Optimization of the operation of hydrogenerator system at Râul Mare Retezat Hydroelectric Power Plant

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The first chapter has a preliminary condition, containing the theme bordering as well as the explanation which establishes the concerning idea of the doctoral dissertation, from the actual stage of the energetic systems evolution and global and national attention, as well as a briefly description of every chapter of the disstertation.

In the last decades mankind witnessed a fast boost of worldwide energy intake due to society development, population and living standards growth, developing countries excess of industrialization, means of transportation growth, etc.

The future of the civilized world actually rests on the quantity of energy people require. The extent to which the necessary electricity can be provided for the permanent development of the society is today`s matter. The oppinions of the experts are dissimilar to this matter. Some opt for intensive use of common means, others consider that the right solution is the use of renewable energy. In both situations water energy will definitely be one of the fundamental resources.

Regarding the European hydropower estimated potential Romania ranks as number 5 with 85TWh/year, of which 23 TWh/year repreesents the convertible energy potential. Actually Dorin Pavel, the founder of romanian hydropower who came down from the Polytechnic School in Zurich (1923) puplished his great monograph „General development plan for Romanian hydraulic forces", identified the romanian convertible energy potential. We must highlight that after graduating Dorin Pavel became an assistent of the Polytechnical School of Zurich where he obtained his doctoral disertation in technical sciences in 1925 and was offered the chance to become prelector and to begin a teaching career. „I gave greetings to all proffessors, showing that I have a duty towards parents and country and I must return home" [53].

The „General development plan for Romanian hydraulic forces" adopted in 1950 is a reference point regarding the hydropower system of the country using the power of water to generate energy.

Hateg Hydropower Branch operates the hydropower potential of Raul Mare and Strei rivers from Hunedoara County. It all started in 1974 when, following the Cabinet Council Decision no. 759, Raul Mare-Retezat hydropower development composed of Gura Apelor dam, underground hydropower plant Retezat which operates the water from Raul Mare River and the secondary adduction from Raul Barbat River and downstream hydropower plant Clopotiva equiped with two Kaplan turbines, were founded as the first investment for developing hydropower potential on Raul Mare River.

Retezat hydropower plant together with the sequence of downstream hydropower plants ensure a very good peak load even in summertime due o the fact that all hydropower plants can engage in a few minutes lapse and the water flow ensured by Raul mare River. Thus the development is an important link in the National Energy System.

Chapter 2 consists in a short history about Hateg hydropower Branch and Raul Mare River hydropower development. Also it details all hydro components of the development in a common course of realization: the dam, sea inlet, adductions, cableway, surge chamber, valves, the turbine and the offtake. The presentation is about their functional role and their characteristics.

Hateg Hydropower Branch development started in 1974 with the development of Raul Mare River and taking in account Strei River. In almost 40 years of existence it transformed from a project phaze into a partially development for Gura Apelor Dam and normal opperation for all the fillings and hydropower plants downstream Retezat hydropower plant.

Raul Mare hydropower development consists in two different areas:

- Upstream Raul Mare development: high head power plant
- Downstream Raul Mare development in stages: chute

Retezat hydropower plant compasses the development of hydropower generation by taking Raul Mare discharges into Gura Apelor Lake, and secondary discharges from Raul Barbat River and water course discharges from the main adduction.

Gura Apelor Dam situated upstream Raul Mare River (influent of Strei River) completes the main filling of Retezat hydropower plant at about 600 m downstream the confluence of Lapusnicul Mare, Lapusnicul Mic and Raul Ses Gills. Gura Apelor Lake is situated on the Caras-Severin and Hunedoara countyes border. The nearest city is Hateg, situated at about 47 km downstream of Gura Apelor Dam has an exclusive use of hydropower generation. The taken discharge is transported through the main adduction (L=18.4 km) and continues through the pressure tunnel turbinated by Retezat hydropower plant.

The activity of the development started in January 10th 1975, following with the activation of Retezat hydropower plant in 1986, and in 1999 with the dam completion.

The development emerged as a need of warhead adjustment in a period in wich the Romanian industry was in full growth. With the help of Gura Apelor lake there is also a multiannual discharge regulation.

The water inlet is equiped with a facility consisting in a 3.0 x 4.5/115 coffer dam kit and a 3.0 x 4.5/115 cut-off kit each weighting 40 tons.

The main adduction is a 18432 m long cableway reaching the surge chamber with an interior diameter of 5.5 m before being embed in concrete, and a final result of 4.9 m in diameter acquiered by common means of dinamite blastings but also with a modern equipment. Robbins drilling equipment was used in this development as a national initial performance. With the help of the Robbins equipment they were drilling a 3 m cableway an hour with a 5.5 section on a 7311 length.

