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Primary control reserve of electric power by feedwater flow rate change through an additional economizer – A case study of the thermal power plant "Nikola Tesla B"

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A B S T R A C T

Coal-fired thermal power plants (TPPs) had been generally designed to cover base loads of electricity consumption. Nowadays, they should be flexible to participate in the primary frequency control of electric system, especially because of increased number of wind and solar plants with intermittent electricity production.

In this paper a new method for the primary power control in TPPs is presented, based on the feedwater flow rate changes between the feedwater heaters (FWHs) and an additional high pressure economizer. The achieved primary power control reserve is demonstrated by measurements at the lignite-fired 650 MWe TPP after its retrofit by the installation of the high pressure economizer in parallel with FWHs. In addition, the TPP transient operation during the primary control are simulated and analyzed with the developed thermal-hydraulic model of the steam turbine heat regeneration system. The control reserve of approximately 10 MWe is shown both by measured data and results of numerical simulations. The control reserve is originally provided by the fresh steam throttling in front of the turbine, but this throttling can be reduced by the application of the new method. The rates of change of wall temperatures of FWHs tubes are within allowed limits during the transients.

1. Introduction

An interconnected electric network is an ensemble of mutually connected electric systems in a synchronous operation. Electric systems are connected for safety and economic reasons. In Europe, 36 countries are interconnected in ENTSO-E (European Network of Transmission System Operators for Electricity) system, which is divided in five permanent regional groups based on synchronous areas and two voluntary regional groups (Northern Europe and isolated systems) [1]. ENTSO-E comprises 43 supply zones. A transmission system operator is responsible for each supply zone. A paramount requirement to be fulfilled by an interconnected network is to enable a reliable supply of consumers with reasonably priced and ecologically acceptable electricity at stable grid frequency (for example, 50 Hz in ENTSO-E and 60 Hz in the US and parts of Japan [2]). The supply must also be guaranteed during an imbalance of electricity generation and consumption. An imbalance in electric network occurs due to unforeseen events like a power plant outage, an outage or a connection of larger consumers as well as because of discrepancies between the prognosis and the actual consumption. In addition, disturbances in an electrical network can arise due to generation uncertainties of renewable power units.

The wind and solar power generation stations are outstanding examples of renewable power units which can cause imbalances in an electric network due to their strong relation to the stochastic weather conditions and, in case of solar energy, to the daytime running sunlight. Although fluctuating, these renewable resources

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are in modern energy production systems being implemented to always greater extent due to strengthening environmental awareness. For instance, in 2014 the contribution of solar and wind power units to the gross electricity production was 23% in Spain, 15% in Germany and 12% in Romania [3]. In such systems, the renewable and conventional power plants have to be reconciled. In this regard, conventional power plants will have to be reconfigured in some technical aspects which increase their control ability to perform high power gradients, low minimal loads, frequent run-up and run-down and a high efficiency in partial loads. This is particularly true for coal-fired power plants which response to requests for power changes is not as fast as in case of hydro or gas turbine power plants.

Regarding the electricity generation in general, the data of International Energy Agency [3] show that in most European countries the coal-fired power plants play an important role. For instance, in 2014 the contribution of coal-fired power plants was 82.7% in Poland, 51.1% in Greece, 45.4% in Germany and 44.8% in Bulgaria, to name just a few. In Serbia this contribution is also high−70.15% in 2015 and 68.6% in 2016 [4]. Therefore, either in modern or in traditional energy systems, thermal power plants are indispensable - they have to stay in the network and beyond that they have to be flexible in regard to the control of the electric network.

Generally, the control of an electric network after the occurrence of an imbalance is graded in three levels i.e. the primary, secondary and tertiary power control [5]. The primary control reserve or the so-called spinning reserve is activated automatically as soon as a deviation of electric current frequency in corresponding electric network emerges. The full reserve of the power unit for the primary control should be activated within 15 s−30 s after the instant at which the frequency has reached the prescribed set-point that triggers the primary control. Although the primary control is designed to keep full power at least 15 min, 30 s after its activation, the secondary control is being started. The secondary control is activated by a regional balancing authority that disposes the power of generation units under partial load operation. Finally, the tertiary power control, also known as the minute reserve, should be activated 15 min after the disturbance occurrence by putting into operation some reserve power units, usually gas turbine or pump storage stations.

