Vladimir Srzentic, B.Sc.E.E.
Director
HPP KRALJEVAC, Zadvarje
Power generation area SOUTH Split,
I. Gundulica 42
HEP – PROIZVODNJA Ltd.
Zagreb, Ul. grada Vukovara 37
MEMBER OF THE HEP GROUP
CROATIA

Igor Šodan, B.Sc.E.E.
Project Leader
Project Engineering Department
Power generation area SOUTH
Split, I. Gundulica 42
HEP – PROIZVODNJA Ltd.
Zagreb, Ul. grada Vukovara 37
MEMBER OF THE HEP GROUP
CROATIA

Miodrag Kulaš, B.Sc.E.E.
Project Leader
Automation Department
E X O R, Ltd.
Engineering for automation,
relay protection and IT
Zagreb, Buzin – Bani 73
CROATIA

Stipe Smoljo, B.Sc.E.E.
Designer
Control & Protection Department
PROJEKTNI BIRO SPLIT Ltd.
Designing and engineering
Split, I. Gundulica 42
CROATIA

HPP KRALJEVAC, MODERNIZATION OF THE CONTROL SYSTEMS AND AUXILLIARY PLANTS

(AN EXAMPLE OF AN OLD HYDRO POWER – PLANT REFURBISHMENT)

Summary

The paper describes control systems and auxiliary plants of the generating units. The existing control and turbine governing system of the biological minimum generating unit is improved by modernizing the existing and installing new turbine governor and control – supervisory systems. Works upon generating units No.1 and No.2 included replacing original, hydraulic, auxiliary plants by the electromotive drives and installing new control - supervisory and turbine governing systems.

Distributed control and supervisory concept was applied on biological minimum unit (BMU), and on generating units No. 1 and No. 2, the integrated one. Refurbishment of described systems upon other functional groups: common equipment, power supply systems, hydro mechanical equipment at the dam, headrace tunnel, surge tank – compensating reservoir and power plant as a whole, was planned in the following years.

The described approach enables phase build up of the process information system, which, with small investments, secures low service expenses of the power plant controlled by the characteristically simple algorithms.

Despite the modernization of the described systems, all of their original parts were preserved, along with their original old appearance and disposition in the powerhouse of classical architectural design from the beginning of the 20th century.

Key words

Supervisory and control systems, auxiliary plants, functional groups, electric breaking, turbine governing

Introduction

HPP Kraljevac is located near a place Zadvarje, at the left bank of the river Cetina. The wider Cetina river – basin area surfaces about 4500 km^2 and comprises the following regions: Sinj, Duvno, Livno, Glamoc and Kupres region. At the narrower part of the river – basin surfaced 1500 km^2, which extends from the Sinj region, over the canyon part to the sea, the river Cetina flows on the surface a 100 km long.

The average annual precipitation comes to over 1300 mm/m^2 and is mostly concentrated at two short periods: in November – December and March – April. About 60% of all precipitation feeds the river Cetina from underground and by floods. Mean annual Cetina river flow comes to 102.6-m3/h. Hydropower - plants built on the Cetina River – basin until now days have the following basic characteristics:

	Installed capacity (MW)	Annual output (GWh)	Year of construction
HPP Kraljevac	46,80	35,00	1912/32/90
HPP Peruca	41,60	120,00	1960
HPP Zakucac	486,00	1700,00	1961/80
HPP Orlovac	237,00	400,00	1973
HPP Đale	40,80	150,00	1990
T O T A L	852,20	2410,00	

The amounts given in the "Annual output" column are general, but generally speaking the water power system of the Cetina river basin makes 23% of installed capacity and 19 % of the annual output of the Croatian power system.

Historical survey and basic power plant's data

In the 19th century the water power of Dalmatia was mostly used in the primitive hydraulic plants, flour –mills (water-mills) and stamping-mills.

Speculations upon the possibility of the Cetina river power potential exploitation emerged at the end of the 19th century. In 1897, the firm Schuchert & Co. designed a basic project for utilization of a considerable natural head of the river Cetina near place Zadvarje. Engineers Deškovic and Wagner have designed a similar project in 1899 for exploitation of the utilizable amount of water flowing 25 m^3/sec and falling 87 m, Velika and Mala Gubavica waterfalls (heads).

Mentioned head of 87 m, represented a small part of a total head of 292 m that stretches through the scenery between a place Trilj and the Adriatic Sea. A financial group in Belgium has authorized engineer Macquet to closely examine all technical and economical possibilities of the power exploitation of the river flow Cetina between Trilj and the sea. After a thorough examination Macquet suggested building an 8.2 km long tunnel to cross over the river Cetina bend. The tunnel stretches between the Culic water mill downstream the town of Trilj, and the place called Zakucac located before the mouth of river Cetina to the sea, near the city of Omiš. Building such a tunnel would be a way to gain a net head of 224m, which with a normal, low water flow of 35 m^3/sec corresponds to the constant power production of 58.8 MW. Amount of the specific investments, according to such a project, was among the lowest in Europe.

The first stage

Despite Macquet's high-grade project, a less economical but cheaper project by engineer Deškovic was approved. Therefore, in 1904 the Viennese association "Wasserwerke" was granted a concession to utilize concentrated head of Velika and Mala Gubavica of 87 m and water flow of 25 m^3/sec, in accordance with the approved project. In 1907, the Italian association "Sufid" has bought a mentioned water resources management concession, and in 1909 has requested its extension to 75 m^3/sec water flow and 110 m head.

HPP Kraljevac was built in the period between 1908 and 1912 (the first stage), when it was put in commission, and the extended concession was not approved until 1915.

A detailed project for building up HPP Kraljevac was designed by engineer Charles de Halle in Geneva in 1906 and was modified by general manager of the "Sufid" company engineer E. Cairo. The first stage of the HPP Kraljevac construction included building of the dam, bypass tunnel, headrace canal, headrace tunnel, surge chamber, two steel penstocks and the power house comprising two generating units with installed capacity of 12.8 MW, and discharge of 15 m^3/sec each. According to its dimensions and specific investments, HPP Kraljevac was in 1912 among the largest and the cheapest hydro power plants in Europe.