The surge chamber is a mixt type of surge chamber with a function of sudden vibration of pressure hampering (rises, dawndowns) from the pressure tunnel and to arrest their conduction into the main adduction, as well as creating a water deposit which allows the hydropower plant to reach a fast maximum load.

The entrance collector from the butterfly valves chamber has a 336 m length. The butterfly valves chamber are located underground at the end of the main adduction. The two VF 360-175 butterfly valves and all their applyances including a 32 tf traveling crane are situated in a 18.4x12.0x13.0 m cavity at a 921 mdM elevation with a 140 m of stone coating. These valves allow the cableway draining without draining the whole adduction.

The penstock ensures water acces from the main adduction to the turbines. It is located between butterfly valves chamber and the spreade's collectors. It's role is to transform the potential energy of water into kinetic energy. It has a 841 m length, a 32 degree bias and an interior diameter of 3.6 m. The armored metal rings are between 25 and 65 mm thick. The reinforcement with concrete is achieved in a approximate 1 m layer.

The Retezat hydropower plant is equipped with two vertical Francis turbines manufactured in Resita in metalic volute chambers, the largest of this kind used in a hydroelectric high head power station.

The turbines are located inside the underground power station with a 65 m in length, 16 m wide and 41.2 m high, the equivalent of a 15 stages building.

The director consists in 24 Fink paddles linked by a ring, operated by two oil thrustors ordered by a speed controller.

The director has a function of adjusting the water discharge which enters the turbin through the volute chamber, according to the need of electricity which must load the generator. This way the overuse of the valves is avoided by gradually closure of the paddles whenever the turbines are shut down.

Chapter 3 brings forward a detailed specification of the electrical field of the Raul Mare Retezat hydropower plant. The hydro generator, and all its components impeller and fixed coil is presented from a constructional point of view as well as a functional one. The spigot, breaking and elevating systems, the fire detecting and extinction system, the driver, the unit transformer and the primary circuits are also circumstancial described.

The „HVS 490/240-12" type vertical alternator is intended for equiping the Raul Mare Retezat hydropower plant. The hydropower unit is elevated and it interlinks directly and positive with the Francis hydraulic turbine which carries-over.

The hydro generator impeller is built-up from a shaft, polar crown, poles, excitation winding backed up and directyed by an axial-radial bearing located in the inferior star. The inferior star is fixed on the concrete endowment. On the next level of the endowment the fixed coil of the hydro generator is located.

The hydro generator fixed coil is built up from an outer casing, the magnetic core and the three-phased winding. The superior star is installed on the upper ring of the outer casing.

Pipe coolers installed inside the oil valves are cooling the oil from the shafts.

The hydro generator is cooled with closed circuit air. Air coolers are fixed on the bottom and sealed on the outer casing. The coolig agent for the oil coolers and air coolers is closed circuit water.

The hydro generator location is separated by the engine house through a plate ingrained on the superior star and endowment and by the turbine pit through a diaphragm ingrained on the inferior star.

The superior star is a laminated sheet iron sealed building built-up from the star's central unit and six double T shaped arms of which two demountable. The demountable arms are fixed on the star with flanges and gudgeons. Inside the superior star's body which forms the oil valve the axial bearing is mounted combined with the superior radial bearing. On the outer surface of the star's body over the specialy made muzzles are mounted 6 baterys for the axial bearing coolers, and on the upper side of the star a covering plate.

The inferior star is a sealed bulding composed from the central part and six double shaped T arms. The central unit consists in the inferior radial bearing valve. The oil coolers of the bearing are located on the bottom of the valve. On the inferior part of the star the diaphragm is ingrained which has the utility of separating the hydro generator pit from the turbine pit and to direct the ventilation air.

The axial bearing is designed to take the axial load composed from the hydro generator's impeller weight, the turbine impeller weight and the water displacement. It is conceived to allow the unit running at a maximum load.

The axial bearing is mounted in the oil valve from the superior central side os the star. The bearing is running on a streamlined drive with a permanent amount of oil from the oil valve, allowing the barring and the arrest of the unit without oil grouting.

The inferior radial bearing is fixed on the cental side of the inferior star which forms the oil valve. It is similar to the superior one and it works in a streamlined drive with a permanent amount of oil, equiped with reciprocicating segments with the ability of radial adjustment for an exact alignment towards the hydro generator shaft. The radial load is transmited through ball-headed bolts fixed in the star's body.

