CONSIDERATIONS ABOVE SYNCHRONOUS MACHINE STABILITY ANALYSIS BY USING PHASE PORTRAITS

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Abstract **– The paper presents the functioning stability problem of the synchronous machine by using phase portraits of current pairs according to the orthogonal model of the longitudinal and transversal (the d-q axis model). Without amortizations the braking and acceleration energies would compensate each other to the infinite, and the functioning point would be fixed anywhere in the energetic balance point. The considered graphics are obtained by the elimination of the time variable from the numeric equations by using the Mathematica software. There are highlighted the differences between the phase portraits at two significant dynamic loads: stable and unstable.**

Keywords: *dynamic stability, phase portrait, electromagnetic torque's angular dynamic characteristic, synchronous machine.*

1. INTRODUCTION – THE SYNCHRONOUS MACHINE MATHEMATICHAL MODEL

The equations of the synchronous machine are expressed in d-q axis. The synchronous machine model is well known in technical literature and it's a nonlinear equation system having seven equations. Their deduction and parameter signification are studied in the [1] monograph. The issue in this paper represents the link between the system's stability concepts (the Liapunov problem) and the dynamic stability of the machine's functioning (the synchronism). The stability study and the Cauchy problem solving are performed by using the Mathematica 5.2 software, especially the *NDSolve* commands for the numerical solving of the differential equations system and the *Plot*, *ParametricPlot* or *ImplicitPlot* command for the graphic visualization. [6] The study of the stability doesn't necessarily require the solving of the differential equation system that models the synchronous machine. From the mathematical point of view, the static stability is equivalent with the stability of the first approximation of the system in the term of Liapunov, so that for the proving of this quality it is enough to study the own values of the associated Jacobean matrix. On the contrary, the dynamic stability corresponds to the Liapunov stability. The static stability involves the normal machine functioning, in equilibrium, as a result of small variations of the load. It is characteristic for long period loads. The dynamic stability involves the maintaining of the machine's functioning after significant and fast load variations, being characteristic to fast regimes. [1] [2]

2. THE ENERGETICAL EQUILIBRIUM

The stability of the synchronous machine is analyzed by using the mathematical model expressed by the differential equations.
From the point of view of the dynamic stability the synchronous machine is inferior to the asynchronous machine, but the first one is imposed at high rated powers. However, the synchronous machine being fed at variable frequency and voltage, it presents certain advantages and is superior to the asynchronous machine from the following points of view:
- Precise control of speed and torque;
- The integral usage, at maximum power factor of the ferromagnetic core and of the windings;
- Higher liability due to the construction (increased air gap);
- The separated control of active and reactive power.

The stability problem is approached in the case of terminal voltage drop out.
For all studied cases there is considered the influence of the rotary inertial moment over the dynamic stability area.
There is defined as **energetically equilibrium** (EE) the single point ($\theta1$, m), situated in the stable zone of the torque's angular characteristic, which verifies the system:

$$\int_{\theta init}^{\theta 1} (m - SMtorque[\theta])d\theta =$$
$$= \int_{\theta 1}^{\theta 2} (SMtorque[\theta] - m)d\theta \qquad (1)$$

$$m == SMtorque[\theta 1] =$$
$$= SMtorque[\theta 2] \qquad (2)$$

The obtained θ angle is named the **energetic equilibrium angle** and is further referred as θ_{ee}, and corresponding torque SMtorque[θ_{ee}]=M_{ee} is the **energetic equilibrium torque.** (figure 1)
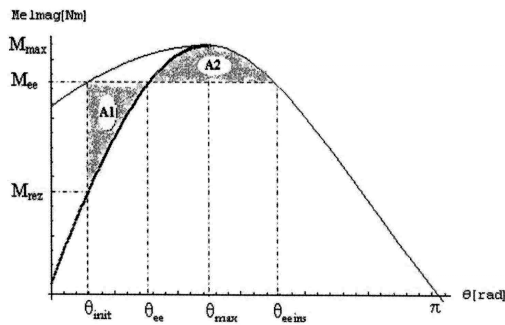

Figure 1. The energetic equilibrium.
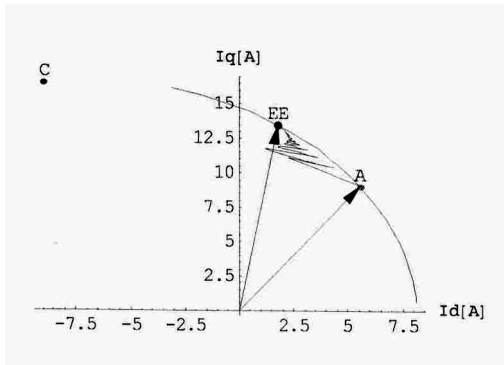

Figure 2i. The phase portrait of the stator current attached to the stationary regime at J_{small}.

