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"Politehnica" University of Bucharest, Machine and Manufacturing Systems Department
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ADVANCED PUMPING STATIONS COMPUTER MODELING

Mircea GRIGORIU

Abstract: *The paper presents a back-to-back supply schema optimization of powerful pumping station, with variable speed pumps. Also, there are presented relevant recommendations on the pumping station design and exploitation. There is analyzed a particular case of a pumping-storage system working as a pumping system in the night time and as hydropower system for a short period during the morning.*

Key words: *storage system, different leveled lakes, pumps units at variable speed, back-to-back supply, islanding conditions, slipping parameters.*

1. INTRODUCTION

For operation in different regimes required by the user there are various modalities to control and adjust the hydraulic system. Traditional adjusting method for the output of the pump, with constant speed is through throttling the discharge valve of the pump. This method is dissipative with energy loss and less efficiency for the pumping system. The new concept of control method proposed here is through changing the rotational speed of the pump achieving the final regime with minor reduction of efficiency in respect of the best efficiency initial regime.

If the control is slow, the quasi-static approximation of the transients is valid. Through the proposed method the new stationary regime of the pumping system has effectiveness, namely a gain, which depends on the inclination of the long axis of the equal - efficiency curves (the ridge of the universal characteristics) – in head-capacity plot – and also from the steepness of the network curves.

The peculiarity of the hydraulic system studied here is that the network is changing not through throttling but with level differences between the reservoirs. So the classic gain in efficiency is higher if the above mentioned axis (ridge) is more inclined from the vertical direction in head –capacity coordinates and if the configuration of the network head- capacity curve is steeper (with high friction losses). These conditions are relaxed in the case studied here.

In closing this frame of the studied problem, we do underline the general assumptions made in order to model the power system under focus, on its both sides, hydraulic and electric. So, the operation on the power hydraulic pumping system may be described in stationary regimes, based on head – capacity characteristics: H (Q) – head-capacity of the pumps and Hi(Q)- head-capacity of the hydraulic network. These characteristics are represented in a graphic way, as characteristic curves, plotting head – capacity pairs of values for each working regime at a constant rotational speed. In this work, they will be represented in an analytical way, by a modeling technique too, having in mind the followings:

- The optimal designed situation reflects the best mass and energetic equilibrium;
- There are various modalities to control the hydraulic system for operation in different regimes, as required by the user. For this very case of application, we could apply the traditional adjusting method for the output of the pump, at constant speed-by throttling the discharge valve of the pump. However, this method known as an energy dissipative one, is with significant losses and thus, less efficiency for the overall pumping system;
- The modern recommended method is to control the regime by continue adjusting the rotational speed of the pumping unit, according to its hydraulic momentary constraints. The final regime is achieved with minor reduction of efficiency of the pump and without any supplementary hydraulic losses. The large scale application of this efficient method is effective only if the rotational speed variation of the hydraulic devices is economic-effective and this is the very case studied here in the present scientific work;
- The hydraulic characteristics of the pump at different rotational speeds can be obtained in two ways: testing the pump on adequate stand and, theoretically, predicting the characteristics by applying the similitude invariant coefficients;
- The modeling - on the power electric side, follows the speed variation law for the counter resistance torque;
- Certain synchronous machine's electromagnetic characteristics ware taken from similar units, closed as rated power and speed;
- Finally, all the losses in the power electric network were cumulated, as one single consumer.

2. CASE STUDY DESCRIPTION

The case study refers to a Romanian hydro-energetic system from which a part is represented in the Fig. 1.
The hydraulic pumping system consists from the pumping station and the hydraulic network.

The main parameters of the pumping station are: CP – centrifugal pumps, concrete 2 pumps operating in parallel, each with two stages and double entrance. The design parameters of each pump are:

– Discharge (capacity) Q_0 = 3 m^3/s;
– Head H_0 = 247 m,H2O column;
– Rotational speed n_0 = 1000 rev/min;
– Pump efficiency η_0 = 90 %;
– EM - synchronous electric motor, asynchronous start;
– Power output P_0 = 10 MW;
– Rotational speed n_0 = 1.000 rev·min^{-1}.

The main characteristics of the hydraulic network are:

– SP – suction pipe with the cross-section 1.92 × 2.76 m^2, and the length L_2 = 6500 m.

– DP– discharge pipe with the cross-section Φ D = 1.3 m, and the length L_1 = 360 m.

The rated level differences between the reservoirs according to Fig. 2 is h_0 = 241 m.

The maximum and minimum aloud level differences between the reservoirs are: h_M = 253 m; h_m = 198 m.

These values are given as initial input design data.

A part of the characteristic diagram $Q – H – n – \eta$ for the two identical centrifugal pumps operating in parallel is plotted in Fig. 1.

