AN ALTERNATIVE SCADA & AGC SYSTEM DEVELOPMENT APPROACH FOR A SMALLER SIZE ELECTRIC POWER SYSTEM CONTROL

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Key Words: *AGC, EMS, LFC, NTC, OO Programming, SCADA, MS Visual Basic*

ABSTRACT:
Each EMS (Energy Management System) relies upon the SCADA system that gathers power system data, processes them and issues control commands. Among all the control functions of an EMS, the AGC (Automatic Generation Control) is the most important one. A SCADA system is characterized by geographical spread, a great amount of data, a complexity of belonging equipment, but by a very long period for the finalization and a very high investment costs, too. The long realization period compared with the extremely fast development of the available computer's hardware and software on the world's market, coupled with a permanent need for EMS upgrades caused by privatization of electric utility companies and deregulation of the electricity market, coerce some smaller size electric power companies to think in a different manner. This paper describes that manner - a unique control application, developed and implemented at the real power system. The specific feature of this control system is that it is based on the relatively poor set of power system data (around 70 input data), but a very good overall observability is achieved (around 300 output process informations). The second feature is the hardware – a single personal computer with the acquisition interface board in it as the SCADA host, and existing "hybrid" telemetric system for power system data gathering and AGC commands transport. Third - the choice of the Visual Basic language provides a lot of powerful features and unlimited possibilities for future easy–to-make upgrades and improvements, such as: object oriented code, encapsulation of functions, full GUI with animation, various communications including and Web-based one etc.

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1. INTRODUCTION

The electric power system that we deal with, is the system of Montenegro. The monitoring of the whole system is performed from the National Dispatching Center, located in the capital Podgorica. The EES (Electric Energy System) of Montenegro consists of connected grid which operates at the level of 400, 220 and 110 kV.The grid has 40 HVL (High Voltage Lines), 3 power plants (totals to 870 MW's) and 19 substations. The maximum hourly peak load reaches 700 MW, and yearly consumption is around 4000 GWh. The theritory of Montenegro spreads over around 14900 km^2.

An efficient monitoring system is necessary, that would be able to deal with the whole EES, and there is no dilemma about that indispensability. But, numerous questions arise. How many power system data are enough to provide global EES observability? Big, classical projects for building global EMS suffer from numerous weaknesses. How much does it cost? How long we must wait? Is it feasible at all? Will it be the obsolete techniques at the moment of its start (if it ever starts)? This article describes an completely different approach, that is implemented at the real EES. It is cost effective, very fast applied, with the state of the art design, and with endless possibilities for further expansions. These future expansions have to answer not only to the future technical expansions of EES but to the future challenges of privatization and deregulation. We think that this system is able to do it.

This SCADA's hardware is a single PC with acquisition interface in it (another one is added, in the meantime, at the same LAN, as redundancy). That acquisition interface-board offers 48 analog inputs, 24 digital inputs and 8 digital outputs. The analog measurements (MW's,MVAr's and kV's) are provided by so called "Hybrid" telemetric system i.e. a number of measurements is transferred by older single-channel equipment, and the rest by new-fashioned telemetric system comprising communication computer and four RTU's. This is an already-existed, modest equipment, but very, very optimally employed.

No one SCADA software, available on the market, satisfied our requirements. Our choice was MS WindowsTM OS, the MS Visual Basic 6 pro and the start from the very beginning. The main reasons for this choice lie in the human resources, familiarity with this software tools and its possibilities. No one third party software control was used, everything was originally developed and implemented. The complete system consists of objects, i.e. classes, collections and ActiveX controls. The complete logic and functionality of each SCADA & AGC function are encapsulated in it's class, which makes implementation extremely easy to do. The overall cost of the project is a story for itself.

2. SYSTEM ARCHITECTURE

The SCADA & AGC system consists of :

- Basic system services
- Data management
- User interface
- Telecontrol interface & Communication block
- SCADA application
- AGC application

Basic system services perform basic functions and consist of OS, MasterLinkTM module for support and an Integrated Development Environment – Visual Basic 6 pro.

Data Management unites, through GUI, all data manipulations.

User Interface is extremely user - friendly with the next characteristics: full graphics with three–dimensional control objects and specially developed ActiveX controls; full mouse-driven GUI; one-line diagrams with objects as elements; the ability to track power system dynamics; multi-medial alarms (animation, sound) and specific GGOA (Graphic Guided Operator Alarming) system; trend diagrams and analog wattmeters; dynamic coloring of bus-bars of an substation under voltage propagation; panning/zooming; drag & drop operations etc.