The project planned installation of four generating units, so the surge chamber, and all constructive parts, from the dam to the tailrace canal have been built during the first stage accordingly. Total installed capacity of the power plant was 25.6 MW. Parts of the penstocks, as well as all parts of the turbines and generators were transported nautically to Makarska and then by horse-drawn cart to the building site.

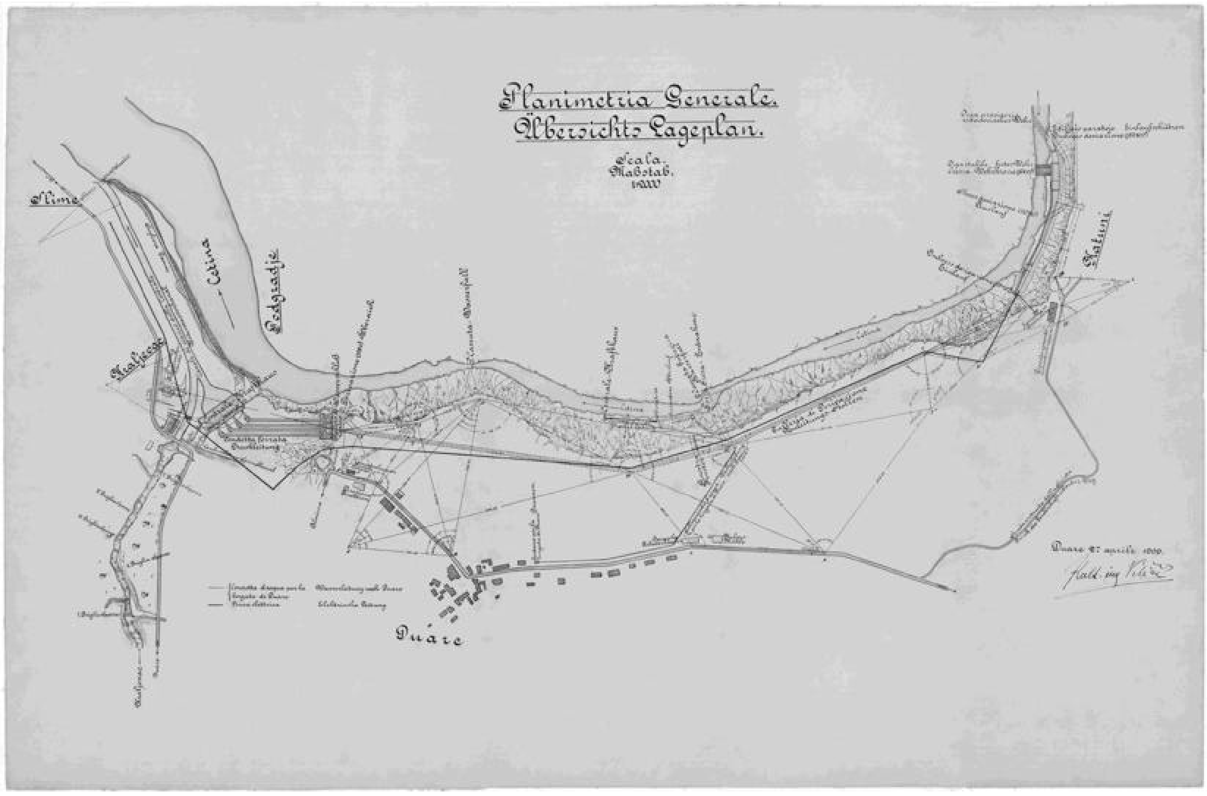

Fig. 1. Original situation plan HPP Kraljevac from 1906 with all nowadays existing objects

Electrical power produced in HPP Kraljevac was transmitted by a 23 km long transmission line to the carbide and Cyanamid factory placed by the seashore in Dugi Rat built in 1912. During the first building stage the power from the hydro power plant was used only to run the mentioned factory that, by the year 1917 could only receive 11.5 MW, and from 1918 about 12 MW, only a bit more than half of the maximum capacity of the hydro power plant. In this period, only a half of the possible hydro power plant production is used. No power production data of HPP Kraljevac were preserved from that period. It was typical that at the time HPP Kraljevac had no generator or transmission line voltage circuit breakers. Shutdown of the power plant was executed by decreasing the generator excitation voltage and by stopping the water flow through the turbines.

Since the commissioning of the power plant (in 1912.) until 1924, the existence of such a large source of electrical power as HPP Kraljevac has had no bearing to the electrification of the surrounding area. In 1926 a 50 kV transmission line Dugi Rat – Split was built. That way Split, only 13 years after HPP Kraljevac was built, enters the supplying area of this power plant.

The second stage

In 1929, a new association called “La Dalmatienne” was founded residing in Paris that repurchased all the property belonging to the “Sufid” association, including HPP Kraljevac. The new association installed newly acquired turbines and generators and finished, until 1932, all the works planned in the second stage of the building up of HPP Kraljevac. The second stage works on HPP Kraljevac include: expansion of the power house, installing of the new two penstocks from the surge chamber to the power house and installing of the two new generating units with installed capacity of 20.8 MW and discharge of 25 m^3/sec per unit. After finishing the second stage of the HPP Kraljevac construction total installed capacity of the power plant was increased to 67.2 MW, and total installed discharge to 80 m^3/sec. Having total installed capacity of 67.2 MW HPP Kraljevac was the biggest hydro power plant on Balkan at the time. After finishing the second stage of HPP Kraljevac construction, generating units were renumbered. Generating units installed in 1912 were numbered 3 and 4, and generating units installed in 1932 were numbered 1 and 2.

Installation of the two new generating units considerably increased the power production possibility of the HPP Kraljevac, which amounted to 451 GWh/year. However, this did not increase the minimal possible monthly production, while the production differences between humid and dry months were considerably increased. Power production of HPP Kraljevac from 1931 to 1939 was constantly increasing, somewhat varying through particular years.