Imbalance events in an interconnected electric network change the frequency of sinusoidal quantities (voltage and current). In relation to this, a required amount of the primary control reserve of a unit is determined via the so-called static characteristic, which represents the ratio between the rotational speed (proportional to frequency) and turbine power (proportional to the unit electric power). The slope of the static characteristic, known as statism, is defined as [6]:

$$R = -\frac{\frac{f-f_n}{f_n}}{\frac{P-P_n}{P_n}}, \quad (1)$$

where f_n is the nominal frequency, P_n is the unit nominal power and P is the unit power under the frequency f. To ensure the primary control reserve, thermal power plants keep R percent of their power free during the normal operation.

Contemporary policy to introduce substantial amount of renewable energy has raised extensive studies in the domain of flexible operation of thermal power plants. The goal is to ensure a stable operation of different plant subsystems (originally designed for base loads) under conditions of large and frequent variations of operational load due to intermittent nature of power production in renewable units. In the framework of these activities, complex dynamic models of thermal power plants are being developed and transients in a wide range of unit loads are being considered: from the primary control reserve to the conditions of start-up and shut down. These models are important for investigations of power plant dynamics as well as for optimization of control design. A comprehensive survey of available dynamic simulation methods and relevant results published by 2016 is given in the review paper by Alobaid et al., 2016 [7]. Regarding the latest publications, not included in this review paper, we mention the following (note that we do not pretend to give a complete list). In Ref. [8] a 550 MWe supercritical hard coal-fired power plant is modelled and a 50 MWe load jump was simulated as a test case. A dynamical model for the simulation of the start-up process of a sub-critical 500 MWe lignite-fired power plant was presented in Ref. [9]. The authors placed the focus on the evaluation of mechanical and thermal stresses due to temperature gradients during power unit start-ups. In Ref. [10] a dynamic model of a coal-fired power plant was developed based on the nonlinear control strategy. A decoupling compensator for the boiler pressure and superheated steam dynamics was introduced and the nonlinear decoupling was implemented with deadtime compensation for each of the plant subsystems. The model was applied to simulate a linear power decrease from 160 MWe to 115 MWe at a rate of 2% per minute as well as a series of step power changes of 32 MWe at 25 min intervals. The obtained results show that the proposed structure for the power setpoint tracking is superior in comparison to the conventional PID control structure.

Regarding the primary control reserve in coal-fired power plants, various technical solutions are reported in the literature, mainly based on the utilization of available energy stored in thermal power plants. Some of these possible measures for the activation of the stored energy are reported in Ref. [11].

The method traditionally applied for the power increase or power decrease at thermal power plants is the action of control valves at high pressure and intermediate pressure turbines, which throttle the steam flow at the turbine inlet. The disadvantage of this method for the power control is increased fuel consumption and lower economy of operation: 5% throttling in turbine pressure results in an increase in plant heat consumption rate of about 5% as reported in Ref. [11].

Some other possible methods for power control reported in Ref. [11] are: change of the feedwater flow rate (an increase of the flow rate in case of an once-through boiler and a decrease of the flow rate in case of a drum boiler), the switching-off of high pressure feedwater heaters, and the reduction of the steam extraction from turbine stages in cases of controlled steam extraction towards the high pressure feedwater heaters and low pressure condensate heaters. The drawback of these measures is related to the occurrence of fast temperature changes in thick walls of plant components that operate under high temperature and pressure conditions, what leads to a decrease in their lifetime. Nevertheless, these methods have advantages when compared to the traditional one, as reported in Ref. [12]. In this reference the adjustment of power unit load by throttling of the turbine steam extraction was considered. The choice of this method for the power control is supported with the fact that the turbine responses to load changes much faster than the boiler [12]. This configuration is tested for the case of a step power increase of 20 MWe. The results show that the power control by throttling of the turbine extraction gives lower steam pressure fluctuations and better load tracking performance than the traditional one.

A rapid change of turbine power can be achieved by the change of cooling water flow rate and corresponding condenser vacuum as reported in Ref. [13]. In the course of this approach, the condenser cooling water control system is proposed in Ref. [14] and applied to