

SUMULATION OF BEHAVIOUR DYNAMICS OF TURBINE DRIVE GENERATING SET

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ABSTRACT

The aim of this paper is to show the efficiency of the application of the System Dynamics Simulation Modelling in investigation of behaviour dynamics, one of the complex marine system and process i.e. “steam – turbine generator”. Steam turbine and synchronous generator without contact shall be presented with mental - verbal, structural and mathematical - computing modules, and will simulate working process of ship propulsion complex.

1. SYSTEM DYNAMICS SIMULATION MODELS OF THE MARINE STEAM TURBINE

1.1. Mathematical model of the Marine Steam Turbine and UNIREG-PID regulator

The steam turbine working process is the conversion of water steam energy to mechanical energy converted to trust on the mechanical units. Therefore, turbine is subjected to various loads transmitted from the units. The steam turbine working system can be derived into two parts: regulating valve and nozzle ring steam space that can accumulate steam energy and rotational part that accumulate kinetic energy. The mathematical model or level equations could be represented as follows:

$$\frac{d\varphi}{dt} = \frac{1}{T_1} (K_1\psi_1 + K_2\psi_2 - \varphi - K_3\alpha) \quad (1)$$

$$\frac{d\psi_1}{dt} = \frac{1}{T_2} (K_0\psi_0 - \psi_1 + K_4\mu) \quad (2)$$

The first differential equation for the first part is defined according to (Siromjatnikov 1983):

T_1 - Time constant of rotating parts;
 φ = FI - Relative increment of turbine shaft angular velocity;
 ψ_2 = PSI2 - Relative pressure increment in main condenser;
 α = ALPHA - Relative turbine load change;
 K_1, K_2, K_3 - Gain coefficients.

The second differential equation is defined:

T_2 - Time constant of the steam space;
 ψ_1 = PSI1 - Relative value of the steam pressure increment in the steam space;
 ψ_0 = PSIO - Relative value of the steam pressure increment before regulating valve;
 μ = MI - Relative value of regulating valve opening change;
 K_0, K_4 - Gain coefficients.

The PID regulator incorporates in itself proportional (M1), integral (M2) and derivation (M3) regulators. The input function in the regulator is the discrepancy:

Mathematical model of the UNIREG-PID regulator is:

$$UNIREG = PREG + IREG + DREG$$

$$PREG = KPP * X$$

$$IREG = KPI * \int X * dt$$

$$DREG = KPD * \frac{dX}{dt}$$

Where there are:

$UNIREG$ = Output of the Universal-PID regulator,
 $PREG$ = Proportional regulator,

IREG = Integral regulator,
DREG = Derivative regulator,
X = Input Function in the PID regulator,
KPP = Amplification Factor of the Proportional regulator,
KPI = Amplification Factor of the Integral regulator
KPD = Amplification Factor of the Derivative regulator.

In this case, *X*= input function in the first UNIREG-PID regulator is *DISC1*= discrepancy between *CFI*= nominal relative changing of angular velocity and φ = *FI*= relative changing of angular velocity, or exactly:

$$DISC = CFI - FI$$

The *UNIREG*= output of the first Universal-PID regulator is function $\chi_1 = \chi = KAPA = KAPA1$ = relative shift of high pressure fuel pump.

The UNIREG-PID regulator make connection between angular velocity discrepancy *DISC* and relative shift of high pressure fuel pump variable $\chi = KAPA$.

In the reality, this UNIREG-PID regulator self-regulated variable φ to be equal the *CFI*= goal of regulating process of the relative changing of angular velocity $\varphi = FI$.

The PID regulator incorporates in itself proportional (*M1*), integral (*M2*) and derivation (*M3*) regulators. The input function in the regulator is the discrepancy-*DISC*.

1.2. Structural and Mental-Verbal Models of the Marine Steam Turbine and UNIREG-PID regulator

Fig.1. determinates the Structural Model of Steam Turbine and PID Regulator. It is determined in the accordance with System Dynamics Methodology. Mathematical model could be very suit for determining the mental-verbal qualitative model of the steam turbine and PID regulator.

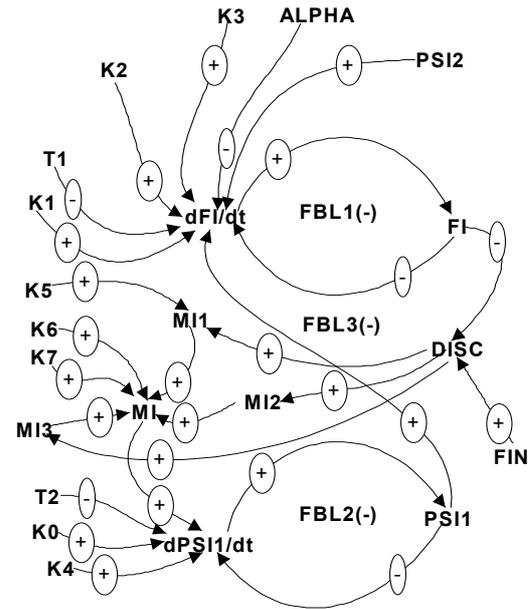


Figure 1. System Dynamics Structural Model of the Marine Steam Turbine and UNIREG-PID regulator

Three self-regulating (-) dominated Feed Back Loops (FBL1, FBL2 and FBL3) are determined in the structural model (Fig. 1.) with a lot of Cause-Consequences Links (CCL).