At the middle of the Second World War, the partisans removed the copper cable at dual transmission line to Dugi Rat, in the section from Pavic Bridge to Omiš thus making impossible for Omiš, Dugi Rat and Split to be supplied with electrical power from HPP Kraljevac. After that, the Italian army totally removes the copper cable, through the whole length of the transmission line. In the period between Italian military occupation and repeated occupation of HPP Kraljevac by German army in September 1943, vital parts of the power governor at all four generating units were dismantled, transformer oil was drained to the river Cetina and crane equipment was disabled. During the continuation of war the power house and the generator bus bars were damaged by American bombing.

In 1946, all four generating units of HPP Kraljevac were repaired. At the middle of 1948 parallel operation of three hydro power plants, Kraljevac, Miljacka and Jaruga was enabled and thus power system of Dalmatia began operation. In 1955 rated voltage of the Dalmatian power system becomes 110 kV, in 1960. HPP Peruca was built with its significant water reservoir, and the power system of Dalmatia was connected to Zagreb by 110 kV transmission line. This was the period of the biggest production of HPP Kraljevac.

The third stage

In 1961, a first stage of the HPP Zakucac was built (using a modified project of engineer Macquet). Considering the 30-year period from 1926 to 1955, the average possible production of the HPP Kraljevac is decreased form 451 to 149.3 GWh, in order to use Cetina's discharge at bigger head in the HPP Zakucac. After finishing the construction of the second stage of the HPP Zakucac in 1980, the possible annual output of the HPP Kraljevac is decreased to only 18.3 GWh.

Mostly through the year the Cetina riverbed, downstream the Prancevici dam was filled with so called biological minimum water (the amount of water necessary to sustain the ecological environment intact). In the raining periods of the year the water of the Cetina riverbed was enriched with other streams. All four generating units of HPP Kraljevac were designed to have relatively high installed discharges (technical minimums were higher than 5 m^3/sec discharge), so discharges up to 5 m^3/sec during hydrological year could not be used in power production.

In the third stage of the HPP Kraljevac construction, which lasted from 1990 to 1991, generating unit No. 4 (dated 1912, 16 MVA) was dismantled, and replaced with the biological minimum generating unit[1] (BMGU), which installed capacity is 5.3 MVA. BMGU is designed to use all discharges from 0.5 to 5 m^3/sec in power production. After installing BMGU, the average annual output of the HPP Kraljevac was doubled.

Generating unit No. 3 is preserved and it is not used in power production. The decision about preserving rather than dismantling this generating unit was made for historical and architectural reasons.

Modernization reasons and approach

During seventies, a power-economical analysis was made and it proved the necessity of HPP Kraljevac to the power system, so during eighties a partial reconstruction of the primary equipment of the generating units 1 and 2 was executed. During nineties this analysis was updated and a present state assessment of the HPP Kraljevac plants was made in order to consider the role of HPP Kraljevac in the power system now days.

The conclusions are that in spite of all the changes that took place in the Cetina river basin, HPP Kraljevac still has an important and multiple roles in the power system. Fundamental task of the power plant is the permanent utilization of ecologically acceptable water flows (a water flow higher than the highest mentioned biological minimum to this day) downstream the Prancevici dam, its own inflows and power production when occasional water excesses occur. The value of this power plant is also evident while operating in extraordinary conditions, and as a power system reserve in case the upstream power plants are damaged.

Motives for the HPP Kraljevac construction as well as its subsequent reconstructions, annexes and modifications have been stipulated by economical, technical and historical reasons. Historical reasons concern the role of the power plant through various historical periods and these reasons caused different modes of HPP operation. In the early days, HPP operated under conditions when no power system existed, when power plant operated in the "island" mode. During fifties, it becomes the main power plant in the power system of this European sub region, and now days it has a certain polyvalent role that comprise functions of power production, transmission and distribution.

[1] The correct expression now days is considered to be: ***ecologically acceptable discharge***

Another similar story could be told about hydro technical system of intake, supply and evacuation of normal, high and extremely high water amounts. HPP Kraljevac has been a regional water supplier where human operation upon hydro mechanical equipment was very significant.

Now days all kinds of plants tend to operate with minimal human operation. Personnel are reduced to minimum while plant achieves a very high level of automation. HPP Kraljevac has not yet been modernized in such a way, but personnel is ageing and retiring. Soon, a lack of personnel could be felt.

Therefore, it is necessary to modernize technical systems in the power plant in order to reduce human operation and plant control, managing and maintenance costs to acceptable level. This modernization does not imply numerical reduction of employees, but a need for the new profile of employees, people who will perform skills needed to run new modernized plant. To do that employees have to be prepared to keep up with technology development and constant education.

Modernization of auxiliary plants

Installing of safety-appliance to avoid deformation of turbine blades

Equipment designs of HPP Kraljevac in the first and second stage of construction were characteristic for the given period and technology. In spite of indisputable quality based on robustness of the construction materials, such designs also had certain imperfections. For example, turbine guide vanes installed in the first and second stage of construction of the HPP Kraljevac had no safety-appliance to avoid deformation of turbine blades now of guide vanes closing. It is common knowledge that in the process of guide vanes closing, a piece of material that passed through the intake thrash rack and was brought to the turbine spiral by water stream, could get stuck between two blades, thus preventing turbine guide vanes from closing and eventually a generating unit from shutting down. Such a problem can be solved in several ways. One way to solve the problem is to weaken on purpose particular spots in the construction so that it cracks and is repaired to get the turbine started again. Deficiency of such a solution is that a blade is never hydraulically ideally shaped, so in certain discharge ranges significant oscillations and vibrations can occur.

