DESIGN CONCEPT OF HYDRO CASCADE CONTROL SYSTEM

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ABSTRACT

In this paper a design concept of the complex hydro cascade scheme is presented with the design parameters of the main technical features. The cascade control system architecture is designed considering up-to-date communication and information technology. The control algorithm is based on Pond Level Control and Economic Load Allocation concepts.

KEY WORDS: Hydro cascade, Control system, Economic Load Alocation, Pond Level Control

1. INTRODUCTION

The Tresca Cascade hydro scheme consists of three hydro power plants: HPP Kozjak, HPP Sv. Petka and HPP Matka. All power plants are hydroelectric projects of accumulation type with a dam and different storage vol-umes. On the basis of water economy the projects are multipurpose development. The power plant Sv. Petka (as middle step of the cascade) is of medium-head type oper-ating as peak-load in accordance with operation of HPP Kozjak (up-stream) and HPP Matka (down-stream). The main purpose of HPP Sv Petka within the multipurpose hydro-system Skopsko Pole-subsystem Kozjak-Matka, is to utilize the available hydro potential of the HPP Kozjak discharge and the local waters in the river Treska catchments area, in the part between the HPP Kozjak and the HPP Sv Petka dam sites. The projects are highly depend-ent on following projects that are currently under-way in power system:

- EMS (Energy Management System) and
- Telecommunication Project in Electric power utility with appropriate technical specifications and solutions that should be respected.

The control of each hydro power plant is very complex due to the cascade configuration and the main task is to design a Control Center that shall respect the particularities of the plants, coordinate the power plants and provide optimal cascade operation.

2. TRESCA CASCADE - Hydro Units in Series

Treska cascade hydro system consists of three reser-voirs Kozjak, Sv. Petka and Matka having the following characteristics:

q short or nearly no distance between the reser-voirs,

q different storage volumes,

q power plant/unit discharge between power plants differs in range of 1:2.5

q a number of operational constraints considering power system technical operation and electricity market liberalization and

q three different projects with particularities to be respected

Those characteristics make the Treska cascade unique and very complex hydro-electric system and promote the concept idea of integral control as one Regional Control Center. For such center the authors of the Study propose the name "Treska Cascade Control Center" - TCCC and it is used throughout this document.

Treska cascade is a hydraulically coupled system consist-ing of three reservoirs in series (Fig. 1). The discharge from any upstream reservoir is assumed to flow into the succeeding downstream plant with no time lag. The hy-draulic continuity equations are

$$V_{1j} = V_{1j-1} + (r_{1j} - s_{1j} - q_{1j})n_j$$
$$V_{2j} = V_{2j-1} + (q_{1j} - s_{1j} - s_{2j} - q_{2j})n_j$$
$$V_{3j} = V_{3j-1} + (q_{2j} - s_{2j} - s_{3j} - q3_{3j})n_j$$

where r_j – inflow

V_j – reservoir volume

s_j – spill rate over the dam's spillway

q_j – hydro plant discharge

n_j – number of hours in each scheduling period

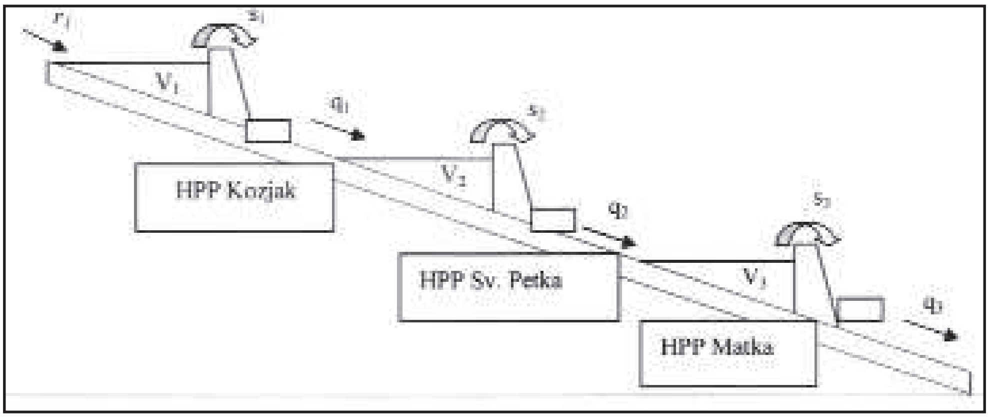

Fig.1 Hydraulically coupled hydroelectric plants in Treska Cascade

3. TRESKA CASCADE CONTROL CENTER

The Control system of the Treska cascade shall main-tain the coordination and optimal operation of the three power plants HPP Kozjak, HPP Sv. Petka and HPP Matka, as Regional Control Centre. The Design of such complex control has to consider the specific functional and operational constraints and project complexity of the power plants and NDC requirements.

