Control System for Cogenerative Power Plants

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ABSTRACT

The paper presents a distributed control system for the realization of cogenerative supply of electricity and heat and, in given case, for their combination with waste heat recovery, particularly in combined (gas-steam) cycle industrial power plants. Modern electric power plants are large complex systems with many processes whose operations need to be optimized. The electrical networks are designed for transmission, repartition and distribution of electrical energy, so that they present various structures.
An optimization problem is usually a mathematical model, where we wish to minimize a numerical value that represents something like costs, energy losses, risks, errors etc or maximize something like profit, quality, efficiency.
Today all the systems that manage the security are characterized by the complexity of their major functions like identification, authentication, access control and data protection. The implementation of these functions is usually and objectively based on a trusted model that uses a trusted architecture, which is the platform of the security architectures.

Keywords : Cogenerative gas power plant, Control of distributed parameter systems, Distribution Management System, Electric power systems, Process control, Optimization, Simulation, Real time systems

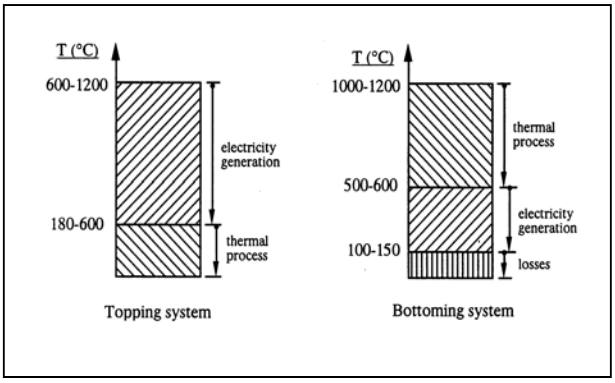
1. INTRODUCTION

Automation systems use more and more communication systems to be able to carry out right their task. 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 (telephone network, Internet, PROFIBUS etc).
But currently the systems both for the industrial automation and for other kinds of control need several devices to be able to work within the network.
In particular, the main device containing the CPU foresees some interfaces for being able to be programmed, some interfaces for being able to talk with the I/O devices, some interfaces for being able to talk with the communication lines.
The concept of co-generation means the combined production of electrical energy and of thermal energy based on the same primary energy source. The thermal energy can be used for heating, or for cooling. The system 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.
The Open Source movement has developed new concepts of making process control algorithms based on transparent and co-operative ownership of software.

2. DESCRIPTION OF TECHNOLOGICAL PROCESSES

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 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 temperature ranges for the two system types are presented in figure below:



- steam turbine cogeneration system – 3 major components: a heat source, a steam turbine and heat tank; operates with Rankine cycle, or in a base form, or in improved versions (with reheating of steam and prior heating of the regenerative water)
- gas turbine cogeneration systems – operates open/close cycle;
- cogeneration systems with mutual internal combustion engines – operates with Otto or Diesel cycle;
- cogeneration systems with combined cycles – topping temperature cycle, eliminates the heat that is retrieved and utilized by the bottoming temperature cycle for producing supplementary electrical (or mechanical) energy; operates with Joule – Rankine or Diesel – Rankine combined cycle.
- fuel cells – electrochemical devices which converts the chemical energy of the fuel directly into electricity, without the intermediary states of combustion and mechanical work
- cogeneration systems with Sterling engine – operates in Sterling cycle.

The paper presents a system with large capacity about calculation and communication in real time but at low cost. The low cost, compared to the devices currently available on the market, is obtained thanks to the fact that the "Intelligent Cell" has an architecture very simple constituted by a microprocessor very powerful with only three single connectors: one for the power supply and two for the communications. The "Intelligent Cell" is produced by the factory only with communication abilities and it can immediately be installed where it will have to reside during its operation activity.

3. GENERAL DESCRIPTION OF A COGENERATIVE POWER PLANT SYSTEM

The paper presents the process for the realization of cogenerative supply of electricity and heat, and in given case for their combination with waste heat recovery, particularly in case of combined (gas-steam) cycle industrial power plants.
The essential feature of the system is that during the season without heat demand the condenser with heating capacity is operated by cooling with cooling tower, and during the heat-intensive season it is operated at a higher temperature required for the heat supplying operation mode, while the cooling tower is disconnected partially or completely, and the resultant reduction of the specific expansion and heating capacity of the steam turbine is compensated by increasing the steam parameters and steam output of the waste heat recovery boiler with supplementary firing.
The control of the electricity generation is executed by the control unit of the gas turbine unit (GTU). The key control devices are special configured PLCs that operate autonomous to any of the other control devices, as the requested set point for the electricity generation is manually settable. 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. The required fuel (natural) gas for the GTU is prepared and delivered at a pressure level of some 26.0 bar g by an also autonomous controlled and operating gas compressor unit (GCU). 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. The operation of the GCU is entirely and exclusively controlled by the PLC-unit 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, which is designated for the Hot-Water-System (HW-system) but contains also some superior control duties for the entire plant, as some essential signals are exchanged between units. 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 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 get controlled by

a PLC-unit. Furthermore the PLC-unit 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 a new unit, two visualization computers or Human Machine Interface (HMI) - stations are foreseen and are located in the central control room (CCR) of the power plant. 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, Distributed Control System type Simatic 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. The CCR is located inside the main machinery building of first unit inside the power plant and which is some 300 meters away from the location of the new unit.

4. THE INFORMATIONAL STRUCTURE OF THE SYSTEM

The overall goal is to foster the usage of FLOSS backend platforms and services and to generate new business opportunities for the Open Source developer community. The open source-based set of tools is supposed to have a high socio-economic effect for both, the providers and users of FLOSS.