The problem of avoiding deformation of turbine blades in HPP Kraljevac is solved by using so called “friction springs”. Originally, a blade shaft is stiffly wedged in the bore of the corresponding guide vane lever. The bore is conically dilated and in such a space, a corresponding conical steel element was placed. The cloak of this conical element was cut obliquely to form a spring. A blade shaft passes through the spring hole. A moment key draws using corresponding screws and supports, conical spring tight until such a friction is achieved between the walls of shaft spring and bore, that it insures transmission of a maximum turning moment from the lever to the blade shaft in the normal turbine operation. Such a mechanism is installed intermittently at half of the blades of the guide vanes of each turbine. If the material should be stuck between two blades during the closing of the guide vanes, a moment upon the neighbouring blade shafts exceeds the maximum turning moment at normal operation. Friction coupling loosens, guide vanes in the closed position leak more because of locally expanded air gap between two blades, but there is no deformation or rupture. After shutting down the generating unit, emptying the penstock and turbine spiral, displaced blade is placed in the original position and the moment key draws it to the same moment value as before.

Lubricating and oil –pressure systems

Old generating units No. 1 and 2 installed in 1932 have two classical two-part bearings, one of them radial and the other radial-axial. Bearings are lubricated by forced circulation and cooling of oil. Original systems for circulation and cooling of bearing oil have consisted of the oil reservoir, cogwheel pump driven by a small Francis turbine and cooling spiral sunk into the pool of running water. Therefore, the source of energy for the generating unit lubricating system was the water pressure from the penstocks. Opening manually a corresponding gate that brought water to a small Francis turbine started the generating unit that pumped oil for bearings’ lubrication. A machinist performed that action.

Described equipment was worn out, and its automation was almost impossible, so old oil-pressure system was replaced with a new one. New system consisted of main and spare circulation pump, main and spare oil filter, electric valves, signalling pressure circuit breakers, flow display and air cooler with main and spare ventilator. Three-phase asynchronous motors directly drive bearing oil pumps. Auxiliary power supply 220 V DC supplies the spare pump via DC/AC converter manufactured by “Omron”, so a continuing bearing oil circulation is ensured even in case of defect of the auxiliary power supply 0.4 kV AC.

Fig. 2. Original turbine governor

Fig. 3. New lubricating and oil –pressure systems

Hydraulic part of the turbine governing system, that is turbine guide vanes control systems is realized with new, higher operating pressure of 120 *bars*. Within the cylinder of the old servomotor a new, standard servomotor is installed. New servomotor is of the differential type, with a diameter reduced proportionally to the increase of the pressure. The existing motion of the engine of 500 mm is preserved. A new hydraulic generating unit supplies the system with pressure oil. All the elements of the new hydraulic system: servis -valve, proportional valve for slow changes, valve for fast changes etc. are standard. Because of high operating pressure, the amount of oil is incomparably minor to the oil amount in the old system. Oil is of the ecological type and therefore there is no danger of pollution in case of possible incident.

Control sequences and interlocks of this subsystem have been worked out in the process station of the generating unit, which is realized upon the standard industrial controller “Simatic type S7-300” manufactured by “Siemens”. This controller also processes control sequences of other subsystems and turbine governing system algorithms.

Connecting the generating unit to the power system

Current single line diagram of the HPP Kraljevac is one of the most complicated that authors have seen through the years of engineering practice. HPP Kraljevac has four voltage levels (auxiliary supply systems 0.4 kV AC and 220V and 48 V DC were not taken into account): 3.5 kV, 3.8 kV, 10.5 kV and 110 kV and numerous transformations. This creates a problem of reliability, and such ageing equipment takes more employees to operate it.

One 16 MVA generating unit and one 26 MVA generating unit are connected via 3.8 kV generator voltage double bus bar system to the 42 MVA power transformer. BMGU is through generator transformer 10.5/35 kV connected to the 35 kV grid. Activating of the preserved generating unit No. 3 (16 kV) is questionable, and if it is realized it will be connected to the power system via new generator transformer.

These days dismantling of the generator voltage (3.8 kV) bus bar systems and switching equipment is in progress in HPP Kraljevac. Generators No.1 and No.2 (installed in 1932.) will be connected to the power system via existing 42 MVA generator transformers 3.8/110 kV. This reconstruction was motivated by inability to further maintain generator voltage (3.8 kV) switching equipment, by possibility to decrease short circuit current and simplify the connection of the generating units to the power system and several other technical and economical reasons.

Cooling and drainage systems

Cooling and drainage systems are practically in the original state as they were installed in 1912 and 1932. The only device installed in the seventies is the rotation filter, which is used for the particle filtering. Water contains exceptionally high level of calcium carbonate ($CaCO_3$), so the reticules of the rotation filter quickly plug. Therefore, it is necessary to install a spare rotation filter. In addition, because of calcium carbonate sedimentation, active cross section of the original pipelines and fittings is reduced at certain parts of the system to approx. 20%. Drainage system was added a corresponding separator for ecological reasons.

The problems mentioned above induced an imminent beginning of the both systems' thorough reconstruction. Main project and tender documents for reconstruction of the both systems are currently in process of elaboration. The reconstruction is scheduled for next year.

A separate process station will be connected to the power plant's process LAN to ensure control of these systems.

Modernization of control and supervising systems

Current state of the secondary equipment of functional groups for **C**ontrol, **I**ndication, **P**rotection, **M**easurement and **R**egulation (CIPMR) at HPP Kraljevac is very different. Secondary equipment associated with generating units, switchgears and hydro mechanical equipment (HME) of the first and second stage of construction is the eldest, obsolete, exclusively of electromagnetic relay type. When BMGU and its corresponding parts of switchgear and HME are in question, its secondary equipment was of electronic-analogue type. At the time of commissioning that generation of equipment was already technologically expiring. Old equipment (installed in 1912. and 1932.), in spite of its age is more disposable, but also less reliable than the new one.

In spite of the fact that BMGU is operating since 1990, the choice and quality of installed primary and secondary equipment has resulted by relatively frequent operation failures, some of which were very serious. There is relatively large number of shut downs caused by protection operation that acted upon transient voltage phenomena in the 35 kV grid to which BMGU is connected to. Because of low-quality sensors, actuators, feedback and analogue type electronics, turbine-governing system frequently failed and caused operation of turbine protection. Operating intermittence of BMGU is therefore significantly higher than expected for such a type of generating unit. There is also frequent failure of sequence automating device realized by auxiliary relays (type PR 41) and very poor control and indication elements on the front side of the BMGU control cubicle. All the problems mentioned before required very frequent and complicated, non standard and unexpected manual intervention of operator and maintenance staff.

