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Measurement and Simulation of Hydro-Generator's Asynchronous Operation

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SUMMARY

The extended testing of hydro-generator with Pelton turbine (rated 35 MVA) was performed on a generator whose lifespan expired and it was going to be replaced. This was the perfect opportunity to do some specific and uncommon testing. The complex testing plan was designed in order to enable recording of as much relevant data as possible (electrical, electromechanical, mechanical). Therefore, in some phases of testing, 29 to 44 quantities were measured simultaneously. Among the tests, there are short circuits with lowered voltage, bad synchronization at approximate angle of 15 degrees, asynchronous operation, generator over-speed and operation with short circuited field winding on one pole.

The most interesting and the most critical operation during this testing is asynchronous operation of hydro-generator [1, 2, 3, 4, 5], which is also very dangerous for generator and drive equipment. During such operation synchronous generator operates at a speed unequal to rated speed. This slip causes increased damping winding currents, which increases the thermal stress of this winding beyond the designed level. This makes these tests very infrequent. Asynchronous operating was achieved by decreasing the excitation current.

Complex mathematical model for computer simulation of hydro-generator's asynchronous operation has been made, taking into consideration the magnetic saturation, damper winding and generator transformer's influence. Results obtained by simulations have been compared to those obtained by measurements.

KEYWORDS

Hydro-Generator, Asynchronous Operation, Testing, Simulation

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1 INTRODUCTION

Asynchronous operation of synchronous machines connected to a power system can be caused by loss of excitation, slow clearing of faults, sudden and large change in load or when synchronization conditions are not fulfilled. The most frequent cause for asynchronous operation is the loss of excitation. Conventional practice in such conditions is disconnection of the machine from the power system. The downside of this is the period of generator's unavailability during the resynchronization process and possible significant disturbance in the power system.

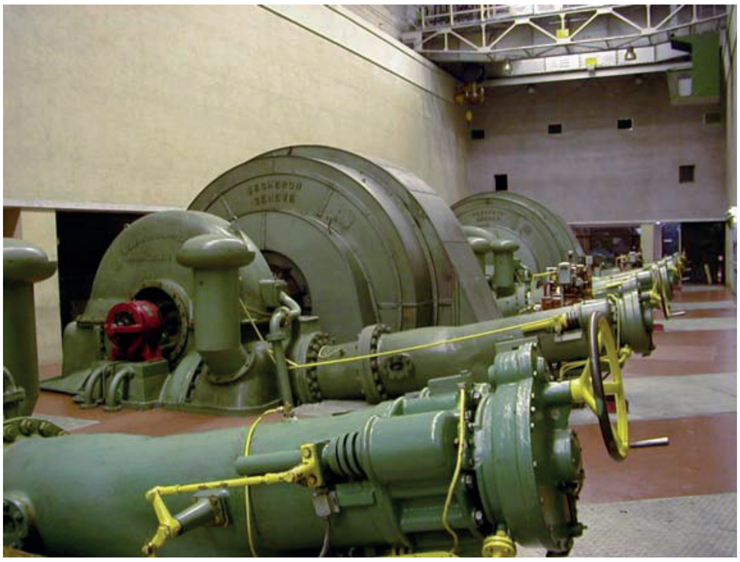

Figure 1 - Hydro-generators (35 MVA) with Pelton turbines

2 MEASUREMENTS AND SIMULATIONS

Asynchronous operation of hydro-generator is very dangerous for generator and drive equipment. This makes these tests very infrequent. The extensive testing was performed on a hydro-generator (Table I) whose lifespan expired and it was going to be replaced. This was the perfect opportunity to do some specific and uncommon testing. Asynchronous operation in this case was achieved by decreasing the excitation current.

