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Analysis of the Transitional Process into Naval Electrical Equipment

The analysis is based on a naval power with synchronous generator and consumers of various powers. The paper presents a systemic approach to naval power systems based on mathematical models of specific generators and consumers.

***Keywords**: transitional arrangements, electric power system, synchronous generator, mathematical models, the shock load*

1. Introduction

Naval power system usually contains type synchronous generators driven by a Diesel engine. Consumers are various electric power and importance of different steps (eg communications system is crucial in ensuring the safety of the vessel). Occurring in ship operation can appear a random event (short-circuit, connecting disconnect of important loads), which should be evaluated in a professional and controlled so that the ship's safety is not affected. Based on mathematical models of generator and consumer examines the transitional operation of the naval power in the stable and unstable conditions.

2. Mathematical models used in simulation

Mathematical model of synchronous generator (GS) is characterized by the equations [1, 2, 3]:

$$\begin{cases} -U\sqrt{3}sin\Theta = R_d I_d + L_d \frac{dI_d}{dt} - \omega R_q I_q + M_E \frac{dI_E}{dt} + M_D \frac{dI_D}{dt} - \omega M_Q I_Q \\ -U\sqrt{3}cos\Theta = \omega L_d I_d + R_q I_q + L_q \frac{dI_q}{dt} + \omega M_E I_E + \omega M_D I_D + M_Q \frac{dI_Q}{dt} \\ U_E = M_E \frac{dI_d}{dt} + R_E I_E + L_E \frac{dI_E}{dt} + M_{ED} \frac{dI_D}{dt} \\ 0 = M_D \frac{dI_d}{dt} + M_{ED} \frac{dI_E}{dt} + R_D I_D + L_d \frac{dI_d}{dt} \\ 0 = M_Q \frac{dI_q}{dt} + R_Q I_Q + L_Q \frac{dI_Q}{dt} \\ J\frac{d\omega}{dt} = p_1\left[(L_d - L_q) I_d I_q + M_E I_q I_E - M_Q I_d I_Q + M_D I_d I_D\right] - M_{motor} \end{cases}$$

Dynamic stability are analyzed with this system of differential equations in the original terms are derived from solving an algebraic system. Machine parameters are:

R_E = 40 [Ω] resistance of excitation involution
R_D = 7.95 [Ω] resistance depreciation involution of the axis d
R_Q = 30.22 [Ω] involution resistance depreciation of involution q axis
L_D = 0.07 [H] own inductance depreciation of the axis d
M_{ED} = 0.56 [H] mutual inductance between excitation and involution D
M_{Dd} = 0.05 [H] mutual inductance between involution and stator d
L_Q= 0.25 [H] own inductance depreciation of q axis
M_{Qq} = 0053 [H] Mutual inductance between stator q and involution Q
R_1= 1.6 [H] stator resistance
L_D = 0.08 [H] own inductance of stator d-axis
Lq = 0.07 [H] own inductance of stator q axis
M_{Ed} = 1 [H] mutual inductance between excitation and involution d
L_E = 18.51 [H] own inductance of excitation involution
Ψ_{sN} = 0.7 √ 3 [W b] nominal stator flux

We noted:

I_d= X -stator current from axis d,
I_Q = Z -stator current of axis q,
I_E= Y current excitation,
I_D = D current depreciation of the axis d,
I_Q= Q current depreciation of the axis q.

Analyzing 2 cases of operation: - stable operation to a variable load,
- unstable operation at short.

3. Stable operation of marine power system

Is presented in the following operation for a stable connection to a major consumer of the ship (the fire pump, ballast pump). The results presented below are for 3 cases for grant of voltage regulators, current frequency and excitation. The system of differential equations is [2, 4, 5, 6]:

$$
\begin{cases}
1{,}6X + 0.08\dfrac{dx}{dt} - 0.07\omega Z - 0.053\omega Q + \dfrac{dY}{dt} = -U\sin\theta \\
0.08\omega X + \omega Y + 0.05\omega D + 0.053\dfrac{dQ}{dt} + 1.6Z + 0.07\dfrac{dz}{dt} = U\cos\theta \\
\dfrac{dX}{dt} + 40Y + 18.51 + 0.56\dfrac{dD}{dt} = E \\
0.053\dfrac{dx}{dt} + 7.95D + 0.07\dfrac{dD}{dt} + 0.56\dfrac{dY}{dt} = 0 \\
2(0.01XZ + ZY - 0.053DZ) - 15 = 0.01\dfrac{d\omega}{dt} \\
\dfrac{d\theta}{dt} + \omega - O = o \\
\dfrac{dE}{dt} = 5000(52 - E) \\
\dfrac{dO}{dt} = 10000(209.3 - O) \\
\dfrac{dU}{dt} = 10000(263.36 - U) \\
X(0) = -0.95 \\
E(0) = 50 \\
U(0) = 223.6\sqrt{3} \\
O(0) = 314 \\
Y(0) = 1.25 \\
Z(0) = 4 \\
\omega(0) = 314 \\
\theta(0) = 0.25 \\
D(0) = 0 \\
Q(0) = 0
\end{cases}
$$