Quality and automation level standards of particular function groups and power plant as a whole are also so different that neither power plant nor BMGU in present condition can be included in the system of remote supervision and control.

On the other hand, present role of the HPP in the power system, as it was explained in the section 3, imposes the need for automation of the power plant to the level that will ensure technology process control without human operation. Considering the described state of the power plant and funds available, secondary equipment of BMGU was first reconstructed, because of its importance regarding time spent in operation. During last three years gradual improvement and modernization of the control and supervising system of that generating unit was made.

The new control and supervising system of BMGU is designed and realized with standard equipment that can be found on domestic market. It is realized as distributed digital system, which consists of two "Siemens" controllers, type S7-300, with processors CPU-315 and two control panels UNIOP ECT-16, a product of domestic firm "Exor" from Zagreb. Controllers and control panels are connected via network that uses MPI (**m**ulti **p**oint **i**nterface) protocol, and all four devices mutually communicate.

The first controller, witch is in function of PLC (Programmable Logic Controller), replaced old relay logic and is now controlling all the plants of the BMGU: turbine governor oil system, system for oil lubrication of bearings, turbine inlet valves, servis-valves and turbine governors. Driving machines of BMGU are two Francis turbines in tandem conjunction placed on the same shaft as generator, and therefore there are two turbine governors, that are selected and started from this controller. Parallel to the old analogue governor a new one was added in form of yet another controller. Besides mentioned, the first controller is also the interface towards other parts of the generating unit such as excitation system, synchronizer, generator circuit breaker, etc. Master control functions (emergency shut down, switching off of the generator and excitation system circuit breaker, etc.) were realized fully redundant. Besides existing master control circuits realized with quality bi stable relays same functions were added in parallel via generating unit controller.

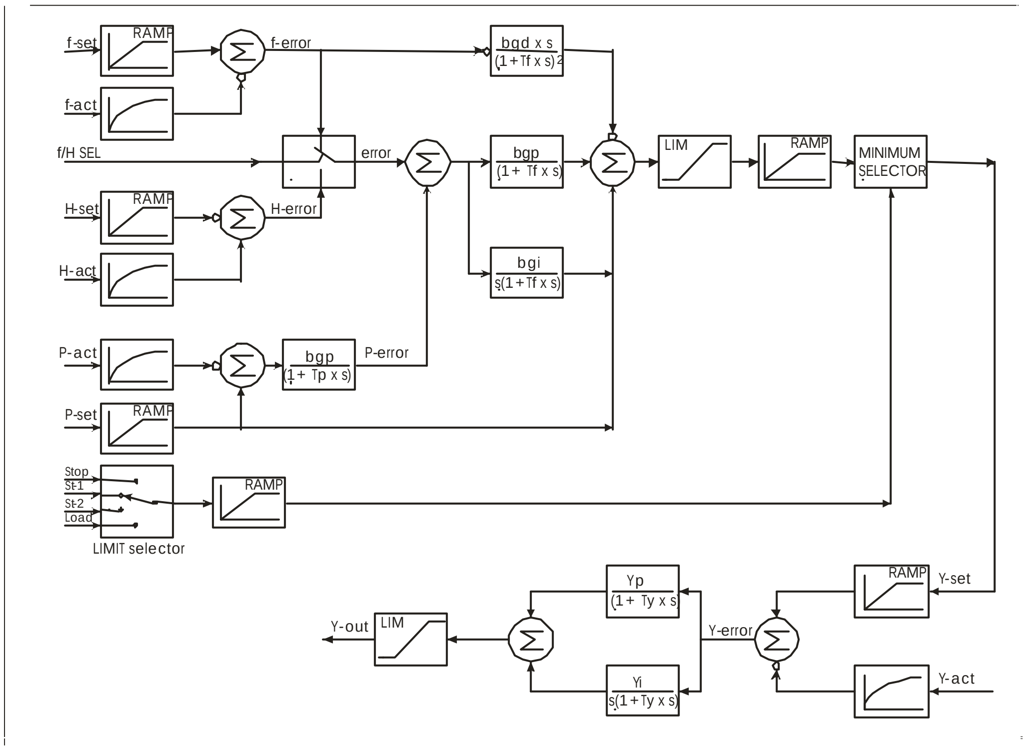

Fig. 4. Turbine governor control diagram

Control panels are identical and equal. One is placed in the control room, and the other is placed on the front side of the turbine plants' cubicle. These are stations with TOUCH LCD monitors, size 5.6'', 16 colours and resolution 320x240 pixels or 40x16 characters. Their capacity is 80 pages (pictures), 512 kB flash memory, 1024 alarms and 256 events. The function of control panels is to display all active process values, process parameter setting, manual start of the particular parts of process and alarm display and observation. Alarm list is printed on printer connected to the station in the control room. Alarm list is printed chronologically at the moment alarm occurs, when operator confirms acknowledgement of the alarm and at the moment of alarm interruption. On this way, all events in the process are chronologically put in order and very clearly displayed and their analysis can explain the real reason of malfunction.

Generating units No. 1 and 2 (26 MVA each) built in the second stage of construction in 1926, did not have automation control systems, and because of those two machinists had to be present in each shift. Turbine governors of Watt centrifugal system type driven by transmission belt, because of age could barely keep the rotating speed steady in the no load operation. This way, when participating in the power system, generating units were practically ungoverned. The similar situation occurred with voltage, segment type controllers manufactured by BBC. Therefore, worn out regulation systems were replaced in a way that function of the sequence PLC automation device and the function of the turbine governor are hardware integrated in one standard "Siemens" controller S7-300. Voltage controller is realized as a separate digital processing unit with "Motorola 6000" processor and fast VMS bus. Digital voltage controller is installed as a constituent part of the excitation system of DC rotating exciter. Constituent part of the excitation system, manufactured by "Koncar – Inem" is the new excitation breaker for demagnetising the main excitation circuit of the synchronous generator, and equipment and devices for excitation system supervision and protection. Parts of the excitation system are also limiters of excitation current and voltage peek values of the generator.

