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CELOVITA OBNOVA MALE HIDROELEKTRARNE (PRIMER RUDNIŠKE ELEKTRARNE MEŽICA)
INTEGRAL REFURBISHMENT OF MINI HYDRO POWER PLANTS (CASE STUDY OF A MINE HPP)

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Glavni cilj obnove hidroelektrarne po 30 ali več letih obratovanja je, da se oprema elektrarne obnovi tako, da bo zagotavljeno nemoteno obratovanje elektrarne naslednjih 30 ali več let. Istočasno pa je obnova priložnost, da se povečata moč in proizvodnja energije, zmanjšajo stroški delovanja elektrarne z vgradnjo sistema daljinskega vodenja. V članku je opisan primer celovite obnove hidroelektrarne v nekdanjem rudniku Mežica. Po petinpetdesetih letih neprekinjenega obratovanja je bila obnovljena elektrarna z dvema agregatoma. Prva enota je bila v celoti zamenjana, medtem ko je bil na drugi razvit nov turbinski rotor, druga strojna oprema pa je bila obnovljena. Vgrajena sta bila popolnoma nova turbinska regulatorja in dodan nov sistem avtomatike posamezne enote. Obnova malih hidroelektrarn je včasih celovitejši in zahtevnejši projekt kot obnova večjih. Izhodiščne točke so enake: boljši izkoristek, večja moč, popolna avtomatizacija, daljinsko vodenje, minmalno vzdrževanje. Lepi cilji, ampak težko dosegljivi z omejenimi sredstvi namenjenimi obnovi elektrarne.
Ključne besede: *obnova, orodje CFD, sistem upravljanja, regulator*

The purpose of the integral refurbishment of old power plants is to bring the power plants into a condition that will enable them to work for the next 30 or 40 years without needing new expenditure. At the same time, a refurbished power plant has to produce more energy, operate automatically and require less maintenance work. A case study of such an integral refurbishment of the ex-mine power plant is presented in the article. A two-unit power plant was refurbished after 55 years of uninterrupted operation. The first unit was totally exchanged with a new one. On the second machine, a new runner was developed and other mechanical equipment was renovated. Also, on both units, new governors were built, and a full automatic system was created.
Key words: *Refurbishment, CFD tool, Control system, governor*

1. UVOD

Glavni namen celovite obnove elektrarn je podaljšati življenjsko dobo elektrarn za 30 do 40 let. Obnova male hidroelektrarne je podobna obnovi velike hidroelektrarne, vendar z bistveno manj denarja. Polega tega so male hidroelektrarne spremenile svojo vlogo v elektroenergetskem sistemu. V času izgradnje so bile projektirane za vzdrževanje lastnega električnega omrežja, danes pa so pretočne in morajo optimalno "predelati" razpoložljivo vodno energijo

Obnova običajno ni le obnova ali zamenjava obstoječe opreme, ampak tudi preprojektiranje agregata. Vsaka obnova se mora začeti s kratko študijo o izplačljivosti obnove in preprojektiranja elektrarne. Pri tem je treba:

1. INTRODUCTION

The purpose of the integral refurbishment of old power plants is to bring them into condition to work for the next 30 or 40 years without any greater later investment. he refurbishment of small hydro units is generally similar to the refurbishment of larger ones, but can be accomplished with a relatively smaller budget. Small units also change their role in the electrical system. When they were first assembled, some 40 or more years ago, they were relatively large units and very often they had to maintain an island net.

Refurbishment today does not mean only the renovation of existing electro-mechanical and hydraulic equipment, but also the redesigning of units. Every refurbishment has to begin with a short feasibility study in which the next points have to be executed:

- ugotoviti podrobno stanje obstoječe opreme.
- raziskati vodne razmere
- poiskati in prebrskati obstoječo dokumentacijo!
- izmeriti karakteristike stare turbine!
- ugotoviti, pod kakšnimi pogoji je varno obratovanje elektrarne brez posadke?
- kam z obstoječo posadko?
- ugotoviti posebnosti posamezne elektrarne, ki vplivajo na obratovanje, proizvodnjo,..

Če študija da pozitivne odgovore na navedena vprašanja, potem sledi izdelava projekta, ki mora zagotoviti:

- boljšo izrabo potencialne vodne energije
- varno in zanesljivo delovanje agregatov in elektrarne
- visok in sodoben nivo tehničnih rešitev
- za okolje prijazne rešitve
- avtomatsko delovanje agregatov in druge opreme v elektrarni nadzorovano preko sistema daljinskega nadzora.

Danes obnova ne pomeni samo vnovične izdelave delov, ki so poškodovani ali obrabljeni, temveč je treba upoštevati nova spoznanja in tehnične rešitve s področja hidravličnih strojev in hidroelektrarn. Tako oprema ne bo samo obnovljena, ampak se dvigne na višjo tehnično raven. Obstoječi vodni potencial je bolje izkoriščen na podlagi višjega izkoristka obnovljene opreme in povečanega pretoka. Rezultat je večja moč agregata kot celote in večja proizvodnja energije

Povečan pretok in večja izhodna moč agregata zahtevata poglobljeno študijo drugih delov opreme s stališča hidravličnih, mehanskih in električnih možnosti, stabilnosti,… Sprememba glavnih parametrov agregata ne sme imeti nobenega vpliva na varno in stabilno delo celotnega sistema agregata in elektrarne.

2. TEHNIČNI PROBLEMI OBNOVE

Obnova izpostavlja množico specifičnih problemov. Na agregatu se največkrat pojavijo problemi z možnimi rešitvami, predstavljenimi v preglednici 1.

- A detailed examination of the existing equipment condition.
- Ascertain the water power conditions.
- Perform a survey of available documentation!
- Measurement of old turbine and generator characteristics!
- Determine how safe the operation of the power plant will be in the future without a staff?
- Decide how to solve the problem of employees after the refurbishment?
- Solve many other case-to-case specific problems.