At Jhigh, the EE point is reached by oscillating near the final EE point and the I current values overshoot in the meantime of the transient process the final steady state regime value. (as depicted in figure 2i).

3. THE DYNAMIC STABILITY OF THE SYNCHRONOUS MACHINE

Initially the synchronous machine will operate at the A point (figure 2i) and due to the torque variance ΔM, maximum possible from the dynamic stability point of view (Jhigh), reaches the EE energetic equilibrium point. At Jsmall the reaching of the energetic equilibrium point is performed asymptotic

and therefore meantime the transient regime there are not overshoots on the EE point and the I current has the stationary value. In the next figures (2ii and 2iii) are depicted the results for Jhigh and the ΔMhigh. There have been considered two machine with same electrical parameters, but with different inertia moments (Jsmall=0.01 [kg.m^2] and respectively Jhigh=50 [kg.m^2]). The variation of the stator currents Id and Iq depend on the values of the rotary inertial moment. At the beginning of the transient process the current's oscillations present higher values for Jhigh that in the case of Jsmall. However, the final values of the Id and Iq currents are the same regardless to the J rotary inertial moment, its influence being performed only in the mean while of the transient process. In the first transient's periods at Jhigh the actual current I values are with about 50% higher then in the case of Jsmall. As a consequence, in the practical applications, such as the case of synchronous hydro generators (that have a higher J value), the transient process is much rougher from the point of view of the current stress then in the case of synchronous turbo generators (that usually have a smaller J value). The stator currents evolution regarding the load angle θ, doesn't depend on the J inertial moment value.
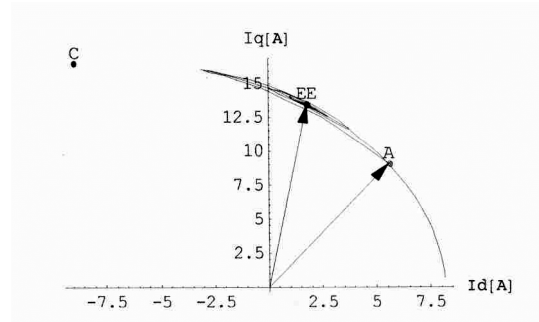

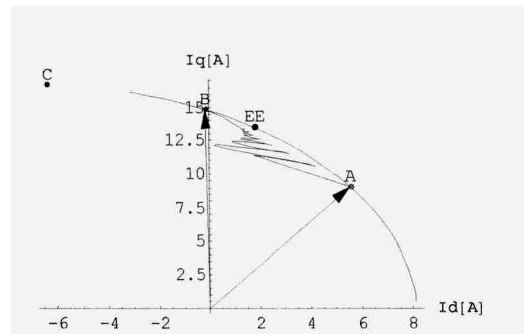Figure 2ii. The phase portrait of the stator current attached to the stationary regime at J_{high}.

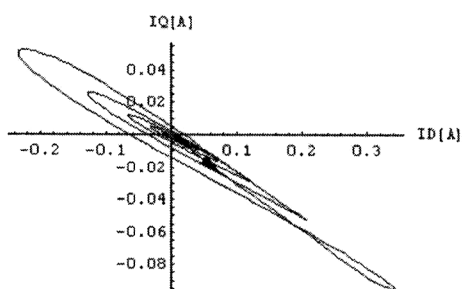Figure 2iii. The phase portrait of the stator current attached to the stationary regime at $ΔM_{high}$

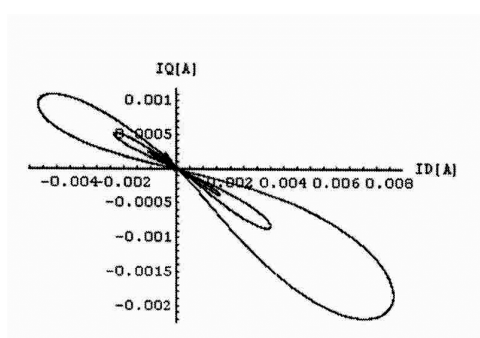Figure 3i. The phase portrait of the amortization currents Jsmall.

Figure 3ii. The phase portrait of the amortization currents Jhigh.