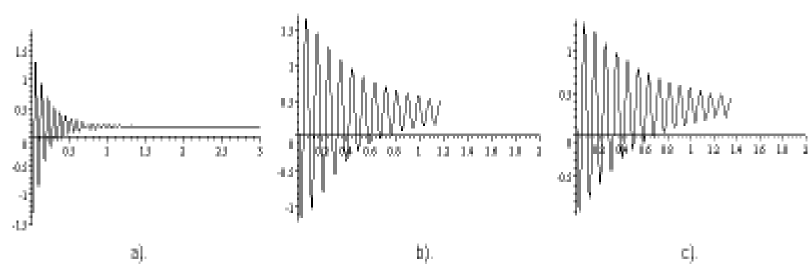

Figure 1. Load angle variation in the three cases

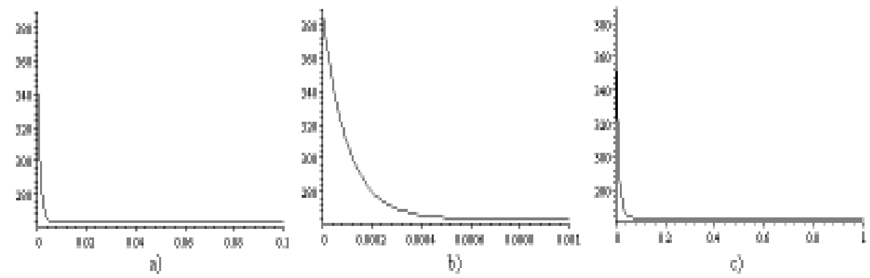

Figure 2. Statoric tension variation over time

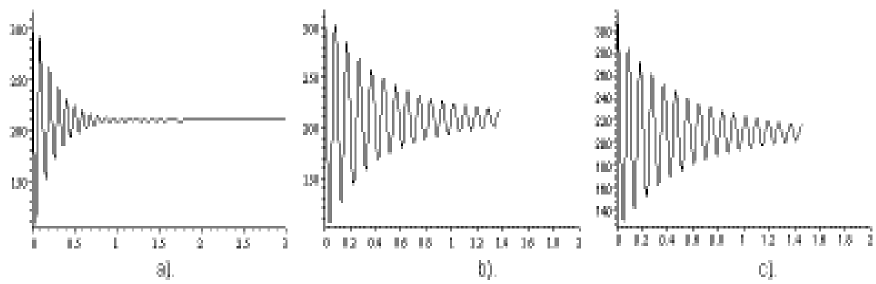

Figure 3. Changes in time of mechanical angular velocity

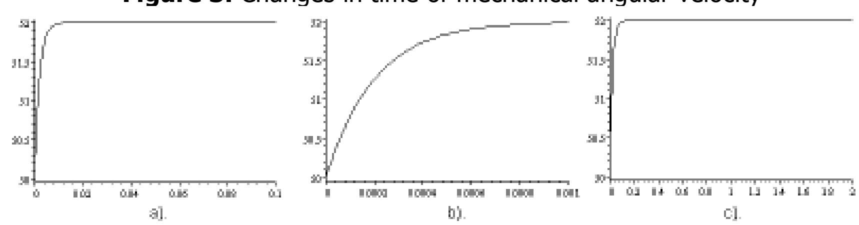

Figure 4. Variation in time of tension U_Σ

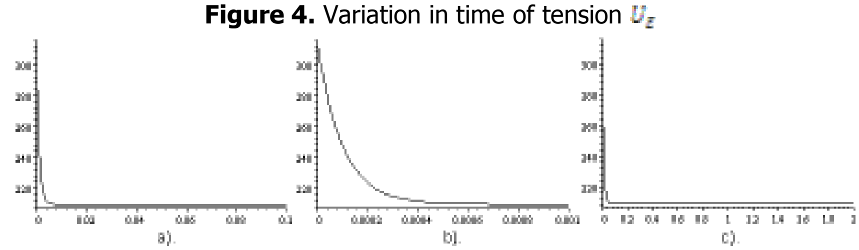

Figure 5. Changes in time of angular stator pulse ω_Σ

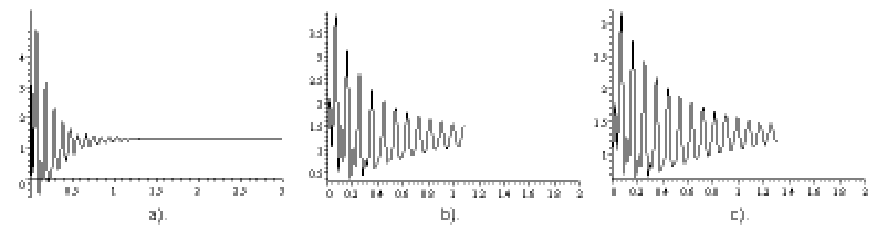

Figure 6. Variation in time of excitation current

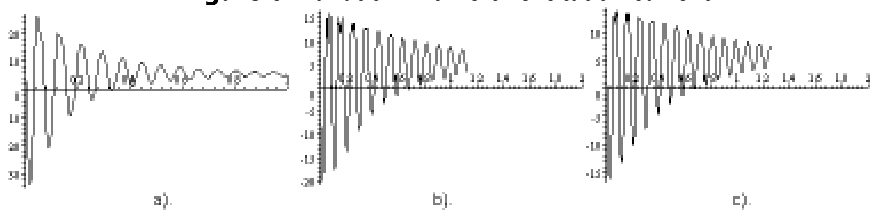

Figure 7. Variation in time of stator current in q axis

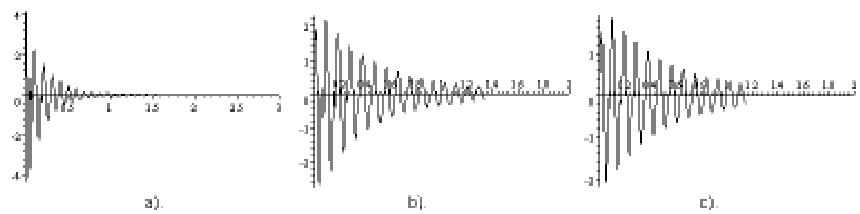

Figure 8. Variation in time of current I_Q

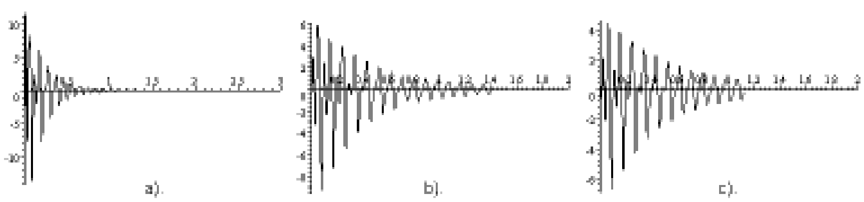

Figure 9. Variation in time of current.