If the feasibility study gives the proper answers, the refurbishment of power plant equipment enables:

- Better exploitation of water energy potential
- Safe and reliable operation of each unit and of the entire power plant
- A higher level of particular technical solutions
- Safer technical solutions for the environment
- Units and power plant automation and remote control operation.

Following the rule of technical updating, new components should not only include the remaking of the old ones, but also feature up-to-date technical achievements in the field of water units design and manufacturing. In this way, the equipment will not be only refurbished, but its technical level will also be upgraded. This leads to better exploitation of the existing catchment. Better exploitation is based on better efficiency and increased discharge, which results in higher turbine and unit power output, higher energy production and a shift of production to the field of peak demand.

Increased discharge and unit output requires an intensive investigation of all unit elements in the sense of hydraulic, mechanical and electrical ability and stability. A change of one parameter must not have undesirable results limiting the ability and stability of the whole unit and system.

2. TECHNICAL PROBLEMS OF REFURBISHMENT

The refurbishment of units presents many specific problems. Within the unit, the next problems appear, and possible solutions are given in Table 1.

Preglednica 1. Pregled delov agregata in dela na njih.

Del agregata	Stara oprema	Obnova
Gonilnik	Stari gonilnik je obrabljen, poškodovan zaradi kavitacije, erozije, pojavljajo se razpoke.	Novi gonilnik ima novo hidravlično obliko. Izpolniti mora vse zahteve po višjem izkoristku in povečanem pretoku. Da se zniža cena, se uporabi poenostavljena izdelava varjene izvedbe gonilnika.
Turbinska gred	Utrujen material, razpoke	Nova gred omogoča povečano moč agregata
Nosilni ležaj	Običajno je obrabljen	Obnova (bele kovina) ali včasih zamenjava
Vodilne lopatice	Stare lopatice puščajo (v zaprtem položaju) in ne dovoljujejo povečanega odprtja.	Skrajšane vodilne lopatice (po popravilu) rešijo oba problema.
Gonilnikov labirint	Relativno velike volumetrične izgube	Zmanjšanje izgub
Drsne puše	Stalno mazanje in onesnaževanje vode.	Samomazalne puše – ni več potrebnega vzdrževanja in ni onesnaževanja okolja.
Tesnilka	Usnjene tesnilke puščajo	Nova tesnilka ne pušča
Regulacijski obroč	Dvojni obroč togo povezan z regulatorjem. Omejeno odpiranje	Podaljšan obroč, povezan z novim servomotorjem, delujočim na visokem tlaku olja.
Regulator	Običajno dotrajan s težavami pri vzdrževanju (ni več rezervnih delov, slaba natančnost regulacije, nizek tlak olja.	Hidravlična naprava z zračnim akumulatorjem, standardnimi hidravličnimi elementi, visok obratovalni tlak, procesorski turbinski regulator vgrajen v opremo avtomatike agregata.
Predturbinski ventil	Pušča, ročno upravljanje	Nova tesnila, obnovljen z mehanizmom za avtomatsko odpiranje/zapiranje.
Generator	Izolacije razreda B, izstrošeni ležaji	Nova izolacije razreda F omogoča povečanje moči. Obnova ležajev enako kot pri turbinskih ležajih.
Vzbujalni sistem	Dinamični vzbujalnik z ročno regulacijo napetosti	Novo statično vzbujanje z avtomatskim primarnim napetostnim regulatorjem..
Mehanske meritve	Nekaj membranskih manometrov in termometrov	Novi elektronski pretvorniki za merjenje nivojev, tlakov, temperatur
Električne meritve	Klasični instrumenti	Pretvorniki električnih veličin z instrumenti in signali, pripeljanimi na sistem vodenja agregata.
Mehanske zaščite	Ni posebnih zaščit	Sistem zaščit agregata, ki obsega: – varnostni hitrostnik – merjenje temperatur na ležajih, navitju generatorja – kontrolo tlakov v oljetlačnem sistemu.
Sistem vodenja	Ni sistema vodenja. Ročno obratovanje	Novi PLC sistem, ki zagotavlja avtomatski zagon in zaustavljanje agregata, turbinsko regulacijo, sekundarno regualcijo faktorja moči, električne in mehanske meritve, signalizacijo in daljinski nadzor.

Table 1. List of the turbine unit parts and measures.

Unit part	Old	Refurbish
Runner	Old runner is worn out and suffers from fatigue crack.	New runner has new hydraulic shape. It has to fulfil new requirements due to efficiency needs and greater flow. To lower costs, a simplified construction by welding the blades between the hub and the rim is applied.
Turbine shaft	Fatigue problems and damaged shaft.	New turbine shaft also allows greater power output and meets other requirements.
Radial axial turbine bearing	Is usually worn out.	Repair, or maybe replacement.
Guide vanes	Old guide vanes leak and do not afford an increase in the opening.	Shorter guide vanes (by repair) solve both problems.
Runner band labyrinth	Relatively large volumetric loses.	Reduces volumetric loses.
Sliding bushes	Periodically greasing and grease in water (pollution).	Self-lubricated bushes – no maintenance and no environmental problems.
Shaft seals	Leather seals had great leakage.	New rubber seals - no leakage.
Regulating ring	Double arm, connected to governor. Limiting opening.	Extended regulating ring with new actuator, prepared for higher oil pressure.
Governor	Usually worn out; difficult to maintain (no spare parts), inaccurate, low pressure.	High pressure with standard hydraulic elements, hydro pack with air accumulator, digital governor integrated into main START/STOP automation.
Turbine valve	Leakage, manual drive.	New seals, automated with new hydraulic actuator.
Generator	Class B insulation, exhausted bearings.	New class F insulation, which also allows greater output power. Bearing repairn as turbine bearing.
Excitation system	Dynamic exciter with manual voltage control.	New static excitation system with automatic primary voltage control system. Secondary control from Unit control system.
Mechanical measurement	Some piston manometers.	New pressure, level and temperature transducers.
Electrical measurement	Classical instruments.	Transducers for electric values.
Mechanical protection	No special protection systems.	New overspeed device, level, pressure and temperature protection in bearing, hydraulic pack and generator stator wire.
Control system	No control system. Manual operation.	New PLC control system, which includes Start/Stop sequence automation, turbine governor, secondary reactive power control, electrical and mechanical measurement and annunciation.

