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On the optimization of energy systems: Results utilization in the design process

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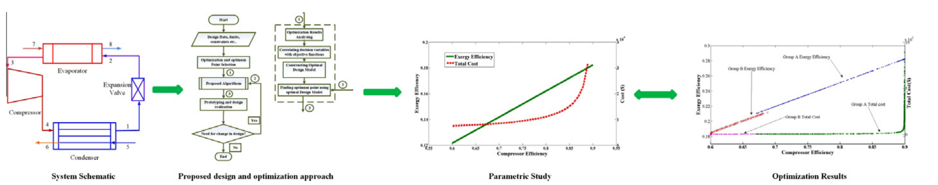
HIGHLIGHTS

- To propose a new method to show the significant of the optimization results and utilization.
- To perform the parametric study of the system.
- To apply a multi-objective optimization based on genetic algorithm.
- To demonstrated the optimum design correlations for all design parameters.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper proposes a new methodology to provide a flexible optimum design tool for the multi-objective optimization of energy systems. There are many articles published on the optimization of energy systems, which use a multi-objective evolutionary algorithm for different cases. However a general method for optimization results utilization in design process is not presented to the authors' knowledge and usually equilibrium point concept is used to select the optimal solution. Here a new method is proposed to improve the optimization results utilization in the design process. This method is applied on a simple energy system to consider the correlations between the design parameter and objective functions. The proposed method is flexible and easy to implement in any design problem. Results provide a neat process of optimum design includes cost limited maximum efficiency and components parameters selection like the condenser pressure and sub cool and superheat degrees. Results also show that compressor efficiency is the most powerful parameter in the case, which has the most significance effects on the optimization results.

1. Introduction

As one of the main crucial items in our daily life is the depletion of non-renewable energy, people's awareness about environmental pollution has increased. Technology policies are one of the options available for the reduction of carbon emissions and the usage of energy [1,2]. Most utility systems in current industrial plants are fossil fuel-fired systems. In fact, fossil fuel resources deplete day by day, and they will finish soon [3]. The fluctuations of the oil price affect the economy of most countries. Indeed, environmental problems created by the increasing rate of fossil fuel utilization threaten the very life of humankind. Therefore, utilizing energy in an effective way and improving energy systems should be prioritized [4,5]. Since 1960s and 1970s energy resource crises and the environmental impacts of human activities have attracted strong attention. Energy resources in the market are becoming fewer and fetching higher prices as globalization progresses. This is due to several reasons, such as the growth in the global economy, the depletion of energy resources and the environmental impacts of energy production [6–8]. Besides efficiencies, the economic issue is also important in the evaluation of energy technologies, energy conversion devices and the costs of energy systems. Some

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Nomenclature

1, 2, 3, ...	states of working fluid
$\dot{Ex}_7$	exergy flow rate (J kg^{-1})
h	specific enthalpy (J kg^{-1})
T	temperature (K)
$\dot{W}$	specific work (J kg^{-1})
P	pressure (kPa)
Z	cost ($)
Q	heat (kW)