Annexes of the new supervising and control systems

Because of rather high BMGU operation intermittence, it has proved useful to have a corresponding breaking (shut down) system of generating unit. Originally, no breaking systems were designed or installed, and the lubrication of the horizontal generating unit bearings is realized with high-pressure, initial (starting of the generating unit), and low pressure (steady state of the generating unit) lubricating system. Because there was no breaking system installed, stopping of the generating unit, during shut down, lasted approximately about 30 minutes. Moreover, generating unit has to be in idle state before any interventions were taken upon it or it is restarted. New electrical breaking system was installed, because there was no space to install mechanical breaks. Electrical breaking system was placed in the cubicle, and realized upon the platform of the excitation system digital voltage controller as described in the previous section. Transformer for the excitation system power supply in the electrical breaking regime is also installed, together with corresponding relays for switching the sources of the excitation system power supply, and vacuum connector to short circuit the BMGU generator outlets. Sequences for insulation drying and excitation system's control during testing of the relay protection system, for example, were implemented.

Old bus bar's disconnectors of the preserved generator No. 3 (generator voltage bus bars) were used as jumpers in the drying process of the stator windings insulation. The generators are directly air cooled, so after being in idle state for a longer period, the insulation has to be dried by rotating the generator in the short circuit regime (stator windings were reinsulated to the F class 30 years ago). A drying sequence is also fully automated. Disconnectors for the drying process will be used in future as disconnectors for the electrical breaking process too. To achieve that it is necessary to ensure the corresponding independent power supply source for the excitation winding of the synchronous generator. A possible source could be electrical breaking generating unit, which is to be dismantled in the HPP Orlovac when generating unit excitation systems in that power plant are to be replaced.

Originally, the power plant is designed and constructed in a way that, every generating unit has it own penstock. As it was mentioned before, the generating units built in the first stage of the HPP construction in 1912 are no longer in operation. One of the reasons is their worn out state. Penstocks of the second stage generating units (installed in 1926.) are still in good condition and worth maintaining. Therefore, a bifurcation upon the penstock of the generating unit No. 2 (26 MVA) is built to ensure operation of the BMGU. Behind the bifurcation, in the penstock of the generating unit No. 2, a butterfly valve was installed, which opens only when generating unit No. 2 need to be in operation. Butterfly valve is originally equipped with a by-pass for the pressure equalization. Practice showed that one by-pass is hardly enough to compensate leaking of the generating unit No. 2 turbine guide vanes; so another by-pass of the same capacity was installed. This way the opening of the butterfly valve is reduced to a 30 second period. The valve and by-pass drive is a standard engine manufactured by AUMA. Control sequence is operated upon the separate controller S7-300.

Fig. 5. PLC with turbine Governor GU 2

Fig. 6. Control Cubicle of GU 2

Fig. 7. Digital voltage regulator of G 2

At the time of publishing of this paper, old electromechanical BBC generator protection systems are being replaced in HPP Kraljevac on generating units No. 1 and No. 2 and static analogue protection system by "Koncar-Inem" on BMGU. New numeric protection systems are installed. Protection systems are manufactured by "Siemens", type 7UM62. Besides classic functions of the numeric generation protection system, this type of protection includes all these functions "in one box". Considering small annual operating hours of the generating units No. 1 and 2, protection systems of these units will not be fully redundant. Protection system of the generator and generator transformer together is redundant in combination with new protection systems of the generator transformers, type "Siemens 7UT". Generator protection systems will be connected to the power plant process station, manufactured by "Siemens", type SICAM SAS with corresponding IEC protocol with millisecond tagging resolution. Generator transformer protection systems will use PROFIBUS real time protocol.

Further development, modernization and efficiency increase of the generating units, primary and secondary systems

Dam and surge chamber hydromechanics equipment (HME) systems

HME systems at the dam and surge chamber are more or less originally preserved in spite of certain refurbishment attempts. The dam is equipped with flap gate placed in the by-pass tunnel, spillway structure and in the intake structure if the headraces tunnel. Surge chamber has "fish belly" gate in front of the penstocks' entrance and gate valve at the bottom outlet. Driving mechanisms of all gates are of electromotive type. They were refurbished numerous times, but the refurbishment results were unsatisfactory.

Main design and tender documents for the refurbishment and replacement of the gates' driving systems will enable performing of these works next year. Refurbishment task foresees a hydraulic drive of the gates satisfying also all ecological conditions. This drive was tested by installing it to drive small gate valve at the bottom outlet. Test proved satisfactory results.

Flap gates will be driven by hydraulic rotation motors, and "fish belly" gates by hydraulic cylinders at both segment ends. Segment gates are very wide and strictly, parallel operation of the hydraulic cylinders is required to avoid possible torsion of the valve construction.

Gates control will be realized by controllers of the same type as other process stations or PLC, in distributed manner, i.e. one controller to control the dam gates and the other for the surge chamber gates.

Air gap reduction of the guide vanes

Because of the technological possibilities, construction solutions, unsatisfactory overhauls, and turbine revisions, increased air gaps of the turbine guide vane blades were noticed at the generating units No. 1 and 2 a few years ago. Air gaps were increased between blades it selves in the closed position, but also at the blade bases on the turbine housings. The first problem is solved as described at the beginning of the section 4, and the other is planned solved in one of the next year's overhauls. Dismantling of the turbine covers and their treatment upon the turning lathe is necessary.

Air gap reduction of the guide vanes in the closed position caused the turbine spiral to fill with water faster when starting the generating unit therefore significantly reducing starting time of the generating unit and increasing its efficiency. Generating units will be even more efficient once the air gaps at the bases of the blades are reduced.

