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Monitoring Systems for Hydropower Plants

One of the most important issue in hydro power industry is to determine the necessary degree of automation in order to improve the operation security. Depending upon the complexity of the system (the power plant equipment) the automation specialist will build a philosophy of control following some general principals of security and operation. Helped by the modern digital equipment, today is relative easy to design a complete monitoring and supervising system including all the subparts of a hydro aggregate. A series of sensors and transducers specific for each auxiliary installation of the turbine and generator will be provided, together with a PLC or an industrial PC that will run an application software for implementing the security and control algorithms. The purpose of this paper is to offer a general view of these issues, providing a view of designing an automation & control and security system for hydro power plants of small, medium and big power.

***Keywords**: automatic control, frequency and power control, principles of monitoring in hydro power, protection and remote control of hydro power plants*

1. Basic principles

The main purposes of modern automatic control systems in hydro power plants are:

- Automatic control of speed (frequency) and/or output of the power group, known as automatic speed control systems (SRAV).

- Automatic control of generator voltage, known as automatic control of excitation systems (SRAE).

- Control of water level in the storage reservoir and of the swirling flow, depending on the plant requirements.

- Protection of hydropower group to failures and defects, either on the electric part or on the hydraulic part .

These main purposes are the same as 100 years ago. But, the development of digital systems currently allows implementation of additional functions to the control systems of the hydro power plants in order to increase the efficiency in operating the hydropower resources and power generation.

Among these additional functions are mentioned:

- Optimization of the entire system to ensure high availability and efficiency of the hydropower group in order to decrease the costs of power generation.
- Long-term optimization of hydro power plants assemblies operating on the same stream in order to obtain maximum power generation.
- Overall control of power plant equipment and monitoring of operation from a local or central dispatcher.
- Automatically start-up/shut-down by remote control and choosing the optimal number of units in operation.

The structure and functions of the driving systems depend on a number of factors such as: type of the power plants, net heads, swirling flows, types of turbines, output of power groups and their classification in the hydro power plant and energy system.

It is impossible to provide a unitary structure of these systems. Following is a presentation of some structures and monitoring control systems for certain categories of hydro power plants with references to Romania.

2. The advantages of automation in hydropower

The hydro power plants allow a high degree of automation so as to automatically provide the following actions:

- Automatically start-up/shut-down by remote control or by a local time programmer, to ensure the requirements for real and reactive power in the energy system, choosing the optimal number of power units in operation within a hydro power plant, and economical distribution of load between the power units by decreasing the idle running times;
- Quick start-up of the hydropower group, achieving the synchronization and coupling operations to the energy system, without needing additional lengthy preparation such as in the case of thermo-power units, which ensures fast charging at nominal in order to cover the stringent power requirements in the energy system in case of accidental shut-down of other groups, without sacrificing the level of frequency;
- To avoid idle running of hydropower units, decreasing the energy consumption of their own service facilities, being able to restart in a very short time the group when needed compared to thermo-power groups;
- The protection and automatic control systems of the hydropower groups allow timely detection of deviations from the nominal operating conditions and provide putting into operation of the spare equipment or decommissioning of the affected equipment to avoid damage;
- Given that within the national energy system (SEN) there are several hydro power plants (HPP) of high output with storage reservoir (Lotru-Ciunget - 510MW,

Raul Mare Retezat-Clopotiva - 350MW, Vidraru-Arges - 220MW, Sebes - 350MW, Bicaz - 210MW) quick coupling of closed hydro power units is feasible in case of fail in other power plants, solving the issue of real power shortage within SEN, in order to restore the balance between the consumed/generated power and bringing of the frequency at the nominal value.

Some of the hydro power plants can be programmed for injection of reactive power into the system, in order to maintain the power factor (cos Φ) in areas required and, in this case, these plants must be provided with a high degree of automation.

