RELITALIZATION OF SMALL HYDRO POWER PLANTS – INTEGRATION INTO THE SMART GRID CONCEPT

J. Dragosavac[*], T. Gajić[*], P. Ninković[*], S. Dobričić[*], M. Janković[*], D. Arnautović [*], G. Sarić[**]

Electrical Enginerinig Institute „Nikola Tesla“, Koste Glavini'a 8a, Belgrade, Serbia [*]
University of Belgrade

[**]*Public enterprise "Elektrosrbija", Kraljevo*

Abstract: With on-going high penetration of intermittent renewable power sources, like wind and solar, increases significantly the importance of hydro energy. Due to permanent rising of flexible hydro energy price, the investments in increasing the energy efficiency and availability of existing small power plants are justified and encouraged. In this paper, the development of a small hydro power plant (SHPP) control system is presented. The control system hardware is based on programmable logic controller (PLC) platform, which is highly flexible industrial-grade equipment, together with original equipment manufactured (OEM) devices, such as measurement's transducer, primary equipment controllers and synchronization units. The goal was to obtain a control system which can interface with equipment of different generations and follow new trends in control and smart grid concept. The system is installed and in operation in SHPP "Raška".

Key words: Renewable, hydro power plant, control system, smart grid

REALIZACIJA UPRAVLJANJA MALOM HIDRO ELEKTRANOM UKLAPANJE U KONCEPT PAMETNIH MREŽA

J. Dragosavac[*], T. Gajić[*], P. Ninković[*], S. Dobričić[*], M. Janković[*], D. Arnautović [*], G. Sarić[**]

[*]*Elektrotehnički institut "Nikola Tesla", Koste Glavinića 8a, 11000 Beograd**
Univerzitet u Beogradu

[**]*Privredno društvo "Elektrosrbija", Kraljevo*

Kratak sadržaj: Sve značajnije učešće solarnih i vetro elektrana čija je raspoloživost snažno zavisna od resursa povećava značaj hidro energije i direkno utiče na povećanje cene energije proizvedene u malim hidroelektranama (MHE). Zbog toga raste interes za investiranje u povećanje energetske efikasnosti i raspoloživosti postojećih HE. U radu je prikazan razvoj jednog sistema upravljanja u HE. Hardver na kome je primenjen kontrolni algoritam je baziran na PLC platformi dok je hardver periferija, mernih pretvarača, turbiskog regulatora i sinhronizatora baziran na specijalizovanim kontrolerskim pločama. CIlj je da se razvije upravljački system koji se svojom modularnom kostrukcijom lako može prilagoditi opremi starijih i novijih generacija i omogućiti uključenje elektrane u "Pametno" upravljanje elektroenergetskim sistemom. Razvijeni sistem upravljanja je u upotrebi u MHE " Raška ".

Ključne reči: *Obnovljivi izvori, hidroelektrana, system upravljanja, pametne mreže*

1. INTRODUCTION

In accordance with the strategic documents of Electric Power Industry of Serbia (EPS) and its development interests, EPS aims to increase the share of renewable energy in total electrical energy production, [1]. As being one of the largest companies in the electricity production in the region, EPS is committed to applying the latest technologies in the field of renewable energy, increasing efficiency and economically justified and sustainable energy development, primarily on the basis of hydro resources. In this sense, the EPS priorities are revitalization and modernization of existing large and small hydropower plants.

Another important segment, which is gaining in importance and has been recognized as one of the priorities in the Sustainable Development Strategy of the Republic of Serbia is energy efficiency. Given that EPS has identified energy efficiency as an important element of its energy policy. The EPS has undertaken the activities in raising the energy efficiency of their facilities.

To further increase the production of electricity from renewable resources reconstruction of 15 small hydropower plants is planned in years to come. Small hydro power plant (SHPP) “Raška” is the largest of them therefore asking for majority of efforts. Significant amount of activities in this direction have already been taken. The feasibility study performed recently suggests that both units in SHPP “Raška” rated 4MVA, 6.3kV should be replaced by two units rated 3.6MVA, 6.3kV and 1.6MVA, 6.3kV. This reconstruction claims high investments as well as long period of activity.

