

# Monitoring System for Co-generative Power Plants

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**Abstract :** Electric power systems are an integral part of the way of life in modern society. The electricity supplied by these systems has proved to be a very convenient, safe and clean form of energy. The monitoring of the gas co-generative processes is the main source of information for the technological and economic management. Based on a high performance system, a real-time model provides a permanent updated image of the efficient working status of the electrical power process, providing beside the direct acquired information complex calculations of specific consumptions. The purpose of the automatic functioning of the entire co-generative power plant is the optimisation of the co-generative electrical energy commissioning in the national energy system and the commissioning of thermal energy to the consumers.

**Keywords:** Electric power systems, Co-generative gas power plant, Control of distributed parameter systems, Distribution Management System, Process control, Optimisation, Simulation, Real time systems

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## 1. Introduction

Most of the electric power plants have been subject to a continuous step-by-step modernization process lately. In many cases this process ended with the purchase and installation of a variety of modern equipment and software applications, which was satisfactory for a certain level of development of the power plant.

Obviously, this challenging goal can only be achieved, at a reasonable level of investment, by integration of the all existing sources of information on the power plant - equipment and software applications.

Automation systems use more and more communication systems to be able to carry out their task properly. Therefore, today it's already available a wide catalogue of products that allows the embedded systems used for the automation to interface to one or more field bus networks and to one or more wide range communication networks such as telephone network, Internet, PROFIBUS etc.

Most of the co-generation 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 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.

The system presented is based on a RT-ARCH (Real Time ARCHitecture), architecture of software tools used in process control. The system is composed by classical algorithms running on a network of PLC-s and controlling algorithms implemented in a process computer. Some of them are typical numerical algorithms, and the others are adaptive control algorithms.

## 2. Description of Technological Processes

The concept of co-generation means the combined production of electrical 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). The thermal energy can be used for heating, or for cooling. The cooling process is attained by means of 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 like steam condensers, cooling towers, water coolers from the Diesels / Otto engines, or by residual gases. 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. The cogeneration was first introduced around 1880 in Europe and USA. At the beginning of the 20th century, most

industrial factories were generating the necessary amount of energy by using boilers with coal as fuel and also by using steam turbines. Many factories made use of the residual steam in industrial processes. It is estimated that almost 58% of the total power produced around 1900 by the industrial power plants in USA was obtained by cogeneration. After the development of centralized power plants and reliable utility networks, many factories began to buy electrical energy, renouncing to produce it by themselves.

Main factors that contributed to the decline of the industrial cogeneration were the increase of regulations regarding the generation of electrical power, the low prices of the energy from the whole industrial process, the technological developments (easy installing boilers), the great amount of liquid and gas fuels at low prices and the restrictions regarding the environment.

The cogeneration situation significantly changed after the first important increase of the fuel prices. The systems which were efficient and could use alternative fuels were on demand and more important in times of rising prices and uncertain fuel supply. More than the low prices for used fuels; the cogeneration diminishes the environmental pollution. For these reasons, the governments of Europe, USA and Japan took position in the favor of increasing the implementation of cogeneration. There are three principal forms for encouraging the use of cogeneration:

- Regulations or exoneration from regulations
- Monetary stimulations
- Financial support for research and development.

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.

## 3. Cogeneration Technologies

The main cogeneration system types are:

- the steam turbine co-generation system has three major components: a heat source, a steam turbine and heat tank; the steam turbine operates with Rankine cycle, or in a base form, or in improved versions with reheating of steam and prior heating of the regenerative water
- the gas turbine co-generation systems operate open/close cycle;
- the co-generation systems with mutual internal combustion engines operate with Otto or Diesel cycle;
- the co-generation systems with combined cycles topping temperature cycle, eliminates the heat that is retrieved and utilized by the bottoming temperature cycle for producing supplementary electrical energy; operates with Joule - Rankine or Diesel - Rankine combined cycle.
- the fuel cells are electrochemical devices which convert the chemical energy of the fuel directly into electricity, without the intermediary states of combustion and mechanical work
- the co-generation systems with Sterling engine operate in Sterling cycle.

engines, compact and efficient. Generally, they are capable of a fast startup and fast response at the load change. Both gas turbine projects were successfully used in cogeneration, having as main advantages the initial low cost, the capacity of modifying the fuel, the high quality heat easy to recover and also a significant efficiency in case of greater dimensions.

