

EXERGoeonomic OPTIMIZATION OF GAS TURBINE POWER PLANTS OPERATING PARAMETERS USING GENETIC ALGORITHMS: A CASE STUDY

by

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Original scientific paper
UDC: 621.438:66.011
DOI: 10.2298/TSCI101108010G

Exergoeconomic analysis helps designers to find ways to improve the performance of a system in a cost effective way. This can play a vital role in the analysis, design, and optimization of thermal systems. Thermoeconomic optimization is a powerful and effective tool in finding the best solutions between the two competing objectives, minimizing economic costs and maximizing exergetic efficiency. In this paper, operating parameters of a gas turbine power plant that produce 140 MW of electricity were optimized using exergoeconomic principles and genetic algorithms. The analysis shows that the cost of final product is 9.78% lower with respect to the base case. This is achieved with 8.77% increase in total capital investment. Also thermoeconomic analysis and evaluation were performed for the gas turbine power plant. The results show the deep relation of the unit cost on the change of the operating parameters.

Key words: *exergoeconomic, gas turbine, cost balance, power plant, exergoeconomic optimization, genetic algorithms*

Introductions

The importance of developing thermal systems that effectively use energy resources such as natural gas is apparent. Designing efficient and cost effective systems, which also meet environmental conditions, is one of the foremost challenges that engineers face [1]. In the world with finite natural resources and large energy demands, it becomes increasingly important to understand the mechanisms which degrade energy and resources and to develop systematic approaches for improving systems and thus also reducing the impact on the environment. Exergetics combined with economics represents powerful tools for the systematic study and optimization of systems. Exergetics and microeconomics forms the basis of thermoeconomics, which is also named exergoeconomics [2]. Combining the second law of thermodynamics with economics (thermoeconomics) using availability of energy (exergy) for cost purposes provides a powerful tool for systematic study and optimization of complex energy systems. Its goal is to

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mathematically combine, in a single model, the second law of thermodynamic analysis with the economic factors. Exergoeconomics is the branch of engineering that appropriately combines, at the level of system components, thermodynamic evaluations based on an exergy analysis with economic principles in order to provide the designers of a system with information that is useful to the design and operating of a cost-effective system, but not obtainable by regular energy or exergy and economic analysis [3]. Exergy analysis usually predicts the thermodynamic performance and the inefficiency of an energy system [4]. Furthermore, exergoeconomic analysis estimates the cost of product such as electricity and quantifies cost rate due to irreversibility. Exergoeconomic rests on the notion that exergy is the only rational basis for assigning monetary costs to the interactions that a system experiences with its surroundings and to the sources of thermodynamic inefficiencies within it. Exergoeconomic accounting means determining and assigning economic values to the exergy flows [5]. When there are various in- and outflows, the prices may vary and if the price per exergy unit does not vary too much, we can define average price. This method allows comparison of the economic cost of the exergy losses of a system [6]. Monetary balances are formulated for the total system, and for each component of the system, being investigated. Exergy accounting gives a good picture of the monetary flows inside the total system and is a way to analyze and evaluate very complex installations. History of second law costing methods was comprehensively reviewed by Gaggioli *et al.* [7]. They reported the use of availability of energy (exergy) for appropriate allocation of costs associated with co-generation of electric power and steam. In the sixties, the pioneering works in thermoeconomics were carried out by El-Sayed [8]. However, comprehensive efforts to apply thermoeconomics systematically to analysis, optimization, and design of energy systems did not commence until the eighties [9]. Cammarata *et al.* [10] formulated the objective function, the sum of the capital, and the operational and maintenance costs, of a district heating network using exergoeconomic concepts. Bhargava *et al.* [11] analyzed an intercooled reheat gas turbine, with and without recuperation, for the co-generation applications using exergoeconomic principles. Their result provides useful guidelines for preliminary sizing and selection of gas turbine cycle for co-generation applications. Attala *et al.* [12] have used exergoeconomics as a design tool for the realisation of a gas-steam combined power plant principle, where as Misra *et al.* [13, 14] have optimized a single- and double-effect H₂O/LiBr vapour absorption refrigeration system, and Sahoo *et al.* [15] have optimized an aqua-ammonia vapour absorption system using exergoeconomic principles. The optimization techniques used by the above mentioned researchers are mainly based on iterative local optimization procedure, which requires the interpretation of the designer in each of the steps to arrive at the final configuration. The optimization of energy system design consists of modifying the system structure and component design parameters according to one or more specified design objectives. In general, multiple objectives are involved in the design process: thermodynamic (*e. g.*, maximum efficiency, minimum fuel consumption), economic (*e. g.*, minimum cost per unit of time, maximum profit per unit of production), and environmental (*e. g.*, limited emissions, minimum environmental impact) [2]. However, most of the analyses performed in the past consider either only the thermodynamic objective or only the economic one. In the field of thermoeconomics [16-18], design optimization aims at minimizing the total levelized cost of the system products, which implicitly includes thermodynamic information in the fuel cost rate through the fuel exergy flow rate. Various methodologies have been suggested in the literature as ways to pursue this objective, based on different approaches [6]. In the last decades, the development of exergoeconomics has been impressive in more than one direction and the usefulness of this concept was acknowledged by a