TC Interface & Comm. Block provides the connection with the EES, and consists of an acquisition board that accomplishes local acquisition of remote measurements. Communication block performs remote data acquisition via RTU's, LAN/WAN & Internet data exchange.

SCADA application accomplishes the next set of functions: Basic data processing – acquisition and processing; Advanced data manipulation and ODB (Operational Data Base) refreshment; Visualization and Operator alarming; Disturbance data acquisition; Topological configurator of EES - topology analysis & bus-bar coloring of substations (the visible part), and on power system level automatic changes of incidence matrix A and Ybus matrix (the invisible part of configurator); The supervisory control & tagging - manipulations with controls that represent circuit breakers, and power system status setting (triggering Ybus & A changes).

AGC is an application based on SCADA, that plays a very important role of automatic regulation of a power system ACE (Area Control Error), i.e. reducing ACE to the near-zero value.

3. SCADA DESIGN

The complete operator's communication with the SCADA & AGC application is accomplished through the main display that represents the global one – line diagram of EES of Montenegro. This display is present all the time, and every system – operator action is performed by mouse, because the whole surface of the display is mouse – sensitive. The SCADA & AGC application is started by mouse double click at the icon on the desktop surface. The process of data acquisition starts by a mouse click on the command button with start flag picture on it. The data-flow is presented at the Figure 1.

The first step of data processing is evaluation of telemetry status of every analog channel (in operation/in outage). If this status is OK – the measurement is acquired. In the opposite case – the simulation is made from ODB. The next step is replacement with manually set data (if necessary) and software filtering. This procedure ends with data conversion (in MW's etc). The advanced data manipulation comprises a variety of functions and calculations: virtual data deriving, calculated data and transmission losses calculation, integrals of specific data from the beginning of each hour up to the moment etc. The next step consists of security monitoring functions, such as: overload monitor, gradient changes detecting and power system dynamics tracking, performing Algorithm for a fast estimation of switching occurrence and placement of data in ODB (Operational Data Base) and DDADB (Disturbance Data Acquisition Data Base).