Greek letters

η	efficiency (%)
Δ	rate of change
ξ	effectiveness

Subscripts

ex	exergy
sup	superheat
eV	evaporator
co	condenser
is	isentropic
com	compressor

researchers [9–11] have suggested several methods to show that costs are better shared among outputs based on energy. Therefore, industries are encouraged to revise their technologies and use more green options (such as utilization of renewable and sustainable energy and alternative fuel) [12] and also highly efficient cycles with lower cost. One of the main ways to revise and improve current energy systems is the optimization of the systems and the utilization of the optimum variable in a new plan or the revision of the current variable. Optimization finds the most suitable value for a function within a given domain. On the other side, multi-objective optimization means optimizing several objectives simultaneously, with various numbers of inequality or equality constraints. Recently powerful computers are equipped with several methods which can do the optimization. To carry out an optimization, some elements of optimization formulation need to be explained. These elements include system boundaries, optimization criteria, variables, and mathematical model. Therefore, to optimize the efficiency and cost effectiveness and lessen the environmental impact of such plants, it is important to determine the locations, types and magnitudes of true inefficiencies (irreversibilities) [13–17]. To improve the application efficiency, various energy systems are studied. In this regard, there have been various studies on optimization, which have mainly been associated with cogeneration heat and power (CHP), gas turbines, steam turbines, combined cycle power plants and so on [18–21]. In most of these studies, the scientists have tried to improve the energy systems from different aspects, such as efficiency, the economy and the environmental footprint [22–25]. But a clear link between the optimization results is not proposed to the best of authors' knowledge. Hence, a new methodology to provide a scientific approach for using results in the design procedure is extremely important.

Hua and Cho [26] proposed a large number of deterministic and stochastic optimization models to study a combined cooling, heating and power (CCHP) system. They optimize a CCHP with multiple objectives, such as primary energy consumption and minimizing the operational cost and carbon dioxide emissions, considering the reliability of the CCHP operation strategy for different climate conditions based on operational cost. Results show how the incentive values for primary energy consumption and carbon dioxide emissions reduction can be effectively determined using the proposed model for different climate locations. Mohamed et al. [27] investigate the economic viability of small-scale, multi-generation systems including combined cooling, heating and power and combined heat and power along with conventional heating and cooling systems. Results determined the cost optimal solutions for a net zero-energy office building with minimum life-cycle costs by using photovoltaic panel system yields. Ganjeh Kaviri et al. [23] optimized a combined cycle power plant with three main objective functions. To assess the effect of each design parameter on the objective functions, a parametric study and a sensitivity analysis were conducted and discussed in detail. The output optimum results were compared to the basic operation data. The results show that the optimum emission-cost frontier trend matches with the emission-efficiency trend. Comparing the plant operating data and the optimized data shows that the heat recovery steam generator and the duct burner are more sensitive to the optimization and that this is mainly due to the lower cost per improvement. In addition, by using the optimum values, exergy efficiency was increased to around 6% while CO_2 emission was reduced by 5.63%. The variation in the cost was less than a percent due the fact that a cost constraint was implemented. Suresh et al. [28] performed an analysis of advanced power plants on the basis of high ash coal. They suggested the best power plant configuration based energy, exergy and environmental analysis for a coal based thermal power plant in India. They also estimated the environmental impact of the power plant in terms of CO_2, SO_x and NO_x emissions. Results showed that, by using high ash Indian coal under Indian climatic conditions, the maximum possible plant energy efficiency is about 42.3%. Braslavsky et al. [29] investigated the optimal options for distributed energy resource technologies to reduce greenhouse gas emissions in a shopping center. They indicated the carbon reduction of the shopping center by applying a multi-optimization method using the distributed energy resources customer adoption model (DER-CAM) tool. They showed, by investigating a combined cooling, heat and power technology, the annual energy costs and carbon dioxide-equivalent emissions reduced by 8.5% and 29.6% respectively. Ehyaei and Mozafari [30] analyzed the optimization of a micro gas turbine by exergy and economic and environmental analysis employed for combined heat and power production. They optimized a system by using energy, economics and environmental analysis to meet the electrical, heating and cooling loads of a building. They indicated that the initial investment is a considerable portion of the electricity cost. Results also showed that, for an annual interest rate of 10%, the portion ranges between 31% and 40% depending on system design configurations and that lower interest rates resulted in the smaller portions. Sanaye and Hajabdollah [31] presented the thermal modeling and optimal design of compact heat exchangers. They selected six design parameters and applied multi-objective optimization to obtain the maximum effectiveness and the minimum total annual cost.

In the mentioned previous studies, multi objective optimization is used to find the optimum point. Not a general method for obtaining optimum point has been presented up to now. In addition there is no a flexible approach in which design point variations due to