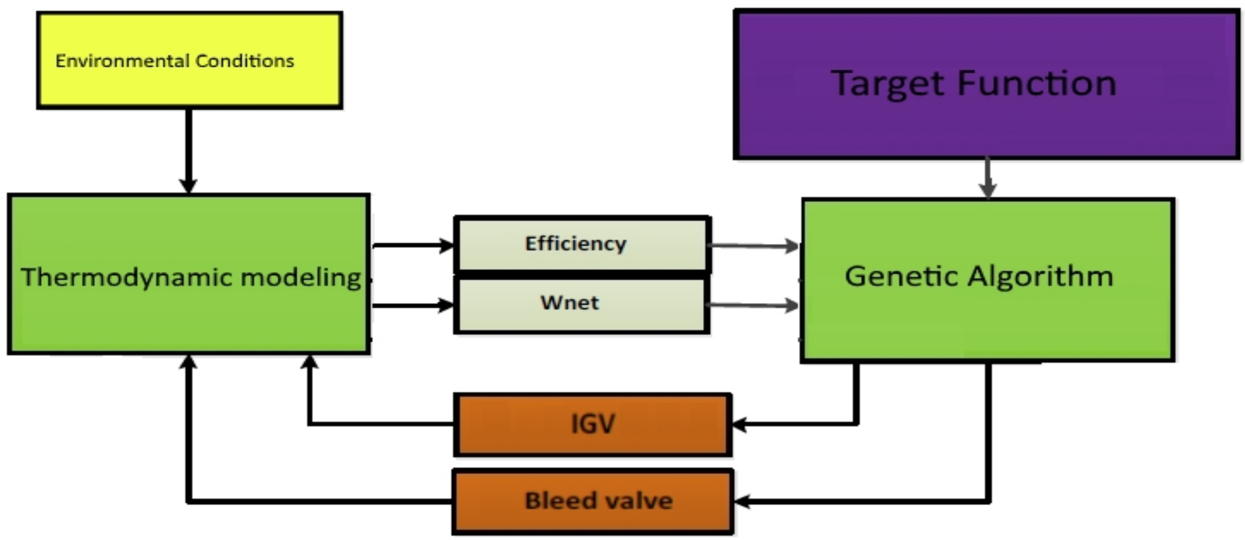

Figure 2. General Optimization Flowchart

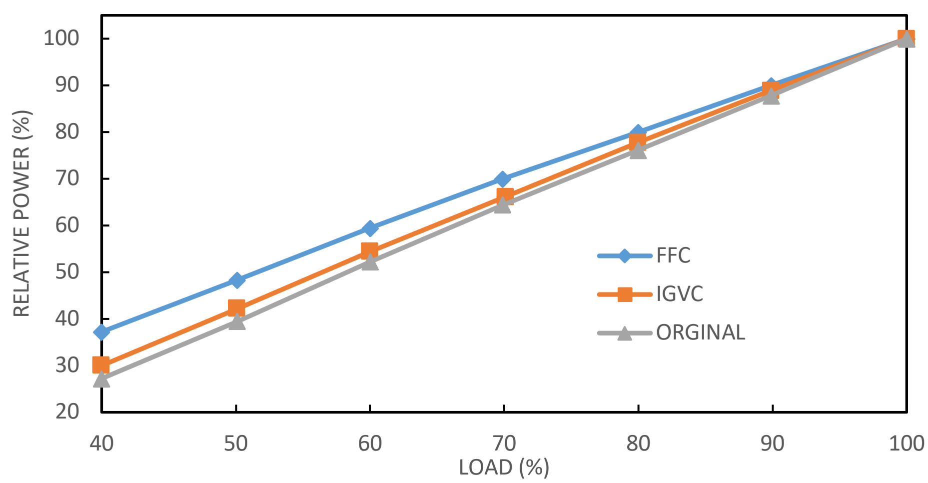

Figure 3. Relative power optimization diagram

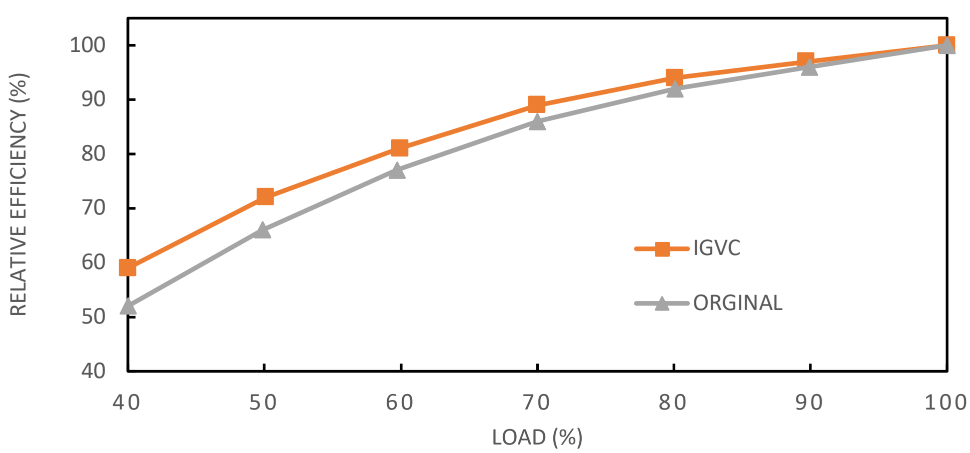

Figure 4. Relative efficiency optimization diagram

The Amount of Pollutants Produced

The contaminants in turbines are mainly due to the production of NOx and CO2. Different authorities have different relations in terms of production of these pollutants. By means of chemical balance, Rosak offered an analytical relationship to produce carbon dioxide based on fuel consumption. This Equation (4) is applicable to hydrocarbon fuels with the formula C_xH_y.

$$1\ kg\ of\ fuel = \frac{44}{12+\frac{y}{x}} kg\ of\ CO_2 \tag{4}$$

The relations that exist for the production of nitrogen oxides are mainly those obtained from empirical results. Different relations have been proposed for the production of pollutants. The amount of nitrogen oxide production is calculated through the experimental Equation (5).

$$NO_x(ppmv) = 62 \times P \times FAR^{1/4} \times exp(-635/T) \tag{5}$$

In equation 5, the pressure in Pascal is the temperature in degrees Celsius. The production rate is in terms of ppmv at 15% oxygen. According to the obtained values, the optimization of the power and efficiency of gas turbine in the partial loads, Figure (5) compares the NOx emissions (ton per year) in the various partial loads for both gas turbine and its optimized state.