In order to achieve these aspects in automation of hydropower groups, the tasks of the automatic system can be divided into three main categories:

a) To provide the internal requirements for the safety of the hydropower group, its maneuverability, the control and safety of the hydro power plant (storage reservoir, transfer pipelines, penstock, water drainage systems, possibly re-pumping systems) and the control of their own services.

b) To maintain the balance between the generated power and the consumed power, providing the values required for frequency and voltage into the energy system.

c) Operation of the entire energy system at economic rating through optimal distribution of outputs between the power plants within the system, economic transportation at distance and maintaining the loads of transformers and transmission line within the given limits.

A quick solving of system tasks stipulated in paragraphs b) and c) can be provided by the complex automatic control of the hydro power plants, in particular, by the automatic control systems of the excitation SRAE (providing voltage control in the system) and by the automatic speed control systems SRAV (providing frequency control) [5], [1].

SRAE provides increased stability of HPP operation in parallel with SEN and promotes rapid recovery of voltage after short-circuits that can occur on the power transmission and supply lines.

SRAV provides preservation of frequency in SEN and speed control of power units to avoid dangerous transients (over and under speed) [4].

A hydro power plant is equipped with the following regulating, control and protection systems:

- System for automatic star-up/shut-down of the group by pressing an on/off button);
- System for automatic synchronization and coupling to the energy system;
- System for automatic speed control of the group (SRAV);
- System for automatic control of synchronous generator excitation (SRAE);
- System for automatic control of water level in the storage reservoir and of output in HPP;
- Systems for automatic protection of electrical and mechanical equipment in the power plant;

- Systems for automatic detection and fire fighting;
- Systems for automatic lubrication of hydropower unit bearings;
- Systems for automatic braking/lifting of hydropower unit rotors;
- Systems for remote control of valves and bulkheads;
- Systems for monitoring of water levels and flow rates in various points of the hydro power plant;
- Systems for automatic closing of the substitute (AAR) and fast reclosing (RAR).

The automation degree of a HPP, advanced or simply, is determined from the construction phase and is chosen depending on the operating conditions provided by the designer and its role in the energy system [3].

3. Functional principles of monitoring and control systems in HPP

The automatic control system of a HPP comprises a series of equipment grouped on specific tasks and functions to provide permanent control of all installations and their protection in case of exceeding the normal operating limits. These equipment are grouped into two main categories: equipment related to each hydropower group and equipment related to the control of the hydropower plant as a whole.

a) Automatic control systems for hydropower groups

Figure 1 shows the structure and functions of a control system that provides signaling and protection of the hydropower group and control group and control of the automatic adjustment of parameters and ancillary facilities related to the group [2], [3].

