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Economical considerations about combined cycle power plant control in deregulated markets

Erica Battisti, Giovanni Mercurio Casolino, Federico Rossi, Mario Russo *

Dipartimento di Ingegneria Industriale, Università degli Studi di Cassino, via G. Di Biasio, 43, 03043 Cassino (FR), Italy

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Abstract

Electrical energy markets around the world present various structures, which are evolving to pursue perfect competition. Then, it is essential to choose the best generating cost structure of power plants with respect to present and future market opportunities. In this view, the paper analyzes the economical impact of some technical choices for gas–steam combined cycle power plants. Attention is paid to the effects on the generating cost structure of the various types of combined cycle regulation and of the environmental parameters and constraints. The results for two different plants are reported as examples. Eventually, conclusions are drawn on how such technical features may influence the positioning in the market and the bidding opportunities of the power plant.

Keywords: Electric energy market; Gas–steam combined cycle; Power generation economics

1. Introduction

Deregulation in electric power generation industry is offering companies new opportunities of investment. Gas–steam combined cycle technology is nowadays preferred for both re-conversion of outdated plants and new installations, thanks to its short times of return on investment, limited effects of economies of scale and optimal sizes which are small compared with the market size [1,2].

Deregulation influences not only the choice of the energy conversion technology, but also the analysis that are performed and the optimization criteria that are adopted in the planning and operation of power plants [3]. Then, it is urgent to support the decision making of combined cycle power plant management with adequate tools accounting for both technical and market issues [4].

In this paper attention is focused on the economical impact of some technical choices in terms of structure of generation costs. Some mathematical models, previously presented in [5,6], are briefly recalled and used to analyze the combined cycle power plant features that significantly influence the generation costs. Attention is paid to the effects on the cost structure of the various types of combined cycle regulation and of the environmental parameters and constraints. The results for two different plants are reported as examples. Eventually, conclusions are drawn on how such technical features may influence the positioning and the bidding opportunities of the power plant in a competitive market.

2. Steady-state operation modeling of combined cycle power plants

Combined cycle power plant operation modeling is quite difficult due to the tight interaction between the gas turbine and the steam turbine generating units. In addition, the interaction with the power system influences the generating capability of the units.

The steady-state operation of combined cycle power plants is considered. To account for the dynamic performance, compact models cannot be adopted and detailed simulations are needed. Yet the steady-state modeling is suitable to the present studies.

The models proposed in [5,6] are structured into two subsystems: the thermal one and the electrical one. In practice, the coupling between the two subsystems is represented by the mechanical power that is transferred from the turbines to the synchronous generators. A modular approach is adopted to simplify the numerical solution of the models and to easily account for different plant configurations. In fact, combined

* Corresponding author. Tel.: +39 0776 299 3636; fax: +39 0776 299 3886/3653.
E-mail address: russo@unicas.it (M. Russo).

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cycle power plants present a wide range of design options and configurations with reference to the number of units, the type of Heat Recovery Steam Generator (HRSG), the regulations and the electrical circuits.

Concerning the thermal subsystem, the models are based on the classical thermodynamic equations and take into account the effects of several factors:

i. The gas turbine regulations, which can be performed basically in three ways:
   – acting only on the fuel mass flow to regulate the gas turbine output power (P_{GT});
   – acting on both the fuel mass flow and the compressor Inlet Guide Vanes (IGVs) to regulate both the output power and the inlet gas temperature of the gas turbine;
   – acting on both the fuel mass flow and the IGVs to regulate both the output power and the outlet gas temperature of the gas turbine;
ii. the environmental conditions, such as the ambient air pressure and temperature, the cooling water temperature;
iii. the dependency of the operating conditions of the steam cycle from the ones of the gas cycle by modeling in details the HRSG characteristics (the levels of evaporation pressure, the layout of the heat exchangers, etc.).

In the modular approach each gas turbine and steam turbine section is modeled by some simultaneous equations, a set of assigned external parameters, a set of input variables and a set of inner variables, whose number is equal to the number of equations. Some inner variables are identified as outputs to be used as input variables to other modules.

Combining the models of the gas turbine cycles and of the steam turbine cycles yields the overall thermal model which has some input variables (i.e. the required net output power of each gas turbine), a set of assigned external parameters (i.e. the ambient air temperature and pressure, the cooling water temperature at the condenser inlet) and some output variables (i.e. the net output power of each steam turbine, the fuel mass flow and the cooling water temperature at the condenser outlet).

A modular approach is adopted also for the electrical subsystem modeling. In the steady-state operating conditions classical phasor equations are derived from the equivalent electrical circuit of synchronous generator and step-up transformer. Refer to [5] for more details. The generating unit model has some input variables (i.e. the net output power of the prime mover), a set of assigned external parameters (i.e. the HV busbar voltage amplitude, the excitation voltage and the transformer ratio) and some output variables (i.e. the active and reactive powers injected into the HV busbar).

In [5,6] a software tool has been presented to solve the mathematical models. The tool allows to evaluate the performance, the capability of offering services and the related generation costs of combined cycle power plants. It is developed in an open software CAD environment [7] assuring the following positive features:

i. the program modules are independent;
ii. a library of modules is available so that it is easy to graphically interconnect various modules and account for different plant configurations and layouts;
iii. external algorithms and software packages can be easily interfaced (for example, commercial software packages to model in details some plant components).

3. Technical factors influencing the generation costs

Using the mathematical models and the software tool recalled in the previous paragraph, in the following the performance of the power plant in terms of technical efficiency and of generation costs is analyzed with respect to:

i. the choice of the type of regulation;
ii. the variation of some environmental parameters.

For sake of clarity, numerical results are presented, referring to two study cases. Anyway, the considerations that are drawn are general and not case dependent.

3.1. Study cases

Two combined cycle power plants are considered: a small sized one (about 56 MW) and a large sized one (about 530 MW). The first plant is equipped with a gas turbine, whereas the second plant has two twin gas turbines; both plants are equipped with a HRSG with two levels of evaporation pressure and a steam turbine.

Using the software tool recalled in Section 2, the gas and the steam turbine net mechanical powers, the fuel mass flow and other thermodynamic quantities are evaluated for different operating conditions, types of regulation, environmental parameters and constraints.

The plant global efficiency is obtained from the ratio between the total output power (P) and the heat consumption.

Using a unit price for the gas equal to 0.1653 €/kg, the fuel cost per hour (C_{fuel}) is calculated for the analyzed off rated operating conditions; the fuel cost functions are obtained by numerically interpolating the calculated points with a third order polynomial:

$$C_{fuel}(P) = aP^3 + bP^2 + cP \tag{1}$$

The best values of coefficients 'a', 'b', and 'c' (expressed, respectively, in €/MW^3 h, €/MW^2 h, €/MW h) are evaluated by solving a least squares problem.

On a short-run basis, variable production costs are assumed to be equal to:

$$C_v(P) = C_{fuel}(P) + d = aP^3 + bP^2 + cP + d, \tag{2}$$

where 'd' represents the fixed share of the short-run operating costs (expressed in €/h).

The average variable costs (AC) and the marginal costs (MC) are given by the following functions: