Automation System for Optimization of Electrical and Thermal Energy Production in Cogenerative Gas Power Plants

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***Abstract*—**The system is made with main distributed components:

- **First Level**: Industrial Computers placed in Control Room (monitors thermal and electrical processes based on the data provided by the second level);

- **Second Level**: PLCs which collects data from process and transmits information on the first level; also takes commands from this level which are further, passed to execution elements from third level;

- **Third Level**: field elements consisting in 3 categories: data collecting elements; data transfer elements from the third level to the second; execution elements which take commands from the second level PLCs and executes them after which transmits the confirmation of execution to them.

The purpose of the automatic functioning is the optimization of the co-generative electrical energy commissioning in the national energy system and the commissioning of thermal energy to the consumers.

The integrated system treats the functioning of all the equipments and devices as a whole: Gas Turbine Units (GTU); MT 20kV Medium Voltage Station (MVS); 0,4 kV Low Voltage Station (LVS); Main Hot Water Boilers (MHW); Auxiliary Hot Water Boilers (AHW); Gas Compressor Unit (GCU); Thermal Agent Circulation Pumping Unit (TPU); Water Treating Station (WTS).

***Keywords*—**Automation System, Cogenerative Power Plant, Control, Monitoring, Real Time.

I. Theoretical Considerations Regarding The Cogenerative TPS

A. Overview

THE concept of co-generation means the combined production of electrical (or mechanical) energy and of thermal energy based on the same primary energy source. The produced mechanical energy can also be used for the operation of auxiliary equipments (for example, compressors and pumps) [4]. The thermal energy can be used for heating, or for cooling. The cooling process is attained thru an absorption unit which operates with hot water, steam or gas at high temperatures. In the process of operating a conventional value power plant, a significant quantity of heat is exhausted in the atmosphere, by some cooling circuits (steam condensers, cooling towers, water coolers from the Diesels / Otto engines), or by residual gases [7]. Most of this heat quantity can be retrieved and used for thermal necessities, therefore increasing the efficiency from 30~50% (the case of a normal power plant) to 80~90% (in case of a cogeneration power plant). Considering total efficiency as a parameter, the classic systems of separated production of thermal and electrical energy get a total efficiency of 58% compared to the cogeneration system which has a value of 85% total efficiency [3]. The systems which were efficient and could use alternative fuels were on demand and more important in the phase of rising prices and of doubt fuel supplying. More than the low prices for used fuels; the cogeneration diminishes the environmental pollution [8]. For these reasons, the governments of Europe, USA and Japan took position in the favor of increasing the implementation of cogeneration [6]. There are three principal forms for encouraging the use of cogeneration: Regulations or exoneration from regulations; Monetary stimulations; Financial support for research and development [1].

The researches, the development and the demonstrative projects created over the last 25 years conducted to a significant enhancement of the technology which become today mature and reliable. Meanwhile, new techniques are in research, for example the combustion cells.

B. Performance Parameters for the Cogeneration Systems

The main parameters indicated in the specialty literature [5] are: the efficiency of the first „engine” (for example, gas turbine, Diesel motor, steam turbine); the electrical efficiency; the thermal efficiency; the total energetic efficiency of the cogeneration system. The heat quality is lowered compared to the one of the electricity and is decreasing with the available temperature. For ex., the heat quality in the case of hot water is reduced compared to the case of steam. Therefore, at the first analysis it could seem that it’s not indicated to sum electricity and heat [12], [13].

C. Actual Cogeneration Technologies

Most of the cogeneration systems can be characterized as topping systems or as bottoming systems. In the topping systems, a high temperature fluid (residual gas, steam) fuels an engine for producing electricity, while the low temperature agent is utilized in thermal processes for heating / cooling the

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extent. In the bottoming systems, the high temperature agent is produced mainly for a process (for example, in a furnace, or a cement oven); after the end of this process, the hot gases are used directly for powering a gas turbine if the pressure is proper, or indirectly for producing steam (in a recuperation boiler), after which is used for powering a generator with steam turbine. For a complete description of these systems one can see [2] and [11]. The temperature ranges for the two system types are presented in Fig. 1:

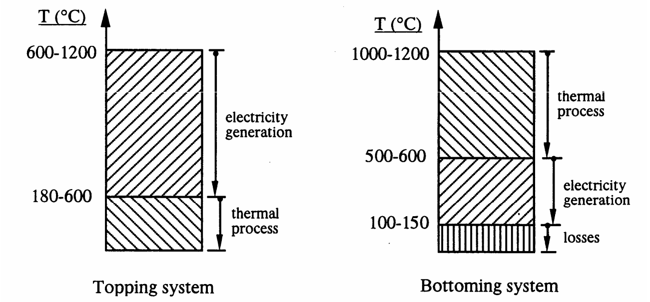

Fig. 1 Temperature ranges for topping and bottoming Cogenerative Systems

II. Functions of an Applied Optimisation System

In order to describe the technological functions of the Cogenerative Gas Power Plant, for exemplifying has been chosen an application made by IPA SA at TPS Bacau, Romania, into 2007 year: Automatic Control and Monitoring System of the unit # 3.