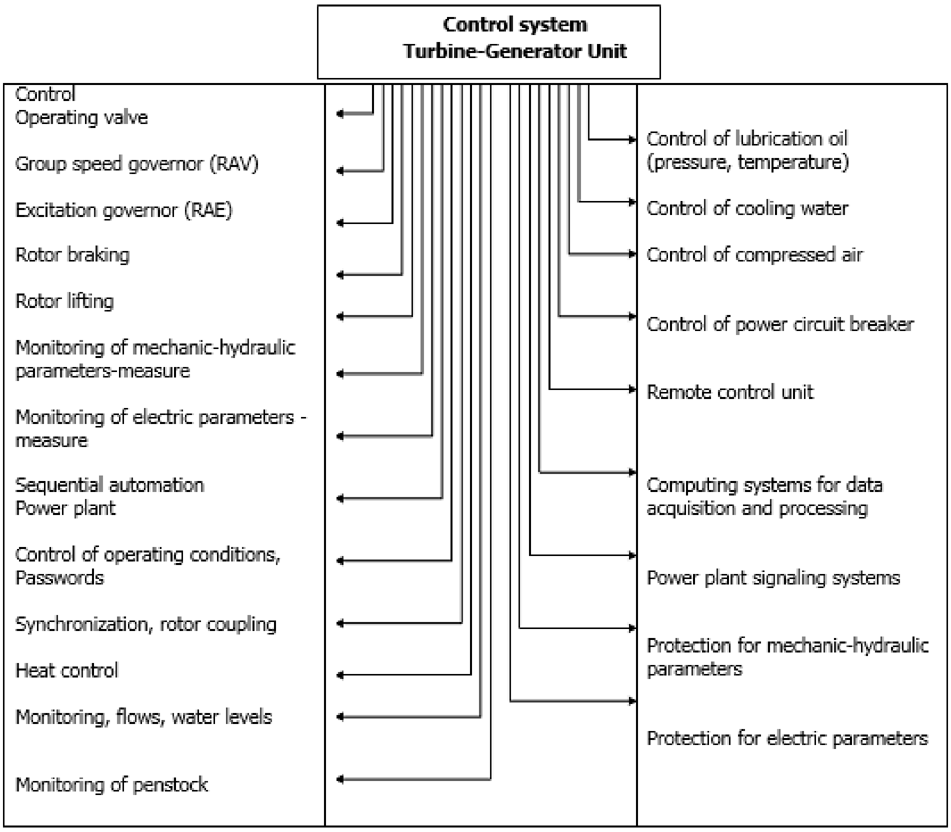

Figure 1. Control systems for hydropower groups

Fig. 2 shows the structure and functions of a system for acquisition of data from the components of the hydropower group, for the mechanical-hydraulic part, and Fig. 3 shows the structure and functions of a data acquisition system for the electrical part.

