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Tests Regarding the Transitory Regimes of Putting off Load of the Hydroagregate

For high power and high revolution aggregates it is required that the operation should take place in safe conditions, for all the running regimes. The most difficult regimes for a hydro aggregate are the transitory regimes. Although, these regimes generally last a rather short period of time, for high power aggregates these regimes are accompanied by electric and mechanic solicitations which sometimes can surpass the admitted values. In the present paper, we present an evaluation method of the rotating parts' dynamic stability of the hydro aggregates in the transitory regime of putting off load. We present the results obtained from the recordings of putting off load and those obtained after the dynamic equilibration of the hydro aggregate's rotor.

Keywords: *hydro aggregates, vibrations, dynamic stability*

1. Introduction

The analysis of the transitory regimes of electric machines is a field which, lately, has attracted the interest of many researchers in the field. Thus, some mathematical relations were defined which are able to describe the dynamic regimes, namely the variation of the electric and mechanic values in these regimes. The validation of the considered relations was achieved by numerous simulations and tests.

The dynamic stability of an electric machine represents its capacity to absorb the load variation, thus the loss of synchronism should not be produced [1], [2]. In the case of putting off load of hydro aggregates, we cannot talk about dynamic stability, but of a special transitory regime which solicits the machine from the electric and mechanic point of view. These solicitations are determined by the sudden and uncontrolled increase of voltage of the armature and revolution winding.

For synchronous machines, especially high power ones, the study of transitory processes is difficult to achieve due to the magnetic asymmetry of the rotor, this presenting symmetry only on the two axis d and q. During the transitory processes, due to the transitory currents which appear in the windings, the magnetic field of the machine modifies and determines the change of the values of the machine parameters, respectively the disturbance of its normal running [3].

For high-power hydro-aggregates, some hypothesis and mathematical relations are available which were defined by the specialists in the field for dynamic regimes. Taking into account that for the writing of the mathematical equations which define these regimes there are certain simplifying hypothesis, the real values of the electric and mechanic values obtained in transitory regimes differ from those obtained by simulation.

In order to know exactly the values of these measurements it is necessary that for all functional hydro-aggregates and for those that are to be built, these should be equipped with monitoring system. Nowadays, most hydro-aggregates are not endowed with online monitoring system of the measures which describe the respective operating regime. This system must be capable to register and transmit in the best possible way, the values of the electric and mechanic measures of all the operating regimes, in order to detect and eliminate in due time the problems of exploitation and operation [4].

The transitory regime analysed in this paper is putting off load. This regime can appear at any hydro-aggregate and consists in disconnecting the load from its terminals. In this case, the revolution of the rotor surpasses the nominal value and determines the appearance of vibrations and the increase of the induced voltage.

The increase of the tension of the armature is also determined by the fact that in the moment of load disappearance, the hydro generator is idling. Thus, the electromagnetic field produced by the excitation winding is higher than the resulting field existing in the machine before putting off load, this because it lacks the reaction of the armature. The increase of the armature voltage leads in time to the wearing out of the isolation and the destruction of the hydro generator winding.

For the limitation of the value of the armature voltage in hydro generators the tension regulator was introduced (RAT) which disconnects automatically the excitation winding and for the limitation of the revolution value, the regulator of speed or revolution (RAV), which orders the closing of the directory apparatus of the hydro aggregate.

The transitory regime which accompanies the transitory process of putting off load is characterized by mechanical and electric solicitations which can sometimes be very dangerous and this is why it is compulsory to know the evolution way of these solicitations.

2. The acquisition system and the acquired values

In the acquisition of the values of interest the kit of acquisition VPA323- an analyzer of electric and process parameters was used by means of which we recorded the active power and reactive discharged power, the line tensions and the currents at the generator terminal, the excitation tension of the generator, the vibrations at the level of bearings. According to the radial direction the rotor revolution.