Qualitatively, what will be calculated starting from the rated regime to the extreme regimes (for maximum and minimum level differences of the reservoirs), is represented in Fig. 2.

Knowing the rated regime's parameters in the hydraulic network namely the head H_0 = 247 m and the discharge in the pipes $2Q_0$ = 6 m^3/s it will be calculated the constant C of the network with the formula:

$$Hr = h_0+C(2Q_0)2 = H_0. \quad (2)$$

It results $C = 1/6\ s^2/m^5$.

Taking into account the turbo-machinery similitude formulas:

$$Q = k{\cdot}Q_n, \quad (3)$$

$$H = k{\cdot}H_n. \quad (4)$$

The calculus of the parameters of the extreme regimes means solving the systems of equations (5) (6) and (7), respectively (8) (9) and (10):

$$H_m = (H_0 / (2Q_0)2)\ Qm_2, \quad (5)$$

$$H_m = h_m + C\ Qm_2, \quad (6)$$

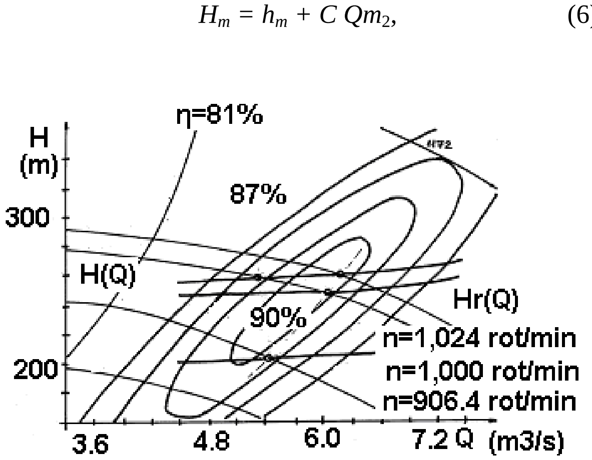

Fig. 1. A sequence of the characteristics curves of the two centrifugal pumps in parallel.

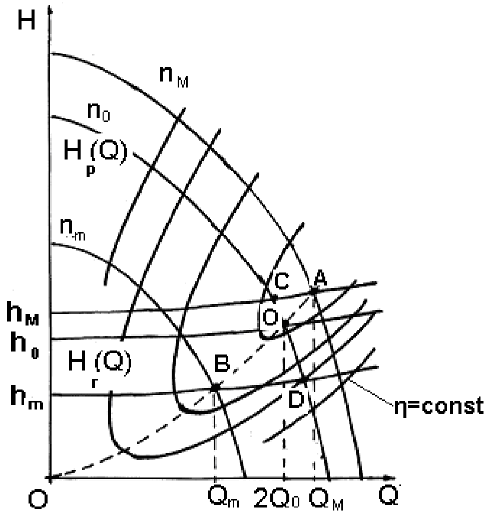

Fig. 2. Explanatory plotting head-capacity-speed-efficiency of the pumps with network.

$$n_m = (n_0 / Q_0)\ Q_m. \quad (7)$$

The results are: discharge Q_m = 5.438 m^3/s, head H_m = 202.929 m and speed n_m = 906.4 rev/min.

$$H_M = (H_0 / (2Q_0)2)\ Q_{M2}, \quad (8)$$

$$H_M = h_M + C\ Q_{M2}, \quad (9)$$

$$n_M = (n_0 / Q_0)\ Q_M. \quad (10)$$

The results are: discharge Q_M = 6.148 m^3/s, head H_M = 259.299 m and speed n_M = 1024.6 rev/min.

Analyzing the universal characteristics of the pumps, Fig. 1, it may be interpolated and estimated the corresponding efficiencies and powers. They are given in Table 1.

The maximum efficiency gains are about $\Delta\eta_{AC}$ = 1.63 % and $\Delta\eta_{BD}$ = 7.23 %. These values give a measure of the effectiveness of the speed control in comparison with the operation at constant speed or the throttling control of the pumps.

3. THE POWER ELECTRIC DRIVING SYSTEM

The power electric driving system, shown in Fig. 3, is at variable controlled speed for pumps, operates at specific hydro-constraints, and offers some remarkable advantages. However, the most important among these advantages, remains the higher efficiencies over constant speed or throttling; also we have to add the more reliable working with lower speeds, plus better computer controlled speed changes for preset operating conditions (head, discharge flow).

The method of speed control over the hydraulic turbo-machinery may be used in any hydraulic system, especially for higher power ratings of MW, as it could be seen in this herewith focused practical example.

The power electric energy – at variable frequency is to be power plant HPP, working in this particular case with one single generator rated – 24 MVA, 10/110 kV; it is injecting its MVA in islanding conditions of operation, through its second separate power electric overhead line, LEA 110 kV.