The Automatic Control and Monitoring System is compounded from the following main distributed components:

- **level no. 1**: An industrial computer **IL 43 Siemens** (placed in Control Room) in which is implemented an application program (developed on PCS7 Siemens base program) which monitories thermal and electrical processes from Power Plant based on data delivered via Ethernet (through optical fiber) by level. 2;
- **level no. 2:** PLCs **S7 300 Siemens** (interconnected at level 1 through Ethernet) which collects the data from process using the field elements from level 3 (transducers) and, based on an application program, transmits information to level 1 and receives from this level the commands for level no. 3; these PLCs controls the Power Plant equipments as follow: **Turbine & Generator unit – GTU (U3 CBC01)** (own control supervised via satellite and connected via Ethernet at IPA's PLC: **U3 CBC21**); **Gas Compressor Unit – GCU (U3 CBC11)** (own control supervised via satellite and connected via Ethernet at IPA's PLC: **U3 CBC21**); **Main Hot Water Boiler – HWMB (U3 MBR01)** (controlled and monitorised by IPA's PLC: **U3 CBC21**); **Auxiliary Hot Water Boiler – HWAB (U3 HMA11)** (controlled and monitorised by IPA's PLC: **U3 CBC21**); **Heat Exchangers no. 1, 2, 3 – HE#1, HE#2, HE#3 (U3NDD01, U3NDD01, U3NDD03)** (controlled and monitorised by IPA's PLC: **U3 CBC21**); **Auxiliary Installations (valves, slide valves, pumps, cooling ventilators, etc.)** (controlled and monitored by IPA's PLC: **U3 CBC21**);
- **level no. 3: Fields Elements** as follow: **Transducers** (4-20mA) for pressure, level, flow, temperature, electrical power, etc.; **Data Transfer Elements** (signal cables, PROFIBUS cables, Ethernet cables, NET switch converters, etc.); **Operation Elements**

A. General Description of a Cogenerative Gas System Operation

The control of the electricity generation will be executed by the control unit of the gas turbine unit (GTU) - U3 CBC01. Their key control devices are some special configured PLCs which are operating autonomous to any of the other control devices as the requested set point for the electricity generation is manually settable [10]. Additionally to the manually setting of the requested power generation capacity value by the control devices of the gas turbine unit there is also the possibility of setting the requested power generation capacity value by the overall HMI-monitoring system related to the control unit U3 CBC21. The required fuel (natural) gas for the GTU will be prepared and delivered at a pressure level of some 26.0 bar g by an also autonomous controlled and operating gas compressor unit (GCU). The respective control unit or PLC for the GCU is tagged as U3 CBC11. For this fuel gas provision the gas compressor unit (GCU) is considered to be operated automatically and autonomous by its control unit or PLC-unit U3 CBC11. The operation of the GCU is entirely and exclusively controlled by the PLC-unit U3 CBC11 and is not depending for starting and operating to any other control device / PLC. Nevertheless it is possibly to start the GCU remotely by the PLC-unit U3 CBC21 which is designated for the Hot-Water-System (HW-system) but contains also some superior control duties for the entire plant (unit #3) as some essential signals are exchanged between U3 CBC11 and U3 CBC21. For the heat extraction from the delivered exhaust gas into an hot water system (HW-system) a main HW-boiler is foreseen which is capable of a thermal heat extraction of up to 22 MW_{th} at nominal power generation capacity. To obtain the contractually specified heat generation capacity of 25 MW_{th} an auxiliary HW-boiler with an additional heat generation capacity of 3.25 MW_{th} get established beside the main HW-boiler. Finally the heat extraction out from the exhaust gas of the running gas turbine and its transfer into the secondary circuit HW-network (district heating system of the city of Bacau) get controlled by the PLC-unit U3 CBC21. Furthermore the PLC-unit U3 CBC21 is controlling some auxiliary systems as the instrument air provision units, some building ventilators, an emergency cooling equipment for the primary HW-circuits etc. For the monitoring and remote operation of the new unit #3 two visualization computers or HMI-stations are foreseen and are located in the central control room (CCR) of the power plant of TPS-Bacau. The first HMI-station is exclusively considered for the monitoring and operation of the gas turbine (and is provided by the gas turbine manufacturer Turbomach) as the second HMI-station (with a visualization system of Siemens, type PCS7) is

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considered for the monitoring and visualization of the HW-system, the gas compressor unit (GCU) and all side and auxiliary equipment as well as for some superior operational demands of the entire unit #3 (and is provided by IPA SA). The CCR is located inside the main machinery building of unit #1 inside TPS-Bacau and which is some 300 m away from the location of the new unit #3.