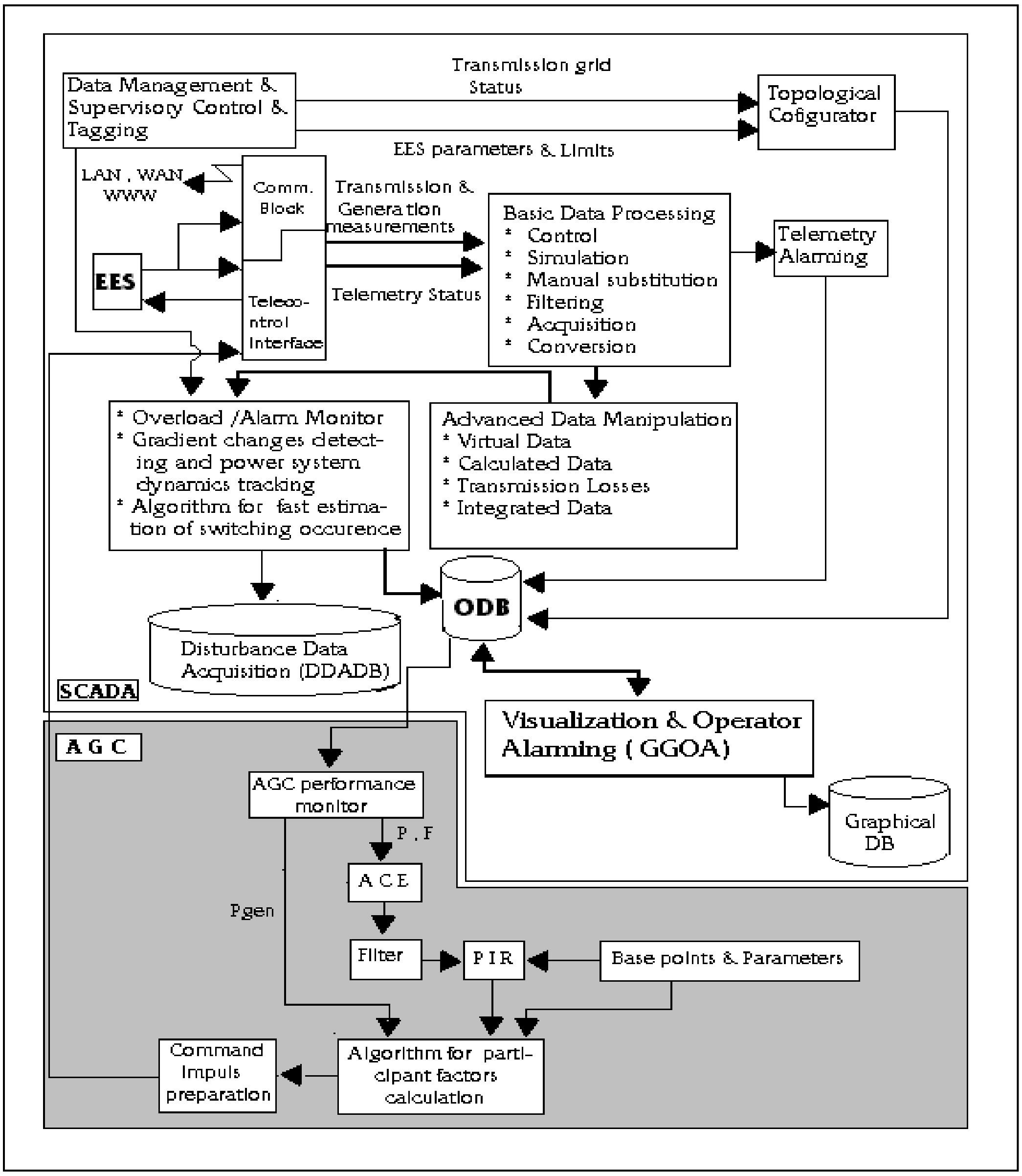

Fig. 1. Data flow through SCADA & AGC system

This SADA system doesn't deal with circuit breaker's status signalizations (open/close), but this is accomplished through the Data Management block. Every manually done change, triggers process of A (incidence) and Ybus matrices recalculation. An modified node-order-down technique combined with the real system measurement data is employed. At the next figure (Figure 2.), the main screen of system is presented.