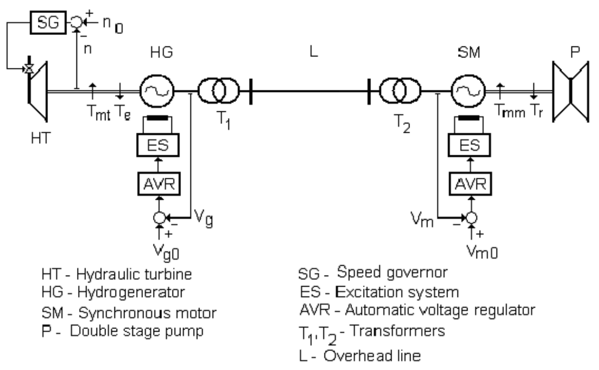

Fig. 3. The power electric simulated system.

The other one hydro generator HG from the HPP could remain connected to the system at fixed frequency; the two units are to be separated by one coupling cell deliberately newly-introduced in this scheme, in order to gain elasticity for the new operational regimes.

The powerful pumping station PPS – rated 2.10 MW, 110/6 kV, 2.3m^3/s, 1000 rot.min-1 is located at 30 km distance approximately, up in the mountains; it is loaded by the specific hydraulic conditions given by the two lakes' levels, of small and bulky capacity l, L.

The two levels are to be communicated via GPS to the basic generating HPP, and the whole driving system power electric energy – is working at the requested variable frequency, in order to gain the overall maximum efficiency for the PPS in question.

In this respect, we see that the same specific hydraulic conditions imposes the practical spectrum of speeds to the electric power driving system; as indicated above, the speed limits are non-symmetric scaled and are ranging from 906.4 to 1024.6 rev/min, more below than above the synchronous speed of 1.000 rev/min.

Up to now, the fixed speed of 1.000 rev/min was given (imposed) by the fixed frequency of the national electric power grid, 50 Hz and, clearly proved not to be the best chosen solution for the PPS operating in this specific hydraulic challenging conditions, between the two different (heights and capacity) distant located lakes – the small l, and the bulky one L.

As far as the local conditions for this – quite unique application, we can suggest how favorable these are, represented by the existing infrastructure, so: the neighboring generating HPP where only one single unit is able to perfect match the requested power for both motor units at the PPS.

On the other side, the common overhead supplying 110 kV line links over medium distance the two power stations HPP-PPS, generating-motoring, at pooling conditions within its independent frequency.

4. SIMULATION RESULTS

The results (Fig. 4) released from the simulations are based on the standard synchronous machine's equations. So, one small step-up, average 10 rev·min^{-1} or equivalent 3% increased during seconds the hydro generator's HG speed, by opening its turbine's gate: the remote motor slower responds by reaching its upper speed limit of 1025 rev/min over some delay, but no more than 10-15 s.

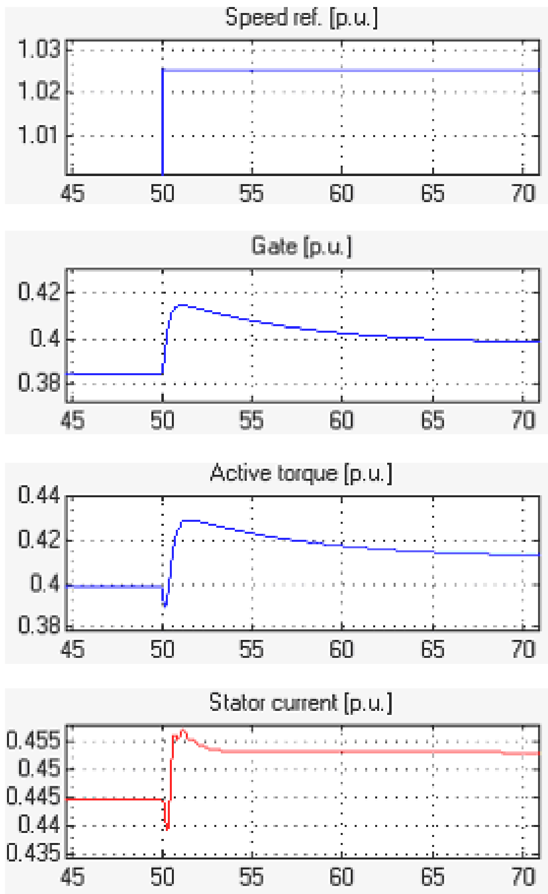

Fig. 4. The main transients on the hydro generator' side.

On the HG side (Fig. 3), as a result of increased active torque, promptly increases the stator current and the active power injected at the terminals (small reverse swings probably mark the AVR's small delayed intervention).