Table I – The main generator parameters

Manufacturer	SECHERON
S_n [MVA]	35
U_n [kV]	10.5
I_n [A]	1925
$\cos\varphi_n$	0.8
n_n [rpm]	500
f_n [Hz]	50
U_{fn}[V]	300
I_{fn}[A]	510

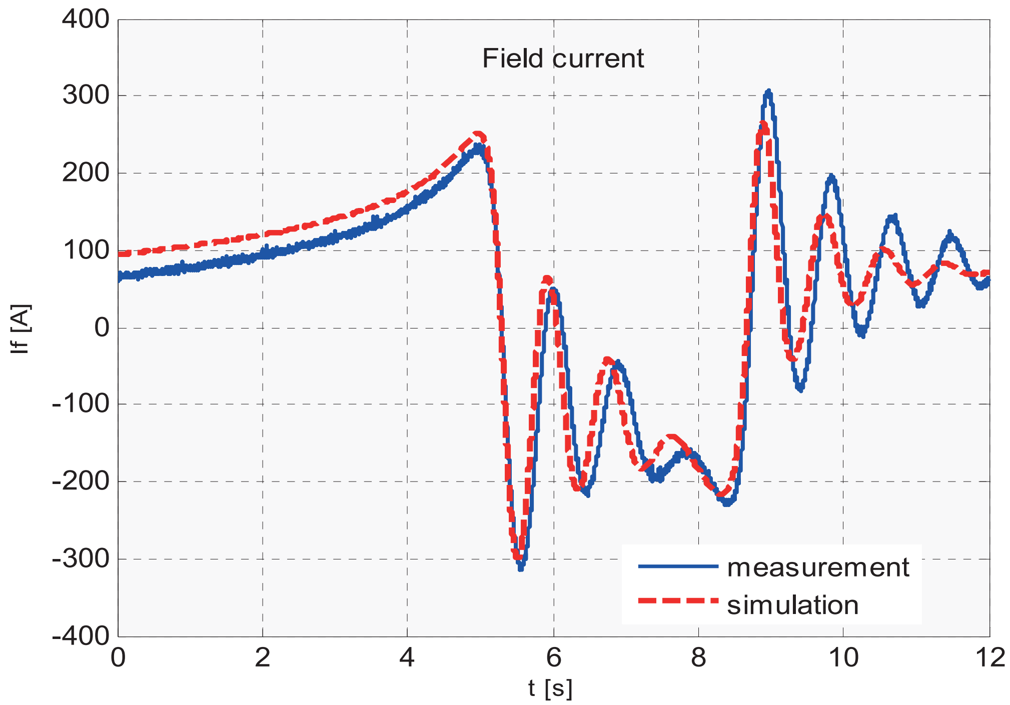

Figure 2 - Measured and simulated field current

Figure 2 shows the measured and simulated field currents. This is a case of the short term asynchronous operation and return of the loaded generator to synchronism. The field current barely exceeds half the rated field current value. It can be concluded that the field winding is not overheated. In case of the higher excitation current value, its thermal capacity and duration of asynchronous operation should be taken into consideration.