large number of scholars and the development is still continuing today [19, 20]. Exergoeconomic can play a vital role in the analysis, design, and optimization of thermal systems. In recent years, exergoeconomic concepts have been used with search algorithms, such as genetic algorithms, to find out realistic optimal solutions of thermal systems [21-23]. In this study, exergy costing principles and exergoeconomic optimization using genetic algorithm were applied for a gas turbine power plant that produces 140 MW of electricity which is an existing plant located in Mazandaran, north of Iran and schematically shown in fig. 1.

Power plant description

Figure 1 shows the schematic diagram of a gas-turbine plant and shows the exergy flows and the state points which was accounted for in this analysis. In this model, the compressor pressure ratio r_p , isentropic efficiency of the compressor η_{sc} , temperature of the combustion products entering the turbine T_5 , and isentropic efficiency of the turbine η_{st} are considered as decision variables. The net power generated by the system is 140 MW. This model is treated as the base case and the following nominal values of the decision variables $r_p = 10.27$, $\eta_{sc} = 85\%$, $T_5 = 1320$ K, and $\eta_{st} = 88\%$ are taken.

For the purpose of analysis the following assumption are made:

- environmental conditions of the air at the inlet are: $P_0 = 1.013$ bar and $T_0 = 25$ °C,
- the power plant operates at steady-state,
- fuel is assumed to be pure methane (CH_4),
- air and the combustion gases are considered ideal gases with constant specific heats,
- the exit temperature is above the dew point temperature of the combustion product,
- the pressure drop in the air preheater and combustion chamber is 4%, and
- the effectiveness of the air preheater is 75%.

Economic analysis and exergy costing principles for the gas turbine

All costs due to owning and operating a plant depend on the type of financing, required capita, expected life of a component, etc. The levelized cost method of Moran [6] is used here. Using the capital recovery factor $CRF(i, n)$ and present worth factor $PWF(i, n)$, the annual levelized cost may be written as:

$$\dot{C} \text{ [\$ per year]} = [PEC + (SV)PWF(i, n)]CRF(i, n) \quad (1)$$

where $SV = 0.1$, $CRF(i, n) = i/1 - (1 + i)^{-n}$, $PWF(i, n) = (1 + i)^{-n}$, and PEC is the purchased-equipment cost. Equations for calculating the purchased-equipment costs for the components of the gas turbine power plant are [2]:

- air compressor

$$PEC_{ac} = \frac{711\dot{m}_a}{0.9 \eta_{sc}} \frac{P_2}{P_1} \ln \frac{P_2}{P_1} \quad (2)$$

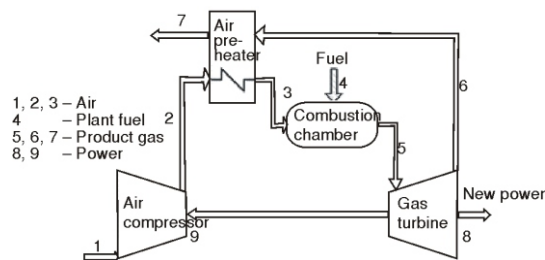


Figure 1. Gas turbine system

– combustion chamber

$$PEC_{cc} = \frac{46.08 \dot{m}_a}{0.995 \frac{P_5}{P_3}} [1 - \exp(0.018T_5 - 26.4)] \quad (3)$$