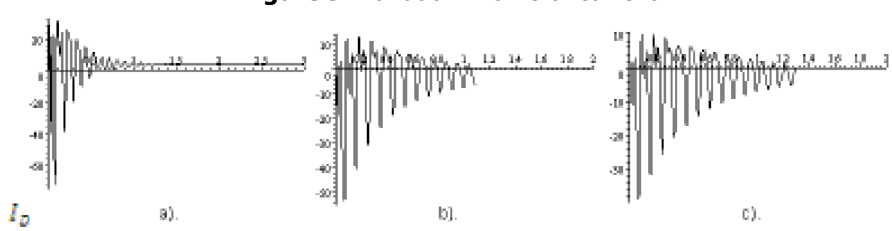

Figure 10. Variation in time of stator current in d axis

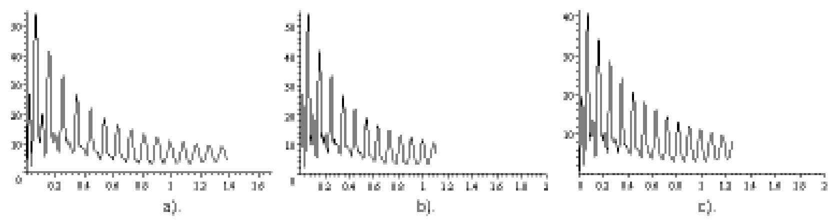

Figure 11. Variation in time of current stator $\sqrt{X^2+Z^2}$

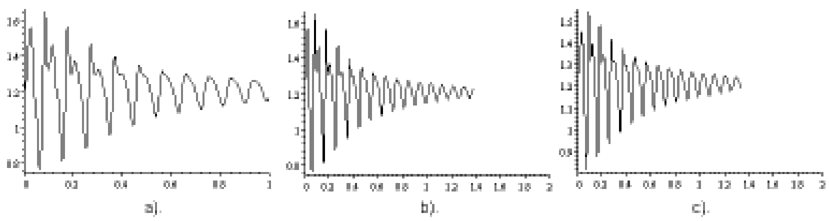

Figure 12. Variation in time of stator flux $\sqrt{(L_q I_q)^2 + (L_d I_d + M_E I_E)^2}$)

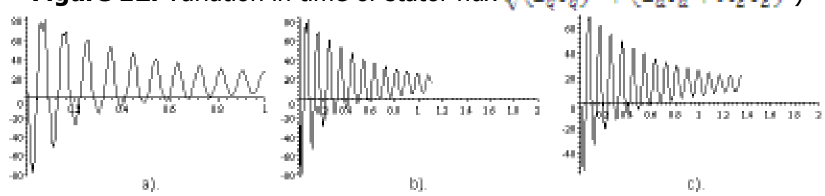

Figure 13. Variation in time of the electromagnetic torque

The system is dynamically stable in numerical simulations the results above, in the sense that:

1 load angle θ oscillating is stabilized at 1 in the end [s] or 1.5 [s] -2 [s];
2. stator voltage decreases from 380 [V] to 263 [V] the same;
3. frequency/pulsation stator has an oscillating character and tend to the value ω=209.3 [rad/s] [f=209.3/6.28 Hz];
4. excitation current oscillates towards the 1.3 [A];
5. stator current oscillates him in the same timing for the 30 [A];
6. currents involution of depreciation is "sting" in 1 [s], 1.5 [s], 3 [s].
7. magnetical flux finally reach face value after the same time;
8. torgue electromagnetic generator is amended over time as see in figure 13. Magnetic coupling between stator and rotor does not "break" when the system is dynamically stable.

4. Operation unstable of naval power

If below operation unstable to the emergence of short-circuit the system, the differential equations in this case is [1, 2, 3, 7, 8]:

$$\begin{cases} 1{,}6X + 0.08\frac{dx}{dt} - 0.07\omega Z - 0.053\omega Q + \frac{dY}{dt} = -U\sin\theta \\ 0.08\omega X + \omega Y + 0.05\omega D + 0.053\frac{dQ}{dt} + 1.6Z + 0.07\frac{dz}{dt} = U\cos\theta \\ \frac{dX}{dt} + 40Y + 18.51 + 0.56\frac{dD}{dt} = E \\ 0.053\frac{dx}{dt} + 7.95D + 0.07\frac{dD}{dt} + 0.56\frac{dY}{dt} = 0 \\ 2(0.01XZ + ZY - 0.053DZ) - 15 = 0.01\frac{d\omega}{dt} \\ \frac{d\theta}{dt} + \omega - O = o \\ \frac{dO}{dt} = 10000(209.3 - O) \\ \frac{dU}{dt} = 100(1.47 - 0.0049Z^2 - (Y + 0.08X)^2) - 0.098Z\frac{dZ}{dt} - 20(Y + 0.08X)(\frac{dY}{dt} + 0.08\frac{dX}{dt}) \end{cases}$$

In 3 cases, by simulation, they obtained the following results:

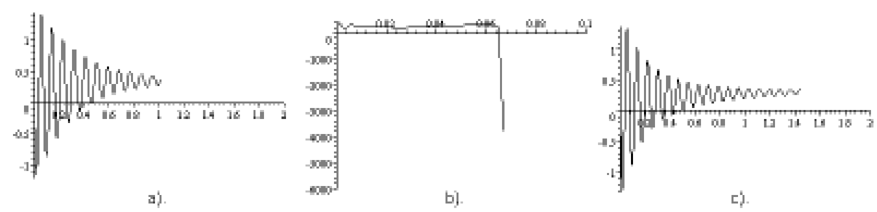

Figure 14. Changes during pregnancy angle θ

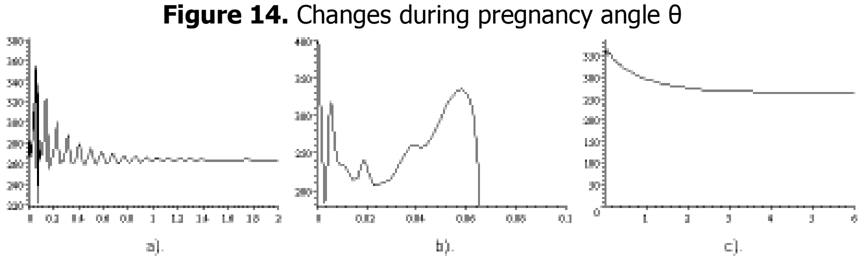

Figure 15. Variation of stator voltage U while

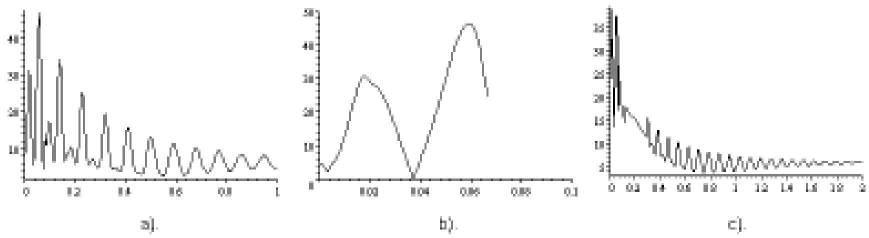

Figure 16. Variation in time of current stator $\sqrt{X^2+Z^2}$

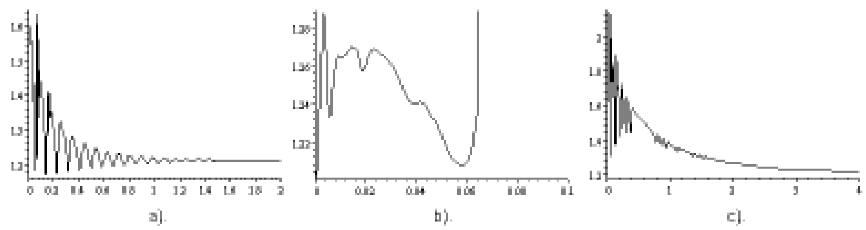

Figure 17. Variation of stator flux $\sqrt{(L_q I_q)^2+(L_d I_d+M_E I_E)^2}$ in 3 cases

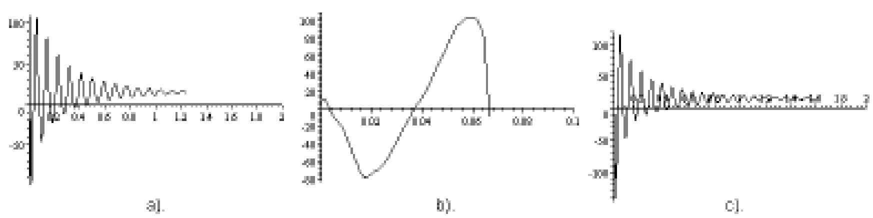

Figure 18. Variation in time of the electromagnetic torque

Following the analysis of simulations above operation became unstable after approximately 0.065 s, resulting in this:

1. load angle becomes, in absolute value greater than 180 °;
2. stator voltage becomes null;
3. stator current is unreliable and very large;
4. stator flux exceeds the nominal value;
5. electromagnetic couple change meaning, magnetic coupling between stator and rotor tip is asynchronous.

In this case the generator loses synchronism in the operation and protection of current maximum and minimum voltage is offline from the system.

5. Conclusion

In the paper there were 2 types of dynamic function: stable and unstable if stable operation of the basic dimensions of the system reached the final after a finite time interval. If unstable operation, operation in synchronism of the generator is no longer possible and this can be seen from the analysis of variations over time, mainly the electromagnetic torque, voltage and load angle. In numerical simulations given in the paper used orthogonal model. Equation of motion is achieved rapid change in frequency over time. Using the voltage regulators and frequency lead to a stabilization which depends on constants regulators

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