Operation of GTU leads by generation of electricity. Due of the nature of gas turbines in general it is strongly recommended by the manufacturer to run the gas turbine best at rated capacity (100%) or if deviating from full capacity operation to operate it inside a range of minimum 65% up to 100% of unit nominal capacity. Furthermore and as mentioned above it is strongly recommended to lead the operation of the new generation unit #3 by the generation of electricity. According to this electrical generation priority the generation of hot water (HW) is in dependency of the thermal energy content of the exhaust gas delivered by the gas turbine at any operational stage [9]. The set point for the requested capacity of power generation can be inserted manually into the control unit of the GTU–U3 CBC01–at the local screen inside the control compartment of the GTU or at the HMI-station of the GTU (located in the CCR) or at the superior HMI-station (PCS7-type) of the HW-system (also located in the CCR. If the gas turbine is running at any set and automatically controlled capacity the co-generated waste heat out of the exhaust gas shall be extracted consequently at full capacity and transferred into the HW-system and further on into its secondary circuits which are hydraulically linked with the HW-district-network of the city Bacau.

Operation of GTU leads by generation of heat (Hot Water). Though, not advisable at all, the led operation of the gas turbine unit according to the requested heat demand is also considered following a strong request of the operator and future owner of the new unit (CET-Bacau). Therefore an automated program has to be created and programmed inside the PLC-unit U3 CBC21 (which is beside its control tasks towards the heat extraction and HW-systems also designated for superior control duties), which allows the setting of the thermal HW-demand as prior operational set point for the entire gas turbine unit. For the heat demand led operation of the gas turbine unit a respective control loop has to be established inside the PLC-unit U3 CBC21. This control loop shall control the set point for the electrical power generation set point inside U3 CBC01 which is than corresponding to the providing of a respective heat generation according the set point curve, as presented in Fig. 2.

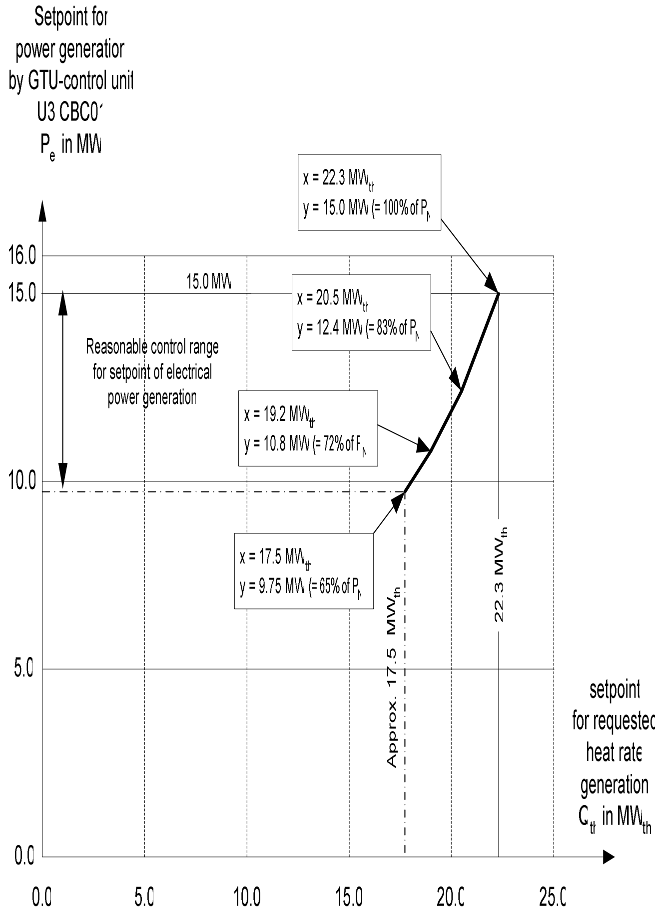

Fig. 2 Thermal and electrical generation capacities

The above stated capacity figure for thermal and electrical generation capacities are varying slightly from the respective nominal figures of the gas turbine and the main boiler; this is caused by the empirical elaborated curve values which are taken during respective operational test sessions.