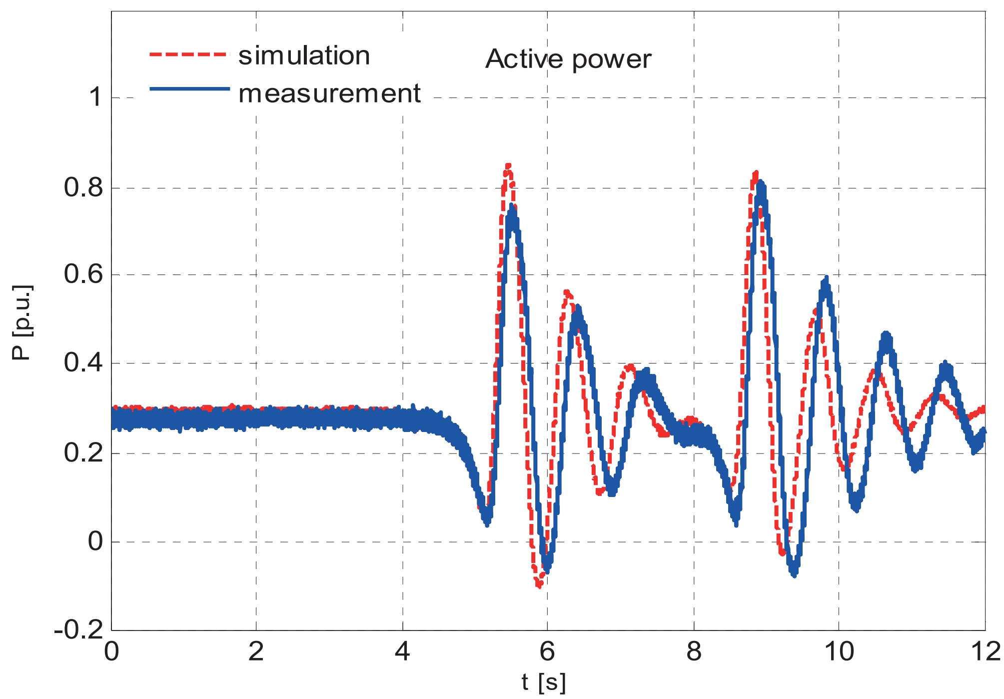

Figure 3 - Measured and simulated active power

Figure 3 shows the measured and simulated active power. Before the asynchronous operation the active power was 0.3 p.u. During the asynchronous operation it reaches the rated value. Such large active power changes cause dangerously high torsional strain of the shaft.

