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DEVELOPMENT AND APPLICATION OF A TURBOGENERATOR MODEL

DVORNIK, J[osko]; TIRELI, E[nco] & OROVIC, J[osip]

Abstract: *In this paper the authors will present the application of scientific methods for the research of complex dynamic systems called qualitative and quantitative simulation methodology of System dynamics. This will allow continuous computer simulation of various models and significantly contribute to acquisition of new information about the non-linear character of performance dynamics of turbo generator systems in the process of designing, failure diagnosis, optimization and education.*

Key words: *steam turbine, simulation and heuristic optimisation, failure diagnosis*

1. INTRODUCTION

The model of marine steam turbine machinery which drives electric synchronous generator (Hind, 1968) has two essential situations of energy accumulation: in the steam volume (steam area, steam volume of the turbine) and in the turbine rotor. The main condenser is observed as a special governing object. Each of the stated parts can be described by its mode equation, that is, by the differential equation which describes the performance dynamics.

2. SIMULATION MODELLING OF MARINE STEAM TURBINE

The system dynamic mathematical model of the marine steam turbine can be defined by means of differential equations.

Equation of the turbine steam volume (Nalepin, 1975):

$$\text{—} \quad \text{—} \quad \text{—} \quad \text{—} \tag{1}$$

Equation of the turbine rotor dynamics (Nalepin, 1975):

$$\text{—} \quad \text{—} \quad \text{—} \quad \text{—} \tag{2}$$

Where the following symbols stand for:
ψ_1 - relative increment of the steam pressure in the steam volume, φ - relative increment of the turbine rotor angular velocity, $T_{\psi 1}$ - time constant of the turbine rotor, T_φ - time constant of the turbine rotor, R_μ - time constant of the steam volume, $R_{\psi 1}$ - time constant of the steam volume, ψ_0 - relative increment of the steam pressure before the manoeuvring valve, $R_{\psi 0}$ - time constant of the turbine rotor, μ - relative change of the position of the manoeuvring valve, ψ_2 - relative increment of the steam pressure in the main condenser, $T_{\psi 2}$ - time constant of the boiler.

On the basis of a mathematical model, or the explicit form of the mode equation of the marine steam turbine (1) and (2), it is possible to determine the mental-verbal model of the marine steam turbine.

If the relative increment of the steam pressure in the turbine steam volume ψ_1 increases, the speed of the relative increment of the steam pressure in the turbine steam volume ψ_1 will decrease. This gives a negative cause-effect link.

If the relative increment of the steam pressure before the manoeuvring valve ψ_0 increases, the speed of the relative increment of the steam pressure in the turbine steam volume will increase. This gives a positive cause-effect link.

If the relative change of the position of the manoeuvring valve μ increases, the speed of the relative increment of the steam pressure in the turbine steam volume will increase. This gives a positive cause-effect link.

If the time constant of the steam volume R_μ increases, the speed of the relative increment of the steam pressure in the turbine steam volume will decrease. This gives a negative cause-effect link.

If the time constant of the turbine rotor $R_{\mu 0}$ increases, the speed of the relative increment of the steam pressure in the turbine steam volume will decrease. This gives a negative cause-effect link.

If the time constant of the steam volume $R_{\mu 1}$ increases the speed of the relative increment of the steam pressure in the turbine steam volume will increase, which gives a positive cause-effect link.

If the relative increment of the steam pressure in the steam volume ψ_1 increases, the speed of the relative increment of the turbine rotor angular velocity will increase. This gives a positive cause-effect link.

If the relative increment of the turbine rotor angular velocity φ increases, the speed of the relative increment of the turbine rotor angular velocity will decrease. This gives a negative cause-effect link.

If the relative increment of the steam pressure in the main condenser ψ_2 increases, the speed of the relative increment of the turbine rotor angular velocity will decrease. This gives a negative cause-effect link.

If the time constant of the turbine rotor $T_{\psi 1}$ increases, the speed of the relative increment of the turbine rotor angular velocity will decrease. This gives a negative cause-effect link.

If the time constant of the turbine rotor T_φ increases, the speed of the relative increment of the turbine rotor angular velocity will increase. This gives a positive cause-effect link.

If the time constant of the turbine rotor $T_{\psi 1}$ increases, the speed of the relative increment of the turbine rotor angular velocity will decrease. This gives a negative cause-effect link.

If the time constant of the turbine rotor $T_{\psi 2}$ increases, the speed of the relative increment of the turbine rotor angular velocity will increase. This gives a positive cause-effect link.

On the basis of the stated mental-verbal models it is possible to produce structural diagrams, flowcharts and quantitative simulation model of the marine steam turbine in the POWERSIM simulation language (Munitic, 1989).