### 3.2 Co-generation systems with turbine with open cycle

Majority systems with nowadays steam turbine, from any application field, operate with open cycle Brayton, named also Joule cycle if the irreversibility is ignored, Figure 3.1 shows one compressor use environmental air, and transmits it with high pressure to a combustor. Also, the air temperature is raised due to the compression. Old or small units operate to a pressure report of 15:1, while the recent or biggest ones work with a pressure report of 30:1.

### 3.3 Co-generation systems with steam turbine with closed cycle

In close cycle systems, the working fluid,

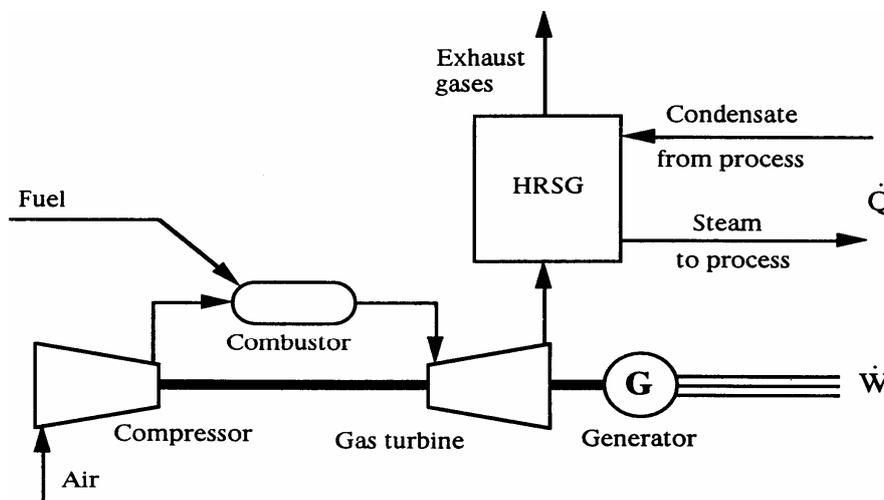


Figure 3.1. Co-generation systems with steam turbine with open cycle

### 3.1 Gas turbine cogeneration systems

The gas turbines, with simple or combined cycle, are for the moment the most often used technology in the cogeneration systems of mean and high power. The gas turbines have been developed as heavy-duty units for industrial and adjacent utilities, or for ship

generally helium or air circulates in a close cycle. It is heated in a heater exchanger before coming into the turbine, and cooled after coming out from the turbine, useful heat being eliminated. In such a way, the working fluid remains clean and it cannot cause corrosion or erosion.

## 4. The Monitoring and Control System

The first level of integration is achieved at the equipment level. At this point it is typical to find in operation equipment using either standard or proprietary communication protocols, also using communication media like RS232, RS485, current loop, Ethernet, radio, GSM.

The final integration level is provided by the system's client application. Under the same interface, the user can obtain information about the entire process at the real-time level, at the technological management level and at the economical management level.

The monitoring and control system is made up of the following main distributed components:

- the high level : An industrial computer IL 43 Siemens (delivered by IPA SA and placed in Control Room) in which is implemented an application program (made by IPA SA and developed on PCS7 Siemens base program) which monitors thermal and electrical processes from Power Plant based on data delivered via Ethernet (through optical fiber) by the low level;
- the low level : 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 (developed by IPA SA), transmits information to the high level and receives from this level the commands for level 3; these PLCs control the Power Plant equipments as follows: 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 monitored by IPA's PLC: U3 CBC21); Auxiliary Hot Water Boiler – HWAB (U3 HMA11) (controlled and

monitored by IPA's PLC: U3 CBC21); Heat Exchangers no. 1, 2, 3 – HE#1, HE#2, HE#3 (U3NDD01, U3NDD01, U3NDD03) (controlled and monitored by IPA's PLC: U3 CBC21); Auxiliary Installations (valves, slide valves, pumps, cooling ventilators, etc.) (controlled and monitored by IPA's PLC: U3 CBC21);

- the field elements level: 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

## 5. The Co-generative 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. In addition 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 autonomously 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 possible 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 a hot water system (HW-system) a main HW-boiler is foreseen which is capable of a thermal heat extraction of up to 22 MWth at nominal power generation capacity. To obtain the contractually specified heat generation capacity of 25 MWth an auxiliary HW-boiler with an additional heat generation capacity of 3.25 MWth 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, and 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 CET-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 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 CET-Bacau power plant and which is some 300 m away from the location of the new unit #3.