The technical characteristics of the equipment are [5]:

- resolution 16 bits, sampling rate 25 kS/s/ch, precision 0,1%;
- three-phased analyser CA/CC, 100V/600V, 5A with galvanic separation on each channel;
- 12 entries of ±20 mA or ±10V;
- 10 entries of±10V;
- 3 entries type IEPE;
- 1 entry for revolution and reference speed;
- 4 entries optocoupler 0 – 24 Vcc to visualise the state of the car;
- 4 entries optocoupler 0 – 24 Vcc/100 mA with warning function, protection or command;
- 2 analogic output to generate signals with form, programmable amplitude and frequency;
- USB Interfaces (communication PC conditioner), Ethernet (distance surveillance by fixed internet), GSM – GPRS (distance surveillance by mobile internet).

The supply of the equipment is achieved at tension 230/150V with a frequency of 50 Hz/60 Hz.

The revolution of the hydro-generator was measured with a laser sensor for revolution, type QS30LDQ, 120000 rpm, 2 m sensing distance.

The vibrations on the superior bearing of the generator and the bearing of the turbine were measured with three vibrations sensors, having the following characteristics: serial number 066921 with sensitivity of 533,3 mV/g, serial number 066922 with sensitivity 546,1 mV/g, serial number 066923 with sensitivity 497,5 mV/g. F.

3. Experimental results at putting off load of the hydro-aggregate

The nominal data of the analysed hydro generator are: power 20000 kW, voltage 10500 V, current 1221 A, revolution 750 rot/min.

For the stationary regime before putting off load, the equation of the synchronous generator, for one phase, is [6]:

$$U = U_e - I(R + j \cdot X) = U_e - Z \cdot I \quad (1)$$

Where: U is the tension at the hydro generator terminals, U_e is the electromotor tension induced by the resulting flow, I is the current in the winding of the armature, R, X, Z are resistance, dispersion reactance, the impedance of the phase of the armature respectively.

When the connecting switch of the hydro generator to the network is turned on, the value of the current through the winding induced becomes null and the equation (1) becomes [7]:

$$U = U_e \qquad (2)$$

Thus, it appears an overvoltage at the terminals of the hydro generator determined by the lack of reaction of the armature.

The variation way of the acquired values during the transitory process of putting off load is presented in Fig. 1.

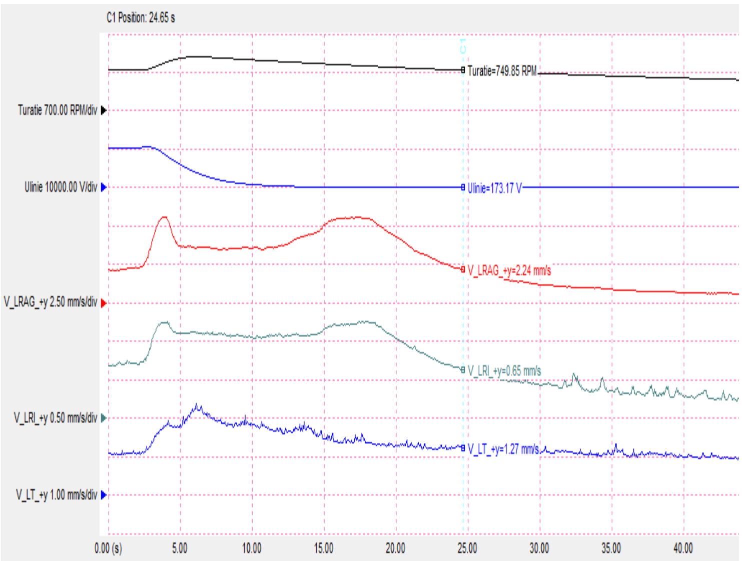

Figure 1. The variation of the recorded values at putting off load

These values are: the revolution of the rotor n, the line tension t of the generator U_{linie},the vibrations of the superior radial axial bearing on the radial direction +y VLRAG_Y_rad, the vibrations of the inferior radial bearing on the direction +y VLRI_Y_rad, the vibrations in the turbine bearing on the direction +y VLT_+y.