3. INVESTIGATING PERFORMANCE DYNAMICS OF THE MARINE STEAM TURBINE IN LOAD CONDITIONS

After system dynamics qualitative and quantitative simulation models were produced, all possible operating modes of the system will be simulated in a laboratory, using one of the simulation packages, most frequently DYNAMO (Richardson & Aleksander, 1981) or POWERSIM (Byrknes).

After the engineer, designer or a student has conducted a sufficient number or scenarios to verify the model, and an insight has been obtained about the performance dynamics of the system using the method of heuristic optimisation, the optimisation of any parameter in the system may be performed. In the presented scenario the two phases of the momentum (starting) of the marine steam turbine will be presented, as well as connecting the marine synchronous generator in TIME = 100 seconds in the following way:

1.The manoeuvring valve of the marine steam opens for 5% of the rated opening in TIME = 10 seconds. The lower RPM is maintained for 50 seconds (about 5% of the rated RPM or 500-600/min.) for even heating of turbine masses.

2.In TIME = 50 seconds the manoeuvring (governing) valve opens to the rated opening (100%) MI=STEP (.05, 10) +STEP (.95, 50) and increases the marine steam turbine to the rated RPM. In TIME = 10 seconds the relative increment of the steam pressure in steam volume (PSI1) and the relative increment of the angular speed of the marine steam turbine rotor (FI) are increasing.

3.In TIME = 100 seconds a step load is made from 50% of the rated load, the same as in the previous scenario, and by adding stochastic load: TFI.K=STEP (2.5,100)*(1-NOISE())

4.Electronic PID governor has been installed with parameters: KPP = 100, KPI= .1 and KPD = 100.

5.In the period between Time=140 – 180 seconds a scenario is simulated in which the relative pressure in the main condenser is equal to 2,5 times of nominal pressure. The consequence is a sudden increase in steam chest pressure.

Graphic presentation of the simulation results:

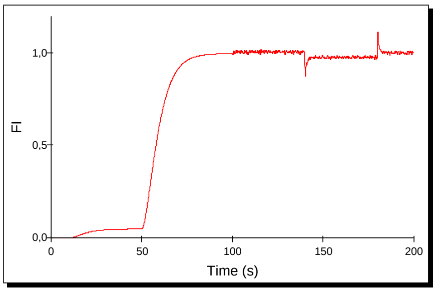

Fig. 1. Relative increment of the angular speed of the rotor FI

The results of the simulation show the real performance dynamics of the marine steam turbine, which at idle speed starts in at least two stages, and which gives sufficient time for all the parts to heat equally. This scenario may be used in heuristic optimisation of the PID governor coefficient. In fact, if the allowed criteria are reached, then in normal operating conditions the selected combination of PID governor will certainly be satisfactory.

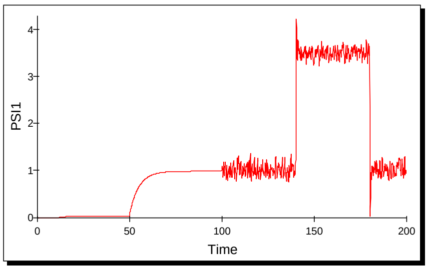

Fig.2. Relative increment of the steam pressure in the steam volume PSI1

The scenario shows that when selecting the coefficient of the universal PID governor (KPP = 100, KPI = .1, KPD = 100), it will soon lead to stabilisation of the transition phase, within the limits of the rated speed deviation of the marine steam turbine rotor (approx. 4% of the rated RPM). The model can also be used to simulate deviation of operating parameters such as main condenser pressure (as shown in the example), inlet steam pressure, opening and closing of manoeuvring valve and etc. Change of these parameters will have an important influence on the performance (frequency and voltage) of turbo generator when working in load operating condition. All these results of simulation are very valuable in process of failure diagnosis, optimization of steam turbine thermodynamic process and educational purposes for future marine engineers.

4. CONCLUSION

System dynamics is a scientific method which allows simulation of the most complex systems (Forester, 1973/71). The method used in the presented example demonstrates a high quality of simulations of complex dynamic systems, and provides an opportunity to all interested students or engineers to apply the same method for modelling, optimising and simulating any scenario of the existing elements.

Furthermore, the users of this method of simulating continuous models in digital computers have an opportunity to acquire new information in dynamic system performance. The method is also important because it does not only refer to computer modelling, but also clearly determines mental, structural and mathematical modelling of the elements of the system.

This brief presentation gives to an expert all the necessary data and the opportunity to collect information about the system in fast and scientific method of investigation of a complex system. This means: “Do not simulate the performance dynamics of complex systems using the method of the "black box", because education and designing practice of complex systems confirmed that it is much better to simulate using the research approach of the “white box”, i.e. System dynamics methodology."

This simulation method can be applied to engine models, steam boiler models, gas turbine models and etc.

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