Mental-Verbal Simulation Model of the FBL1 is:

Link 1. - "If the variable *dFI/dt* (first derivation of *FI* – relative increment of turbine shaft angular velocity, or speed of *FI*), grow up, and the variable *FI* grow up also, then CCL (Cause-Consequences Link) has "positive" (+) dynamics character!";

Link 2. "If the variable *FI* grow up and the variable *dFI/dt* will be drop, then Link 2. will have "minus" (-) dynamics character"! The FBL1 has "minus" (-) global dynamical character, because : sum of negative (-) sign in the FBL1. is odd-number.

In accordance with the System Dynamics (Forrester 1968) quantitative (mathematical) and qualitative (structural) models and POWERSIM-simulation symbols and its program package, it would be possible to work out the System Dynamics Structural Flow Diagram (Fig. 2.)

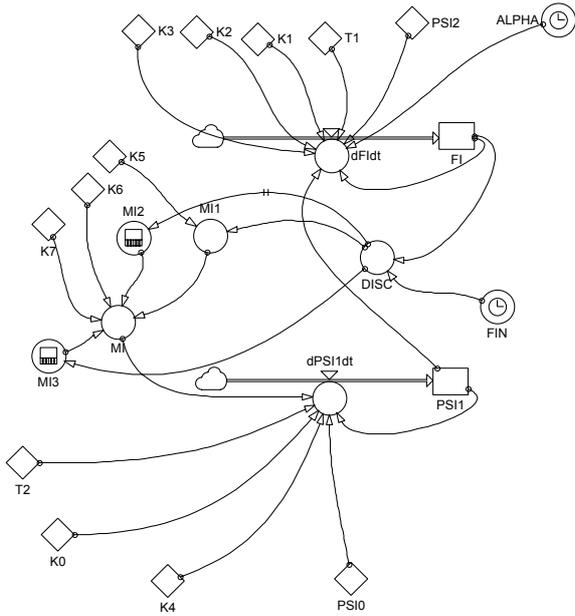


Fig. 2. System Dynamics Structural Flow Diagram of the Steam Turbine and PID Regulator in the PowerSim Symbols

2. SYSTEM DYNAMICS SIMULATING MODELLING OF MARINE SYNCHRONOUS GENERATOR

In this short paper, it is impossible to give a complete model; complete model (30 equations) has been presented in IASTED, Pittsburgh, 1998, 372-375, (7).

Where are:

- $\Psi_d = \text{PSID}$ - stator flux linkage in the d-axis,
- r_s - stator resistance
- x_s - stator reactance,
- $\Psi_q = \text{PSIQ}$ - stator flux linkage in the q-axis,
- $\omega = \text{OME}$ - diesel-engine angular velocity (angular frequency),
- $\Psi_{ad} = \text{PSAD}$ - stator mutual flux linkage in the d-axis,
- u_d - stator voltage in the d-axis,
- $\Psi_{aq} = \text{PSAQ}$ - stator mutual flux linkage in the q-axis,
- u_q - stator voltage in the q-axis,
- u - summary stator voltage,
- $\Psi_f = \text{PSIF}$ - rotor exciting flux linkage,
- r_f - rotor exciting resistance,
- u_f - rotor exciting voltage,
- $\Psi_{1d} = \text{PS1D}$ - damping coil flux linkage in the d-axis,
- r_{1d} - damping coil resistance in the d-axis,
- x_{1d} - damping coil reactance in the d-axis,
- $\Psi_{1q} = \text{PS1Q}$ - damping coil flux linkage in the q-axis,
- r_{1q} - damping coil resistance in the q-axis,
- x_{1q} - damping coil reactance in the q-axis,

- r_L - load resistance,
- x_L - load reactance,
- $M_e = \text{MEL}$ - generator electromagnetic moment,
- i_d - stator current in the d-axis,
- i_q - stator current in the q-axis,
- i_f - rotor exciting current and
- i - summary stator current.

System Dynamics Flow Diagram of Synchronous Generator Set with UNIREG-PID regulator shown in Figure 3.