The hydro generator has a rotative excitation with rectifier diodes. The driver is mounted above the hydro generator on the mutual shaft, it delivers alternating current to the revolving rectifier. This transforms it into direct current wich charges the operating winding of the hydro generator.

Chapter 4 is an acctual trial rate about the operating conditions of Raul Mare Retezat hydropower plant in terms of standing wave values from the surge chamber at low operation levels of Gura Apelor accumulation. The energetics performances actuation trials of the power units have been performed according to SR EN 60041:2003 prescriptions: inspection trials performed on the actual machinery in order to determine the speciffic hydraulic performances of the hydraulic turbines, accumulators and pumping turbines.

Standing waves trial assigns from the surge chamber have been established in the following operating conditions: the lake level between 978.970 mdMN and 977.380 mdMN.

In order to determine the load losses the levels were measured from all accessible points (lake, surge chamber, upstream globe valves sections, downstream spillway tunnels). The collected parameters found in different locations were checked and linked through hydrostatic probations.

Trials execution was accomplished through multiple parameters measurement using transducers as well as the Hidrosmart monitoring system located in the hydropower plant and the byte.NET hardware.

A pressure transducer was mounted in the surge chamber in order to measure the water level from the surge chamber, a HidroSmart transducer which remains in the installation of the user. SCADA software application displays the on line value of the surge chamber level.

Mounting, calibration and measuring equipment testing, energetic loads performances, load loss a determination tests and coefficients of retardance and standing waves from the surge chamber were field trials. All drills were executed by the Retezat hydropower plant qualified personell.

Lake level was measured through SCADA system which used a Rittmayer transducer placed on a dewatering conduit flooding flap of Gura Apelor dam. Reading accuracy was *10 mm.

The manometric level from the surge chamber was measured at the gate chamber upstream from the auxiliary butterfly valve and at an almost 62 m distance from the surge chamber where a pressure intake port. Given the short distance if we do not consider the kinetic term from the measurement section, we can state that the manometric level from this location is accurate enough.

A relative pressure of 8000, 20 bar and 0.1% accuracy Sensortechnic type of transducer was mounted for measurements.

Due to the fact that the pressure from the entrance in the spiral outer casing is not accessible, the differential heads upstream the globe valves were measured and a level difference of 26.70 m from the turbine average position indicator and the pressure intake port was added.

Relative pressure SIEMENS transducers from Hidrosmart System located in the valve cabinets of the valves from the globe valves chamber were used.

We developed a Delphi program to highlight a better visual obsevation and a simpler SCADA diagrams comparison but also to simulate different scenarios of Retezat power unit's barring/ arrest and shock absorbesd oscillation from the surgechamber and the oscillations next to the director located upstream the globe valve behavior .

In Chapter 5 synchronous generator balance analisys is described during two major events which occured in the hydropower plant evacuation transmission line. It is all about a two phased short circuit and a lightning. Such studies and case studies were made in technical writen works, a series of case studies being very similar to this chapter. Therefore [16] the hydraulic transitory condition impact over the electroenergetic system dynamic stability is described. In [33] there are presented simulations about insulation of a unit of a hydropower palnt.

The transitory stability analisys consists in the behavioural study in time of the electric system when sudden disturbances occur, opened through initiation of power units or power lines, and also when disturbances occur.

Three different stages are considered in transitory stability analisys: the stage before the disturbance, during disturbance stage and post disturbance stage or permanently final condition.

During disturbance the transition from a balanced stage to another balanced stage of a SEE can be a normal process of operation or an accidental incident generated on external grounds (a short circuit occuring on a transmission line, followed by a non simultaneous release of the line at both ends and perhaps its automatic or manual reclosing.

For establishing a transitory stability, one of the most used indicators is turn-off time, defined as the maximum period between disturbance occuring and damaged area insulation second, so the electric system will keep the capability of coming back to a post disturbance permanent condition (after disturbance remediation). It must be stated that the disconected period consists in the coating and contact involvement drive time and if is necessary the time in which the contact signal is transmited to the other end of the power line which was the starting spot of the disturbance.

In worldwide practice the most used common method for transitory stability evaluation is the temporary method.

The analized extensions from chapter 1 were registered during real malfunctions from Raul Mare Retezat hydropower plant with the help of Modular Digital Recorder.

Electric events recording systems are modular structures of recording, supervision and analisys of power systems events. They are built up on a numeric modules basys. The Modular Digital Recorder is part of programmable electronic equipments destined to equip the protection pannels, monitoring and automatisation of the line cells, converters, generators, power bus-bars from the Energy System.

With the help of this equipment the short term information can be saved and transfered to a local or a distance calculation equipment, following to be processed. Using more Modular Digital Recorder type equipments more diverse modular flexible structures of acquisition, monitorising and analisys can be created.