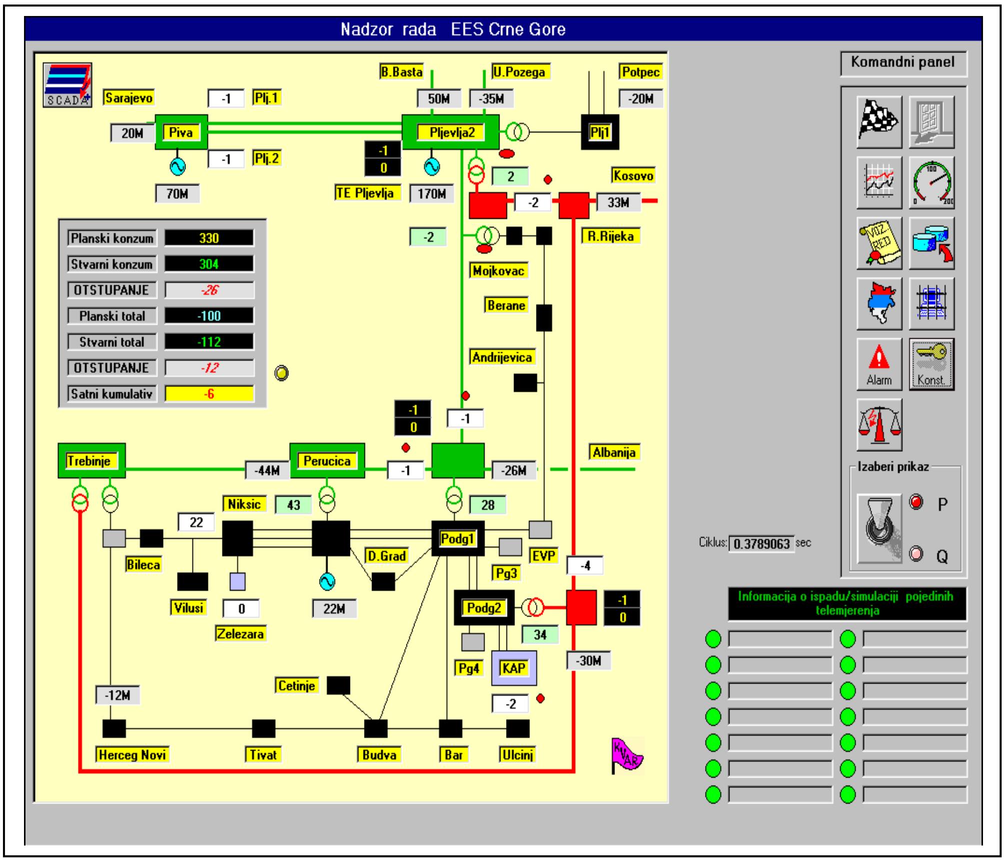

Fig. 2. The main SCADA display

3.1.SECURITY MONITORING

Each power system measurement is permanently tested on upper/lower limits, and adequate alarm flag is settled. At each step a comparison of a data with the previous step data is made and absolute gradients and relative gradients are calculated. Adequate gradient flags are settled. This is a basis for power system dynamics tracking, and this is achieved through visualization. As we said earlier in the text, the specific algorithm for a fast estimation of circuit breakers activities is developed. It is a quite simple but a very efficient algorithm:

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If    |Pi(k)-Pi(k-1)| >APSGrad   AND   |Pi(k)-Pi(k-1)|> RELGrad*Pi(k-1)    Then
             Set  Gradient  Flag for "i" measurement
         If  Pi(k) < DeadBand ; (possible outage)
             Set  CircuitBreaker Outage flag
      End If
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End If

where : Pi(k) – active power flow through element “i” at the cycle “k”
APSGrad – the limit (adjustable) for absolute gradient (in MW’s)
RELGrad - the limit (adjustable) for relative gradient (in %)
DeadBand – adjustable value around zero to take into account inaccuracies.

In the practice this algorithm has shown a very good behaviour. It is possible, sometimes, to turn on alarm without a breaker’s status change (for near-empty element), but not to “see” a real outage – never! The security monitoring implemented in this SCADA application provides the possibility for power system operator to prevent an element’s overload and, further, it’s outage. One year exploitation proved its effectiveness.

3.2.VISUALIZATION AND OPERATOR ALARMING

This part of SCADA & AGC system is the most visible partof the system. The main display is presented at the Figure 2., and in the mean time it was changed, i.e. a few new command buttons were added to it. The new buttons serve for AGC start and for some additional filtering/reset functions. An overall control of EES steady state is achieved. By using a simple two-state breaker a usual “P” - sight can be changed with a “Q/V”- sight. The global EES data (momentary consumption, exchange and deviations from planned values) are always present on the display. A single mouse-click on the EES nodes opens a detailed one-line diagram for that node, as on the Figure 3.

The breakers and insulators are three-dimensional controls, each busbar is a control too, and by a single click on the command button you can present the data from ODB, or set new topology state, with busbar coloring in accordance with the voltage propagation. One of the additional displays that can be used is the geographical presentation of the EES of Montenergo as can be seen at the Figure 4.

The aim of this picture is not only to display active power flows, but also to help EES operator to make insight in the NTC (Net Transfer Capacities) at the moment. This is an important help for power system operator, because the problems concerning the transit of a huge amount of energy over this EES has arrived especially during the last period of the time. Using this visual tool operator is capable to estimate the transit capabilities of the EES at the moment and in the next few hours.At this display the energy exchanges with the neighboring EES are presented, which enables the planned energy exchange checking at the moment.

The GGOA is implemented with the visualization block which performs a straightforward visualization of alarms. An overload condition changes background and foreground colors of data presentation box and turns on alarm sound. An gradient alarm makes the same thing but with the different sound and colors. After the disappearance of alarm condition – the visual and sound effects disappear, too. The breaker’s switching alarms appear as the little red circuit/ellipse at the place of that breaker. The only way to eliminate this alarm is to “click” it. Therefore, each alarm is visualized at the place of its occurrence and the operator can doubtlessly see it and perform an adequate action without any additional searching (through menus, submenus, etc.).