On the other hand the SHPP “Raška” dates from 1950s. Ever since it was put into operation no significant reconstruction had ever been performed and the maintenance applied was almost exclusively corrective. Preventive care has been limited to very small amount. The total period of operation exceeded the projected lifetime several times and with insufficient care failures and loss of production are very frequent. The equipment installed is outdated and very hard to repair or purchase. Also, according to current standards the control equipment in use has very modest capabilities of monitoring and diagnostics. Additionally, during the exploitation the focus in the maintenance of the plant is given the functionality of equipment and the functionality of signalization was in the background. Poor and irregular indication complicates the control and maintenance of the equipment. The power plant can be operated only by experienced operators and training period of the plant staff is unnecessarily prolonged. Signalization issues reflect to the time required for recovery from power failure. Diagnosis of failure is much more complicated and a large number of faults can be removed only by experienced. The start-up of the unit after transient faults is prolonged because the equipment has to be checked and operated locally and manually. These procedures significantly affect the length of the downtime of the plant

In the particular case, periods of time when plant is out of operation result in several consequences. Besides the loss of energy production, the water supply of around 70 000 inhabitants of Novi Pazar is threatened due to the fact that SHPP pipeline is a part of local water supply system. In case that both units should be stopped, the front gate must be closed and the town water supply will be cancelled. In order to prevent this scenario, the decision is made that at least one unit should be repaired and automated to a degree which will ensure continuous water supply. As a result, the significant reconstruction of governor and control system were requested.

This paper presents an attempt to design unit control which can ensure automated start up with existing degree of automation of primary equipment and integration into the modern concept of smart grid after the SHPP reconstruction.

2. SMART GRID

Smart grid is a new concept of electrical grid which is improved in the efficiency, reliability, economics, and sustainability of the production and distribution of electricity by the means of intensive information exchange (analogue, digital and comunication technology) between the participants (generation, suppliers, distribution etc.) [2]. Use of smart technology such as state estimation enables fault detection and even self-healing of the network without the intervention of technicians. The efficiency of energy infrastructure is achived by greater utilisation of energy available at generators at lower power prices by lowering the redudancy of transmission and distribution lines. Active load menagement (automation of switching on/off heating devices) results in flater load demand during the day as well as active price policies combined with use of communications and smart devices installed at home and bisiness. The smart grid allows systematic communication between suppliers (their energy price) and consumers (their willingness-to-pay), and permits both the suppliers and the consumers to be more flexible and sophisticated in their operational strategies. Sustainability of penetration of large amount of renewable electricity on the grid is achieved through flexibility of smart grid. The consumer could lower expenses for consumed energy by using peak price energy solely for critical loads while buying cheap off-peak energy for others. Finally generators which can offer greater flexibility will achieve better energy price while base-load steam power plants will receive a varying tariff based on the level of demand and the status of the other generators currently operating. So all the participant that exist, energy generation (solar, wind, hydro, steam), micro grids and large networks, energy storage, consumers , are by communications, smart metering, smart control and smart consumption integrated in the smart grid, fig. 1.

Nowadays that penetration of large amount of solar-produced electrical energy is expected it is even more justified to invest in raising the efficiency and flexibility of existing small SHPP so they could sell energy for maximum profit.