– gas turbine

$$PEC_{gt} = \frac{479.34 \dot{m}_g}{0.92 \eta_{st}} \ln \frac{P_5}{P_6} [1 - \exp(0.036T_5 - 54.4)] \quad (4)$$

– air preheater

$$PEC_{aph} = 4122 \frac{\dot{m}_g (h_6 - h_7)^{0.6}}{18 \Delta T_{lm,aph}} \quad (5)$$

Dividing the levelized cost by 8000 annual operating hours, we obtain the capital cost rate for the k^{th} component of the plant:

$$\dot{Z}_k [\text{\$ per hour}] = \frac{\phi_k \dot{C}_k}{8000} \quad (6)$$

The maintenance cost is taken into consideration through the factor $\phi_k = 1.06$ for each plant component whose expected life is assumed to be 15 years and the interest rates is 17%. The number of hours of plant operating per year and the maintenance factor utilized in this study are the typical numbers employed in standard exergoeconomic analysis [6].

The exergoeconomic costs of all the flows that appear in the system's schematic diagram are obtained through exergy costing principles. In exergy costing, a cost is associated with each exergy stream. Exergy costing involves cost balances usually formulated for each component separately. For a component receiving a heat transfer and generating power, cost balance equation may be written as [2]:

$$\dot{C}_{e,k} - \dot{C}_{w,k} - \dot{C}_{q,k} + \dot{C}_{i,k} - \dot{Z}_k = 0 \quad (7)$$

where the variable \dot{C} denoted a cost rate associated with an exergy stream and the variable \dot{Z} represents non-exergy-related costs which is calculated by economic analysis.

The formulations of cost balance for each component and the required auxiliary equations are:

– air compressor

$$\dot{C}_2 - \dot{C}_1 - \dot{C}_9 - \dot{Z}_{ac} = 0 \quad (8)$$

where the subscript 9 denotes the power input to the compressor.

– air preheater

$$\dot{C}_3 - \dot{C}_7 - \dot{C}_2 - \dot{C}_6 - \dot{Z}_{aph} = 0 \quad (9)$$

$$\frac{\dot{C}_6}{\dot{E}_6} - \frac{\dot{C}_7}{\dot{E}_7} = 0 \quad (10)$$

– combustion chamber

$$\dot{C}_5 - \dot{C}_3 - \dot{C}_4 - \dot{Z}_{cc} = 0 \quad (11)$$

– gas turbine

$$\dot{C}_6 - \dot{C}_9 - \dot{C}_8 - \dot{C}_5 - \dot{Z}_{gt} = 0 \quad (12)$$

$$\frac{\dot{C}_5}{\dot{E}_5} = \frac{\dot{C}_6}{\dot{E}_6} \quad (13)$$

where the subscript 8 denotes the net power generated by the turbine. Auxiliary eq. (10) and (13) are written assuming the same unit cost of incoming and outgoing fuel exergy streams.

The cost of the fuel stream to the system (\dot{C}_4) is taken as 0.1 \$ per kg and a zero unit cost is assumed for air entering the air compressor:

$$\dot{C}_4 = 30672 \text{ $ per hour} \quad (14)$$

$$\dot{C}_1 = 0 \quad (15)$$

Additional auxiliary equation is formulated assuming the same unit cost of exergy for the net power exported from the system and power input to the compressor:

$$\frac{\dot{C}_8}{\dot{W}_{\text{net}}} = \frac{\dot{C}_9}{\dot{W}_{\text{ac}}} \quad (16)$$

The information of the cost streams help in exergoeconomic evaluation of the system. In exergoeconomic evaluation of thermal systems certain quantities, known as exergoeconomic variables, play an important role. These are the average unit cost of fuel ($c_{F,k}$), average unit cost of product ($c_{P,k}$), the cost rate of exergy destruction ($\dot{C}_{D,k}$), and the exergoeconomic factor (f_k).