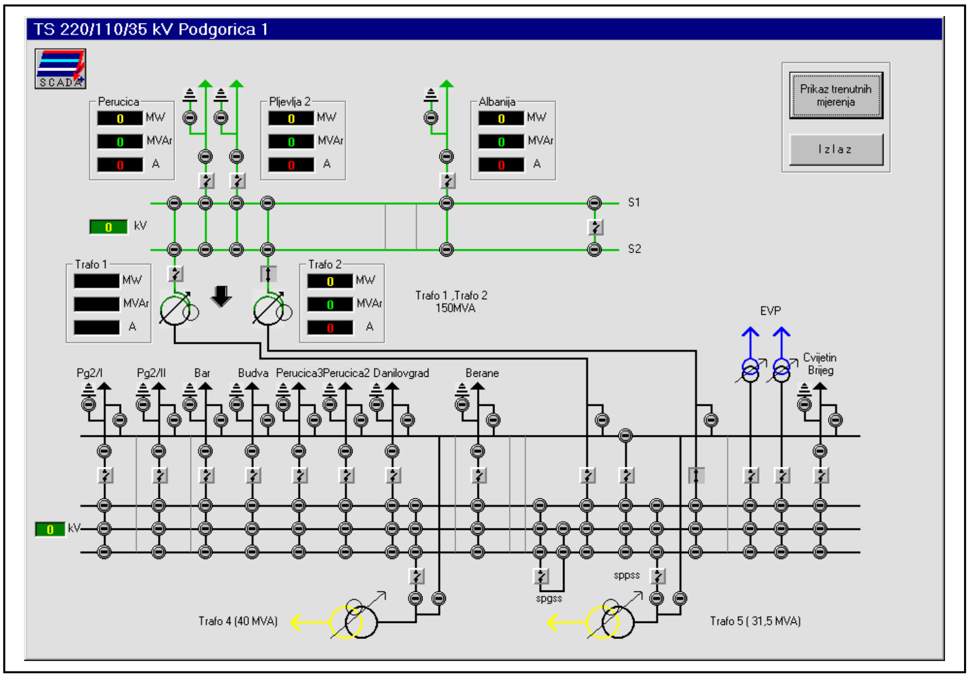

Fig.3. One-line Diagram

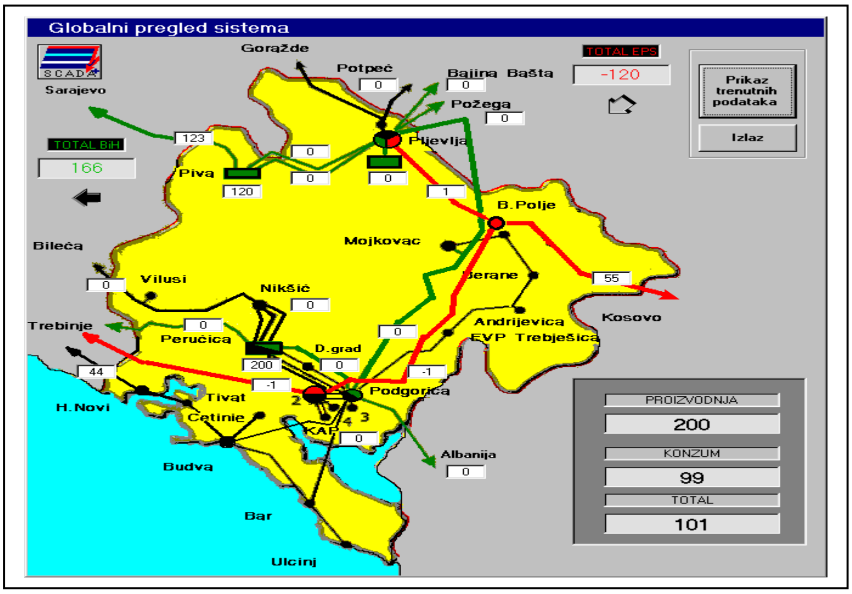

Fig.4. The Map of Montenegro

3.3.SOME DETAILS

A few details have to be stressed. The first, due to the size of system of Electric Power Company of Montenegro it was possible to implement an specific function of the monitoring system – deriving of the real-time power system losses. The choice of location for each real power system measurement was made in such manner to make it possible to derive the maximal number of virtual & calculated data. Pursuant to that choice the very favorable ratio between input/output data (1:4) is achieved. So, two sets of data are permanently calculated and this monitoring system can present the gross consumption, the net consumption and the real-time losses. These losses are generated in 400/220 kV grid including and transformers, too. Therefore, the losses are calculated which are used in two ways. The first is the usage of the losses purely to monitor them and the second purpose of the losses is to provide us a manner to unambiguously detect bad data occurence. Namely, whenever some of the measurements generates an error - the losses will automatically increase in spite of its sign (+/-). It indicates that something is wrong and that the source of the problem has to be found. The behavior of this function in the real – system operation is absolutely satisfactory.