In Chapter 6, on the basys of the theoretical conclusions introduced in the previous chapter tests on machine no. 1 from Retezat hydropower plant have been made in order to optimize it's motion drive. For a mathematical simulation of the dinamic behaviour of Raul Mare Reteat hydropower plant it was considered that the plant works with only one hydro electric units the other being kept as a backup, this way were reproduced the most common real situations of a hydropower plant activity. The dinamic behaviour of the primary facilityes computational simulation from Retezat hydropower plant has been analyzed through an application by suddenly change of electric load at the sincron generator terminals with a 10% growth up against the stationary drive state. The evolution in time of the mechanical and hydraulic values was followed on a 200 seconds period and the results were compared to those monitorysed by SCADA in a similar situation.

The active load, the intensities and the currents on the generator's terminals were measured with an electrical parameters and process parameters analyzer.

The hydropower unit revolution was measured with a laser revolution sensor QS30LDQ type, 120000 rpm, 2 m catchment distance, made by Banner.

The vibrations from the superior bearing of the hydropower unitand the turbine bearing were measured by three vibration sensors, made by Hansford Sensors.

It is noticed that during the off-load start non excitated the vibrations do not go over 3.2 mm/s, and in an stabilized drive of off-load start non excitated the maximum value of the vibrations from the turbine bearing is 1.956 mm/s.

In the transitory process of magnetization of the hydropower unit it can be notticed that no significant vibrations growth occurs in the bearings, there is actually a tendency of vibrations decreasement in the turbine bearing. This indicates a correct centration of the impeller in the fixed coil from a geometrical and magnetic point of view.

From the vibrations measurements is concluded that in an operation load drive, the vibarions tend to stabilyze at an inferior level from the normal one in a off-load start non excitated.

At the turbine bearing level the vibrations in an off-load start non excitated are 1.956 mm/s and in a load drive at P=110 MW decrease at 1.174 mm/s.

In a load drive at P=110MW it is noticed that the hydropower unit works appropriate from an electric point of view, all the electric parameters situated in the limits described in the technical documentation. In the same time it is noticed that the hydropower unit has a normal mechanical behaviour, the level of vibrations being according to a „well" parameter drive.

Partially discharges are in general the consequence of a local concentration of electric requests in insulation or on the surface of insulation. Generally speaking these discharges generate under impulses form with a duration smaller than 1 μs.

Thus there can appear continuous forms of discharges of low intensity („pulse-less") in dielectrical gass.

We can generally consider that the partial discharges from the insulation systems are „symtoms" of phenomena which occur in that specific insulation and can be associated with insulation malfunctions due to fabrication technology, complexe usage (mechanic, electric, termic, chemical) on the material from which the insulation is made of.

The time period of the partial discharges is very small, nanoseconds kind, contrary to a voltaic arc which is mentained until the infeed load dissapears.

The system used to measure partial discharges consists in more devices: hitch device, transmission device (link cable or optical cable) and a measurement device.

The hitch device is integrated in the measurement system and the trial circuit, its components being specially concieved to ottain an optimum sensitivity with a certain trial circuit.

This means that different hitch devices can be combined with one measurement device.

The hitch device is in genereal an active or passive network with four terminals (quadripole) and converts the accession electricity in outcome voltage signals.

These signals are transmitted to the measuring device through a transmission system. The frequency answer of the hitch device, defined by the ratio between the escape voltage and the admission current is chosen to prevent the voltage frequency of trial and inherented harmonics to reach the measurement device.

The answer of this device towards a current impulse (non-oscillatory) due to a partial discharge is in most cases a strong harmonised oscillation. The apparent load as well as the current impulse polarity of the DP can be determined from this answer. The resolution time of the impulses is low and usually between 5 and 20 pC.

The trials were developed with off-load start hydropower unit. The determination of the partial discharges level were made at different values of voltages at the terminals of the unit. For each level of voltage the partial discharges were measured on every phase, taken into consideration a number of 30 entryes. From the average values measured in time the average values on every phase were determined.

The computational simulation of dinamic behaviour of main hydro energetic appliances of Raul Mare Retezat hydropower plant was analysed through an aplication consisting in the sudden change of electric load at the terminals of the sincron hydropower unit with a growth of 10% towards the value of stationary drive. The evolution in time of the mechanical and hydraulic admeasurements was observed on a 200 seconds period, and the results were compared to the results monitorised by SCADA application from a similary situation.

Chapter 7 consists in a synthesis of the doctoral dissertation and personal contribution.

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