Mathematically, these are expressed as [2]:

$$c_{F,k} = \frac{\dot{C}_{F,k}}{\dot{E}_{F,k}} \quad (17)$$

$$c_{P,k} = \frac{\dot{C}_{P,k}}{\dot{E}_{P,k}} \quad (18)$$

$$\dot{C}_{D,k} = c_{F,k} \dot{E}_{D,k} \quad (19)$$

$$f_k = \frac{\dot{Z}_k}{\dot{Z}_k} \frac{\dot{Z}_k}{\dot{C}_{D,k}} \quad (20)$$

Exergoeconomic analysis and evaluation

Table 1 shows properties and exergy flow rates at various state points shown in fig. 1. These flow rates were calculated based on the values of measured properties such as pressure, temperature and mass flow rate at various points in the gas turbine power plant sited in Mazandaran.

Table 1. State properties and exergy streams of the system corresponding to fig. 1 at rated conditions

State	\dot{m} [kgs ⁻¹]	T [K]	P [bar]	E^T [MW]	E^P [MW]	E^{PH} [MW]	E^{CH} [MW]	E^{tot} [MW]
1	510	298.15	1.013	0.00	0.00	0.00	0.00	0.00
2	510	630.16	10.404	58.68	101.63	160.32	0.00	160.32
3	510	781.61	9.98	109.32	99.85	209.17	0.00	209.17
4	8.52	298.15	30	0.00	4.46	4.46	437.81	442.27
5	518.52	1320.21	30	368.12	100.75	468.87	0.00	468.87
6	518.52	832.09	1.07	138.55	2.66	141.21	0.00	141.21
7	518.52	669.67	1.03	76.21	0.83	77.04	0.00	77.04

Solving the linear system of eqs. (8)-(16), the cost rates of the unknown streams of the system are obtained. Results are shown in tab. 2. For this system, the exergy costing method gave 5.253 \$G per J for the product electricity.

Table 2. Levelized cost rates and average costs per unit of exergy at various state points

State points	\dot{C} [\$h ⁻¹]	C [\$GJ ⁻¹]	c [\$kW ⁻¹ h ⁻¹]
1	0.000	0	0
2	3642.663	6.311	0.022721
3	4840.778	6.428	0.023142
4	3067.252	1.926	0.006935
5	7925.711	4.695	0.016904
6	2387.023	4.695	0.016904
7	1302.380	4.695	0.016904
8	2658.907	5.253	0.018912
9	3215.233	5.253	0.018912
9	3215.233	5.253	0.018912

The exergoeconomic variables calculated for each component of the power plant for 100% load condition are summarized in tab. 3.

The components having the highest value of the sum of $\dot{Z}_k + C_{D,k}$ are the most important components from the exergoeconomic viewpoint. The combustion chamber has the highest value of $\dot{Z}_k + C_{D,k}$ and low value of exergoeconomic factor f , and this suggests that the cost rate of exergy destruction dominates. Hence, the component efficiency should be improved by increasing the capital investment. This can be achieved by increasing the combustion temperature T_5 . The maximum temperature of the combustion

Table 3. Exergoeconomic parameters of the gas turbine components

Component	C_p [\$GJ ⁻¹]	C_F [\$GJ ⁻¹]	\dot{E}_D [MW]	\dot{C}_D [\$h ⁻¹]	\dot{Z} [\$h ⁻¹]	$\dot{C}_D + \dot{Z}$ [\$h ⁻¹]	f [%]
AC	6.31	5.25	9.68	183.20	427.42	610.63	69.99
APH	6.81	4.69	15.30	258.77	113.47	372.24	30.48
CC	4.69	3.37	182.58	2216.32	17.732	2234.05	0.79
GT	5.25	4.69	17.06	288.41	335.45	623.87	53.76

chamber, however, is limited due to the metallurgical conditions. A relatively high value of the exergoeconomic factor in the air compressor suggests a reduction in the investment cost of this component. This may be achieved by reducing the pressure ratio and the isentropic efficiency. In the case of gas turbine, the exergy destruction and investment cost are almost equal. The system performance may be improved by increasing the investment cost of this component. Capital investment of the gas turbine depend on temperature T_5 , pressure ratio P_2/P_1 , and isentropic efficiency η . To increase the capital investment \dot{Z} , we should consider an increase in the value of at least one of these variables.