The Tresca Cascade Control Center (TCCC) shall di-rectly control and coordinate power plants operation. Since the hardware shall be located in HPP Kozjak con-trol room, the Center shall remotely control HPP Sv. Petka and HPP Matka (Fig.2). However, off-site from NDC for all three power plants shall also be available.

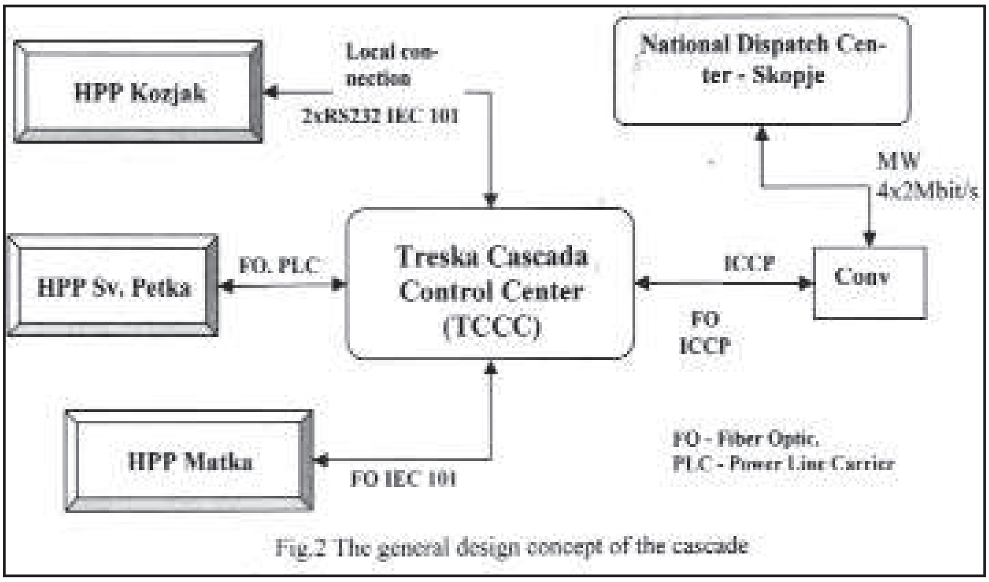

Fig.2 The general design concept of the cascade

TCCC will implement a state-of-the-art Control System to provide extensive remote control of all three power plants (HPP's), their switchyards and substations (S/S's) for connection to the transmission network (110 kV, 35 kV).

Overall Treska Cascade Control System, will consist of the following major parts:

Real Time Computer System (RTCS) that will perform real time control functions as well as planning/scheduling functions located in TCCC,

Plant Control Systems installed in HPP's (Kozjak, Sv. Petka and Matka) which will perform allo-cated control functions and provide real time data for RTCS,

Intelligent digital telecommunication network in-stalled along the Treska river HPP's which will provide all necessary voice and data communica-tion facilities for HPP control and

Interface to existing telecommunication system that shall provide necessary data communication between 110 kV substations and RTCS.

Other control and monitoring systems that will be im-plemented in HPP's on Treska River are:

Metering System (MS) dedicated to collect meter-ing values in HPP's (intelligent meters and meter-ing system registration) and to communicate with metering system concentrator (metering data evaluation) located in TCCC,

Oscultation Monitoring System (OMS) dedicated to collect oscultation data (HPP dam and building observation) in HPPs

The Treska River Control System will be hierarchically organized with following control levels:

zero control level in HPP (Technological /functional group control),

first control level in HPP (Local control),

second control level in HPP (Plant control) and

third control level in TCCC and NDC (Remote control)

Communication between TCCC and NDC according to ICCP TASE.2 communication protocol is proposed. Al-located functions in NDC that must be considered in RTCS design are:

automatic generation control (AGC) and

remote control of circuit breakers and disconnect-ing switches in 400/220/110 kV transmission net-work (substations).

RTCS will be basically designated for:

- remote operation of HPP's and substations,
- HPP operation, optimization and
- HPP water and energy management.

