Renewable and Sustainable Energy Reviews 67 (2017) 507–519

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Exergoeconomic and exergoenvironmental analyses of an integrated solar combined cycle system

Eduardo José Cidade Cavalcanti

Department of Mechanical Engineering, Federal University of Rio Grande do Norte, 59072-970 Natal/RN, Brazil

ARTICLE INFO

Article history:
Received 4 December 2014
Received in revised form
4 January 2016
Accepted 7 September 2016

Keywords:
Exergoenvironmental analysis
Exergoeconomic analysis
Combined cycle
Parabolic trough solar
Eco-indicator 99

ABSTRACT

The exergoeconomic and exergoenvironmental analysis of cogenerative system that combine a gas/steam turbine system and a solar field have been performed. The model is developed in order to produce around 400 MW of electrical power to investigate the effect of solar collector field in performance of each component. In addition, the exergy destruction, exergetic efficiency, cost rate and environmental impact per exergy unit, cost rate and environmental impact per exergy unit of product and fuel, cost rate and environmental impact rate associated with the exergy destruction, exergoeconomic and exergoenvironmental factor for each component are evaluated. The results reveal that the condenser needs to increase investment costs to increase the total thermodynamic efficiency and it needs to increase its exergetic efficiency to reduce the total environmental impact from an exergoeconomic and exergoenvironmental point of view. The exergoeconomic and exergoenvironmental analysis show that the effects of solar field leads to 4.2% increasing in the net produced electricity; 2.6% increasing in the average cost rate per exergy unit of electricity and −3.8% decreasing average environmental impact per exergy unit of electricity.

Contents

1. Introduction

Electricity is one of the most important goods to ensure the country development. Several techniques try to improve his efficiency with low cost. The cost analysis can be evaluated by Exergoeconomy which combines exergy and engineering economics principles. Researches of exergoeconomic analysis of power system for evaluate the cost rate per exergy unit have been carried out. Some values of electricity cost at simple, combined and trigeneration systems were summarized [1]. The electrical power of cost rate per exergy unit at combined system of gas turbine and steam turbine were accounted to be 13.96 $/GJ and 37.69 $/GJ respectively and its average cost rate was 18.89 $/GJ, by Ref. [2]. In country with high solar irradiation, the solar collector is

Abbreviations: CEP, Condensate extraction pump; H/A, Hierarchist and average perspective according Eco-indicator 99 methodology; HRSG, Heat recovery steam generator; ISCCS, Integrated solar combined cycle system; LCA, Life Cycle Assessment; LHV, Lower heat value; NGCC, Natural gas combined cycle

E-mail address: educanti@gmail.com

http://dx.doi.org/10.1016/j.rser.2016.09.017
1364-0321/

Nomenclature

A	area (m^2)
AC	air compressor
BFP	boiler feed Pump
$\dot{B}$	environmental impact rate (mPts/s)
b	environmental impact per exergy unit (mPts/GJ)
CC	combustor chamber
CCPP	Combined cycle power plant
CEP	Condensate extraction Pump
COLL	Collector
COND	condenser
D	diameter (m)
DEA	deaerator
$\dot{E}$	exergy (kW)
EI	environmental impact
EVA	evaporator
ECO	economizer
f	exergoeconomic factor
f_b	exergoenvironmental factor
FS	safety factor
HP	high pressure
GT	Gas turbine
LP	low pressure
$\dot{m}$	mass flow rate (kg/s)
OILP	oil Pump
p	pressure MPa
r_k	relative cost difference (%)
SH	super heater
SHE	solar Heat Exchanger
ST	steam Turbine
t	thickness (m)
vel	velocity (m/s)
$\dot{Y}$	component-related environmental impact (mPts/h)
Z_T	total cost rate of component ($/h)

Greek letters

ε	exergetic efficiency %
ρ	specific mass kg/m^3
σ	rupturing stress MPa

Subscript

D	destruction
F	fuel
P	product

Superscript

CI	capital investment
CO	construction, including manufacturing, transport and installation
DI	disposal
OM	operation and maintenance

combined with turbine cycle to produce electricity. The parabolic trough solar is utilized at configuration called to integrated solar combined cycle system (ISCCS). An exergoeconomic analysis of ISCCS located in Yazd, Iran was performed [3]. The power plant contained two gas turbines, a steam turbine and solar field. The authors developed a multi-objective optimization in this system. The exergetic efficiency has increased in 3.2% and the product cost rate has decreased in 3.82%.

However, the electrical power should be produced with low cost and low environmental impact. The environmental aspect has started attracting attention due to problems as such as Global warming potential (GWP), ozone depletion potential (ODP) and environmental acidity. The combination of environmental assessment with exergy analysis has been first discussed in the late years 19 [4,5]. The components life cycle has been allocated in the environmental assessment [6,7]. The authors developed the exergoenvironmental analysis considering the materials used for manufacturing the components in LCA. In general, The Life Cycle Assessment (LCA) includes cradle to grave assessment of any process or product. The LCA of components should include the five phases [8]: materials, production processes, transport processes, energy generation processes and disposal scenarios. The exergoeconomics analysis may suggest modifications in the components design as such as to increase the heat exchanger area to increase the heat transfer or to use novel materials for allow higher temperature operation. However, the materials and energy needed for manufacturing a component consume natural resources. In addition, a component may consume energy and other resources and may generate additional pollutants during its operation. Furthermore, after the end of its life a component has to be disposed of, which may again require energy and emit part of its materials into the environment. These life-cycle-related effects of components and the resulting impact on the environment should be taken into account in the system analysis [6]. The authors developed of exergoenvironmental analysis and was conducted a case study of energy conversion system, a high-temperature solid oxide fuel cell integrated with biomass gasification process [6]. This approach was investigated at combined power plant [7]. The environmental impact was splitted into avoidable and unavoidable parts, called advanced analysis. The combustion chamber caused the most of environmental impact within the plant. The environmental impact of plant is mainly influenced by the environmental impact of fuel. An exergoeconomic and exergoenvironmental evaluation of power plants were evaluated [9]. The oxy-fuel plants, a plant with chemical looping combustion (CLC) with near 100% CO_2 capture and two advanced zero emission plants (AZEPs) with 100% and 85% CO_2 capture were compared to a similarly structured reference plant without CO2 capture. They concluded that the three oxy-fuel plants are significantly more expensive, when compared to the reference plant without CO2 capture, resulting in almost double the investment cost. Moreover, they result in an increase in the cost of electricity by a minimum of 23%. However, the overall environmental impact of the oxy-fuel plants is lower by 19–27%. The choice of the best option depends on the results of both the exergoeconomic and the exergoenvironmental analyses. If the environmental impact or monetary cost is of greater importance for the decision-maker, then the evaluation result is different. There is other paper with application of fuel cell, as [10] which considering the stage of material extraction, manufacturing, use, and disposal/recycling at a SOFC (solid-oxide fuel-cell) to generate electricity. The energy mix of a country influences in the environmental impact associated with electricity generation and it varies in time. The energy mix is composed by coal, oil, natural gas, nuclear, hydro-power, wind energy, import and others. The results demonstrated that the more coal is used in a country, the greater the environmental impact for this country. Furthermore, the manufacturing stage and the disposal stage have relatively small contributions to the total environmental impact.

The exergoenvironmental analysis is recent, it useful to take decision in project at environmental point of view. The potential