The informational system is designed first for data and technical parameter acquisition and then for operative supplying of information required for the process control, optimization, for exploitation and maintenance of the equipment. The entry information is received as digital or analog signals from transducers through the process interface. As a result of data processing, the computing system elaborates the output information, analog or numerical, that can be used for controlling, adjusting or for displaying on video terminals.

The system has a database for data and programs on the mass memory (one or more magnetic hard drives).

5. TECHNIQUES DESCRIPTION

Typically, classical control techniques use analog PID (PI, filtered PID) controllers, or on/off controllers for slower processes. Controllers are used in structures like:

- Simple adjusting with imposed reference
- Cascade adjusting
- Combined adjusting by perturbation and reference

These types of controllers have the advantage that they can be easily implemented, but very often their parameters are fixed. That's why classical control structures can be used only for those subsystems of technological installation that have very well defined models, or have modest control requirements.

From all the diverse modern control techniques we have chosen to implement some algorithms by computer programs. This implementation has a great flexibility: it is very easy to modify the dates of the program that contains the adjusting parameters.

6. HARDWARE AND SOFTWARE ARCHITECTURE

The hardware platform used as a support of the control programs is composed by several personal computers with a Pentium IV processor Dual Core, 1024 Mb RAM, 256 bits video graphic accelerator, SCSI 160Gb HDD, data acquisition cards, one multiplex for 64 serial ports and a network of PLC-s. On these machines we have used Unix operating system and the Distributed Control System Simatic PCS7. This system offers multitasking facilities for parallel managing aspects regarding data acquisition, data transmission, adjusting and data displaying. Using multitasking we could manage more control loops on the same computer even though some of the processes are controlled only by PLC-s.

The development platform used was Visual C++ because it can compile programs for Unix operating system and it has the following facilities:

- Permits creation of separate threads with different adjusting algorithms for each of the processes.
- Offers communication methods inter-threads for transferring data between data acquisition processes and controlling processes. Communications are made using message boxes and critical sections.
- Permits realization of communication modules in a TCP/IP network. That makes possible implementation of the hierarchical architecture.
- Offers the possibility to create a user-friendly interface for the product, in Unix environment.

The only disadvantage of this platform is that it hasn't any dedicated functions for complicated mathematical calculus needed in adjusting algorithms, so that we had to write them ourselves.

The process computer is placed in the control room of technological installation because it must be protected from the environment of the technological process.

7. PROCESS OPTIMIZATION

Many forecasting models have been proposed and implemented in this field, based on time-series, regression, expert system models etc. A special attention has been paid to the use of Artificial Neural Networks

ISSN: 1790-5109

ISBN: 978-960-6766-94-7

(ANN) to model load. In the last years, control centers in distribution went through some drastic changes. Evolving from Supervisory Control and Data Acquisition (SCADA) systems, the concept of Distribution Management System (DMS) gained growing acceptance. A DMS must provide a set of functions, namely for switching decision and operation, which rely on the basic tool of power flow calculus.

The mathematical problem posed by the general optimization formulation is often remote from that of a practical design problem.

The optimization problem is "given a dynamic system (S) that evolves on a finite time interval $[T_0...T_f]$ and the performance index J(u) it is required a command that minimizes J". In this standard formulation there are no restrictions, but it follows a movement in the states space for minimum energy consumption. Using the computer we have chosen dynamic optimization, that relies on the idea of finding a procedure for generating a "relaxing" array defined by the following condition:

X1, X2, X3, …Xn, so that $f(X1) \geq f(X2) \geq f(X3) \geq \ldots$ with the property that if $Xk \rightarrow X$, then $f(Xk) \rightarrow f(X)$, where X is the extreme value of the objective function in a specific domain.

The relaxing arrays generating procedure has two components:

- Choosing the descending direction of the function with the modified Newton method. This is a gradient method that means successive approximations of the function.
- Determining the step on the descending direction.

Newton-type method calculate the Hessian matrix H directly and proceed in a direction of descent using a line search method to locate the minimum after a number of iterations. Calculation H numerically involves a large amount of computation. Quasi-Newton methods avoid this, by using the observed behavior of f(X) to build up curvature information, in order to make an approximation to H using an appropriate updating technique.

8. CONTROL SYSTEM FUNCTIONS FOR THE COGENERATIVE POWER PLANT

The automation system works in a collecting-processing way, interfering with and conducting the controlling processes. The system does the following functions:

- Supervision of technological equipment and devices
- Displaying and printing any damage that may occur, showing the moment of appearance, the kind and the place of the damage
- Displaying and printing the alarms at the moment of the occurrence
- Showing the entries and outputs from the programmable logic controllers for debugging any anomaly or damage
- Controlling the measuring equipment and supervising the process
- On demand, displaying the parameters of the technological process

Some of the subsystems of the technological installation are variable in time due to action of stochastic perturbations. That determines large variations of the parameters of the attached mathematical model, but fortunately the structure of the model remains the same.

The control takes place at the level of the central computer, and also at the level of the PLC-s. We have used a hybrid adjusting method, i.e. some adjusting loops are implemented with classical algorithms (PI, PID), and the others are adaptive.

The system is composed by:

- Classical algorithms running on the PLC-s that also have implemented data acquisition modules, and analog and digital command modules. Programs are written in the PLC's language.
- Controlling algorithms implemented with the process computer. Some of them are typical numerical algorithms, and the others are adaptive control algorithms.

9. CONCLUSIONS

Implementation of this system in a Romanian cogenerative power plants 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 uses secure socket connections (SSL) to transmit all sensitive information during the control process. The application has been tested in an integrated system, with several servers running Unix, 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 prominent adantages 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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