B. Main Hot Water Boiler U3 MBR01 BB001

The exhaust gas from the GTU is lead into the Main Hot Water (HW) Boiler U3 MBR01 BB001. Depending on the HW-demand by the heating net of the city of Bacau this high temperature exhaust gas flow can be used for heat extraction by the main boiler or if no respective thermal energy demand is given the exhaust gas flow can be bypassed on the main boiler into the exhaust flue gas chimney. For the control of heat extraction a respective pair of inverse to each other acting control gate valves is located at the intake conduct to the boiler as well as in the bypass conduct.

If, for whatever operational reason, the main HW-boiler is completely bypassed - meaning the intake control gate valve is completely closed – there will remain a certain rate of exhaust gas inflow into the main HW-boiler (equal to the leakage share of the control gate valve). The respective leakage rate of the control gate valve is figured by 1% meaning the maximum expected heat intake into the HW-boiler will be up to 220 kW. To prevent any excess temperature at the HW-output of the HW-boiler an emergency cooling system is foreseen.

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If the control valves in the primary circuit(s) of the heat exchangers are in a limited position due of the minimum limit controller from the secondary circuits and the HW-outlet temperature is still decreasing the limit controller U3 NDA01 DT003(2) is intervening and will partly open the HW-control valve at the primary circuit outlet U3 NDD01/02/03 AA050 to increase the heat intake into the heat exchanger (originating from the HW-boiler), as presented in Fig. 3.

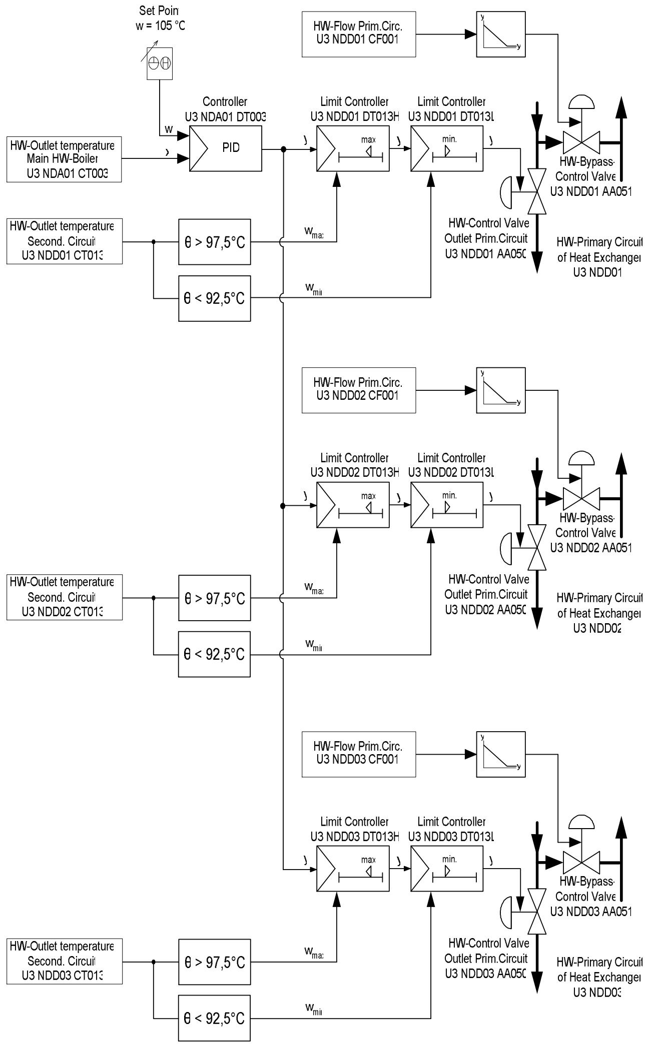

Fig. 3 Temperature control on HE output acting on input

C. Hot Water Heat Exchangers

As presented in Fig. 4, the thermal energy of the generated hot water (HW) from the main HW-boiler – U3 MBR01 BB001 – and in case of maximum thermal demand additionally from the auxiliary HW-boiler – U3 HMA11 BB001 – will be transmitted via a total of 3 units of HW-heat exchangers into the HW-network of the city of Bacau. The rated capacity of each HW-heat exchanger is 12.5 MW_{th}. Corresponding to the maximum generated HW-heat of 25.0 MW_{th} – by the main HW-boiler plus the auxiliary boiler – the operation of the three HW-heat exchangers will be in a 2+1 – redundancy configuration (equal to 2 x 50% of normal capacity plus 50% redundant capacity).

