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The Temperature Time Responses of the Heat Exchanger Equipped by the Protective Control

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Abstract. VITKOVICE POWER ENGINEERING joint-stock company designs and constructs the decentralized flexible energy cogeneration system (FES) with combined Brayton - Rankine cycle which represents a new solution of decentralized cogeneration energy sources. In FES, the heating medium is flue gas generated by combustion of a solid fuel. The heated medium is power gas, which is a gas mixture of air and water steam. Power gas is superheated in the main heat exchanger (MHE) and is led to the gas turbine that drives the asynchronous generator. In this paper, the principle of FES is briefly described. The protective control which prevents the damage of MHE by overheating is discussed. The dynamics of the MHE with respect to dynamics of protective control is presented.

Keywords: control system analysis, distributed parameter systems, gas turbines, heat exchangers, mathematical models, simulation, temperature control

1. INTRODUCTION

Flexible 110MW energy cogeneration system (FES) designed and developed by VITKOVICE POWER ENGINEERING joint-stock company operates with combined Brayton - Rankine cycle. In FES, the heating medium is flue gas generated by combustion of fuel. Heated medium is power gas, which is a gas mixture of air (75 %) and water steam (25 %). Power gas is superheated in the main heat exchanger (MHE) which is the basic part of FES. The very high superheated power gas is led to two gas turbines. One gas turbine drives an 50 MW asynchronous generator, the second powers the compressor.

The protective control protects the heat transfer surfaces of MHE against damage by overheating. Algorithm of the protective control is integrated in the FES control system.

The principle of FES is shown in Fig. 1. The figure shows a combustion chamber *1* which burns the fuel. Walls of the combustion chamber have evaporative pressure water cooling. Water under pressure is supplied by pump *2*. Generated water steam is fed to the front mixer *3*, where is added to atmospheric air supplied to the power circuit by the compressor *4*. Portion of the generated steam is available for the protective control of the MHE *5*, see below. Resulting power gas enters the MHE *5* where is superheated by the flue gas from combustion chamber. The superheated power gas expands in the gas turbines *6* and *7*. The compressor turbine *6* drives the compressor *4*. The generator turbine *7* drives the asynchronous generator *8* that is linked to the 50 Hz electric network. Residual heat that power gas contains after the decompression in the gas turbines is used to generate electricity in a Rankine cycle. The heat exchanger *9* exploits residual heat of flue gas for the preheating of the combustion air. Discharged combustion products are cleaned in the purification plant *10*.

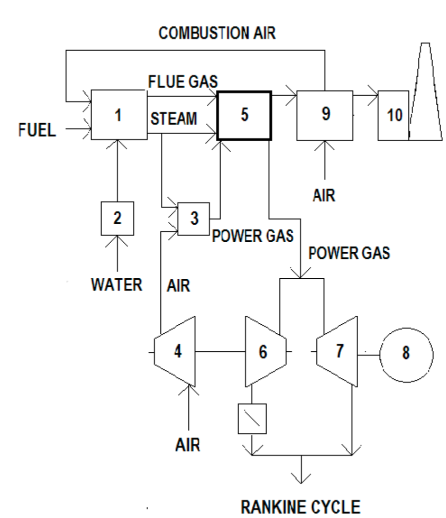

Fig. 1. The principle of FES.

To support the development of FES, VPE built an experimental FES in 2009 – 2013. Mathematical model and some basic experimental information concerning this unit were presented by Pies et al. (2013) and Vitkovice (2010).

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The experimental FES was equipped with a 500 kW generator turbine. It enabled, in addition to the technology program, to set the main principles of FES as a decentralized cogeneration energy source with the possibility of accumulation of electricity.

Good congruence of simulated and experimental results affirmed good quality of the mathematical model. Experimentally were verified the principles of the FES control. From the point of view of control, FES differs from the common cogeneration units in three important control loops. In particular it is the control of the FES output power, the control of the power gas temperature at the input of turbines, and the protective control of the MHE against overheating.

Other parts of FES control system are similar to a conventional steam cogeneration energy sources.

2. SEGMENTATION OF THE MHE

The two FES gas turbines are fed by the superheated power gas directly from the MHE. The turbines are designed for nominal pressure and temperature of the feed gas. In operating conditions, the pressure and in small range also the temperature of power gas varies with the generated power.