### **5.1 Operation of GTU leads by generation of electricity**

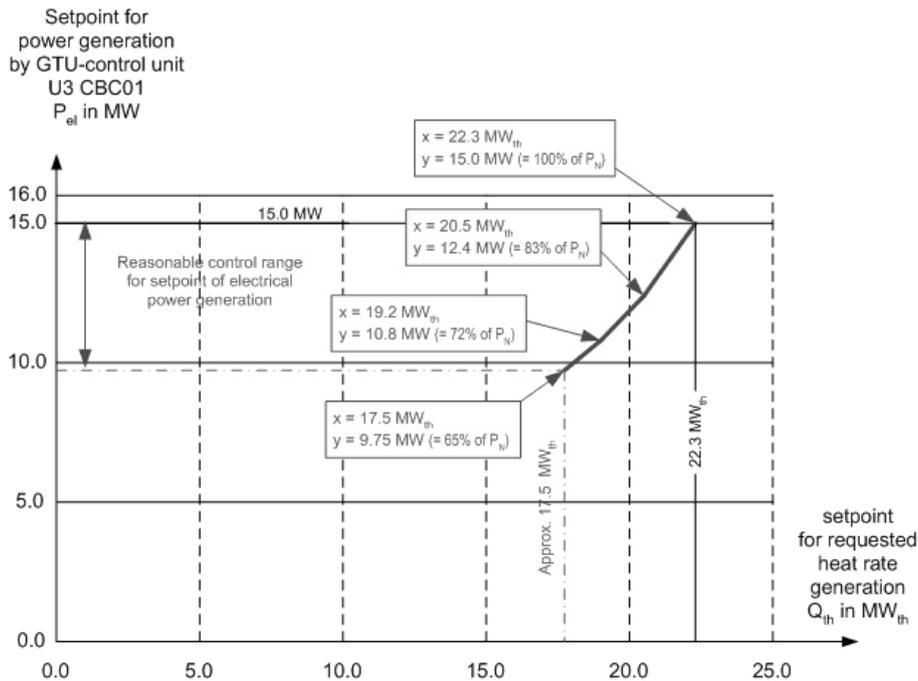
Due of the nature of gas turbines in general it is strongly recommended by the manufacturer to run the gas turbine best at rated capacity (100%) or if deviating from full capacity operation to operate it inside a range of minimum 65% up to 100% of unit nominal capacity. Furthermore and as mentioned above 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) depends on the thermal energy content of the exhaust gas delivered by the gas turbine at any operational stage. 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 type) of the HW-system (also located in the CCR). If the gas turbine is running at any set CCR) or at the superior HMI-station (PCS7- 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 of Bacau.

### **5.2 Operation of GTU leads by generation of heat**

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 following set point curve:



## 6. Main Hot Water Boiler

### 6.1 General description of the main hot water boiler

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.

### 6.2 The hot water control system

a) Control loop HW-outlet temperature acting on primary circuits of HW-heat exchangers

The operation of the main HW-boiler gets controlled by its HW-outlet temperature – U3 NDA01 CT003. If measurements loop U3 NDA01 CT003 fails the instrument loop U3 NDA01 CT004 is considered as its back-up. The exhaust gas intake control gate valve – U3 MBR01 AA050 - is normally complete open (100%) and the respective boiler bypassing conduct is closed (0%) by control gate valve U3 MBR01 AA051. The temperature controller U3 NDA01 DT003 is maintaining the HW-outlet temperature at the given set point (the set point is to choose by the operator; a set point range from 80°C up to 105°C is foreseen) by acting on the control valves inside the primary circuits of the operating HW-heat exchangers ( U3 NDD01, U3 NDD02 or/and U3 NDD03). If the temperature increases above the set point the controller's output signal (y) to the control valve(s) (U3 NDD01 AA050, U3 NDD02 AA050 or/and U3 NDD03 AA050) increases to provide a higher flow through the HW-boiler.