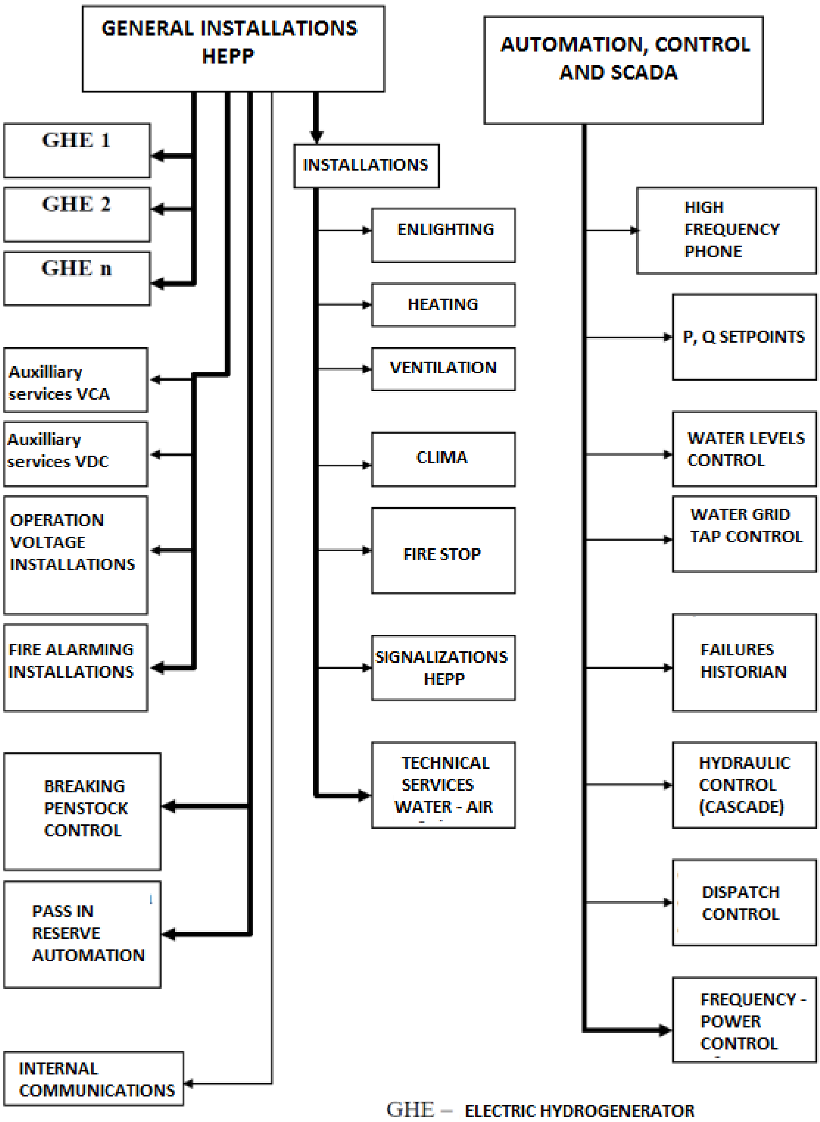

Figure 2. Control systems for HPP

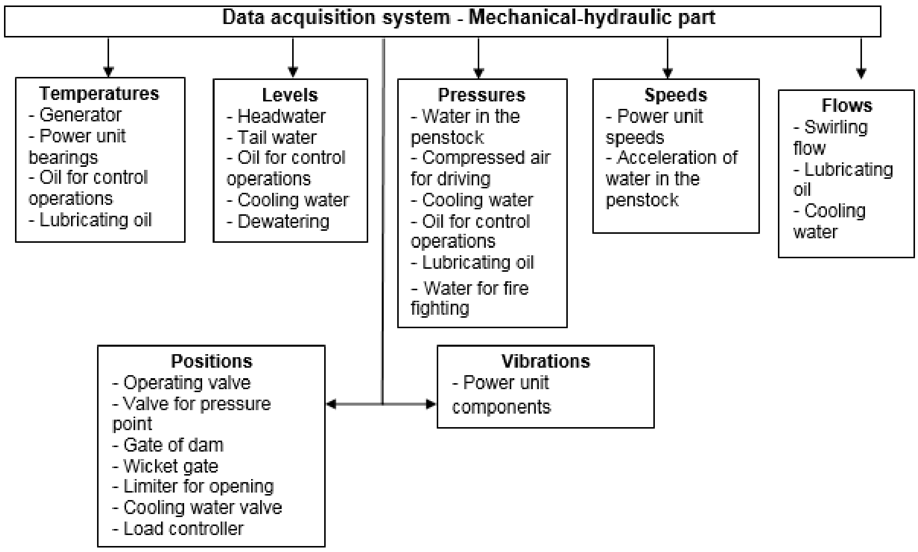

Figure 3. Data acquisition system - Mechanical-hydraulic part

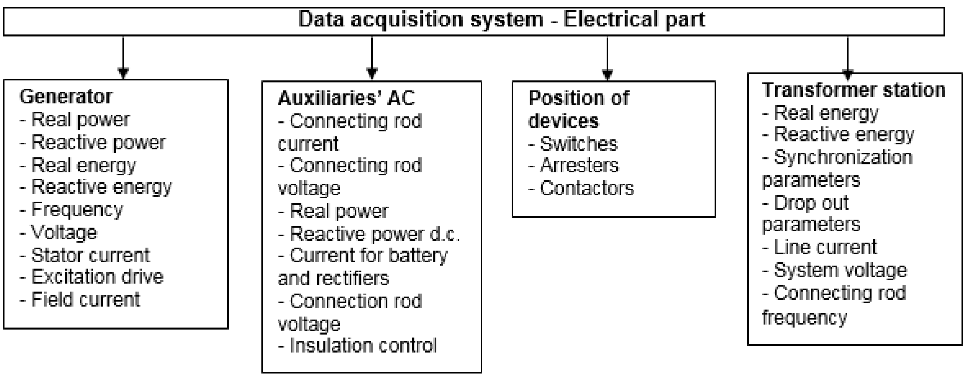

Figure 4. Data acquisition system – Electrical part

All this equipment is arranged on the hydropower unit or in the cabinets or control boards located in the control room. Their arrangement allows direct access of operators both to indicators and maneuver and control equipment.

The equipment in the control room enable the following functions:

- Remote control of HPP groups;
- Control of medium and high voltage substations;
- Control of the operating valve from the pressure point;

- Centralization of information transmitted to the load dispatcher to which the power plant belongs and to the operators of the plant;

- Centralization of information received from the fire detecting element;

- Centralized supervision of the power plant installations and external equipment;

- Control of sluices to evacuate the water surplus or the materials floating on the lake surface.