Plant control systems (PMS's) in HPP's will perform following functions (regarding HPP operation):

- joint load operation,
- joint high voltage (110 kV)/reactive power op eration,
- water flow operation,
- water level operation,
- time determined target value of the head water level operation,
- joint MVAr operation and
- available number of units for operation.

Treska River Control System will be basically two lev-els hierarchical structure with TCCC on the highest and HPP's/S/S's on the lowest level. Overall Energy Man-agement System is of three level topology where Na-tional Dispatch Center is on the highest level and TCCC (located in HPP Kozjak) on the next lower level.

Following main functions will be implemented in RTCS:

- SCADA,
- AGC/Generation control,
- Water/energy planning and optimization,
- High/fllod water operation
- Communications,
- Etc.

SCADA must enable extensive remote control of all HPP's and S/S's and must be supported by modern and user friendly Man Machine Communication.

In the HPP Kozjak existing control system will enable following operation modes:

- joint load operation (joint active power),
- joint high voltage (110 kV), reactive power opera-tion,
- joint Mvar operation and
- water flow operation,
- water level operation,
- time determined target value of the head water level operation,
- joint Mvar operation and
- non-optimal number of units operation;

Generation control software will include also automatic generation control where HPP's on Treska river must cover area control error as calculated in National Dis-patch Center. Automatic interactions among different software modules are requested.

Optimization must take into account all constraints (units in operation, units in revision, operable spillway gates, water levels etc.), requested power (MW) out-put of the chain and river flow. Optimal operation of HPP's will be calculated on daily basis as well as on request (momentary).

Only limited water and energy short and long term planning will be introduced. Short term planning repre-sents calculations for possible power production three days in advance based mostly on flow prediction. Long term planning (one year) must result in revision plans for different equipment in HPP's and power production plan.

Real time data as well as operators messages must be exchanged among different companies either because of high voltage network connections or because of water flow dependence. RTCS must have all necessary func-tionality to transmit necessary real time data to NDC as well as to other control centers.

The architecture of the TCC system is presented on Fig. 3. The full redun-dancy apply on all connections and Human-Machine Interfaces.

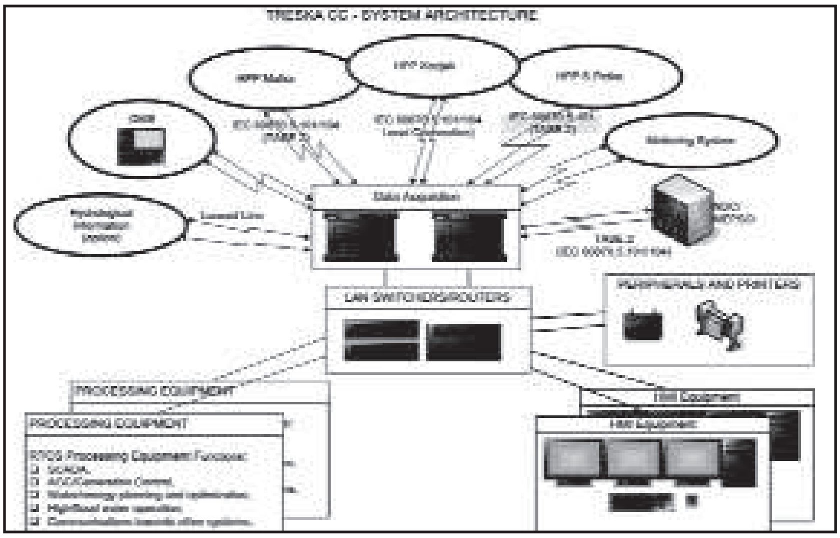

Fig.2 The general design concept of the cascade

4. REAL TIME COMPUTER SYSTEM

The Real Time Computer System will perform real-time operation control, optimization, short term water and energy planning concerning real time operation of HPP's. RTCS will in accordance with TCCC responsibilities and allocated functions, NDC power production requirements, water and other constraints perform above mentioned functions.

RTCS will be based on LAN configuration where one independent operator's work places and one work place for RTCS development/system engineering purposes will be implemented. Man Machine Communication will use full graphic technology with screens and adequate print-ers.

RTCS will perform data acquisition and communication with Plant control in HPPs based on IEC-870-5 -101 communication protocol. RTCS will be capable to per-form also data communication with other control centers based on IEC-870-5 - 101 and/or on IEC 870-6 (TASE.2) communication protocol. RTCS will have all necessary software facilities to enable raw and calculated data to be transmitted to and from required destinations (other con-trol centers).

