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Optimization of the boiler start-up taking into account thermal stresses

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ABSTRACT

The objective of the paper is a proposal of a quick start of the steam boiler from the cold state. Fuel consumption rate necessary for heating the evaporator from initial temperature to a predetermined temperature was determined using a transient mathematical model of the boiler evaporator developed in the paper. The model takes into account that at the beginning of the evaporator water is heated without steam generation and then after reaching the saturation temperature the boiling process is started and steam is produced. The mathematical model of the evaporator was verified experimentally. Heating of the evaporator is carried out with a maximum temperature change rate due to the maximum circumferential stress occurring at the edge of the drum–downcomer junction. After determining the optimum fluid temperature the pressure can easily be determined because the pressure of the saturated steam is a function of temperature. Using mathematical models of the evaporator and the combustion chamber the mass flow rate of the fuel ensuring optimum drum heating was calculated. The mass of heavy oil consumed during optimum warm-up of the drum was also calculated.

1. Introduction

Each year is increasing the share of wind energy in electricity production. For example, in the United Kingdom and other European countries, wind energy production has increased several times. Due to variable wind speed fluctuations in electricity production are large. Growing share of windmills and other distributed energy sources is causing major problems in the operation of the entire energy system [1,2]. In order to balance, production and demand for electricity combined cycle power plants are built [3]. Combined gas and steam units are now widely used to supply power to the grid within a short time. Cyclic and transient operation of gas and steam units is taken into account both in the design and operation [2,4]. The use of combined cycle power plants to stabilize the grid operation is very expensive due to the high price of such fuels as gas or oil, which are fired in these units. Because of the increasing share of renewable energy in electricity production also coal-fired plants should be more flexible [1,5]. There is a great demand for reducing start-up and shut-down costs in European thermal power plants. The main reasons for new requirements are a deregulated electricity market where more frequent and shorter start-ups and shut-downs are indispensable in order to satisfy the short-term load requests from the power load dispatcher. A method for optimizing the start-up process presented in the papers [6,7] can be applied to determine the optimum fluid temperature during heating steam boiler drums in fossil power plants. In the paper [1] the use of hot water storage for increasing flexibility of coal-fired power plants are described. The application of thermal storage is inventive and cost-reducing solution. Hot water storage tanks operate in parallel with the low-pressure feedwater heaters and the feedwater tank (Fig. 1). The water is stored when power demand falls and released when demand for power increases. The opportunity of storage permits the plant to increase very fast the power output by discharging the hot water tank. The power output can also be decreased quickly by charging the tank with the hot water. Such changes can be carried out by relatively small storage systems with filling and discharging times smaller than 30 min and are financially attractive. Larger storage systems are advantageous for reduced low load operation and peak load generation. Charging the storage tanks during low load reduces the minimum power output of the plant. It contributes to the improvement the economics of low load operations. For high electricity demand and prices, the hot water tanks can be used to increase the output of the power unit in a faster way than by increasing fuel mass flow rate. The thermal

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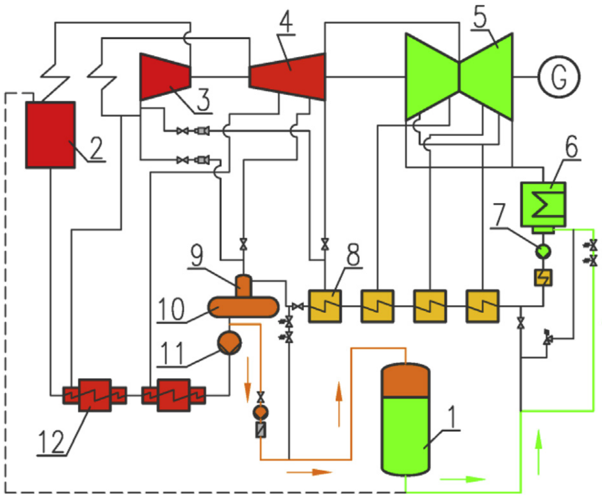

Fig. 1. Output power reduction by charging the hot water storage tank during times of low electricity prices, 1 – hot water storage tank, 2 – boiler, 3 – high pressure turbine, 4 – intermediate pressure turbine, 5 – low pressure turbine, 6 – condenser, 7 – condensate pump, 8 – low pressure regenerative water heaters, 9 – deaerator, 10 – feedwater tank, 11 – feedwater pump, 12 – high pressure regenerative water heaters.

storage option is, therefore, also appropriate for primary and secondary frequency control. During intervals of low electricity prices, cold water is heated to the maximum attainable feedwater tank temperature, which usually does not exceed 180 °C. This results in an increase of the turbine power output. When electricity prices rise, the low-pressure feedwater heaters can be bypassed, and the stored hot water is fed into the feedwater tank. Little or no extraction steam is required, for low-pressure regenerative heaters and the power output rises at once. The flexibility improvement is independent of the boiler control system, which must adjust the boiler to the operation with hot water storage tanks.