Vsaka obnova opreme je povezana z mnogimi problemi in vprašanji, posebno v povezavi z omejitvami stroškov, časa, prostora gradbenimi deli. Optimizacija med vsemi omejitvami, željami, možnostmi je eden najpomebnejših korakov v procesu obnove hidroelektrarne.

3. OBNOVA STROJNE OPREME

Strojna oprema agregata zajema predturbinski ventil, turbino s špiralo, sesalno cevjo, vodilnikom in gonilnikom ter turbinski regulator. V članku je predstavljen postopek izračuna novega gonilnika, numerična analiza toka in zamenjava regulatorja.

3.1 NOVI GONILNIK

Geometrijske danosti stare opreme vključno s hidravličnimi oblikami (špirala s predvodilnikom, vodilnik, premer, spodnji turbinski pokrov in sesalna cev) so omejitve pri hidravličnem projektiranju novega gonilnika. Splošna priporočila so:

- Poveča se vstopni premer. Na ta način se zmanjša vstopni kot.
- Podaljša se dolžina venca, tako se posredno podaljša lopatica. Zmanjša se okavitacijska občutljivost.
- Manjši vstopni kot in daljše lopatice običajno dajejo boljše lastnosti.
- Po pravilu ostaneta višina vodilnika in vstopni premer sesalne cevi nespremenjena.

Oblikovanje površine lopatice je izvedeno z navidezno tridimenzijsko inverzno metodo (Q3D). Lopatice so oblikovane s konstantno debelino na prveh dveh tretjinah površine, na zadnji tretjini pa se tanjšajo. Stari in predlog za novi gonilnik sta se analizirala z uporabo orodij numerične analize (CFD). Na podlagi analize toka skozi vodilne lopatice in gonilnik, je bil optimiran vstopni kot lopatic gonilnika.

Any refurbishment of the equipment is connected with many problems and questions, particularly due to the limitations of cost, time, space, and civil works. Optimising among all the limitations is the most important step in the process of refurbishment of the power plant.

3. MECHANICAL EQUIPMENT REFURBISHMENT

The mechanical equipment of the hydro unit consists of a valve, a turbine with a spiral case, a draft tube, and a wicket gate and runner. In the paper, we present the procedure in more detail, with new runner calculations, a numerical flow analysis and a change of the governor.

3.1 REDESIGN OF RUNNER

The geometrical constraint of the old hydraulic shape (a spiral case with stay vanes, guide vanes, a pitch diameter and control mechanism, a bottom turbine cover and a draft tube inlet) limits the possibilities of the free hydraulic design of the spare runner. In general, the following is recommended:

- Increase the inlet diameter. It reduces the inlet angles according to an up-to-date praxis.
- Extend the length of the rim, and consequently, the length of blade. It reduces the cavitational susceptibility.
- Smaller inlet angles and longer blades usually give better results.
- As a rule, the guide vane height and draft tube inlet diameter remain unchanged.

The design of the blade surface is obtained by using a quasi three dimensional (Q3D) inverse method. The blade is profiled with constant thickness over the first two thirds, and thinning is profiled in the last third. The old runner and the proposals for the up-graded runner are analysed using the CFD tool. On the basis of flow analyses through the guide vanes and runner, inlet angles of the blade are adjusted. Other modifications are feasible as well, but all of them have to be verified by using a CFD tool.

3.2 NUMERIČNA ANALIZA TOKA

Priporočljiva je analiza vseh turbinskih delov: špirale s predvodilnikom, vodilnika, gonilnika in sesalne cevi pri različnih pretokih-odprtjih vodilnih lopatic. V opisanem primeru je bil uporabljen program TASC FLOW.

Glavni namen analize je bil predvideti pretočne razmere in izgube v vsakem delu tubine in zagotoviti mejne vrednosti za nadaljnje izračune.

Natočne razmere na vodilnik so določene za obliko špirale. Nova oblika vodilnih lopatic pa zagotavlja boljše pogoje za natok na gonilnik.

Novo oblikovani gonilnik se primerja s starim. Najprej se analizira stari gonilnik pri različnih odprtjih vodilnika. Nato pa določi novi in analizira pri istih odprtjih, tako da se primerjajo primerljivi rezultati.

Rezultat pretočnih preračunov so prostorske razporeditve hitrosti, tlakov in vektorji hitrosti vzolž lopatice.

Da se dobi optimalna oblika lopatice se za različne modifikacije gonilnika ponovi analiza, dokler se ne dosežejo željeni parametri (izkoristek in kavitacija).

Sesalna cev se običajno ne spreminja.

3.3 REGULATOR

V starih agregatih so mehanski centrifugalni regulatorji, ki jih je nemogoče vključiti v avtomatsko obratovanje agregata, poleg tega jih je vedno teže vzdrževati in ne zagotavljajo kakovostnega obratovanja. Modernizacija starih regulatorjev je mogoča na dva načina:

1. Samo z obnovo obstoječega centrifugalnega regulatorja, ki se obnovi, opremi z elektromotorji in električnimi merilnimi pretvorniki ter s senzorji. Servomotor ostane isti. Regulator še vedno regulira hitrost, vendar je mogoče z njim upravljati preko nadzornega sistema upravljanja agregata. Običajno v takem primeru regulator regulira frekvenco do uspešne sinhronizacije, zatem pa prevzame regulacijo moči ali nivoja sistem upravljanja agregata.

3.2 NUMERICAL FLOW ANALYSIS

Analysing all turbine parts is recommended: the spiral case with stay vanes, different openings of guide vanes, the runner and draft tube. In the Turboinstitut, a computer code TASC flow is used.