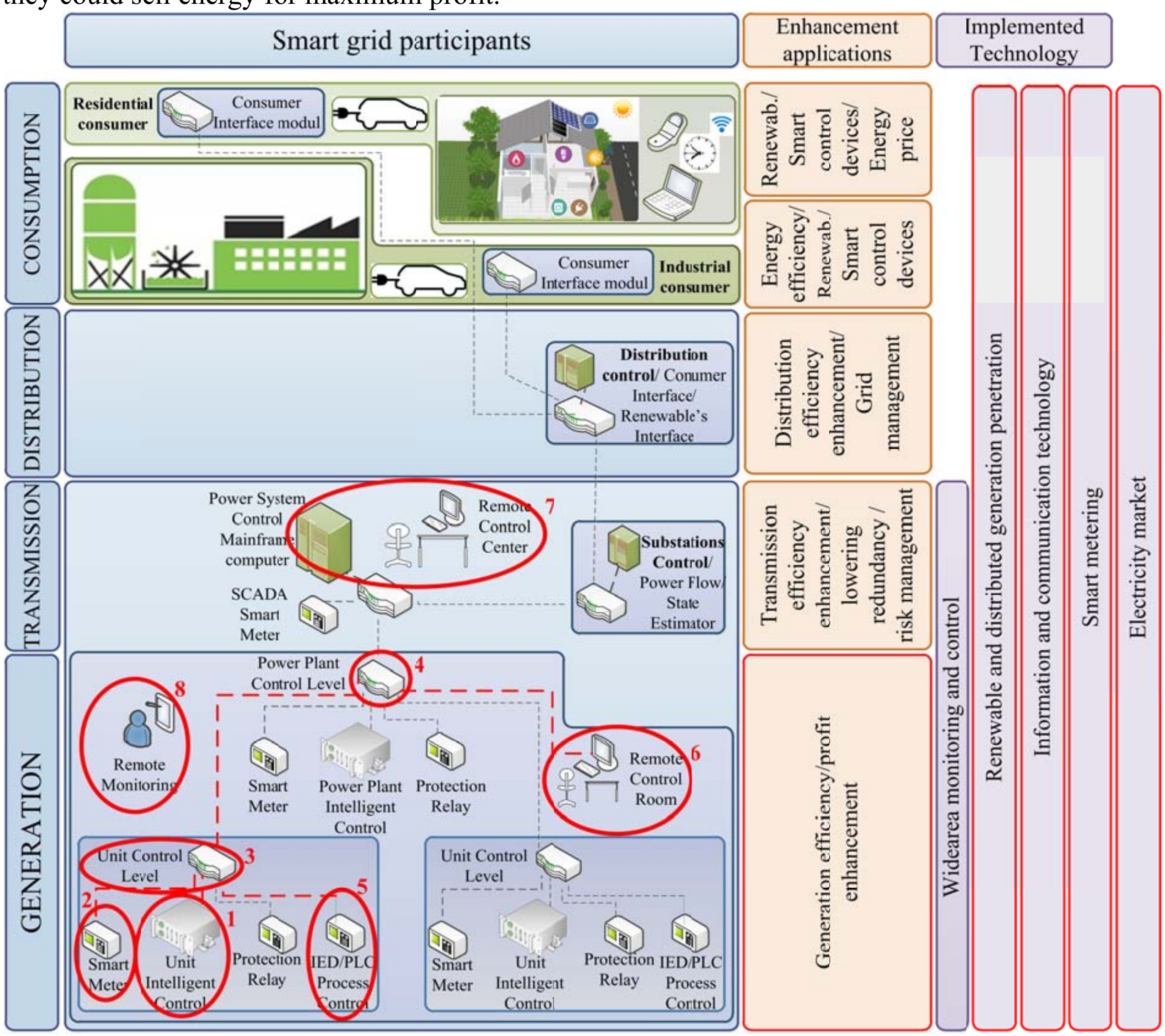


Fig. 1 Smart grid – participants, implemented technologies and achieved enhancements