Genetic algorithms

A genetic algorithm (GA) is a search technique used in computing to find exact or approximate solutions to optimization and search problems [24]. This method is a particular class of evolutionary algorithms (EA) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover [25]. In nature, weak and unfit species within their environment are faced with extinction by natural selection. The strong ones have greater opportunity to pass their genes to future generations via reproduction. In the long run, species carrying the correct combination in their genes become dominant in their population. Sometimes, during the slow process of evolution, random changes may occur in genes. If these changes provide additional advantages in the challenge for survival, new species evolve from the old ones and unsuccessful changes are eliminated by natural selection [24]. In GA terminology, a solution vector $x \in X$ is called an individual or a chromosome and chromosomes are made of discrete units called genes. Each gene controls one or more features of the chromosome. In the original implementation of GA by Holland, genes are assumed to be binary digits [25]. In later implementations, more varied gene types have been introduced. Normally, a chromosome corresponds to a unique solution x in the solution space. This requires a mapping mechanism between the solution space and the chromosomes. This mapping is called an encoding. In fact GA works on the encoding of a problem, not on the problem itself. GA operates with a collection of chromosomes, called a population. The population is normally randomly initialized. As the search evolves, the population includes fitter and fitter solutions, and eventually it converges, meaning that it is dominated by a single solution. Holland also presented a proof of convergence (the schema theorem) to the global optimum where chromosomes are binary vectors. GA uses two operators to generate new solutions from existing ones: crossover and mutation. The crossover operator is the most important operator of GA. In crossover, generally two chromosomes, called parents, are combined together to form new chromosomes, called offspring. The parents are selected among existing chromosomes in the population with preference towards fitness so that offspring is expected to inherit good genes which make the parents fitter. By iteratively applying the crossover operator, genes of good chromosomes are expected to appear more frequently in the population, eventually leading to convergence to an overall good solution. The mutation operator introduces random changes into characteristics of chromosomes. In typical GA implementations, the mutation rate (probability of changing the properties of a gene) is very small and depends on the length of the chromosome. Therefore, the new chromosome produced by mutation will not be very different from the original one. As discussed earlier, crossover leads the population to converge by making the chromosomes in the population alike. Mutation reintroduces genetic diversity back into the population and assists the search escape from local optima. Reproduction involves selection of chromosomes for the next generation. In the most general

case, the fitness of an individual determines the probability of its survival for the next generation. Proportional selection, ranking, and tournament selection are the most popular selection procedures. The procedure of a generic GA [24] is given as:

Step 1: Set $t = 1$. Randomly generate N solutions to form the first population, P_1 . Evaluate the fitness of solutions in P_1 .

Step 2: Crossover: Generate an offspring population Q_t as:

2.1. Choose two solutions x and y from P_t based on the fitness values.

2.2. Using a crossover operator, generate offspring and add them to Q_t .

Step 3: Mutation: Mutate each solution $x \in Q_t$ with a predefined mutation rate.

Step 4: Fitness assignment: Evaluate and assign a fitness value to each solution $x \in Q_t$ based on its objective function value and infeasibility.

Step 5: Selection: Select N solutions from Q_t based on their fitness and copy them to P_{t+1} .

Step 6: If the stopping criterion is satisfied, terminate the search and return to the current population, else, set $t = t + 1$ go to Step 2.

Definition of the objectives and decision variables for optimization using GA

In general, a thermal system requires two conflicting objectives: one being increase in exergetic efficiency and the other is decrease in product cost, to be satisfied simultaneously. The first objective is governed by thermodynamic requirements and the second by economic constraints. Therefore, objective function should be defined in such a way that the optimization satisfies both requirements. For that, the optimization problem should be formulated as a minimization or maximization problem. The exergoeconomic analysis gives a clear picture about the costs related to the exergy destruction, exergy losses, *etc.* The maximization of exergetic efficiency means minimization of exergy destruction costs and exergy loss costs. Thus, the objective function becomes a minimization problem. The objective functions for this problem is defined as to minimize a total cost function $C_{P,tot}$ and maximize an exergetic efficiency which can be modeled as:

$$\dot{C}_{P,tot} = \dot{C}_{F,tot} + \sum \dot{Z}_k \quad (21)$$

$$\varepsilon = \frac{\dot{W}_{net}}{\dot{m}_4 e_4} \quad (22)$$

In this optimization, compressor pressure ratio, compressor isentropic efficiency, turbine isentropic efficiency, combustion products temperature, air mass flow rate, and fuel mass flow rate are taken as decision variables.

