Fuel 209 (2017) 685–693

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Predictive method for low load off-design operation of a lignite fired power plant

Ioannis Avagianos[a,b,*], Konstantinos Atsonios[b], Nikos Nikolopoulos[b], Panagiotis Grammelis[b], Nektarios Polonidis[c], Charalambos Papapavlou[c], Emmanuel Kakaras[a,b]

[a] Laboratory of Steam Boilers and Thermal Plants, Department of Mechanical Engineering, National Technical University of Athens, Athens, Greece
[b] Centre for Research & Technology Hellas/Chemical Process and Energy Resources Institute (CERTH/CPERI), Greece
[c] Public Power Corporation S.A., 30 Chalkokondili Str., GR-104 32 Athens, Greece

ARTICLE INFO

Keywords:
Lignite power plant
Pre-dried lignite
Technical minimum load
Thermodynamic modeling
Aspen Plus

ABSTRACT

The increasing share of renewable energy sources and their stochastic attitude of power production force the conventional fossil fuel thermal plants to operate in a more flexible mode, with rapid load changes (ramp up/down rates) and in lower thermal loads than their current technical minimum. This can be achieved with the use of pre-dried lignite as a supporting fuel, in the place of conventional liquid fuels such as diesel. This study presents a thermodynamic methodology for the prediction of Agios Dimitrios V Greek lignite fired boiler at low power loads; even below the current technical minimum, when pre-dried lignite is employed. The calculations are based on measurement data provided for the current operating thermal loads of 100%, 80% and 60% (current technical minimum). Among the controlling values of critical operational parameters, this model takes into account the thermodynamic properties (pressure, temperature and steam quality) of SH and RH steam, the steam turbine properties, the heat transfer coefficient of the heat exchangers and the fuel combustion specifications. The model of the boiler is developed in Aspen Plus whereas the ST model was built in GateCycle. Furthermore, this house-built model is implemented to estimate the heat transfer coefficients for the theoretical scenario of 35% thermal load operation, which is far below the current technical minimum and no design or measurement data exist for them. Thermodynamic calculations reveal the boiler effective operation of the boiler even at a thermal load of 35% with a quite good overall thermal efficiency. The net efficiency of the theoretical new technical minimum load is 0.9 percentage points higher than the current one. Results of this approach are also compared against corresponding CFD results, with a fairly good accordance.

1. Introduction

The high penetration of Renewable Energy Systems (RES) during the last decades has changed dramatically the approach of power production and management adopted so far [1,2]. The stochastic energy production from PV and wind farms has priority dispatch in most energy markets. This fluctuation of the energy production inserted into the system highly affects the dispatchable energy production from units such as thermal power plants, stipulating for them a new operating scheme. Rapid response in load variations and low load operation are the keystones of the new energy map worldwide [3,4]. For the case of existing pulverized fuel power plants [5], their capability to operate in a flexible mode is vital, while aspects as low operation cost [6] and tackling of high cycling costs [7,8] should be taken into consideration. The units are required to achieve new lower technical minimum loads in order to limit the number of shut-downs/start-ups and warm reserves. In general, the existing pulverized fuel power plants (PF), which have been designed to operate as base load units, nowadays need reforming in order to operate with faster ramp up/down rates and under new thermal loads far below their initial technical minimum. The age of many power plants currently in operation is also an aggravating factor towards flexible operation.

Abbreviations: CCS, carbon capture system; CFD, computational fluid dynamics; CRH, cold reheated steam; ECO, economizer; EVAP, evaporator; FDF, forced draft fan; FGD, flue gas desulphurisation; FW, feed water; HPST, high pressure steam turbine; HRH, hot reaheated steam; IDF, induced draft fan; IPST, intermediate pressure steam turbine; LHV, low heating value; LPST, low pressure steam turbine; LUVO, LuftvorwärmerAir pre-heater; NTU, number of transfer units; OFA, over fire air; PF, pulverized fuel; PP, power plant; RES, renewable energy systems; RGF, recirculation flue gas-; RH, reheater, reheated steam; SH, superheater, superheated steam; ST, steam tubine

* Corresponding author at: 52 Egialias Str., Maroussi, Athens, Greece.
E-mail addresses: avagianos@lignite.gr (I. Avagianos), atsonios@certh.gr (K. Atsonios), n.nikolopoulos@certh.gr (N. Nikolopoulos), grammelis@certh.gr (P. Grammelis), N.Polonidis@dei.com.gr (N. Polonidis), C.Papapavlou@dei.com.gr (C. Papapavlou), ekak@central.ntua.gr (E. Kakaras).

http://dx.doi.org/10.1016/j.fuel.2017.08.042
Received 27 April 2017; Received in revised form 1 August 2017; Accepted 8 August 2017
Available online 26 August 2017
0016-2361/

Among the various solid fossil fuel, lignite has a considerable share in the energy market in several countries because of its relevant low cost, despite of its low heating value. Concerning the lignite fired power plants, their low load operation cannot be easily achieved compared to the hard coal ones, due to the high moisture content of lignite, the high ash content and strong variations in its quality [9–11]. The use of pre-dried lignite so far was suggested as an option for efficiency increase [12–15] through its co-firing with raw lignite. To date, this concept has been examined only for full load operation; however the use of pre-dried lignite as a supporting fuel can significantly contribute to the flexible operation of all PF boilers types, because of its higher reactivity compared to hard coal. Furthermore, the same co-firing concept is considered technically feasible and economically viable for both full and partial load operation [16].