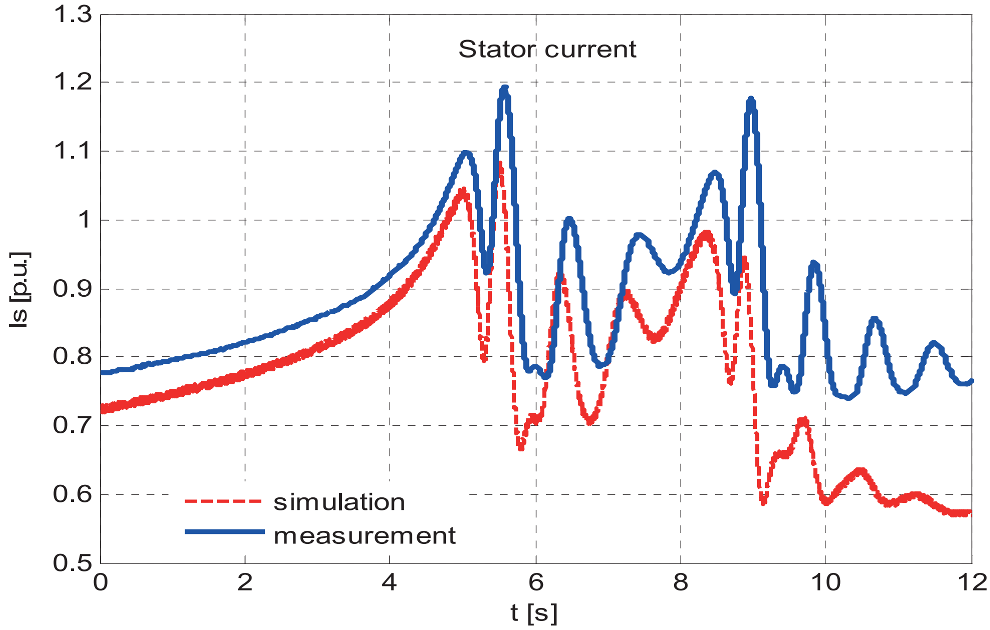

Figure 4 - Measured and simulated armature current

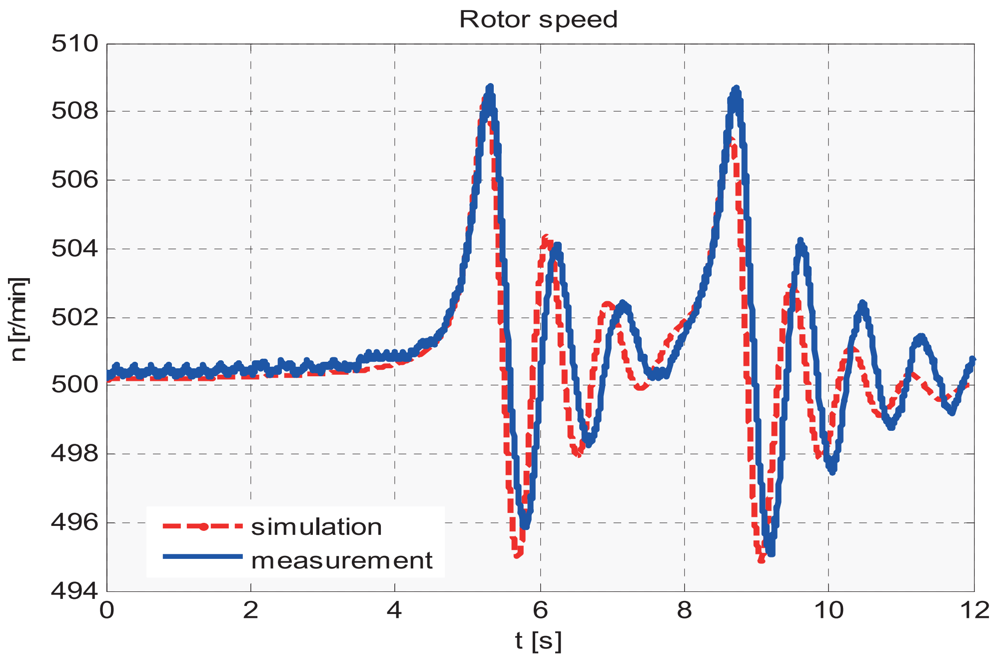

Figure 5 - Measured and simulated rotor speed

Figure 4 shows measured and simulated armature current (rms). During the asynchronous operation the armature current increases above its rated value, even though the active power is relatively small (0.3 p.u.). The underexcited generator draws current for magnetization from the network. This leads to additional heating of armature winding and causes voltage drops which can be harmful to the generator and also to power system stability.

Figure 5 shows the measured and the simulated rotor speed. This relative small change of rotor speed still causes a huge torsional stress on the shaft.