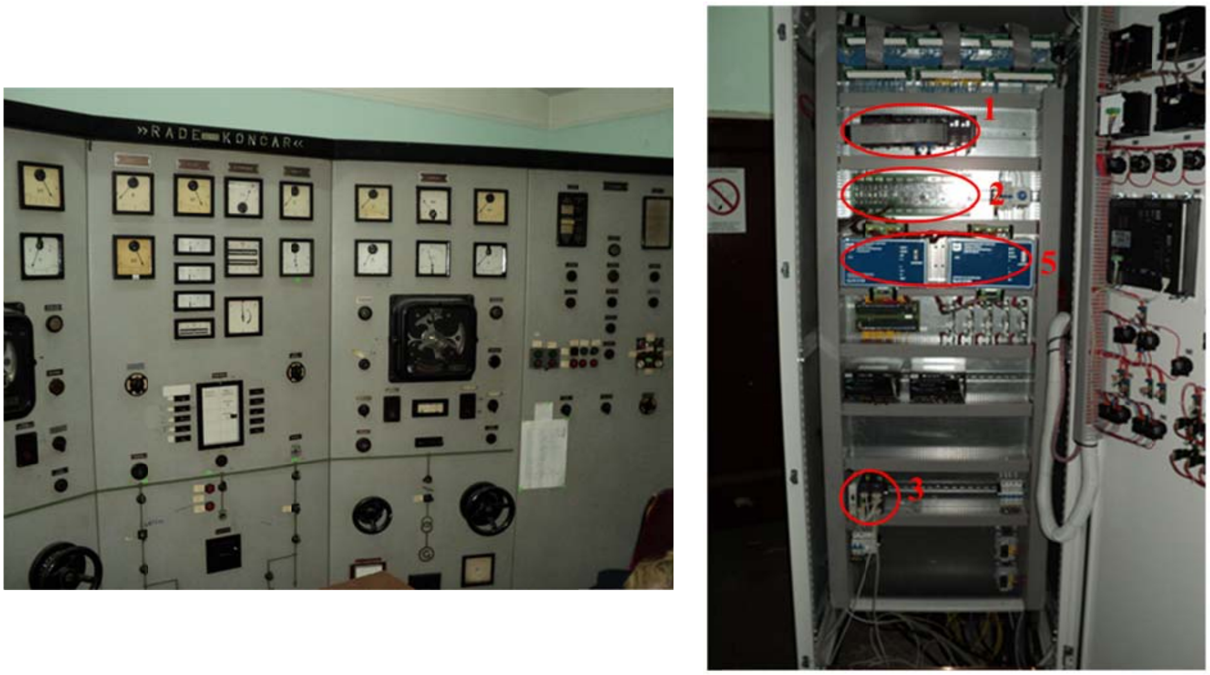
3. CONTROL SYSTEM REQUIREMENTS

The first requirement of the new control system is that it could be integrated into the SHPP, fig. 2. Indication and control signals are by hard wire connected to all subsystems: cooling water system, lubrication, inlet valve, governor, excitation system, switchgears.

Networking with smart meters and intelligent electronic devices (IED) should be implemented.

The smart meters and intelligent electronic devices (IED) should be developed.

The unit should be controlled locally from control cabinet and remotely from control room. Eventually, communication with remote control center will be provided, with control and monitoring functions.



a) b)

Fig. 2 SHPP "Raška" control system a) old control cabinet, b) newly developed control system

4. CONTROL SYSTEM REALIZATION

In this paper an effort has been made to elaborate the use of Programmable Logic Controller (PLC) for control and automation of SHP station, its advantages and cost effectiveness, [4], [5].

Programmable logic controllers (PLC) are widely used for control and automation purposes, [3]. They have advantages in cost, modularity, standardized programming and reliability. Various functions and controls can be achieved by programming the PLC. It can be used for full plant automation including governing of speed control, load control, excitation control, and level control automatic start/stop sequencing, gate control, start/stop of auxiliary systems, and protection requirement etc. Functions other than control, like continuous monitoring, data recording, instrumentation and protections can also be performed. For remote operation, communication with PLC can be established. For continuous monitoring purpose, a personal computer, tablet or smart phone can be interfaced with PLC and continuous data stream can be recorded regularly.

Programmable Logic Controller (PLC) has been chosen as a platform for unit control, detail 1 in Fig. 1 and Fig. 2b. This platform represents industrial grade equipment easily available on the market at different prices so good balance between the price and quality could be achieved. The modular configuration which is easily extendable is one of its main advantages. Having in mind that with reconstruction of all subsystems (cooling water system, lubrication, inlet valve, governor, excitation system, switch gears) the number of status and control signals will be considerably increased, PLC offers the possibility of simply extension the existing platform with suitable modules (analogue, digital, communication, etc.).

Basic algorithm of unit intelligent control is executed on industrial PLC. PLC is linked to the primary equipment through communication network and hard wire connections.

Installation of unit intelligent control should provide turbine and generator start-stop sequencing in fully automatic, step by step or manually controlled procedure. Automated starting sequence begins with pre-start checks of the equipment involved in the procedure. On success, unit auxiliaries are sequentially started until the unit is operating under full-speed no-load condition. Then, the excitation system is started to achieve fully excited unloaded generator. Automatic synchronization is immediately activated and performed until the unit breaker is switched on. Once the generator is connected to network real/reactive power control is performed through control system. Each part of the sequence can be done in local step-by-step or manual manner if appropriate mode of operation is selected.

The stopping sequence differs in normal and abnormal shutdown. Normal stop sequence begins with unit unloading, followed by unit breaker opening and stopping of generator, turbine and auxiliaries. At the end the inlet valve is closed and subsystems are switched off.

Abnormal stopping sequencing includes protective relaying and operator's emergency shutdown. Protective relays detect electrical or mechanical faults or abnormal operating conditions and trip the circuit breaker to isolate equipment in trouble or notify the operator through alarm devices that the corrective action is required. The least amount of equipment is removed from operation following fault. If the fault is transient, the control system, after performing pre-start checks, will allow normal and automatic restart of the unit.

Since the control system is operating with subsystems which cannot be fully automated, the procedures are modified to allow automatic start after the operator confirms that non-automated equipment is in operation. The logic implemented here significantly increases controllability of plant and reduces the time length of applied procedures.