The main purpose of the flow analysis is to predict the flow properties and losses in each part of the turbine and to obtain boundary conditions for further calculations.

The shape of the spiral case dictates the inlet angle to the distributor. A new guide vane profile has to provide the improved runner inlet conditions.

The newly designed runners are compared with the old ones. First, a flow through the old runner is analysed for several operating points pertaining to the appropriate guide vane openings.

The result of the flow calculation is a fully 3D-velocity vector field, and streamlining and pressure distribution along the blade, predicting the runner cavitational behaviour.

To obtain a better runner design, the proposed new runner blade is modified where necessary and numerically analysed for the same operating points. The procedure is repeated more times until a runner with the required performances (efficiency and cavitation) is obtained.

Usually the draft tube remains unchanged.

3.3 GOVERNOR

Existing governors on old hydro power plants are generally still centrifugal mechanical governors without the possibility of being included in the remote control system and they have numerous accuracy and maintenance problems. Modernisation of the old governors is possible in two ways:

1. Refurbishing only the existing centrifugal governor and furnishing it with electrometers and sensors. The actuator remains the same. The governor still controls the unit speed, but it is possible to manipulate it with the remote control system. Usually the governor controls speed only during the synchronisation period. After synchronisation, the remote control system controls the unit power or water intake level.

2. Zamenjava regulatorja in servomotorja z novo oljetlačno napravo, zračnim akumulatorjem in novim visokotlačnim servomotorjem. Nova oljetlačna naprava je skupna tudi za krmiljenje druge opreme agregata - predturbinski ventil, zavoro. Digitalni turbinski regulator je lahko samostojna enota, pri manjših agregatih pa je elektronska oprema skupna s sistemom vodenja agregata. Novi regulator mora zadostiti naslednjim zahtevam:
   - Zanesljivost - vsi elementi morajo biti zanesljivi. Zanesljivost se poveča z zmanjševanjem vgrajenih elementov (integrirani sistem vodenja).
   - Uporaba standardnih industrijskih elementov hidravlike, merilnih pretvornikov, PLC. Na ta način se znižajo stroški vzdrževanja, ki mora biti hitro in preprosto.
   - Uporaba visokih tlakov- danes se obratovalni tlaki hidravličnih naprav gibljejo od 60 do100 barov. Z višanjem obratovalnega tlaka se manjšajo dimenzije ventilov, povezovalnih cevi in druge opreme.
   - Za vse uporabnike v okviru agregata ena sama oljetlačna naprava- vodilnik, predturbinska loputa, obtočni ventil, zavora,..
   - Nizka poraba energje - zračni akumulator se polni le občasno, ko pade tlak v sistemu.
   - Vzdrževanja je malo in je preprosto. Z digitalnim regulatorjem in elektronskimi pretvorniki se zgradi sistem, ki ne zahteva posebnih nastavitev.
   - Inteligentni komunikacijski vmesniki, ki zagotavljajo komunikacijo z nadzornim sistemom. Ni več potrebnih posebnih koncentratorjev signalov.
   - Možnost ročnega upravljanja s turbino.
   - Vgrajene mehanske zaščite- visoka temperatura, nizek tlak. previsoka hitrost

2. Changing of the governor and actuator with a new hydraulic pack, an air accumulator and a new high-pressure servomotor. An oil hydraulic pack and a digital governor control the other governor equipment. In smaller units, a digital governor can be a part of the software in the Unit PLC. The new governor has to fulfil following requirements:
   - High reliability - all elements have to have high reliability. Reliability also increases if the number of elements decreases (integrated unit control system).
   - Use of standard hydraulic, sensor and control elements. The term “standard” means market wide spread elements. In this case, maintenance is simple and cheap.
   - High-pressure hydraulics - today utilised oil pressure is normally 60 bars, but for smaller units, can be also 100 bars. When the pressure is higher, all dimensions of pipes and actuators are reduced.
   - Same hydraulic pack for all actuators of the unit – by-pass valve, main turbine valve, brake, and wickets gate.
   - Low power consumption-air accumulator needs only intermittent pump work and has lower energy consumption.
   - Simple maintenance and simple adjusting procedure. Standard elements allow simple and infrequent maintenance. With a digital governor and new transmitters it is also possible to build a governor with no adjustment.
   - Direct connection with remote control system and supervising system. A stand-alone governor has to have a standard intelligent interface with all data, and be prepared to transmit and to receive commands from the Unit control system.
   - Possibility of manual operation with the unit.
   - Integrated mechanical protections - level, pressure temperature, etc.

4. OBNOVA SISTEMA UPRAVLJANJA

Upravljanje s starimi elektrarnami je zaslužilo svoje ime - res se je rokovalo – vse se je upravljalo ročno. Meritve, signalizacija sta bila izvedena s klasičnimi instrumenti in z žarnicami. Sinhronizacija je izključno ročna. Stalna prisotnost posadke je bila obvezna.

Novi sistemi upravljanja pa mora imeti vgrajene nasledne funkcije:
- popolni avtomatski zagon/zaustavljanje agregata
- vgrajen mora biti merilni sistem za merjenje mehanskih in električnih veličin.
- sistem signalizacije
- komunikacija na nadzorni sistem
- avtomatska sinhronizacija (z možnostjo ročne).

Sodobni PLC sistemi z ustrezno programsko opremo omogočajo realizacijo vseh zgoraj naštetih zahtev v okviru enega samega integriranega sistema upravljanja. Za manjše enote je lahko vgrajen tudi turbinski regulator v isto strojno opremo. Takšen sistem je:
- zanesljiv
- preprost za uporabo in vzdrževanje
- cenovno ugoden
- zagotavljati mora delovanje brez posadke.

Pri projektiranju obnove elektro-strojne opreme, je pomebno, da se predvidijo vsa potrebna dela za pripravo agregata za avtomatizacijo:
- vgrajeni morajo biti vsi senzorji in merilni pretvorniki
- predvideni morajo biti vsi izvršni elementi (motorji, ventili,…).