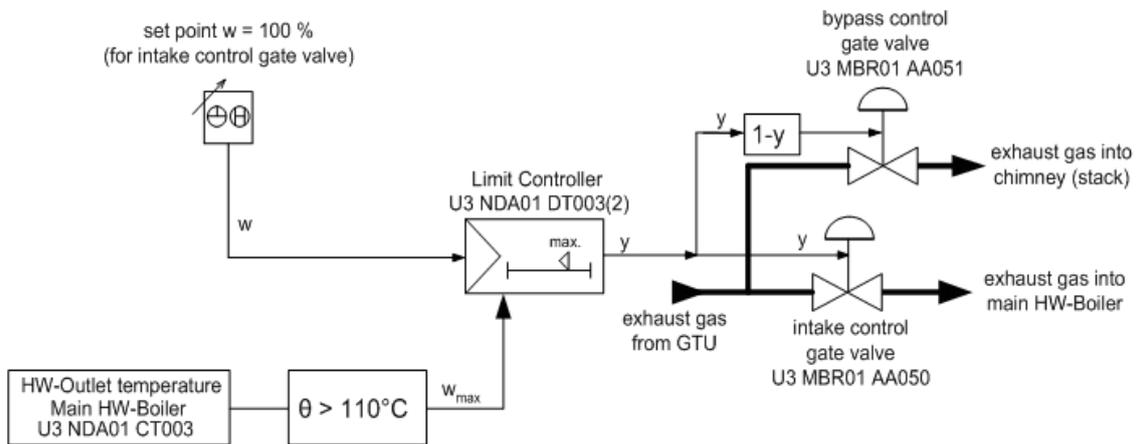
If the control valves in the primary circuit(s) of the heat exchangers are in a limited position due to the minimum limit controller from the secondary circuits and the HW-outlet temperature is still decreasing the limit controller U3 NDA01 DT003 (2) is

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).

b) Limit controller in dependency of HW-outlet temperature acting on exhaust gas control gate valves

In normal (automatic) operation of the main HW-boiler the temperature control loop U3 NDA01 DT003 shall provide a sufficient heat extracting by acting on the respective primary circuits of the HW-heat exchangers. If for any reason the heat transmission into the HW-system will not keep the boilers HW-outlet temperature below a set maximum value of 110 °C the limit controller U3 NDA01 DT003H will limit or reduce the overall heat input into the main HW-boiler by acting on the intake control gate valve U3 MBR01 AA050 (acting closing) and on the bypass control gate valve U3 MBR01 AA051 (acting opening).

The respective limiting control loop is shown on the following control loop diagram (tag-number of this closed control loop is: U3 NDA01 DT003H):



## 7. Hot Water Heat (HW) Exchangers

### 7.1 General description of the HW-heat exchangers

The thermal energy of the generated hot water from the main hot water-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 MWth. Corresponding to the maximum generated HW-heat of 25.0 MWth – 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 at the same time.

Control strategy

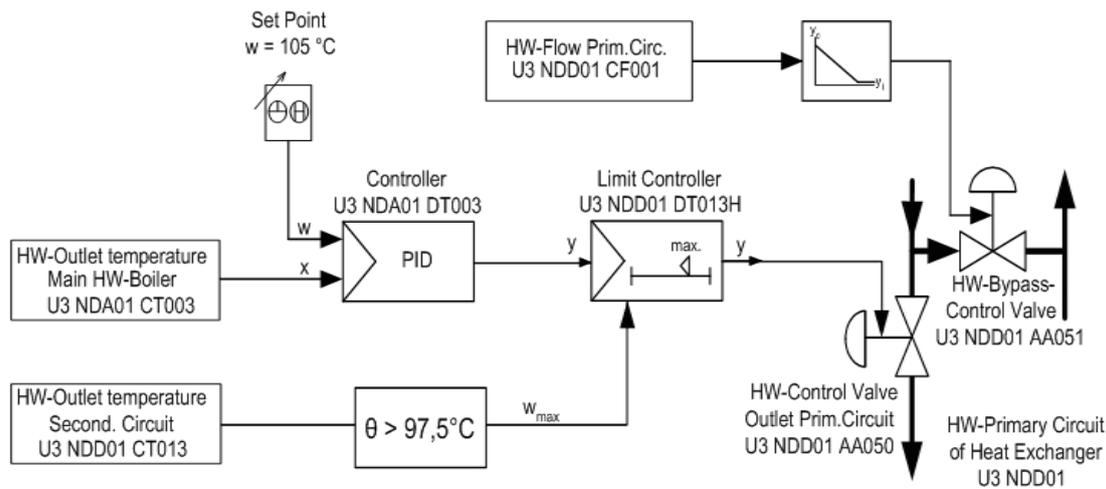
### 7.2 Control loop HW-inlet temperature of primary circuits of HE