The second specific ,mentionworth feature developed and implemented at this control system is so called Graphical Data Base (GDB). It is presented through the ActiveX control that seems like an traditional analog instrument-registrator with the horizontal paper strip and pens on which trend diagrams are drawn. All esential global power system data are simultaneously recorded (drawn) in different colors, “winding up” of the virtual strip is performed (in the left-hand direction) and after reaching the end of one “strip”, automatic replacement is acomplished. The previous strip is placed in GDB, that is circular. An algorithm is developed for rewieving trend-diagrams during their generation. So, using the scroller we can “wind up” the diagrams in both directions in spite of fact that diagrams are simultaneously drawn. In this manner we have achieved an physicaly impossible situation of moving the same trend-diagram in the both directions at the same time. This is an favorite tool for power system operators.

4. AGC REGULATOR

The objective of the AGC is to satisfy frequency and active power exchange schedules, i.e. to reduce ACE to near-zero value, with a minimum of unit movement. The term AGC is used herein and under it we assume LFC (Load Frequency Control). The LFC was developed in compliance with the rules of UCTE (Union for Coordination of Transmission of Electricity) [6,8]. After the completion of LFC, Electric Power Company of Montenegro has fulfilled all the necessary conditions to create a Regulating Area. This is the first time the Electric Power Company of Montenegro has its own LFC, i.e. to be able to send regulating impulses towards its regulating power plants. Some significant and pretty expensive attempts have been made many years ago (by Leeds & Northrup and oth.) but without any substantial results.

The basis for LFC was established by putting our SCADA system into operation in December 1999, [3]. In that way the deriving of ACE became feasible. Two regulating units at the one of our hydro plants are included in the AGC with the satisfactory regulating extents. Regarding [7], necessary regulating reserve for LFC for each Regulating Area is:

$$R = \sqrt{a \cdot L_{\max} + b^2} - b \tag{1}$$

Where: R- proposed regulating reserve (MW)
Lmax- maximal hourly load (MW)
a=10 , b=150 - constants

For the power system of Montenegro R=(-20, +20) (MW) for the most stringent case while two regulating generators possess regulating scope of (22-96) (MW), i.e. (-37, +37) (MW) what can be considered as the satisfactory scope.

4.1. LFC OPERATIONAL PRINCIPLES

Area Control Error has been derived as:

$$ACE = (P_0 - P_{realy}) + B_f \cdot (f_0 - f_{realy}) \tag{2}$$

Regarding Bf > 0 control logic is :

$$ACE > 0 \Rightarrow power\ up\ (\uparrow) \tag{3}$$

$$ACE < 0 \Rightarrow power\ down\ (\downarrow) \tag{4}$$

This “raw” ACE is filtered through two software filters (linear and nonlinear) for noise and sudden power changes suppression and deadbands implementation. After that, this filtered error can be led into PI (Proportionally Integral) regulator or it can be bypassed. PI-regulator is derived from continual form to digitized form in accordance with [5]:

$$PN(t) = K_P \cdot N(t) + K_I \cdot \int_0^t N(t)dt \tag{5}$$

$$PN(j) = PN(j-1) + A \cdot N(j) + B \cdot N(j-1) \tag{6}$$

Where: A= $K_P+K_I\Delta t$
B= $-K_P$
j - cycle index ; Δt – cycle length
N(t) – ACE ; PN(t) – ACE_{PI} (after PI)
KP , KI – proportional and integral coefficients.

Two regulating generators are assumed as two independent units in spite of they are at the same hydro plant. After passing through the PI regulator, ACEPI is tested on upper limit of regulation (if exceeded - LFC has no sense) and upper limit of mandatory deadband (mandatory/permissive regime). If permissive - then two-step algorithm for variable participation coefficients is employed. The first step of the algorithm is performed with reference to the base point power of each regulating unit and the second one is with reference to the maximal/minimal (depends on the direction) unit’s power. Detailed description of the algorithm would deserve a paper for itself but here just to underline that this algorithm warrants even increasing/decreasing of regulating unit’s power outputs, i.e. they divide ACE in accordance with their nominal, base-point and momentary power outputs.