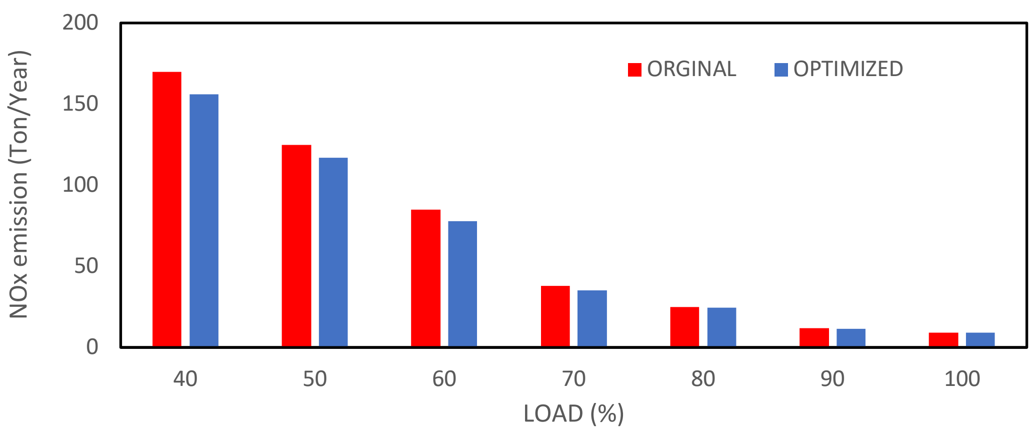

Figure 5. NOx emission diagram (Ton/Year) at different partial loads for the original and optimized gas turbines

Conclusion

In this study, three-axis gas turbine has been studied and thermodynamic model has been developed and completed for all constant and variable parameters (position of inlet guide valves and position of gas turbine discharge valves). Then, by connecting databases and genetic algorithms, the target function is optimized. Based on the obtained results, increasing the gas turbine performance efficiency is obtained based on the position of the blades of turbine inlet guide according to the position of gas turbine discharge valves. NOx emission was then compared to the different partial loads of gas turbine which was observed to reduce the NOx emission through this optimization. In this sense, using this optimization has been instrumental in sustainable development and environmental protection. Therefore, considering the application of gas turbine in the country's power industry and power plant, it can be used to increase the efficiency and power and thus reduce air pollution.

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