V integrirani sistem PLC vsak signal vstopa samo enkrat. Informacija se potem uporabi v več namenov - enkrat za zagon/zaustavitev, za turbinsko regulacijo, signalizacijo, daljinski sistem vodenja,...

Električne zaščite generatorja so ločene in delujejo neposredno na generatorsko stikalo. Nekatere mehanske zaščite so izvedene preko PLC (na primer temperatura ležajev, generatorskega navitja,)...

Izhodni signali- ukazi delujejo neposredno na elektromehanske člene.

Ročno upravljane je omogočeno v dveh režimih - testnem, kjer se deluje neposredno na izvršne člene, in ročnem, kjer se upravlja preko PLC sistema posredno.

4. CONTROL EQUIPMENT RENOVATION

Old small (and also larger) hydro units have only manual or perhaps a sort of semi-automatic control system. Other functions such as measurement and annunciation were realised with stand-alone instruments, panel lamps. Synchronisation is, in most cases, only manual. A permanent staff is required.

A new control system has to realise the next functions:
- start/stop unit completely automated
- electrical and mechanical measurement system
- annunciation system
- communication interface to remote supervision system
- automatic synchronisation

Recent PLC systems, with proper software, carry out all upper functions in only a single hardware system-integrated control system. For small units, the turbine governor can also be incorporated in the same hardware. Such a system is:
- highly reliable
- simple to use and maintain
- simple to adjust
- price/performance optimal
- allows a no-staff power plant operation

When designing the unit refurbishment, it is important to provide all the necessary work to prepare the unit for full automation:
- All sensors and transducers have to be built in.
- Control elements, such as motors and solenoid valves have to be prepared.

Due to the integrated system, each input (digital or analogue) enters into the PLC only once. Information is later used for all the necessary purposes - start/stop automation, the governor, annunciation, supervision, etc. Electrical generator protections are separated and act directly on the generator circuit breaker. Some mechanical protections, such as the bearing and winding temperature are realised with the PLC system.

Output commands act upon the proper electromechanical actuators.

Manual control is also possible in test and normal manual mode.

5. ELEKTRARNE V OPUŠČENEM RUDNIKU SVINCA MEŽICA

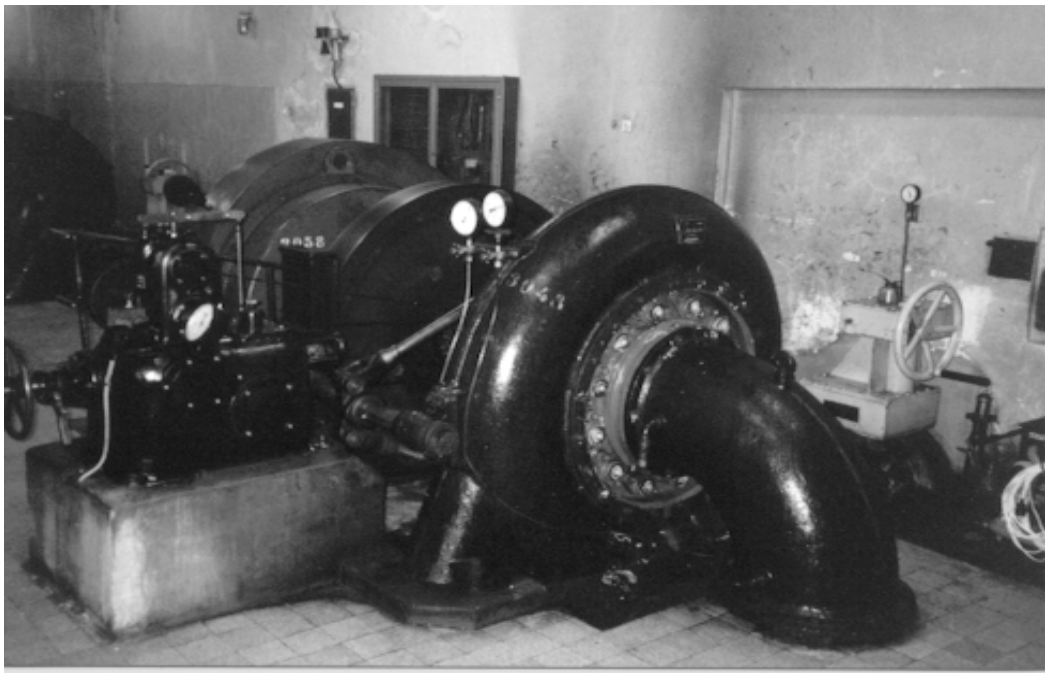
Leta 1940 je lastnik rudnika svinca v Mežici začel izkoriščati vodni potencial reke Meže. Med vojno, leta 1941, je bila vgrajena prva enota - dvojna Francis turbina in generator, ki sta bila izdelana pri Ganzu v Budimpešti. Drugi agregat - Francis turbina je bila izdelana pri Voithu, medtem ko je generator Brown Boveri začel obratovati leta 1948 (slika 1, preglednica 2).

5. HYDRO POWER PLANTS OF THE LEAD MINE MEŽICA

In 1940 an owner of the Mežica mine »The Central European Mines Ltd« began projecting for the exploitation of the Meža stream. During the war in 1941, the first unit – a twin Francis turbine and generator - were manufactured by Ganz, Budapest, and installed (PE1/1). The second unit - a Francis turbine made by Voith St. Poelten in 1942 and a generator Brown Boveri - were installed after the war in 1948 (Figure1, Table 2).

Preglednica 2. Parametri stare in nove turbine.
Table 2. Parameters of old and new turbines.