Since the plant personnel is used to manual operation, implementation of Human-Machine Interface was a challenging task. It was concluded that the HMI should be an education device for operator as well. The start and stop sequences are displayed on human machine interface (HMI) panel at the panel-board of control cabinet in a form that will show for the operator the status of the process and the task that will be performed next in a specific flow-diagram. For easier handling, each action commanded by PLC or operator is shown on HMI, Fig. 4.

As a sequence flows, the fields' colour changes to indicate the status so complete insight of process is provided. When the operator participates in start sequencing status of equipment and following steps are clearly indicated, Fig. 5.

As part of unit control system, modular smart meter devices in the form of intelligent electronic devices (IED) [4] is developed, detail 2 in Fig. 1 and Fig. 2. Meter devices contain motherboard with network capable application processor (NCAP) and required number of measurement modules realized as smart transducer interface module (STIM). In particular case module for temperature measurement and current measurement is implemented. The developed solution is very flexible and can be extended with further modules for measurement of some other quantity.

Considering communication network, PLC uses an independent ethernet module for networking to the upper control level, detail 3 and 4 in Fig. 1. In this way firewall between unit and power plant control level communication network is provided. Ethernet technology used with smart meters offers enough speed of data exchange to provide insight into the state of the primary equipment, Fig. 5. Since the unit intelligent control has a complete picture of primary equipment and is equipped with an interface to the upper control level, system is fully prepared for connection to the upcoming smart grid.

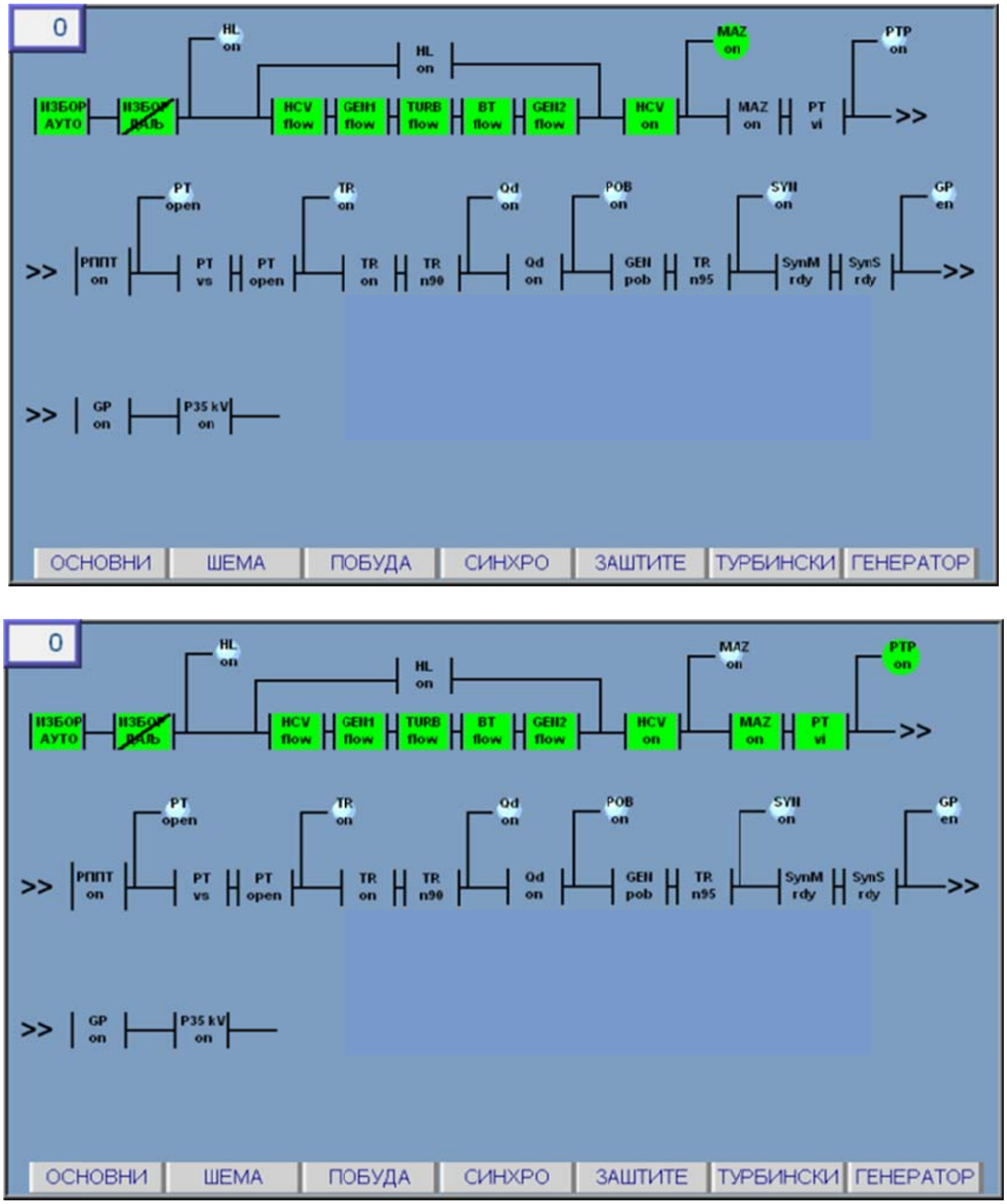
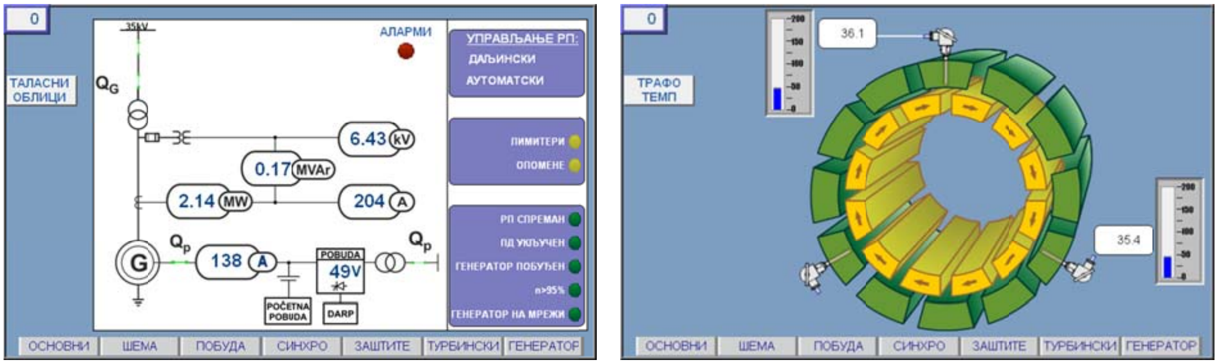