According to the redundancy configuration of 2+1 it is foreseen:

a) to operate only one of the three HW-heat exchanger or
b) maximum two of the three units

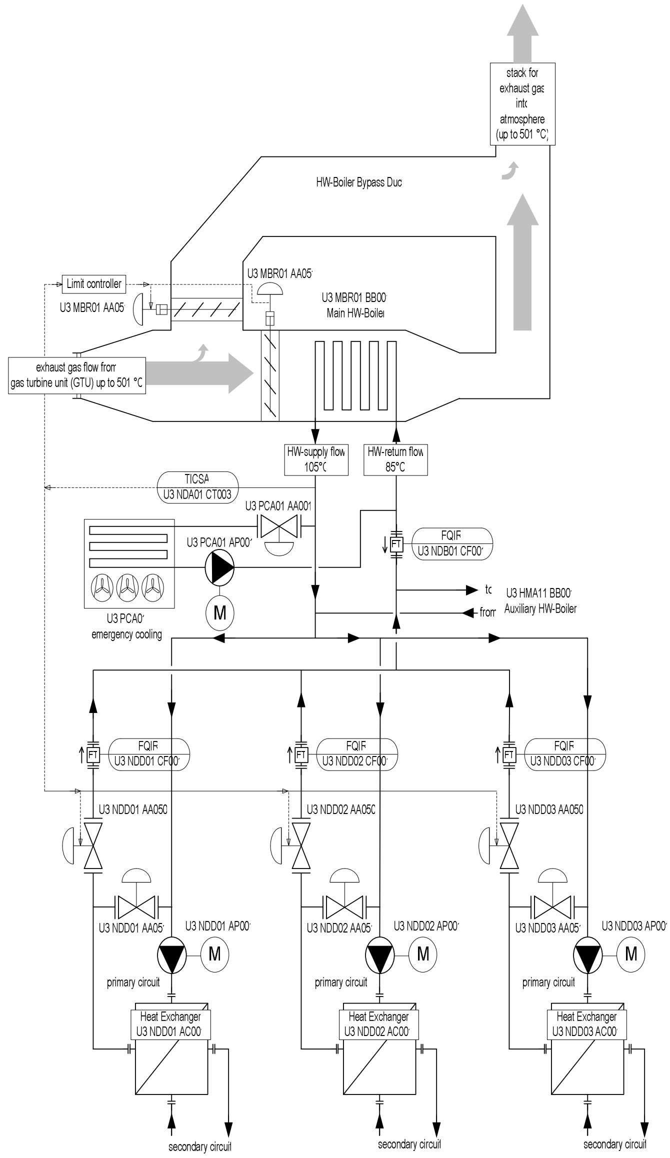

Fig. 4 Simplified P&I-diagram of Main Hot Water Boiler

D. Auxiliary Hot Water Boiler

If the heat generation capacity of the main HW-boiler is insufficient to serve the demand of the HW-consumption, the auxiliary HW-boiler can provide up to 3.0 MW_{th} of additional HW. The heat generation of the main HW-boiler is always dynamised indicated on the FMCS's monitoring system (HMI) by measurement loop U3 NDB01 CF901. Following the indication of the generated HW-capacity (measurement range 0 to 22.0 MW_{th}) the operational staff can recognize any HW-shortage and will exclusively decide about any additional generation of HW by the auxiliary HW-boiler. Consequently the operational staff of the power plant will initiate any starting or stopping of the auxiliary HW-boiler by manual commands from the HMI-system located in the central control room (CCR) of the power plant. The HW-circuit through the auxiliary HW-boiler will be controlled externally by the superior HW-PLC tagged U3 CBC21 via the HW-flow rate. The minimum HW-flow rate through the auxiliary HW-boiler shall be 50 m^3/h as the rated capacity is 134 m^3/h providing a rated heat capacity of 3.0 MW_{th} at a HW-circuit differential temperature of 20 K.

III. Conclusion

Implementation of this system in a Romanian Cogenerative Power Plant has the following advantages: obtaining a high efficiency and combustible saving, limited efforts for developing a new application in a short period of time, and high performance of the system in solving the demands of applications. The system was configured easily, and it has worked very fast because the communication protocol transmits just the information needed.

The prominent advantages of the process control system are the following:

a) - favorable specific heat consumption

b) - optimal utilization of the waste heat during the winter-summer seasons

c) - saving the cost of investment by use of the supplementary firing

d) - stable electric power in the power plants supplying cogenerated electricity and heat.

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