PE1/1	**Prej / *Old***	**Potem / *New***
Padec / *Head*	65 m	65 m
Pretok / *Flow*	1.3 m^3/s	1.5 m^3/s
Hitrost / *Speed*	750 rpm	750 rpm
Moč / *Power*	1100 kW	1450 kW
Leto izdelave / *Year of erection*	1943	1998
PE1/2	**Prej / *Old***	**Potem /*New***
Padec / *Head*	65 m	65 m
Pretok / *Flow*	0.7 m^3/s	0.8 m^3/s
Hitrost / *Speed*	750 rpm	750 rpm
Moč / *Power*	700 kW	800 kW
Leto izdelave / *Year of erection*	1948	1998



Slika 1. Enota PE2/1 (izdelava Voith/Brown Boveri) pred obnovo.
Figure 1. Unit PE2/1 (produced by Voith/Brown Boveri) before refurbishment.

Oba turbinska regulatorja sta bila izdelana pri VOITH St. Poelten. Zaradi nezanesljivosti delovanja, oteženega vzdrževanja in predvidene popolne avtomatizacije elektrarne je bila potrebna celotna zamenjava regulatorjev.

Na obeh agregatih sta bila turbinska regulatorja zamenjana. Slika 2 prikazuje hidravlično shemo obeh regulatorjev. Zaradi bližine obeh turbin je bila izbrana ena sama oljetlačna naprava, s skupnim zračnim akumulatorjem, vendar z ločenim nizom krmilnih ventilov. Za krmiljenje vodilnika je bil izbran proporcionalni ventil. Elektronski del regulatorja je bil vgrajen v PLC sistem upravljanja. PLC sistem z ustrezno programsko opremo zagotavlja, avtomatsko delovanje agregata, turbinsko regulacijo, merjenje, regulacijo nivoja, moči in pretoka ter komunikacijo z nadzornim sistemom. Vsi podatki in zahtevani parametri so dostopni na zaslonu, vgrajenem na prednjih vratih upravljalne omare.

Na generatorju ni bilo potrebnih posebnih del. Sam generator je bil obnovljen nekaj let pred obnovo. Stari ročni sistem vzbujanja je zamenjal novi statični vzbujalni sistem z elektronskim regulatorjem napetosti.

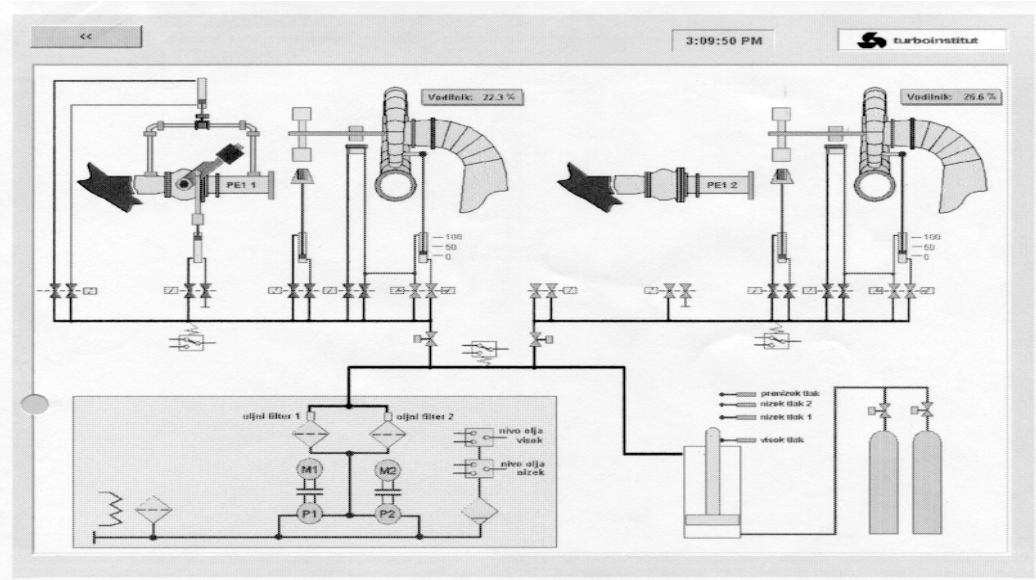
Obnova prvega agregata je bila uspešna, Na sliki 3 sta prikazani krivulji izkoristka in moči stare in nove turbine. Fotografija na sliki 4 pa prikazuje novi agregat.

VOITH St. Poelten made all three mechanical governors. In spite of permanent maintenance, the turbine equipment needed extensive refurbishment. The owner's goal - to introduce remote control - has dictated considerable modernisation.