At the end of process so called regulating error for each regulating unit is calculated:

$$UCE(i) = K_{PART}(i) * ACE_{PI} \quad (7)$$

where: UCE(i) – regulating error for unit "i"

K_{PART} (i) – participation coefficient (factor)

Regulating impulses are generated and sent to the units. The regulation is performed by means of regulating impulses of the constant length and the length can be adjusted during the operation in the range of (0-2) seconds.

4.2 IMPLEMENTATION AND USER INTERFACE OF LFC

The LFC regulator is developed (as the SCADA application is) in MS Visual Basic 6.0 pro, under the MS Windows OS.LFC consists of two classes and one collection and they contain 29 properties and 15 methods. The complete logic and functionality of the LFC are encapsulated in these classes and when necessary the methods are just called from SCADA. Hence, implementation was extremely easy and fast. Adding new generators in LFC would be a very simple procedure. In the process of software design we had no model but in spite of that modelless design the ultimate result was absolutely satisfactory. Our own experience earned during many years of practical, immediate operation in power system control, significantly contributed in reaching our goal. The AGC control display is presented at the Fig. 5.

This display comprises all monitoring and control function of LFC and is extremely easy to use. The specific feature for this LFC is remote control of the waterhead at the regulating hydro power plant. It is included in the regulating algorithm because of preventing possible head drop caused by the LFC operation.

4.3 PRACTICAL RESULTS OF EXPLOITATION

The SCADA system is in the continuous operation for more than 18 months with very satisfactory results. The LFC system is in the phase of test exploitation. Test results of one 15-minutes slice of test operation with only one regulating generator in the LFC are shown on the diagram at the Fig. 6.

Because of colors we must stress that generator's output is presented by the upper line. During the operations ACE was successfully reduced without any sign of power system unstability.

5. WHAT'S SPECIFIC?

At the end a question arises – What is new here? Without the great expectations of our results it is possible to stress a few issues. The first of all – the fully functional monitoring system was put into operation for the first time. We emphasize that this Power Company has never had any kind of computer based control system despite the numerous expensive attempting to build one. The same could be said for the LFC system. We think that each pioneer effort deserves to be mentioned. The second one would be the operational usability of the system that seems to be quite good. The third one is expressed through its open architecture, which provides a wide expandability in accordance with the future needs. This is accomplished by using MS Windows and Visual Basic 6.0 pro that are "de facto" standa-

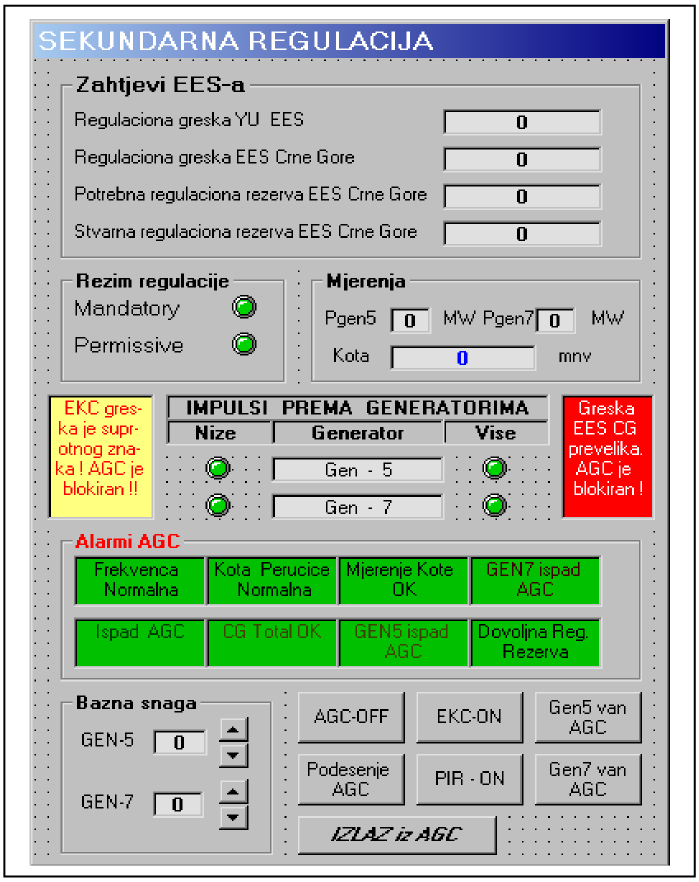

Fig.5. AGC display

rds in the PC world. And as the last but probably the most important is financial aspect, i.e. the overall cost of the project. Including all necessary measurement transducers, hardware, licensed development software and our development and implementation efforts –the overall costs were less than 10,000 US $!