Towards this goal, thermodynamic simulation tools (e.g. Ebsilon, GSE, Gate Cycle, Aspen Plus, APROS, Vali etc.) are employed to enhance the re-design of power plants operation for the whole range of operating loads needed. Numerous steady thermodynamic models have been developed during the last years, not only for the simulation of the boilers themselves but also for the entire thermal plant. Transient thermodynamic modeling of PF boilers [17] and power plants [18–20] is the new state-of-the art in modeling the behavior of a plant under different start-up and load control scenarios. Among the simulation tools, Aspen Plus has been widely used for advanced process schemes, as for example oxy-fuel pulverized fuel combustion and biomass combustion power plant with post CO_2 capture unit [21,22], both for dynamic in time simulations [23,24] as well as for static [13,25–27], but not for elaborated model of pulverized fuel power plants, as the current study presents. Such studies have been developed to include flexibility as a design parameter for new built PPs [28,29]. On the other hand for the case of existing PF power plants, their low-load operation with similar approaches, is investigated from the perspective of a) their integration with CCS units [30,31], b) dispatching scenarios [32] and c) coal consumption [33].

The Aspen Plus software is selected for modeling the boiler as a wide range simulation tool enhancing the modularity of the model. Within the specific tool platform the boiler model can be expanded by adding the turbine island, the cooling system, modeling the whole power plant. Additionally, since the software is capable of thermo-chemical modeling, apart from simulating the combustion of solid fuels, a wide range of additional plants can be incorporated into it such as lignite dryer, flue gas treatment units (e.g. FGD, DeNOx etc.) leading to a fully integrated power plant model. The inter-connection with Simulink supports the modeling of control and electrical system as well.

The majority of the thermodynamic modeling tools have an inventory of all types of heat exchangers available to the developer. In the case of a utility boiler, models incorporate the water wall type heat exchanger, which is used for the simulation of the furnace area, and the cross-flow type, simulating the convective area of the boiler. For the latter heat exchanger type, a variety of methods are applied. Among them, the ε—NTU method [34] is widely used for calculating the heat transfer for a variety of heat exchangers configurations [35] also including any cross-flow type of heat exchangers [36–39]. The prediction of heat exchanger performance in off-design conditions is analyzed when a small deviation occurs around the design point and an analytical solution is provided [40]. To the best of the authors' knowledge, a lack of algebraic solutions for off-design performance for cross-flow heat exchanger is mentioned in the field of power plants, in comparison to numerical proposed solutions [41,42]. The ε-NTU method can be applied for the cross-flow heat exchangers for a more detailed modeling approach.

Scope of this study is to present a thermodynamic methodology for the prediction of Agios Dimitrios V power plant operation at very low thermal loads. The boiler simulations were performed in Aspen Plus and a pre-dried and raw lignite co-firing concept is considered, specifically for the boiler operation at 35% load. The ε-NTU method is used for the cross-flow heat exchangers calculation. Initially the measurement data, available for the three loads, namely 100%, 80% and 60% were used for the calculation of heat transfer coefficients for each cross-flow heat exchanger placed in the convective area of the boiler. Based on these values an exponential fitting curve was built, in order to provide the initial values for the final estimation of the heat transfer coefficient for each heat exchanger, when the Greek power plant is ascertained to operate at the very low thermal load of 35%, following an iterative method. The fitting curve for each heat exchanger cannot provide a single value but an area of values where the heat coefficient lays. The ratio of thermal substitution is set at 25% pre-dried lignite. The simulations aim to verify the technical feasibility of a boiler operation below the technical minimum load. Results derived from thermal calculations are compared against CFD ones.

2. Description of the power plant

The Agios Dimitrios V unit is a subcritical lignite fired power plant

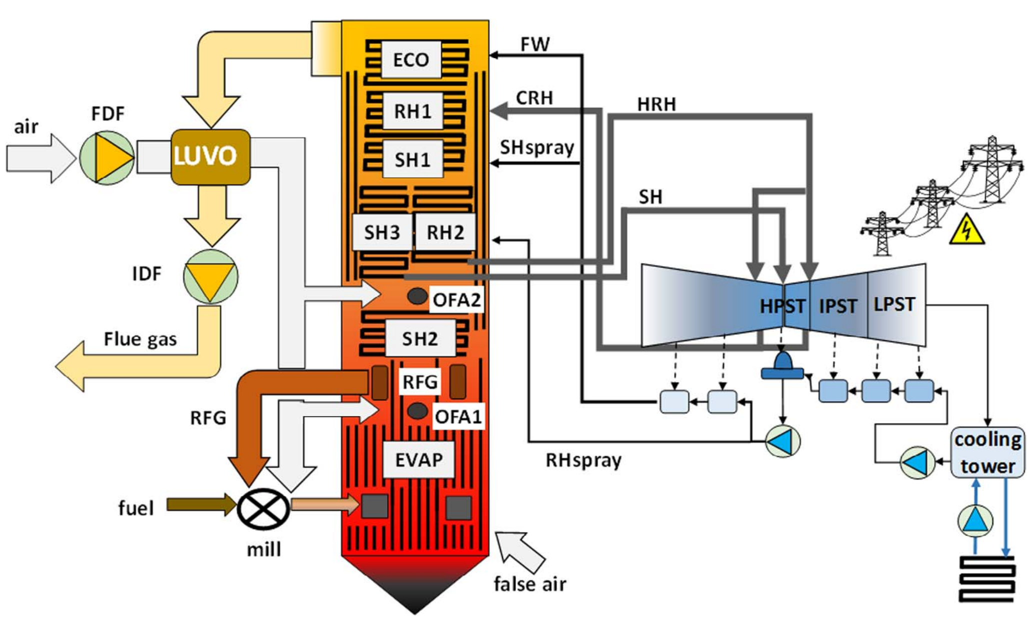

Fig. 1. Sketch of the Agios Dimitrios V power plant.