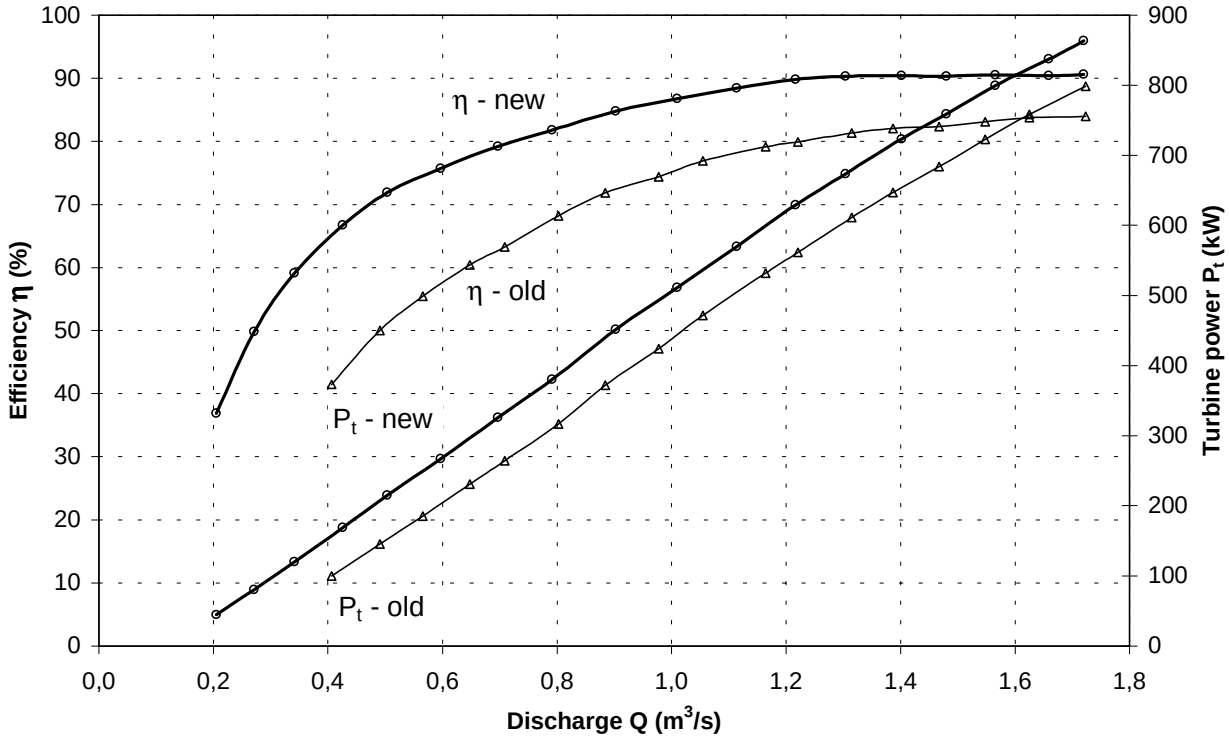
New governors were created on both units. Figure 2 shows the hydraulic scheme of both the hydraulic parts of the governors. There is only one oil reservoir and one air accumulator with two separate sets of control valves. A proportional valve is used for wicket gate control. The electronic digital part of the governor was realised as a part of an integrated PLC control system. The PLC, with proper software, executes all start/stop automation functions, level and power control, speed control, and measurement of all electrical parameters. All information is presented on an MMI monitor on the front cubicle doors.

There were no special works on the generator, except excitation. There was a new static excitation system.

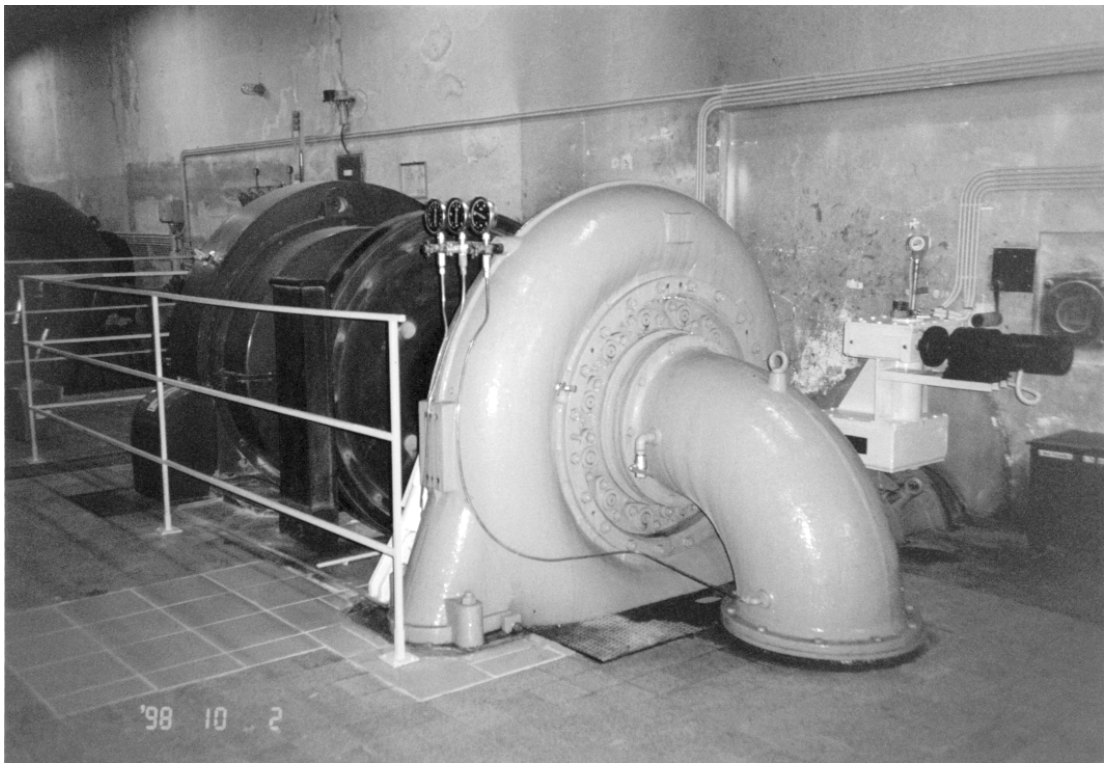
Refurbishment of first unit was very successful. Figure 3 shows the old and the new efficiency and power results. On Figure 4, the upgrading unit is shown.