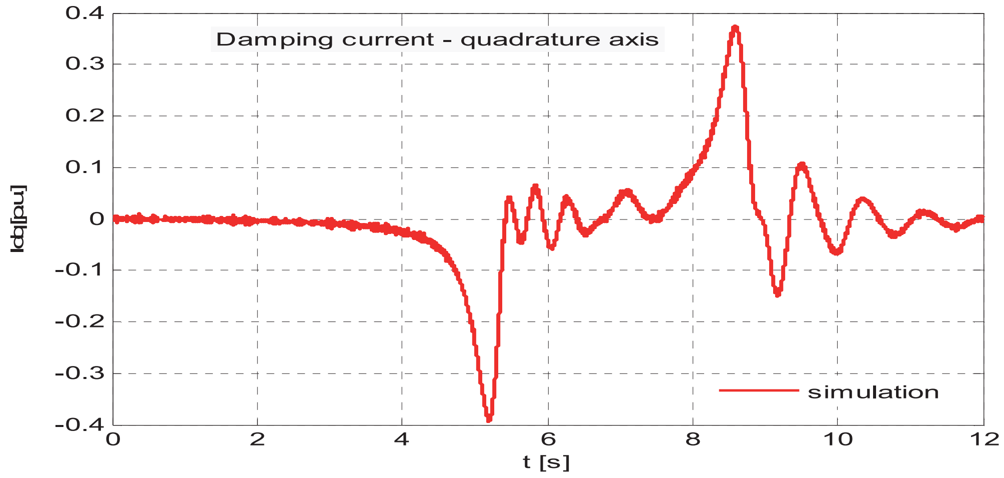

Figure 6 - Simulated damping current in q-axis

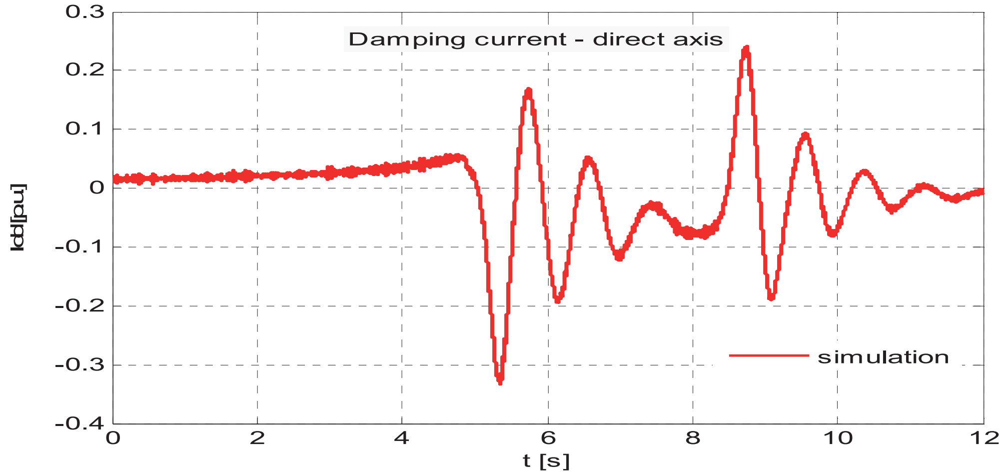

Figure 7 - Simulated damping current in d-axis

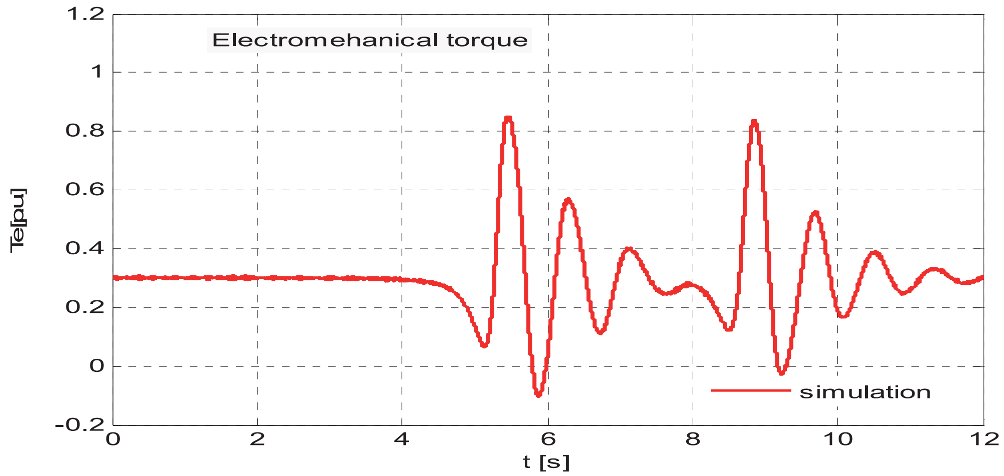

Figure 8 - Simulated electromechanical torque

During asynchronous operation the damping winding of synchronous generator is additionally heated (especially in case of hydro-generator). This winding is not designed for such additional heat strain. It is almost impossible to measure this current. Figures 6 and 7 show damping winding currents in quadrature and direct axes acquired by simulation.