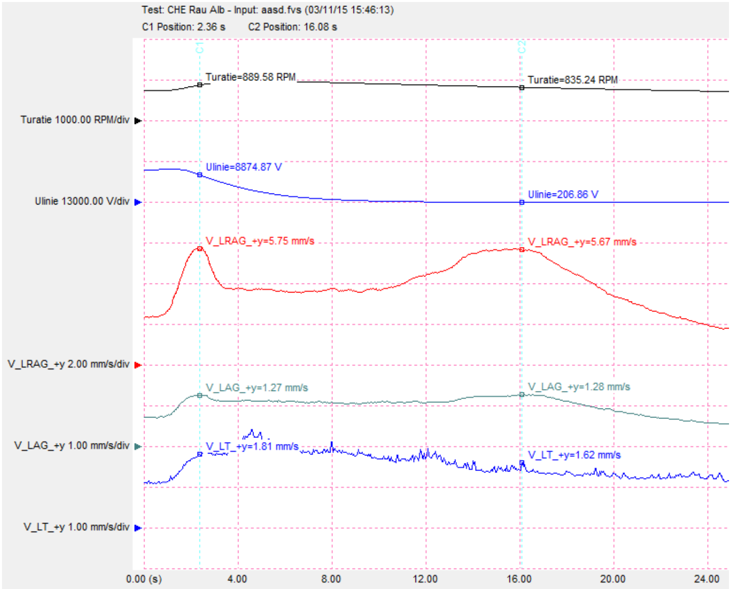

Figure 2. Detail of the transitory regime at putting off load

In Fig. 2 it is presented a detailed image from the recording at the putting off load and during the period of the transitory regime (when the values of vibrations and voltage reach the highest values), and in Tab. 1 the acquired values are presented.

Table 1. The measures acquired at certain time intervals

t [s]	U_l [V]	n [rpm]	VLRAG [mm/s]	VLRI [mm/s]	VLT [mm/s]
0	10583.9	749.7	2.39	0.72	1.14
0.5	10806.2	765.9	2.9	0.8	1.28
1.8	8735.4	896.5	5.76	1.27	1.85
4	3950.5	999.13	3.74	1.14	2.33
6	1764.9	974.02	3.58	1.10	1.88
15.1	209.4	839.9	5.75	1.26	1.48
22.5	173.17	749.85	2.24	0.65	1.27

We observed that the level of vibrations is dependent both on revolution and voltage at the terminals of the generator, thus on the level of magnetization of the rotor.

We can observe that there are two distinct periods in the curve of vibrations variation;

- from the moment of the opening of the switch until the voltage tends to be null;

From the moment when the tension is almost null until the value of vibrations is attenuated at a stationary value.

On the moment of the opening of the switch it appears, in the first moment, a tendency of increasing the revolution and voltage, caused by the inertion of the automatic regulating systems of voltage or revolution. The maximum revolution reaches the value n_{max}=999.3 meaning 1,332 times higher than the nominal revolution, in a period of 2.94 sec, and after other 1.47 sec, it starts to decrease, so the dead time of the regulating system of revolutions is 4.41 seconds. The suprarevolution of the hydro generator does not respect the maximum limit value imposed by standards [8], meaning maximum 1.2 nominal revolution, being thus 1.33 times higher than the nominal revolution.

The increase of the revolution is accompanied by an increase of vibrations at the level of radial bearings of the hydro generator and turbine. The maximum vibrations appear at two revolutions and namely at a revolution of 896,5 rpm in increasing direction, respectively 839,9 rpm in decreasing direction.

In the first period which lasts around 9.41 s, the rotor which is highly magnetized and the vibrations with a certain form of variation. The maximum amplitude of vibrations in the superior radial bearing on LRAG+y on direction y, exceeds the admitted maximal values (2.8 mm/s), [9, 10].

In the second stage which lasts for 13,52 sec, the rotor is demagnetised due to the lack of excitation current, the variation form of vibrations is changed and appears a peak of vibrations at an inferior revolution as compared to the maximum revolution. The maximum peak of vibrations is reached at 6,47 sec and exceeds much the maximum admitted values. When the regulator of revolution starts to close the directory apparatus, the revolution starts to decrease until the complete stop of the turbine.