Results and discussion

In this work, the initial sample size of population of parent individuals, the scaling factor and the maximum number of offspring generations, are taken as 1000, 0.02, and 100, respectively. The admissible ranges of the variables considered for the co-generation system are: $8 \leq r_p \leq 16$, $0.75 \leq \eta_{st} \leq 0.92$, $0.75 \leq \eta_{sc} \leq 0.8$, and $1400 \leq T_5 \leq 1600$. The decision variables are generated randomly within the admissible range mentioned above. The plant life is considered to be 15 years and the interest rate is 17%.

The exergoeconomic parameters for each of the components of the gas turbine system for the optimum operating conditions are summarized in tab. 4. As it is shown, the exergoeconomic factor is decreased to 54.88 from 69.99 for the compressor. This is in accordance with the exergoeconomic evaluation presented in the previous section. It is observed that the exergoeconomic factor of all other components has increased.

Table 4. Exergoeconomic parameters of the system for the optimum case

Plant components	c_p [\$GJ ⁻¹]	c_F [\$GJ ⁻¹]	\dot{E}_D [MW]	\dot{C}_D [\$h ⁻¹]	\dot{Z} [\$h ⁻¹]	$\dot{C}_D \dot{Z}$ [\$h ⁻¹]	f [%]
AC	5.49	4.73	11.16	190.18	231.34	421.53	54.88
APH	5.77	7.25	8.40	219.28	108.52	327.80	33.10
CC	4.07	3.14	143.04	1616.92	41.27	1658.19	2.48
GT	4.73	3.49	30.35	381.43	590.75	972.18	60.76

The cost of the streams in the base case and optimum case are given in tab. 5. Unit cost of electricity produced is reduced from 5.253 \$/GJ in the base case to 4.739 \$/GJ in the optimum case.

The decision variables for the base case and optimum case are given in tab. 6. The optimum air compressor pressure ratio r_p , is 11.9, the air compressor efficiency is 81.3, the exit temperature of the combustion chamber T_3 , is 1481 K, the gas turbine efficiency is 90.1%, inlet air mass flow rate is 425 kg/s, and fuel mass flow rate is 8.05 kg/s.

The comparative results of the base case and the optimum case are given in tab. 7. It is observed that the exergetic efficiency is increased from about 31.79% to 37.39%. In the optimized system the capital investment has increased from 893.54 to 971.88 \$/h while the exergy destruction has decreased from 224.63 to 192.95 MW and the product cost is decreased by 9.78%. The decrease in product cost can be attributed to higher savings in exergy destruction and exergy loss. This is achieved, however, with 8.73% increase in capital investment.

Table 5. Cost of the streams in the system

State points	Base case		Optimum case	
	\dot{C} [\$h ⁻¹]	c [\$GJ ⁻¹]	\dot{C} [\$h ⁻¹]	\$GJ ⁻¹
1	0	0	0	0
2	3642.66	6.311	2974.37	5.494
3	4840.77	6.428	3954.03	5.56
4	3067.25	1.926	2851.25	1.926
5	7925.71	4.695	6836.54	4.078
6	2387.02	4.695	2753.02	5.434
7	1302.38	4.695	1185.07	4.075
8	2658.90	5.253	2544.09	4.739
9	3215.27	5.253	2753.02	4.739

Table 6. Comparison of the decisions variables for optimum and base case

Properties	Base case	Optimum case
Compressor pressure ratio	10.26	11.9
Compressor isentropic efficiency [%]	85	81.3
Turbine isentropic efficiency [%]	88	90.1
Combustion products temperature [K]	1320	1481
Air mass flow rate [kgs ⁻¹]	510	425
Fuel mass flow rate [kgs ⁻¹]	8.52	8.05