AC and DC auxiliary power supply systems

The existing AC 0.4 kV, 50 Hz auxiliary power supply system is to be replaced with a new one. Main design and tender documents for the reconstruction and replacement of the worn out AC and DC auxiliary power supply systems are already in the process of elaboration. New AC auxiliary power supply system will be connected to the new auxiliary power supply transformer, which will be coupled to the BMGU generator outlets via separate connection. Such a reconstruction enables further simplification of the power plant's single line diagram. Distribution switchgears will eventually be separated from the power plant's switchgear, which is situated in the nearby transmission substation. All these switchgears are controlled from the HPP Kraljevac control room. These switchgears, in near future, will be controlled from separate control locations due to reforming of the Croatian electricity and forming of new trading companies.

The existing DC auxiliary power supply system with single rectifiers, distribution and classical batteries 220 V DC and 48 V DC with the grounded plus pole is worn out. Its short circuit protection is not selective, it is not redundant and batteries have lost its capacity. That is the reason that design and tender documents are being made for acquisition and installing of the new system according to the standard and criteria of the Croatian electricity with non-maintaining batteries.

Technological video supervising systems

Eventually, it is planned for the power plant to operate under remote supervision and control. Described reconstruction and automation of the power plant's systems may solve part of the problems occurring in such operation of the power plant. Dam and surge chamber are located in the narrowest and deepest part of the river Cetina canyon, therefore, besides automation of these plants, a corresponding video supervising system (VSS) is necessary.

VSS is digital and cameras operate during nighttimes in infrared (IR) range with IR reflectors. VSS is controlled by a separate process station of the video system. Process station is an industrial PC that registers, saves and evacuates events in the multi-purpose information system. Video process station uses the same operation system and LAN as other PC computers. It does not use any special software but standard web browser as a user interface.

Installing a corresponding power and optical cables of the total length of 1.5 km; parallel to the penstocks and through a tunnel; will enable such supervision. Secondary equipment of VSS will be supplied through AC 400/230 V auxiliary power supply system via UPS (**u**ninterruptible **p**ower **s**upply) device with 2 hours autonomy.

Scada

All process stations and numerical relay protection devices stated in this paper are interconnected through process LAN to the power plant's process station manufactured by "Siemens" type SICAM-SAS. Power plant's process station is connected to the operator's station and are both located in the control room of the power plant. Sicam WIN CC scada system is to be installed upon the operator's station. Such a control supervising system enables a corresponding user interface based on the windows system platform. Besides standard functions, such as: reporting, chronological registration, trending, supervision and control, it enables function of the virtual operation's station, thanks to its supplementary application components based on the server-client architecture and intra (inter) net protocol. This way a supervising spot can be anywhere as long there is Internet available.

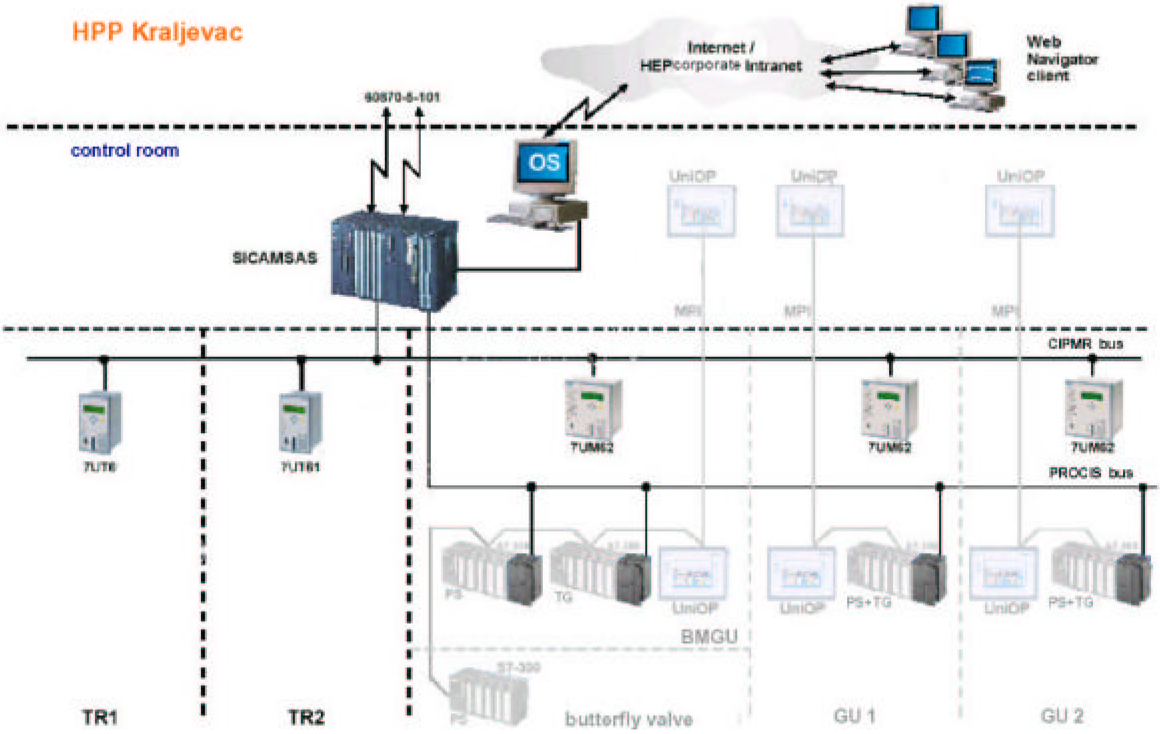

Fig. 8. Process information system in finally form

IT functions and equipment

IT equipment at HPP Kraljevac includes today an Office LAN, process LAN and digital telephone exchange. Office LAN hardware is based upon the horizontal installation with a 10 Mbps switch. System software is Windows 2000. Database is ORACLE, and numerous applications are developed in the server-client architecture at corporation intranet with a standard web browser. Because of considerable amount of data and numerous graphic interface applications, cables, connectors, switches and computer network adapters will be replaced to increase LAN speed to 100 Mbps.