The total time of increase and coming back at the nominal value of the revolution is 22.5 sec, a time interval long enough during which some important solicitations can appear in the machine.

If the rotor is correctly balanced and centred, both from the mechanic and magnetic point of view, the level of vibrations in the bearing depends on the revolution.

The conclusion which comes out from the analysis of the variation form of the acquired values is that the rotor is not correctly centred, namely its magnetic axis is not imbricated on the geometrical axis. This determines a continuous moving tendency of the rotor in space (the dynamic instability of the rotor), dependent on the state of magnetization of the hydro-generator before the putting off load and it affects the dynamic stability of the rotating parts of the hydro-generator.

The vibrations which appear due to the inappropriate equilibrium lead to the premature wear of bearings because the oil film is in danger to be broken due to the sudden movement of the rotor axis during on-load running of the hydro-aggregate.

This is the reason why it is necessary to do a check-up of the equilibrium of the rotor in the stator, and its magnetic centring respectively, by bringing the geometrical axis in the magnetic axis of the assembly rotor-stator.

4. The experimental results at the putting off-load after the dynamic equilibration

For the decrease of the level of vibrations in the bearing we proceed at the equilibration of the hydro-generator. At equilibration we used the same acquisition system with which we acquired: revolution n, the phase voltage U_f, the line voltage U_l, the current through the winding of the induced I, active power P, reactive power Q, the excitation voltage of the hydro-generator UexG, vibrations on the direction +y in the superior radial bearing V_LRAG_+y, in the inferior radial bearing V_LRI_+y, in the bearing of the turbine V_LRT_+y.

In Fig. 3 we presented the way of variation of the acquired values during the dynamic process of putting off load, in fig. 4 a detail from the transitory process and in Table 2 the values at certain time intervals.

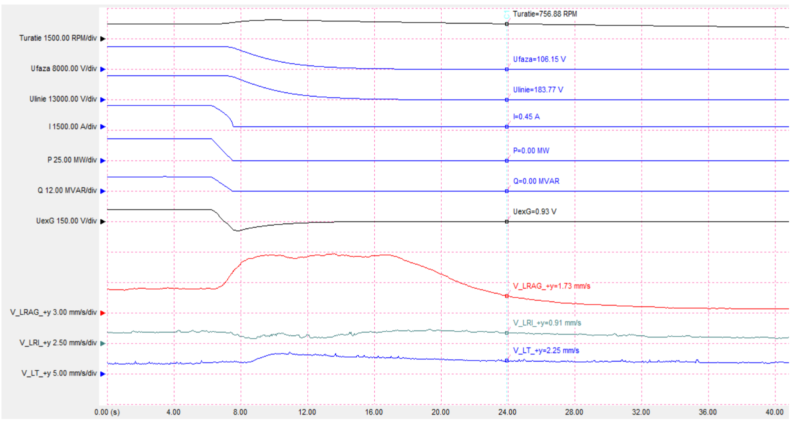

Figure 3. The variation of the values recorded at the putting off load, after equilibration

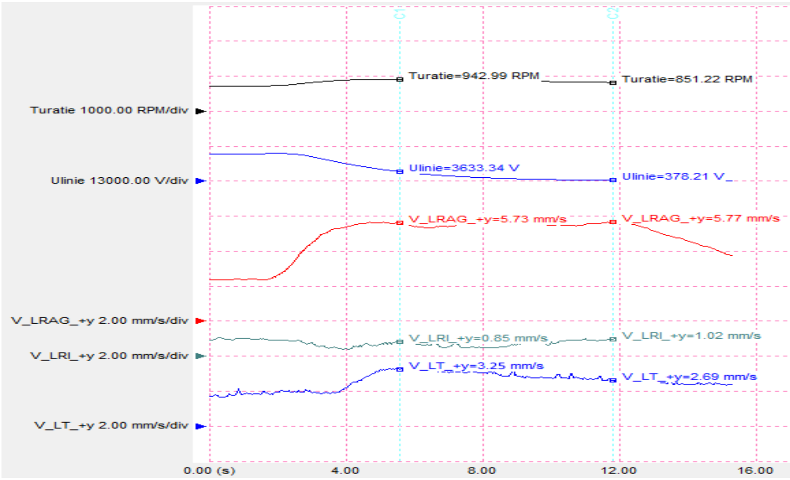

Figure 4. A detail of the transitory regime at putting off load, after equilibration