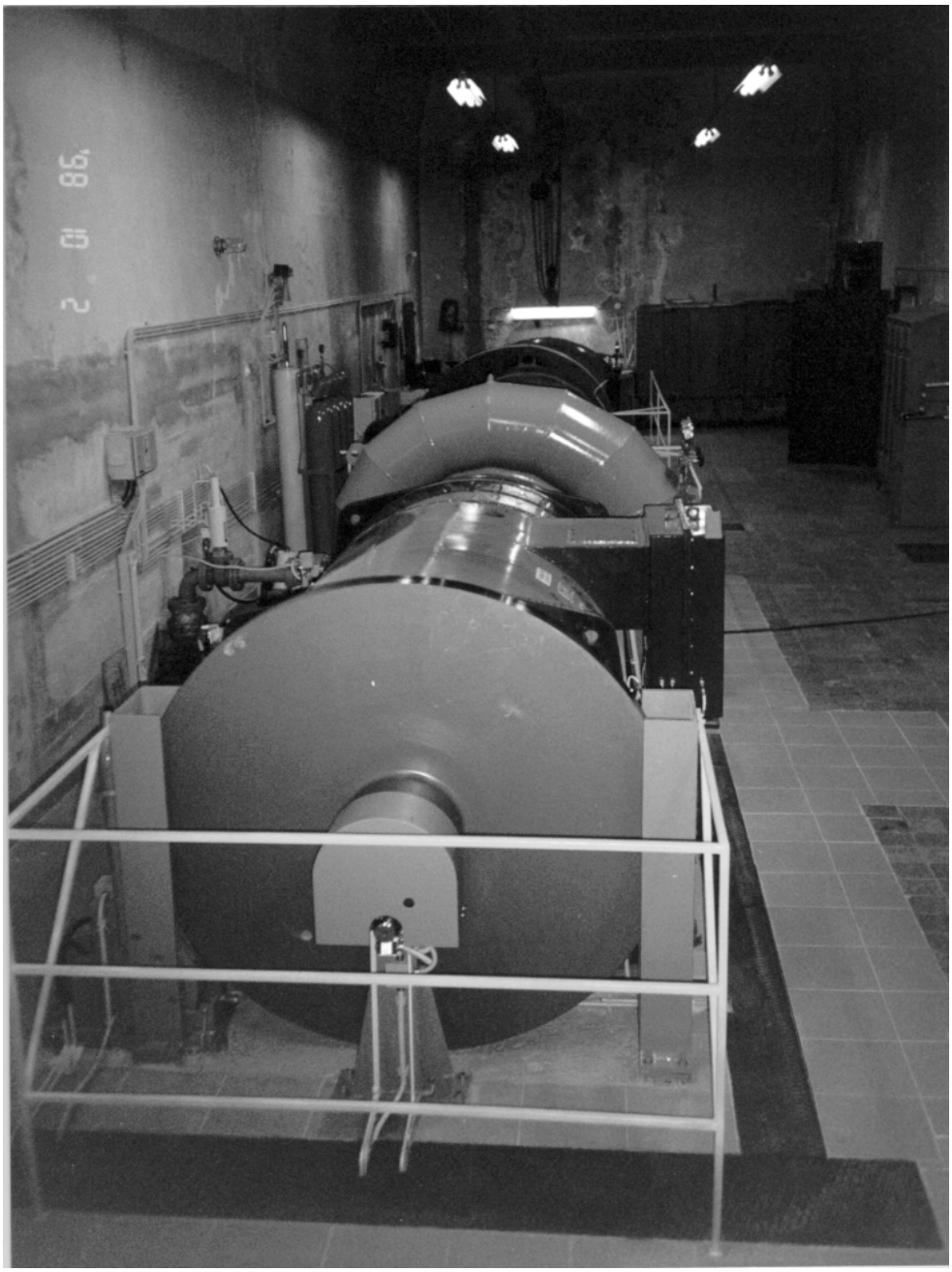
Slika 2. Hidravlična shema regulatorja.
Figure 2. Hydraulic scheme of governor.



Slika 3. Karakteristike stare in nove turbine.
Figure 3. Old and new runner characteristics.



Slika 4. Povečani agregat PE1/1.
Figure 4. Upgraded and refurbished unit PE2/1.



Slika 5. Novi agregat PE1/1 moči 1.45 MW.
Figure 5. New unit PE1/1 of 1.45 MW.

Stari agregat PE1/1 je imel večje poškodbe na ležajih in gredi. Turbinska oprema je bila dotrajana, generator pa ni dovoljeval povečanja moči. Stari agregat je bil v celoti zamenjan z novo horizontalno Francis turbino, s sinhronim generatorjem z drsnimi ležaji, predturbinsko loputo z avtomatskim upravljanjem in z varnostno utežjo za zapiranja. Turbina nima lastnih ležajev, pač pa je rotor turbine prevesno nameščen na

Unit PE1/1 suffered serious injuries on its bearings and shafts. The turbine equipment was worn out and the generator did not allow for upgrading. The old Unit was substituted with a modern single Francis unit with a horizontal axis spiral a Frances turbine, a synchronous generator with slide bearings, a butterfly valve with an 0,8 m diameter, and a bifurcation of 1,4/0,8 m diameter, a flywheel and an over-speed device. The turbine does not have its own bearings. The runner is directly

podaljšano gred generatorja. Turbinski regulator je v celoti nov. Sistem upravljanja je enak sistemu upravljanja obnovljenega agregata PE1/2. Na sliki 5 je prikazan novi agregat.

5. ZAKLJUČKI

Obnova in povečanje moči malih hidroelektrarn je zahteven poseg, tako kot pri velikih elektrarnah. Obnova male hidroelektrarne je lahko temeljitejša kot obnova velikih enot. Dosežki pri povečanju izkoristka so opazni in uporaba CFD orodij daje uporabne rezultate. Izkušnje in rezultati modelnih raziskav in preizkusov ter CFD orodje skupaj dajeta dobro in zanesljivo napoved povečanja izkoristka.

Turbinski regulatorji, sistemi vodenja, napetostni regulatorji predstavljajo opremo, ki mora biti zamenjana. Sodobni sistemi so zanesljivejši, potrebujejo manj vzdrževanja in omogočajo daljinski nadzor.

mounted on the generator shaft. The governor is completely new. The control system is the same as in the refurbished unit PE2/1. It is also a voltage control system. Figure 5 shows the new unit.

5. CONCLUSIONS

The upgrading and refurbishment of a small hydro plant is as considerable as that of larger ones. The refurbishment of a small hydro plant can be more radical than a large one. The achievement in efficiency and power is notable. Experiences with CFD tools are good. Together with experience and support from the existing model, experiments give reliable and good results.

Equipment such as the governor, control system, and voltage control must be changed. Recent technology and development enable a new, effective, reliable approach in the field of control and hydraulics. New systems have to be more reliable, simple to operate, able to be maintained infrequently and supervised remotely.

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