The hot water storage tank is connected with the pipeline between the feedwater tank (10) and feedwater pump (11). Thus, the hot water storage tank is a pressure vessel operating at variable pressure. Maximum pressure usually does not exceed 2 MPa. The same hot water tank can be used for filling the boiler evaporator with hot water at the initial phase of the boiler start-up from a cold state (Fig. 2). In the papers [6,7] a method for optimum heating of

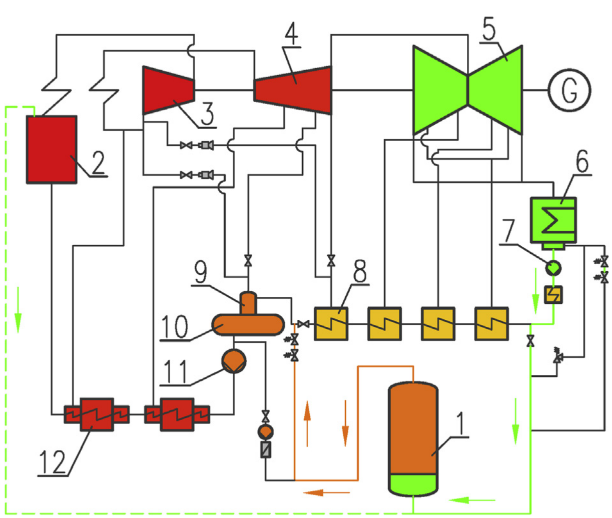

Fig. 2. Filling the boiler evaporator with hot water from hot water storage tank to shorten the start-up of the boiler; designations of power plant components as in Fig. 1.

the boiler drum was proposed, which allows the rapid increase in the fluid temperature. It should be added that if the European standard is used to determine the limit heating rate for the drum, then the circumferential stress on the hole edge in the drum – downcomer junction exceeds the allowable stress which in turn leads to shorter service life of the drum.

2. Start-up of the boiler

Due to the significant start-up losses start-up time of the power block should be as short as possible. Quick connection of the power unit to the electricity grid is beneficial because it allows the sale of electricity to customers. Maximum heating rates of the boiler are limited by thick-walled components such as drums in boilers with natural circulation or water–steam separators in once-through boilers. The superheater and steam attemperator headers, as well as valves and piping tees, may limit allowable rate of the steam temperature rise contributing to a longer start-up time. Permissible heating rates of thick boiler elements are determined by the boiler manufacturers or can be calculated using the European Standard EN-12952-3 [9] or other boiler regulations. Heating rates recommended by manufacturers are usually very small, and start-up of the boiler takes a long time (Fig. 3). Fig. 3 shows the start-up of the power unit with a capacity of 200 MWe from a cold state.

The results shown in Fig. 3 illustrate that the block start-up lasts over 7 h. Larger allowable heating rates of thick-walled components are obtained by performing calculations using the European standard EN-12952-3. However, accurate structural analysis using the finite element method shows that the allowable stresses at the hole edges are exceeded for heating rates calculated according to this standard [7]. A new method was proposed in the papers [7,8,16] for determining the optimum temperature and pressure runs during boiler start-ups, and shutdowns. Unlike the current boiler regulations, the fluid temperature can be raised abruptly at the beginning of the heating process. In the paper, a mathematical model will be presented to simulate transient operation of the boiler evaporator, in particular to simulate boiler start-up from a cold state. A non-linear model consisting of a model of the combustion chamber and evaporator model takes into account that the water is heated first and then an evaporation process begins in the initial phase of the boiler start-up. A mathematical model presented in the paper has been validated experimentally. Then an optimum fluid temperature in the evaporator as a function of time was determined to take into account the stepwise increase in temperature of the fluid at the beginning of the start-up. Using the mathematical model of the evaporator the mass flow rate of the fuel, which provides the optimum heating of the evaporator, was determined. The total fuel consumption, i.e., heavy oil used during the entire process of the boiler evaporator heating was also estimated.

3. Non-linear model of the boiler evaporator

Two phases of the evaporator heating will be considered during the start-up of the boiler from the cold state. In the first phase, after filling the evaporator to the minimum level of water in the drum, fuel oil burners are turned on. Water is heated at atmospheric pressure; i.e. temperature is lower than the saturation temperature. In this period, the heat flow rate supplied to the evaporator is consumed for heating the water without evaporation. The second phase begins when the temperature reaches saturation temperature at ambient pressure, which is equal approximately to 100 °C. In the second phase, the pressure in the drum rises and the water temperature in the evaporator is equal to the saturation