6. CONCLUSION

This paper has described a SCADA & LFC system designed and adapted for a specific and unique usage. The object-oriented design approach and the powerful Visual Basic possibilities allow the user a great flexibility in adding new functional modules as in providing the extra-user-friendly GUI. Some specific algorithms are implemented that provide overall power system observability, despite a poor set of input data and a modest hardware. The system is implemented at the real EES and has shown a very good results during its up to date exploitation.

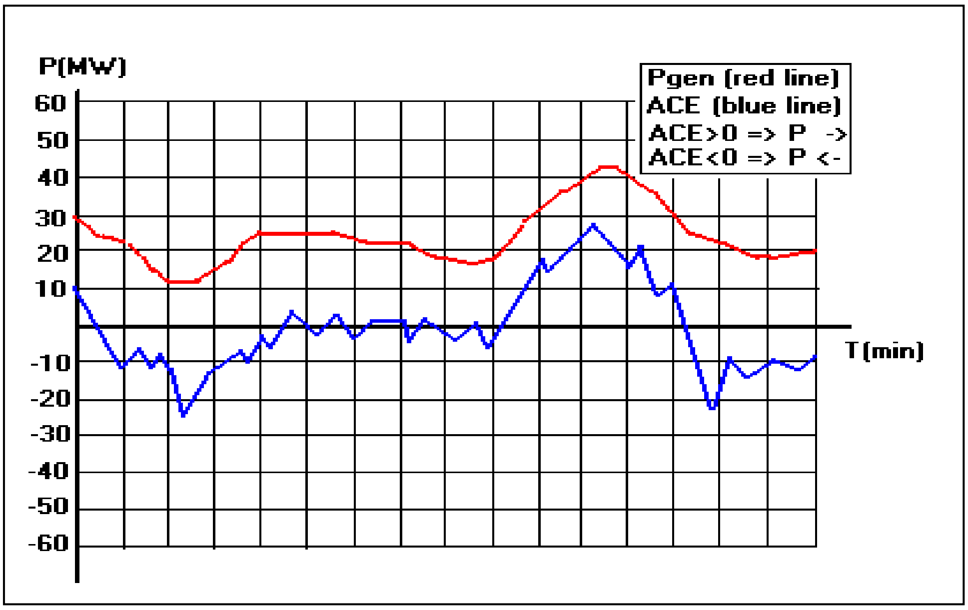

Fig.6. The results og practical operation of LFC

REFERENCES

[1] "MS Visual Basic 6.0 Professional Edition – User's & Programming Guide", *Microsoft Corporation*, 1998.

[2] M.Calovic: "Regulation of Electric Power Systems – Part I", *ETF Belgrade*, Yugoslavia, 1997.

[3] B.Stojkovic: "SCADA&AGC system in Electric Power Company of Montenegro – an innovative Object Oriented solution for a cost effective overall control", in *Poster session at the Black sea El-Net*, pap.p-26, Suceava, Romania, 2001.

[4] A.S.Debs: "Modern Power Systems Control and Operation: A Study of Real-Time Operation of Power Utility Control Centers", *Decision Systems International*, 1996.

[5] K.J.Åström, B.Wittenmark: "Computer Controlled Systems: Theory and Design", *Prentice-Hall*, Inc., 1984.

[6] "Regles du jeu relatives aux reglages primaire et secondaire de la fréquence et de la puissance dans l'UCPTE", *UCPTE*, Luxembourg, 1998.

[7] "Regle du jeu pour la coordination des décomptes et l'organisation du réglage fréquence – puissance", *UCTE*, Luxembourg, 1999.

[8] "Regles du jeu: Suivi de l'application des régles relatives aux réglages primaire et secondaire de la fréquence et de la puissance dans l'UCTE", *UCTE*, Luxembourg, 1999.

[9] B.Qiu, H.B.Gooi: "Web-Based SCADA Display Systems (WSDS) for Access via Internet", *IEEE Transactions on Power Systems*, vol.15., pp.681-686, May 2000.