Table 7. Comparative results of the optimum and the base gas turbine system

Properties	Base case	Optimum case	Variation [%]
Fuel cost rate [$\$/\text{h}^{-1}$]	3067.2	2851.2	-7.04
Total product cost rate [$\$/\text{h}^{-1}$]	2658.90	2544.09	-4.26
Unit cost of product [$\$/\text{GJ}^{-1}$]	5.253	4.739	-9.78
Exergetic efficiency [%]	31.788	37.39	17.6
Exergy destruction [MW]	224.63	192.95	-14.10
Exergy destruction cost [$\$/\text{h}^{-1}$]	2946.75	2407.81	-18.28
Total capital investment [$\$/\text{h}^{-1}$]	893.5	971.88	8.77

Conclusions

Combining the second law of thermodynamics with economics *i. e.* thermoeconomics using availability of energy *i. e.* exergy for cost purposes provides a powerful tool for systematic study and optimization of complex energy systems. Optimization provides the field of science, engineering, and business, which is concerned with finding the best system among the entire set by efficient quantitative methods. Thermoeconomic optimization considers how the capital investment in one part of the system affects other parts of the system. The optimization of energy system design consists of modifying the system structure and component design parameters according to one or more specified design objectives. In this paper, exergoeconomic optimization and analysis has been performed for a 140 MW gas turbine power plant. The two objectives are involved in the optimization process: thermodynamic (*e. g.*, maximum efficiency and minimum fuel consumption), economic (*e. g.*, minimum cost per unit of time and maximum profit per unit of production). The results indicate that in the optimized system, the unit cost of product has decreased from 5.25 $\$/\text{GJ}$ to 4.73 $\$/\text{GJ}$, however with 8.77% increase in capital investment, while the exergy destruction cost has decreased from 2947 $\$/\text{h}$ to 2407 $\$/\text{h}$. Also the exergetic efficiency is increased by 17.6%. Also the results show that the optimum case will achieved in $r_p = 11.9$, $\eta_{sc} = 81.3\%$, $\eta_{st} = 90.1\%$, and $T_5 = 1481$ K, respectively.

Acknowledgement

The authors wish to thank the reviewers for their constructive and helpful comments.

Nomenclature

\dot{C}	– cost rate associated with exergy estream, [$\$/\text{h}^{-1}$]	i	– interest rate, [%]
\dot{C}_D	– cost rate associated with exergy destruction, [$\$/\text{h}^{-1}$]	\dot{m}_a	– mass flow rate of gas, [kgs^{-1}]
c	– cost per exergy unit, [$\$/\text{GJ}^{-1}$]	\dot{m}_g	– mass flow rate of air [kgs^{-1}]
E	– rate of exergy flow [MW]	P	– pressure [bar]
E_D	– rate of exergy destruction, [MW]	P_0	– ambient pressure, [bar]
f	– exergoeconomic factor	PEC	– purchased-equipment cost, [\\$]
h	– enthalpy, [$\text{kJ}^{-1}\text{kg}^{-1}$]	r_p	– compressor pressure ratio, [-]
		T	– temperature, [K]
		T_0	– ambient temperature, [K]

ΔT_{lm} – mean logarithmic temperature difference, [K]
 \dot{W} – power, [MW]
 \dot{Z} – capital investment cost rate, [$\$/h$]
 \dot{Z}_k – capital cost rate of unit k, [$\$/h$]

Greek letters

ε – exergetic efficiency, [%]
 ϕ_k – maintenance factor
 η_{sc} – isentropic compressor efficiency, [%]
 h_{st} – isentropic turbine efficiency, [%]

Subscripts

F – fuel
i – in
P – product
1, 2, ..., 9 – state points

Superscripts

CH – chemical

P – mechanical
PH – physical
n – time period
T – thermal

Acronyms

AC – air compressor
APH – air preheater
CC – combustion chamber
CRF – capital recovery factor
EA – evolutionary algorithms
GA – genetic algorithms
GT – gas turbine
K – kth unite
P_t – rth population
PWF – present worth factor
Q_t – offspring population
SV – salvage value
X – solution vector

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