Fig. 3 HMI Unit start sequence – process flow

a) b)

Fig. 4. HMI a) signaling the equipment status, b) interface with governor (IED)



a) b)

Fig. 5 Smart meters: a) excitation system monitoring with 0-20mA signals, b) stator temperatire monitoring

In the SHPP "Raška" hardware required for power plant control level is partially installed (details 6 and 8 in Fig. 1) and network infrastructure is set. Installed hardware is ready for linking unit intelligent control with remote control room and remote control center, detail 7 in Fig. 1.

Significant savings can be achieved by implementing a remote monitoring, detail 8 in Fig. 1. It can provide insight into the state of the plant from a remote location or send e-mails and text messages when an alarm occurs.

5. APPLICATION RESULTS

The new control system of SHPP "Raška" with existing equipment allows automatic stop and start sequencing, start/stop in "step by step mode" and manual control of the unit. This system performs state and time control of whole start/stop sequence as well as certain parts of the sequence. In that way additional diagnostics and protection functions are available.

Automatic start and stop sequencing reduce operational risks. The personnel engagement in power plant operation is fundamentally changed – instead of being just a repairmen, the operator became a part of intelligent process where he can understand the way the plant and each of its part operates. Using information from the control system he can quickly detect if some device is losing its vitality, he can schedule the time for replacement and do it without the electricity or local water supply being threatened. If the fault happens unexpectedly, operators have complete insight in the status of primary equipment and protection relays pointing to the cause of failure and the way of clearing it. Quick elimination of faults reduces the plant shutdown time thus increasing its availability

6. CONCLUSIONS

The partial automation of small hydro power plant „Raska" has shown that a relatively small investment in modern electronic equipment can significantly improve the functionality of the plant. The control of local processes at the level of primary equipment is realized in the framework of distributed devices. These devices, at hardware and software level are complete product of Serbian experts. So not only that the investment funds remain in Serbia, but professionals are also educated and became experienced in working with such up-to date equipment. Finally the device is equipped with modern equipment for on-line monitoring and diagnostics of synchronous machines and network conditions. The implemeted control system resulted in increasing security of energy supply and its efficient use. The implemented new technologies enable the increase in competitiveness of the price of energy generated in SHPP.

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