Power plant's momentary link to WAN is via leased analogue (modem) data channel of 64 kbps speeds, which practically operates at approximately 30 kbps. Link's quality is poor because local operator, which monopolises the market, is not interested in development of the local immobile telecommunication infrastructure. Because there is a need to transmit a large amount of information, including wide band information (video, audio and similar), there is in progress acquisition and installation of the microwave link 7 GHz frequencies, capacity 8x2 Mbps.

Process LAN described in former sections, is via operator's station connected to office LAN and through Internet to WAN. The other communication path goes directly from process station SICAM-SAS to the remote control centre. This way two 2 Mbps channels will be used.

The third channel will be used to digitally interconnect of the digital telephone exchanges in the HPP Kraljevac and neighbouring HPP Zakucac. This interconnection is provided today through two analogue VF channels via 110 kV transmission lines. Two channels will be used to transmit information from the transmission substation Kraljevac.

Conclusions

In spite of all the changes that happened in the Cetina river basin, HPP Kraljevac continues to have a significant and multiple roles in the power system. Fundamental task of the power plant is the permanent utilization of ecologically acceptable water flows downstream the Prancevici dam, its own inflows and power production when occasional water excesses occur. The value of this power plant is also evident while operating in extraordinary conditions, and as a power system reserve in case the upstream power plants are damaged.

Due to historical circumstances power plant has a certain polyvalent role that comprise functions of power production, transmission and distribution. Its water supply role is also very important and evacuation of normal, high and extremely high water amo unts.

Fig. 9. Penstocks, bifurcation and powerhouse

Fig.10. Headrace canal

Multiple ways of HPP Kraljevac utilization is especially revealed in its possible tourist role. Through the years tourist agencies presented a great interest for the organized visits to the power plant as a historical-technical attraction. This is particularly intensified by a fact that the power plant resides in the immediate vicinity of the famous tourist destinations Makarska, Brela etc. This does not exhaust all the possibilities of this natural phenomenon.

For thousands of years Cetina has shaped the canyon creating miraculous forms in stones of its bed. Crystal pure river with pleasant temperature for bathing, 180 m high cliffs, lakes, underground tunnels and unique waterfall Gubavica (38 m) will enable you to experience unaffected nature.

All this creates new tourist possibilities and activates local inhabitants to offer attractive activities, so called active holidays like rafting, canyoning, free climbing, extreme sports or just long strolls, cycling through the wonderful scenery of the most beautiful canyon part of the river Cetina. Local catering overture has a hundred years old tradition and it is based upon traditionally prepared, ecologically bred food.

Described modernizations significantly increased the safety of the power plant, its environment, employees and visitors from potential danger and incidents, but it also enabled the power plant to integrate to the remote supervision and control system. Controlling HPP Kraljevac from the river basin supervision and control centre will insure optimal utilization of all of its possibilities including insuring corresponding water regimes for all users.

It is important to point out that described modernizations and reconstructions that were or will be carried out in the following years, did not and will not disturb the architecture of the facility, natural features of the environment and wider area where HPP Kraljevac is located. This fact shows a constant concern and care that described actions do not degrade essential historical, technical and ecological characteristics of this facility and its natural environmental fusion.

Everything mentioned before made it necessary to modernize technical systems in the power plant in order to reduce human operation and plant control, managing and maintenance costs to acceptable level. This modernization does not imply numerical reduction of employees, but a need for the new profile of employees, people who will perform skills needed to run new modernized plant. To do that employees have to be prepared to keep up with technology development, constant education and migration to the other economical service sectors.

Fig. 12. Side spillway on headrace canal

Fig. 13.Cetina canyon

Finally, it is important to mention that the level of investing compared to the overall multi purpose character of the power plant facility is relatively low and capital reimbursement relatively fast. Because of that, the price of electrical power is very competitive. It surely covers the costs of the production and after reimbursement of the invested capital make a decent profit. However, if other mentioned possibilities of exploitation of this facility are included, total economical and social effects can significantly increase.

Biographical details of the authors

Vladimir SRZENTIC, born in 1947, graduated in electrical engineering in 1970 from the University of Zagreb, Faculty of Electrical Engineering in Split with a degree of B. Sc. In 1975 joins Croatian Electricity (HEP) as a chief of plant of HPP Orlovac. Since 1978, works as a supervising engineer on various hydro power – plants under construction in HEP Power Generation Area - South such as: HPP Zakucac (2^{nd} phase), RHPP Velebit and HPP Đale. During construction of these plants he is, as a supervising engineer, being responsible for hydroelectric installations, electric – power equipment, automation and remote control system. Nowadays he is a Director of an old HPP Kraljevac (built in 1912), also a part of HEP Power Generation Area - South.

Igor ŠODAN, born in 1970, graduated in 1998 from the University of Split with a degree of B. Sc. majoring in electrical engineering. Since 1999 employed in Croatian Electricity (HEP), Power Generation Area – South, Project Engineering Department. Since 2001, he is a project leader of the control, protection and turbine governing systems' refurbishment at the HPP Kraljevac.

Miodrag KULAŠ, born in 1966, graduated in Electrical Engineering/Industrial Electronic from the University of Zagreb in 1990. He joined SAS-Zadar in 1990, as an automation engineer designing the special machines for the car industry. He transferred to EXOR-Zagreb 1994. Since than he is working as the industrial automation engineer in various automation projects, in different industry branches and mostly on Siemens and ABB equipment.

Stipe SMOLJO, born in 1971, graduated in 1996 from the University of Split with a degree of B. Sc. majoring in electrical engineering. Since 1996 employed in Projektni Biro Split Ltd. as a control and protection systems designer with the following references: HPP Zakucac (2x150 MVA + 2x120 MVA) - Detail design for main generating units synchronization, Detail design for 110 kV switchyard refurbishment, HPP Senj (3x80 MVA) - Detail design for 220 kV switchyard refurbishment, HPP Kraljevac – Detail design for the refurbishment of the generating unit No. 1 and No. 2