For communication with other control system and for optimization/planning functions single servers could be suggested. For all HPP's new intelligent digital telecom-munication network will be installed where two inde-pendent digital channels will be available for real time data communication between HPP (RTU's or Plant con-trol's) and TCCC (RTCS). RTU's in S/S will be connected to RTCS using existing (two independent channels) ana-log telecommunication network.

5. CASCADE OPERATION AND OPTIMIZATION

The cascade control includes both pond control and economic load allocation functions for each power plant and optimization logic. The Treska cascade is very com-plex project and a special attention should be provided to operation and optimization of cascade.

5.1. Pond Level Control

Pond Level control includes the following functions:

- level monitoring and control in the cascade (Kozjak, Sv. Petka and Matka),
- water storage estimation in the reservoirs,
- active power load scheduling for each hour or re-spond for AGC request,
- off-line corrections of load schedule,
- calculations of flow, levels, determination the limits and respecting constraints

According to the measured values for reservoir elevations the Treska cascade pond controller will calculate appro-priate discharge for each plant. The pond control system determines the best flow distribution through the system respecting the available units for operation, current condi-tions, power system demands, and hydro constraints for co-ordinated operation of the cascade. In AGC mode some of the optimization features are not functional since the load control is priority.

Basing on load schedule for each power plant and their models the amount of water flow needed to produce the required amount of power in following day. The power plant models are developed basing on power plant design data, characteristic and historical data.

The estimated water flow/usage is than compared to ac-tual pond level in order estimate the change in pond level. The maximum and minimum load levels are operator enter values. The program checks if pond level constraints are fulfill. The Operator in TCCC or NDC is able to make correction in the schedule in order to re-define the con-straints.

5.2. Economic Load Allocation

The Economic Load Allocation considers the total plant megawatt demand signal from the pond controls and optimizes the load distribution among the available units in cascade to achieve the most economic use of water as possible. Since the optimization is based on efficiency curves for each unit, it is necessary to have current effi-ciency curves.

Economic Load Allocation optimization would automati-cally determine the most effective load dispatch across the units (turbines) at each of the unit in cascade. The optimi-zation software has to consider current plant conditions - power demands, different turbine characteristics, opera-tional constraints, etc. - and determine the optimal plant settings.

Considering the turbines efficiency curves, optimization by the criteria of minimization of water flow shall be performed. These curves are approximated by polynomi-als that assure the needed accuracy. The differences be-tween efficiency/load curves for each unit are used to determine optimum load distribution between units. Units with highest efficiency (and thus - minimum water flow) are chosen with highest priority - they work for the long-est amount of time.

In Treska cascade the power generation in one power plant depends on power production in the other power plants. The load dispatch software should avoid the risk of too big Matka lake level increase or decrease. The data about the levels and allowed water flows are obtained from Pond Level Control calculations.

Since the cascade consists of turbines with different sizes, thus it is not possible to dispatch the load based only on the efficiency of the turbines. In that case priority has to be given to large size turbines first.

5.3. Optimization Algorithm

Such algorithm is necessary to be developed for Treska cascade, since this is a cascade with very complex pa-rameters for optimization. This algorithm should consider all necessary input data, calculations and methodology for co-ordination and optimization. A special attention shall be provided to the operation of the units in cascade power plants on a higher net heads for obtaining power. There-fore a special plant factor shall be determined that is a function of the plant head. In scheduling for cascade op-eration a volume of available water in reservoirs shall also be considered for hourly/daily planning, making optimi-zation procedure flexible to meet the requirements for maximal benefit from $MW or $MWh pricing.

Optimization goals

- Minimization of water flow for maximum output
- Maximization of available power output
- Maximization of benefit for produced power/energy in according to electricity pricing

The necessary pond control data are as follow:

- Maximum and minimum pond levels/elevations for each pond
- Plant Efficiency = f (plant load, pond level, number of units in service)
- HPP and Unit(s) operation constraints and limita-tions
- Unit maximum and minimum load for different pond levels
- Unit restricted zones for different pond levels
- Unit efficiency curves sets for different pond levels
- Unit Efficiency = f (unit load, pond level)
- Unit water flow curve for different pond levels
- Turbine discharge = f (unit load, pond level)

On the following figure an overview of these two func-tions and their interactions in Treska cascade control is presented.