On the motor's side at the PPS (Fig. 5), as a result in promptly command of increased frequency coming from HG via 110 kV line, clearly we can see the same prompt responses with increased stator current, absorbed active power and dropping in stator voltage (small reverse oscillations probably mark also here the AVR's small delayed intervention).

However, as stated above the motor's response in speed-up is much slower – as a mechanical parameter, while the internal load angle displacement marks one intermediate time evolution.

In closing the discussion over the simulated behavior for the first time in this particular back-to-back powerful scheme running at variable speed and exploiting the local favorable conditions, as we can hope – this exercise proves to be a successful one.

However, we do believe after the above shown math simulations, to continue with necessary commitment the researching efforts on reduced physical models, finally ending with real scale tests carefully carried out, by teaming skilful engineering.

5. CONCLUSIONS

The speed control of the pumps operating in the hydraulic systems, has some relevant advantages:

– higher efficiencies than constant speed or throttling,

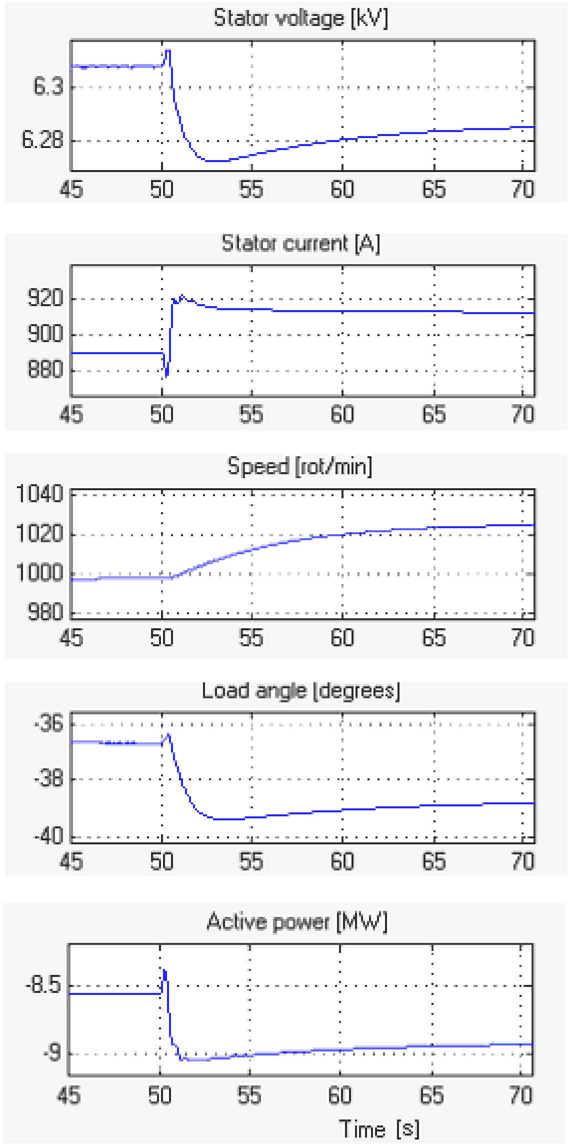

Fig. 5. Synchronous motor transients.

– reliable working with lower speeds,

– better computer controlled speed changes,

– preset operating conditions (head or discharge flow).

The method of speed controlled hydro-turbo machines may be used in any hydraulic system, but for higher MW ratings, the advantages are more pertinent, as for the practical case study herewith under focus.

Following the above simulations, instead of fixed driven pumping units at 1 000 rev/min, we do strongly recommend one operational speed interval, scaled ranging from 906 to 1 025 rev/min. In so doing, it gains significant points in the general efficiency, when transferring water volumes between the lakes. The case study is a practical application; it is now frequently working upstream river in our mountains at fixed frequency of 50 Hz, especially outside peak load.

This application has some unique local conditions (world wide unique!); its specific is done by covering power hydraulic very difficult conditions, which also does reveal an impressive bounty of phenomena.

We did set out here for the first time, by quality simulations, the limits for variable speed and did proposed the most simple and cheaper driving scheme, by using the already existing infrastructure on the local site: one hydro power generator – able to sustain both motor-pumps and the overhead transmission line, with all-together possible working at islanding conditions.

Throughout the world of hydro-electric power engineering, the important HPPs with storing facilities do operates at variable speed, and do underlines the advantages with this method. Commonly world wide scale, are used different electric driving schemes, but the most elegant are those with frequency convertes/soft starters or better a.c. cycloconverters excitation schemes for their rotors at variable speed.

However, in the present paper, was selected the cheapest possible and independent driving scheme back-to-back, in which one down-stream hydro electric power generator is driving the upper stream pumping motors at variable speed.

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Author:

PhD, Mircea GRIGORIU, Profressor, University “Politehnica” Bucharest,
E-mail: `mircea.grigoriu@gmail.com`