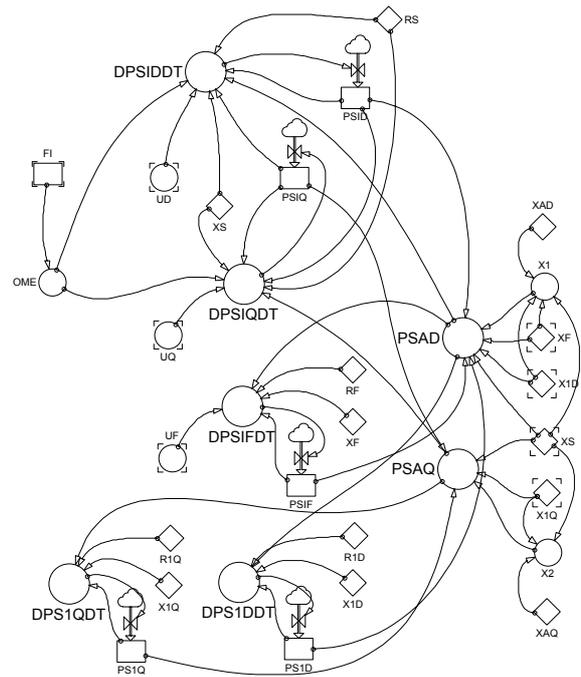


Figure 3. System Dynamics Flow Diagram of Synchronous Generator Set with UNIREG-PID

3. SIMULATION SCENARIO OF THE TURBINE DRIVE GENERATING SET

About zero simulation scenario:

The mixed scenario has been implemented in the computer simulation models of the steam turbine and PID regulator:

- steam turbine with PID regulator starts in TIME = 0 and FIN = .05; TIME = 20 and FIN = .05+.45 = .5; and TIME = 40 and FIN = .05+.45+.5 = 1.0 (100%).
- relative turbine load change ALPHA starts in TIME = 60 and ALPHA = .05; TIME = 100 and ALPHA = .05+.45 = .50; and TIME = 140 and ALPHA = .05+.45+.50 = 1.0 (100%)

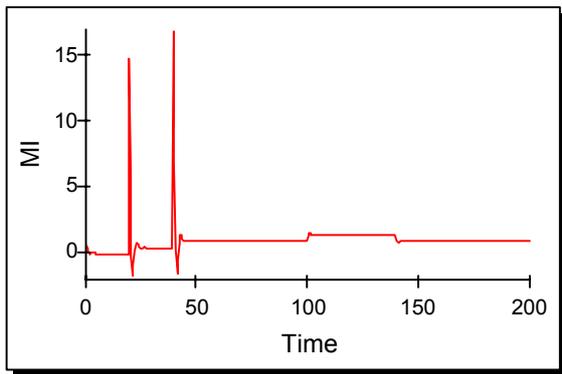
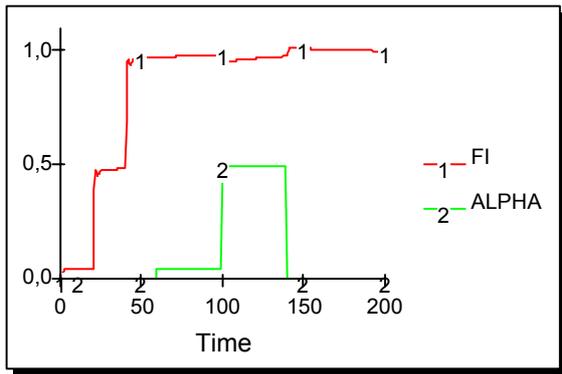


Figure. 4. Graphics Results of Simulation and Heuristics Optimization

4. CONCLUSION

Quality and economical steam turbine functioning depend on many parameters such as steam pressure before and after the regulating valve, condenser pressure, etc. Since successful turbine functioning depends on a large sequence of various parameters, this problem should be solved systematically. By use of the system dynamics in this paper, the complexity of steam turbine dynamics system behaviour has been partially presented. The system dynamics mathematical model, dynamics continued computer simulation model and structural dynamic model of the steam turbine and automatic PID-regulator are presented. Therefore interaction links between each parameter and variables can be analyzed. A simulation model is used to enable optimization of all parameters of the steam turbine system and transient and steady state simulation according to the stated scenario. The most difficult operation conditions can be investigated, even those which in reality are not physically possible.

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BIOGRAPHY



Josko Dvornik was born 1978. at Split Croatia, where he finished elementary and high Maritime school. He graduated in 2000. year on theme "Application on computer simulation dynamics of behavior of ship propulsion system: windlass – asynchronous engine" at Faculty of Maritime studies, University of Split. Today, he is Master of technical science. He has published over 30 scientific papers on system dynamics simulation modelling. He is a member of the SCS, *The Society for Computer Simulation International*, *IASTED*, *The International Association of Science and Technology for Development and System Dynamics Society*.