The power plant "Iron Gates I" has additional control rooms for the power station and for navigation on the Danube in the 'boilers' area.

4. Protection and remote control systems for the equipment in HPP

Safe and economic operation of hydropower plants requires continuous measurement of the hydrodynamic parameters of the water flow also the mechanical and electrical parameters of the hydropower unit, a comparison of their values with the limits imposed by operation also activation of signaling and protection systems in case of exceeding the breakdown limits. Below is an overview of the most important actions for monitoring the installations in hydro power plants.

a) Monitoring of water level

Safe and economical operation of hydropower plants involves knowledge of water level in the hydraulic circuit between the upstream reservoir and the discharge area, namely:

- the water level upstream of the dam, in the loading chambers (or overflowing surge), at sockets, to verify if they are within the minimum and maximum limits set for the plant operating conditions. This is necessary to prevent flooding (internal or external to the power plant) and to avoid the phenomena of intake air in the turbine;

- water level upstream and downstream of the HPP in order to ensure optimal operation of the plant (ensuring maximum net heads) and for regularization of water catchment in case of critical meteorological situations (rain or drought).

Control of water level in various points of the power plant is achieved through manual or automatic operation of valves and gates mounted on the turbine and at the spillway.

Measurement of water levels in different points of the water cycle is done with level transducers provided with water-level float, dipping device, hydrostatic pressure sensor or ultrasonic transreceiver. The adapter of the transducer ensure conversion of the signal from the level sensor into analog or digital electrical signal, which is transmitted remotely to the indicators from the control panel and to the control, signaling and protection systems [3].

In literature and in technical documentation, these transducers are called telemeters. Remote transmission of the signal can be achieved through separate cable, by high frequency currents using as support the medium or high voltage lines of the hydro power plant, GSM or radio signals for transmission over long distances in case of isolated power plants [7], [1].

b) Monitoring of water pipes

Due to high dynamic or hydrostatic pressures, breakage of the penstock or of the headrace may occur. These breakages can bring significant damage to the hydro power plant. Monitoring is designed to trigger the protection system which will block access of water into the penstock by closing the valve from the pressure point and/or in the headrace, by closing the gate valve or the bulkhead at the entrance of the gallery (see Figure 5).

In order to ensure this protection, it is necessary to perform measurements of flows in the penstock and headrace, also of pressures in various points of the hydraulic route and to compare the results with the pre-calculated values or with the values measured in various operating modes of the hydropower units. You have to keep in mind that, usually, there may be two or more hydropower groups that are supplied from the same penstock.

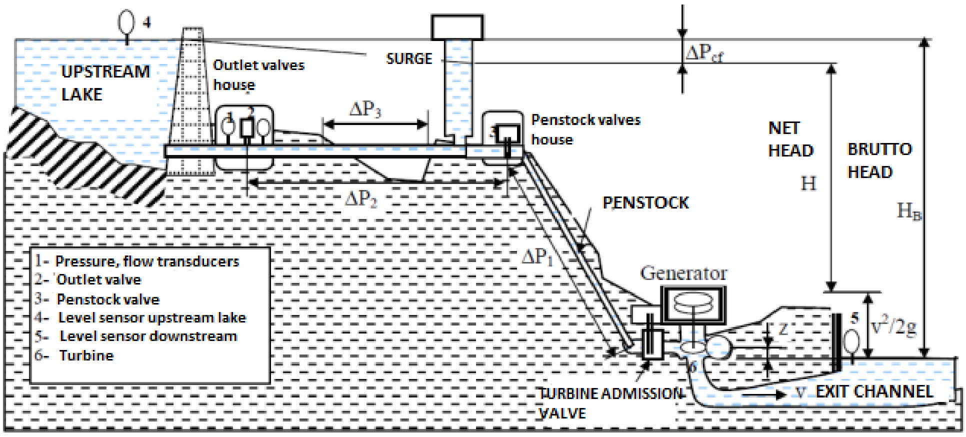

Figure 5. Measurement and drive systems on the hydraulic circuit of the power plant

These groups can operate in the following condition: on, off or idle running until achieving synchronization and coupling to SEN, operation at full load or at sudden discharge (sudden release from SEN in case of breakdown) and as a synchronous compensator. Also, take into account that each group can operate in any of these conditions, independently of the other groups.