6. CONCLUSION

Design of a cascade control center is a chalenging task that should implement expert analysis for technical func-tionality and optimal economic load alocation of all units in the three cascade plants. Control algorithm shall con-sider all operational constraints due to water management of the acumulations and power management in the daily load schedule of the power system operator.

7. REFERENCES

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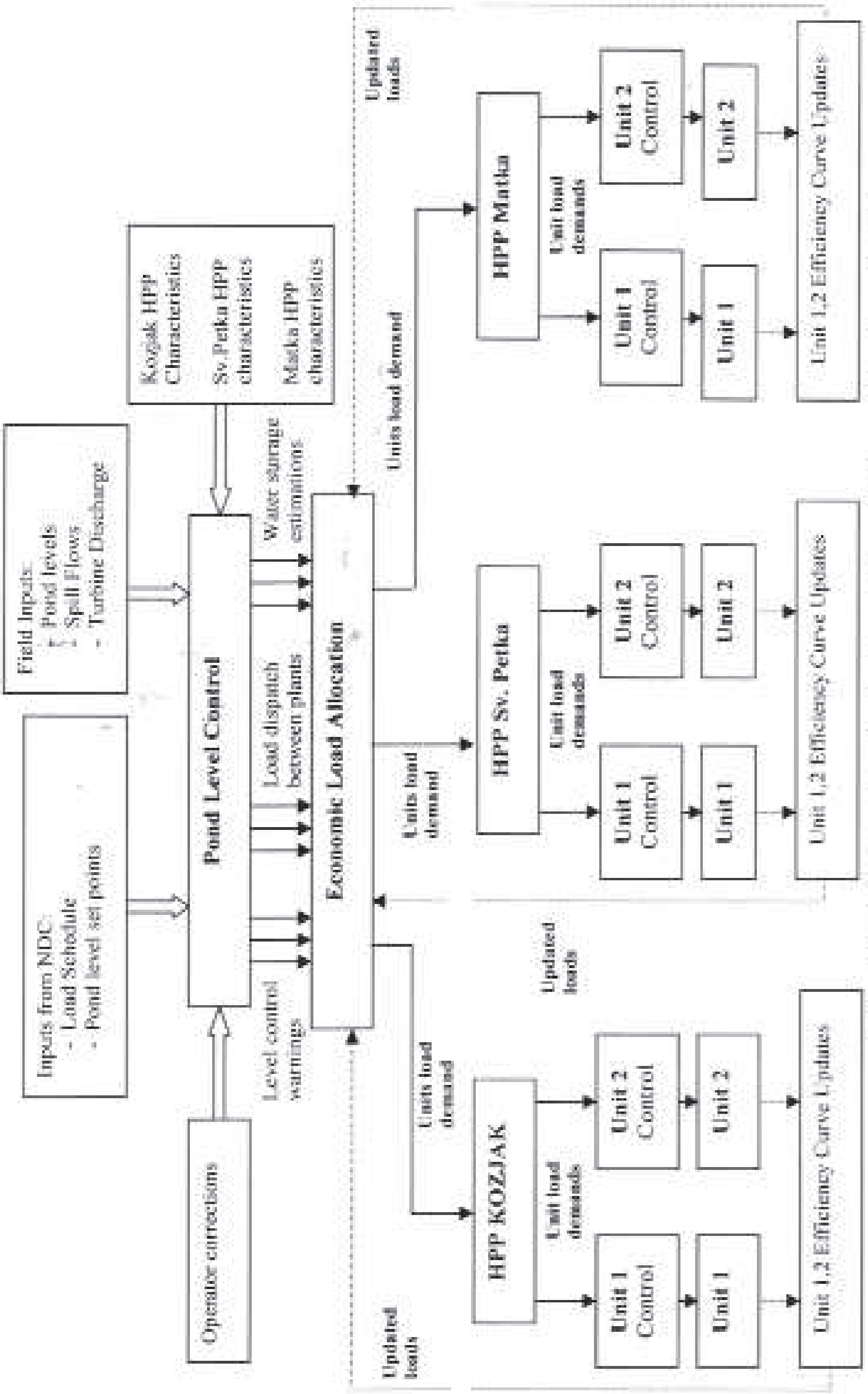

Fig. 4 Treska Cascade pond control operation and ELA optimization principle

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