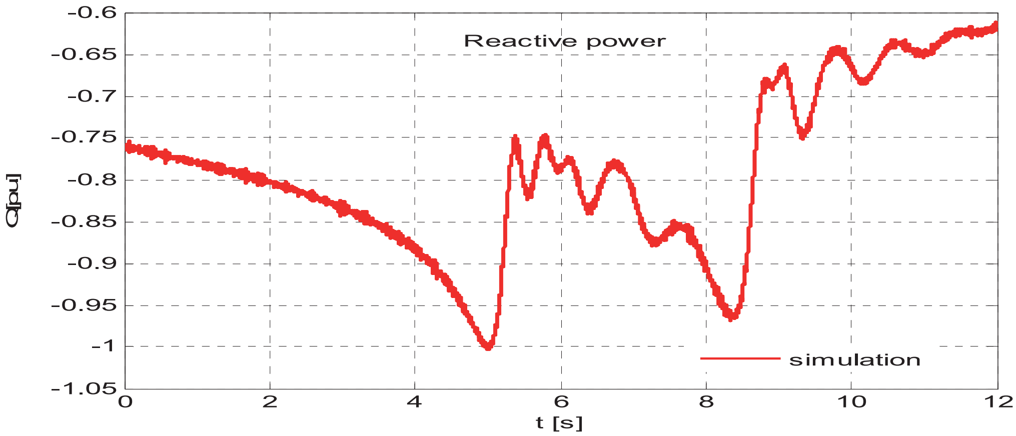

Figure 9 - Simulated reactive power

Figure 9 shows the reactive power which the generator draws from network. It can become a serious problem for power system, if there is not enough backup of reactive power.

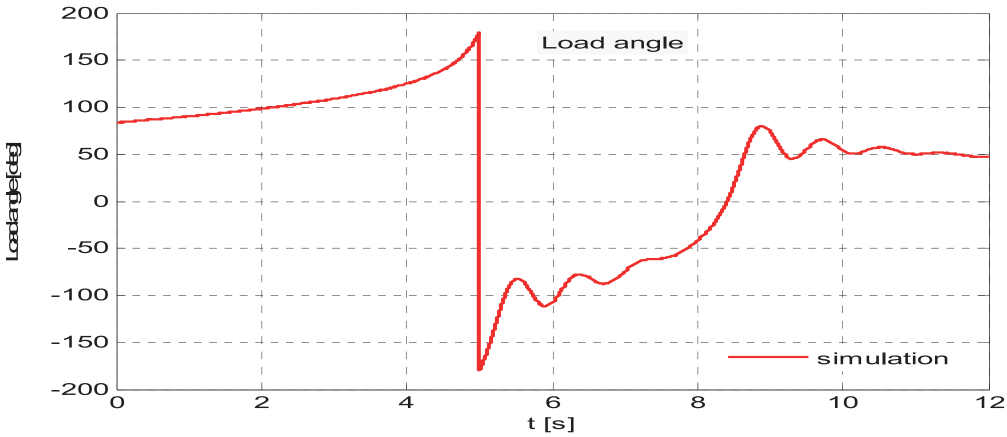

Figure 10 - Simulated load angle

Figure 10 shows a load angle determined by simulation. The same figure also shows one pole skipping at fifth second and generator's return to synchronism.

All simulations were carried out using a "MatLab" software package. Mathematical model for computer simulation of hydro-generator's asynchronous operation has been created, taking into consideration the magnetic saturation, damper winding and generator transformer's influence [2, 3, 5].

Besides these "standard" measured quantities, the whole variety of the quantities was measured. Among them are measurements of the vibrations and displacements during asynchronous operation. Table II shows the comparison of the vibration accelerations during asynchronous operation of the generator and during 3-phase short circuit. Vibration accelerations are measured on one of the foot screws [7].

Table II – Vibration amplitudes (in frequency domain)

ACC. [mm/s^2]	50 Hz	100 Hz	200 Hz
3 phase short circuit	2.7	0.5	0.7
Asynchronous operation	0.1	1.18	0.9

Vibration accelerations at frequencies above the base frequency (50 Hz) are larger during the asynchronous operation than in case of 3 phase short circuit.

3 CONCLUSION

This paper presents results of measurements during the asynchronous operation of the 35 MVA synchronous generator. Acquired results are compared to ones obtained by numerical simulation. Special emphasis is put on case of loss of excitation, the most frequent reason for asynchronous operation.

The generator that has lost its excitation is operating both asynchronously and underexcited. The asynchronous operation has strong influence on the currents, electromagnetic torque and heating. The underexcited operation can, by itself, cause additional temperature increase in the end region stator segments.

The measurements and simulations indicate that the asynchronous operation is particularly harmful to dampening winding, armature winding, shaft and subsequently to the power system generator is connected to.

Therefore, the asynchronous operation is not desirable and in many countries not allowed. The analyses of this operation and applied protection measures have a significant influence on stability and normal operation of power system.

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