For maximum effectiveness, the FES operates with very high temperature of heat carriers. The power gas is heated by the compression to about 240 °C and superheated in the MHE to about 800 °C. The MHE is equipped with standard control functions and emergency control functions. Emergency temperature control acts with period of 5 s. It cools the power gas by injected liquid water. The discussion of emergency control lies beyond the scope of this paper. The standard temperature control at MHE has two goals. The first is the stabilization of the temperature of power gas at the output of the MHE. The second is the protection of the heat transfer surfaces of the MHE against overheating.

The FES controller maintains the temperature of the power gas at the output of the MHE by control of the flow of fuel at the inlet of the FES combustion chamber which subsequently leads to temperature and flow rate change of flue gas at the input of the MHE. This control action has very large time constant of about 6000 s. FES controller can also change the speed of compressor and alter the flow rate and consequently the temperature of the power gas at the input of the MHE. This control action has time constant of about 3000 s. Standard control actions have large time constants and are not sufficient for the protection of the heat transfer surfaces of the MHE against the overheating. This is the goal of protective control.

The overheating of sections of the MHE could result from uneven distributions of flue gas flow rate along the MHE. These temporary anomalies arise at changes of fuel and/or generated power. The time constant of temporary local increase of temperature of the MHE heat transfer surface may be less than 800 s.

MHE is an expensive part of the FES. The protective control is the fast control, which keeps the temperature of the wall of MHE heat transfer surfaces below the specified temperature limits. The limits depend on the materials used for construction of MHE. In this paper, the protective control applied on FES developed by VITKOVICE POWER ENGINEERING joint-stock company is briefly described.

The heat exchanger is a system with distributed parameters. Its dynamics can be characterized by the dominant time constant. The dominant time constant of the FES MHE is about 5000 s.

The protective control is based on technological decomposition of MHE to partly controllable segments. In this paper the MHE divided to five segments is discussed; see Fig. 2. Each of the segments has a dominant time constant of about 1000 s. Segments are connected in series. Cool power gas enters the first segment. The superheated power gas is lead from the fifth segment to turbines.

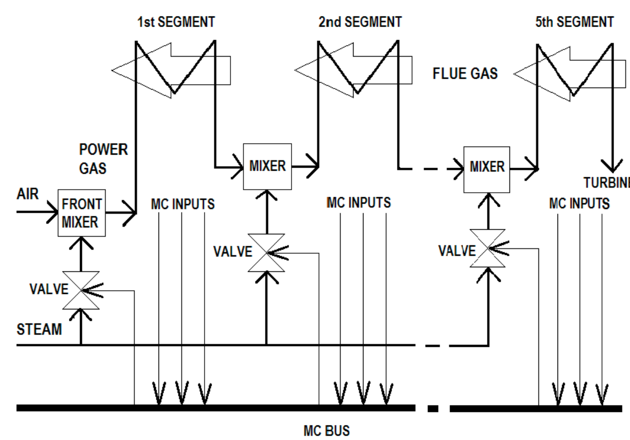

Fig. 2. The five segments of the MHE.

MHE is designed as a counter flow. Hot flue gas enters the fifth segment. The cooled flue gas is lead away from the first segment. Temperature of the wall of the heat transfer surfaces that separate the flue gas and power gas therefore increases from the first segment to the fifth segment. The walls of heat transfer surfaces of the MHE are realized from bundles of thin-walled tubes. Bundles of MHE segments are made from different appropriately chosen steels and alloys which have their own temperature limits. For each segment of MHE is the limit constant. Every segment may be heated below its specific temperature limit.

Protective control of FES maintains temperature heat transfer surfaces of MHE segments under their technological limits. Controller at the inputs of vulnerable segments adds to the power gas cooling steam, lowers their temperature and thus lowers the temperature of the heat transfer surfaces.

FES operates at optimal efficiency when all the cooling steam generated by boiler evaporator is fed into the first segment of MHE. This ideal situation occurs when temperature limits are not exceeded. Temperatures of tubes of the 1st, 2nd, and also 3rd segment are in this state usually deep below their limits.