To design the protection system, are established the steps required to trigger the protection depending on the water flow in the penstock.

As example, below is given a hydropower system for a power plant with two hydropower units. We will present the example of a hydroelectric system for 2 hydropower plant.

The flow Q_S existent in the penstock is determined when both groups are operating at rated load.

The steps to trigger the protection will be established as follows:

$Q_1 = (0 \div 0{,}33)Q_S$ for the groups 1+2 shut down
$Q_2 = (0{,}33 \div 0{,}66)Q_S$ for one group in operation and the other one shut-down
$Q_3 = (0{,}66 \div 1{,}2)Q_S$ for both groups in operation
$Q_4 > 1{,}2Q_S$ for any situation

In order to achieve protection, permanently measure the speed and real power of the group and determine its operation condition, then the protection system establishes the analogy flow Q_1, Q_2, Q_3, or Q_4. It will be compared the actual flow Q measured in the pressure point with the value Q_i, previously established, and the protection system decides whether or not the penstock is fit.

The protection system for pipe breakage consists of two subsystems: *the maximal protection system* and *the differential protection system*.

b.1. Maximal protection system

The maximal protection is based on this principle, according to the hydraulic chart shown in Fig. 5.

By means of a differential pressure transducer, TE3DM, the total flow through the penstock is measured ahead the main valve of the penstock. It is also measured the speed of each turbine by means of a speed transducer (usually a tachogenerator) and the real power discharged by the generator in the network. These signals are introduced to a calculating unit that allows to determine the swirling flow through the turbine. The summer block Σ_1 performs de flow amount Q_1 and Q_n swirled through the turbines connected to the same penstock. The sum signal is compared in the subtraction unit Σ_2 with the total flow given by the flow transducer TF in the penstock. If at the exit from the differential the deviation is greater than the set value, the comparator block activates the signaling circuits of operators and orders the command to close the main water intake valve of the penstock, respectively the groups shut-down [4].

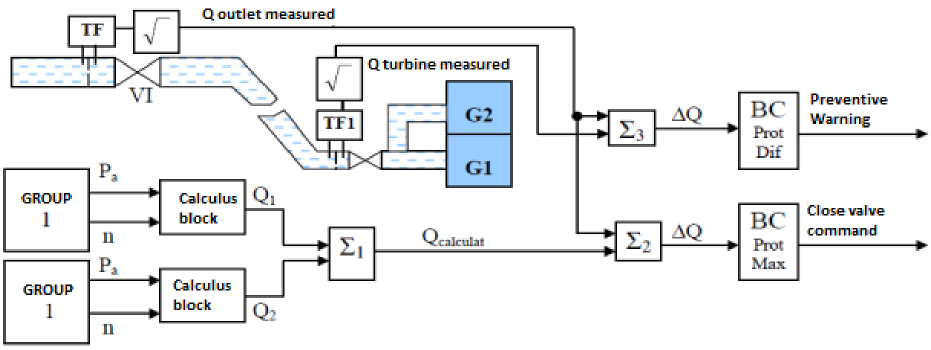

Figure 6. Maximal and differential protection at penstock breakage

This protection applies to both the penstock and the headrace. In this case, a flow transducer is mounted upstream TF and one downstream of the controlled area TF1.

A downward element Σ_3 performs the difference between the signals of the two transducers, the difference is void in normal operation conditions (no losses in the pipe). If the difference is greater than the set value, the comparator block is activated signaling preventive the operators and, if this difference persists, closing of valves VI upstream the pipe controlled circuit is ordered and then triggers the procedures to shut-down the groups. The scheme can be combined with the scheme for maximal protection as shown in Figure 6.

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