Table 2. The acquired values after the dynamic equilibration of the rotor

t [s]	U_l [V]	n [rpm]	VLRAG [mm/s]	VLRI [mm/s]	VLT [mm/s]
0	10451.64	750.95	2.37	0.82	2.08
0.4	10576.6	762.26	2.63	0.78	2.01
3.1	5150.16	942.7	5.73	0.64	3
3.4	4475.11	945.14	5.74	0.76	3.09
4.8	2582.49	931.27	5.42	0.67	3.2
7.2	1035.58	895.56	5.70	0.62	2.93
18	181.28	750.74	1.55	0.88	2.15

From the analysis of the recordings we observe that the time past from the moment of disconnection until the active power has a null value is 1.17 sec. The maximum value reached by the line voltage is 10576 V, approximately 1 % higher than the normal voltage. After the equilibration of the rotor the maximum value of revolution is 945,14 rpm, being 1.26 higher than the normal revolution and this value exceeds the values given in the norms.

Referring to the variation form of the vibrations in the superior axial radial bearing on the direction +Y, we observe the flattening of the two existing peaks before their equilibration and maintenance at a value approximately constant during the whole period of the transitory regime until the line voltage value decreases approximately 98%.

After equilibration the vibrations in the inferior and superior radial bearing decreased, the maximum value in the superior bearing being approximately 1.5 % smaller than before the equilibration. A considerable decrease of the vibrations is observed especially in the inferior bearing (with approximately 20% as compared to the value before the equilibration). This decrease of the vibrations is very beneficent for the whole hydro-aggregate, contributing to the increase of the dynamic stability of the elements in rotating movement.

For a simple comparison of the maximum values of the main values acquired, in Table 3 we presented: the line voltage, revolution and vibrations in the radial bearings and the turbine bearing, before and after the equilibration, and the increase or decrease (in %) as compared to the initial values.

Table 3. The maximum values of the acquired measures before and after the equilibration of the hydro-generator rotor

t [s]	U_l [V]	n [rpm]	VLRAG [mm/s]	VLRI [mm/s]	VLT [mm/s]
Before equilibration	10806	999,13	5,76	1,27	2,33
After equilibration	10576	945,13	5,74	0,88	3,2
Percentage	-1%	-5.5%	-1.5%	-20%	+37%

There is an increase of the vibrations in the turbine bearing determined by the works achieved on this one.

From the comparative analysis of the duration of the acquired vibrations and we observed that the equilibration of the hydro-generator rotor determines their substantial reduction as we can observe in table IV.

Table 4. The length of time of the transitory regime of the accquired vibrations

	VLRAGt [s]	VLRIt [s]	VLTt [s]
Before equilibration	22,8	20,8	25,4
After equilibration	15,8	16	23,4

5. Conclusions

The presented paper has a concrete application in the energetic industry and contributes to the increase of awareness of the decision makers in the acquisition of online acquisition systems and monitoring the electric and mechanic measures of hydro-aggregates. From the paper it results the need to equilibrate the rotors of hydro-aggregates as well as their magnetic centring.

The equilibration of the hydro-generator rotor has determined the diminishing of the vibrations level in bearings, the decrease of the revolution value and of the line voltage at putting off load.

All these advantages brought by equilibration lead to the increase of dynamic stability of the elements in rotating movement as well as the reduction of the period of the transitory regime.

The use of the online acquisition and monitoring system contributes to the increase of safety in operation as well as tracking down in time, the possible errors which can appear during the hydro-aggregate's running.

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