The inlet temperature into the primary circuit of the HE is equal to the outlet temperature of the main HW-boiler and get controlled as described in topic 1.4.1.2 – control strategy

for main HW-boiler’. The respective control loop - U3 NDA01 DT003 – is acting equally to all HEs, which are currently in operation. The control loop output signal (y) to the HW-outlet control valve of the primary circuit of each operating HE will be the same. If the HW-outlet temperature of the main HW-boiler – U3 NDA01 CT003 – which is equal to the HE-primary circuit inlet temperature is increasing the controller is acting on the HW-

outlet control valve (in the primary circuit of the HE) U3 NDD01 AA050 and will open it to provide a higher energy assumption by the HE. If the temperature U3 NDA01 CT003 will decrease the controller will close the control valve U3 NDD01 AA050 to admit less HW-energy intake into the HE and therefore to keep the temperature on the set point level.

The complete closed control loop with the limit controller is shown on the following control loop diagram (tag-number of this closed control loop is: U3 NDA01 DT003):



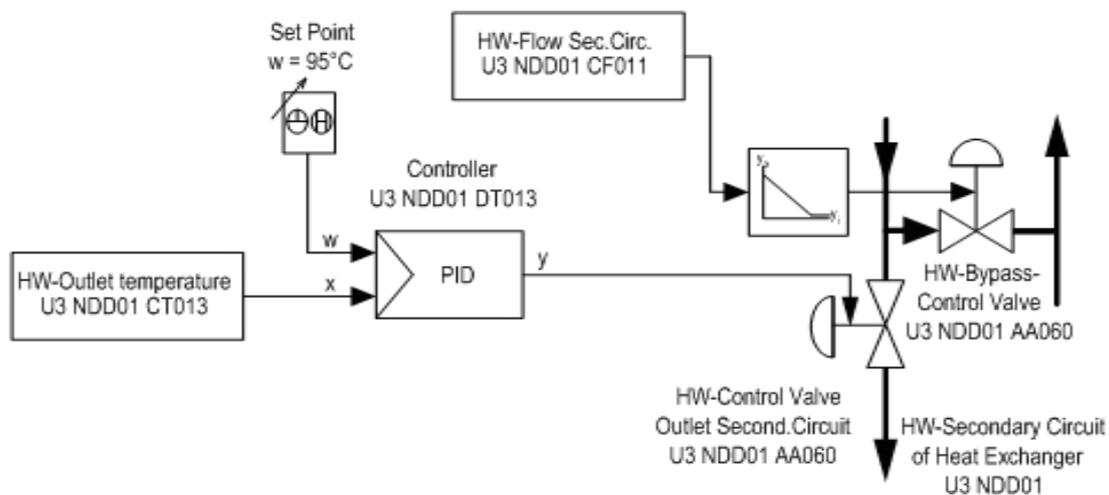
### 7.3 Control loop HW-outlet temperature of secondary circuit of HE

The outlet temperature from the secondary circuit of the HE will get controlled on a

DT013. The temperature set point of this control loop can be chosen by the operator via the HMI-system inside a set point range from some 70 to 100°C. A direct control of the HW-capacity to be transferred into the HW-network is not considered; instead it is aimed to transfer the full capacity of the available heat from GTU into the HW-network of the city of Bacau. However, the HW-transfer will be controlled only indirectly via this here described HW-secondary circuit outlet temperature control.

The complete closed control loop for the HW-outlet temperature control is represented on the following control loop diagram (closed control loop tag: U3 NDD01 DT013):

Additionally to the direct control of the HW-



temperature level corresponding to the inserted set point of control loop U3 NDD01

outlet secondary circuit temperature there is one limit controller depending on this

secondary circuit outlet temperature considered which will in case of an exceeded max. value acting on the temperature control loop U3 NDA01 DT003 which is acting towards the HW-outlet control valve in the primary circuit of the HE – U3 NDD01 AA050. This controller is described in topic ‘a) Control loop HW-inlet temperature of primary circuits of HE’.

## 8. Conclusions

The final result of the monitoring and control system is to ensure the power plant management with on-line real-time and synthetic reports, created by running a specific mathematical model over the entire collection of the technological information.

The application has been tested in an integrated system, with several servers running PCS7, connected in a network. The system was configured easily, and it has worked very fast because the communication protocol transmits just the information needed. The aim of the system is to realize a network of Intelligent Cells with large capacity about calculation and communication in real time but at low cost.

The implementation of this system in co-generative power plants has the following advantages: obtaining a high efficiency and fuel 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.

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