The phase portraits of the amortization current pairs – the excitation current (I_D, I_E) and respectively (I_Q, I_E) are closed curves: their starting point is also the final point $(0, I_E(0))$. From the phase portrait there can be noticed that the closing of the I_Q amortization current is much faster then the stabilization of the I_E current to the U_E/R_E value. Of course, the value of the rotary inertial moment determines the shape of the phase portrait, fact that can be noticed from the analyzing at Jhigh of the I_E and I_D current that stabilizes in comparable time periods. (Figures 3i and 3ii). [3] [5]
The oscillations of the electrical and mechanical powers, considering their amplitudes, are less influenced by the value of the J inertial moment. At Jsmall the power oscillations are higher, such as in the case of electromagnetic torque variations. The issue that must be considered is the stability of the national eletroenergetic system, the worst case being at higher values of J, because in this case the period of the transient process increases significantly and it can reach until several minutes.
The overall complexity of the transient phenomena can be noticed by studying the angle versus torque characteristic in dynamic and static regime,

completed with the corresponding time variation of the θ load angle. (Figures 4i and 4ii). [6]. In the case of small inertial moments the passing from initial functioning point A to the final point B is done asymptotically; in the mean time of the transient there are no overshoots regarding the stationary value of the θ load angle. At higher values of the rotary inertial moment, the oscillations are much rougher in amplitude and the θ load angle overshoots during the transient process the steady state regime value $θ_B$.
In the extreme case, when J → ∞, the θ load angle at EE point reaches the maximum value 1.632 [rad/sec] instead of 1.25 [rad/sec] which is the maximum value for J=50 [kg.m^2]. Results that the maximum value of θ load angle depends on the J rotary inertial moment.
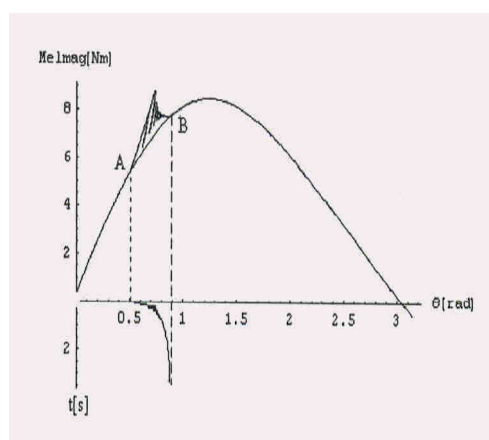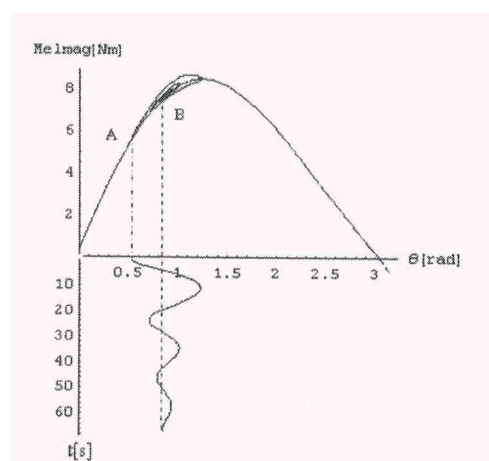

Figure 4i. The torque versus the load angle at Jsmall.

Figure 4ii. The torque versus the load angle at Jhigh.

4. THE SYNCRONISM LOSE ISSUE

The synchronism lose can be noticed in the figure 5 by analyzing the phase portrait of the stator current. Starting with the initial point A, the I vector overshoots the EE point and reaches the unstable zone, and increases further until the synchronous machine becomes unsynchronized. The synchronism lose is depicted by the time variations of the of the I_D and I_Q amortization currents. (figure 6). [4] They are no longer stabilized to the zero value during the transient process. In the period when the synchronous machine still operates in synchronism, the values of I_D current are with a measure order under the previous case values, this being also due to the fact that in this case the rotor doesn't oscillate near an equilibrium position, having only a tendency to reduce its rotation speed and consequently the rotary induced voltage has reduced values. The phase portrait of amortization currents highlights the synchronism lose issue. Initially, the I_D and I_Q currents where null, but afterwards they increase constantly until the machine drops out the synchronism. The I_E excitation current increases slightly (appreciatively to 7% for the studied machine) near the steady state regime value, without being noticeably influenced by the load modification (the excitation winding is fed by a separate power supply). The moment time when the synchronisms lose issue occurs is the same with the moment time when the electromagnetic torque is null. As a result, of a too high torque variation, the ω angular velocity drops until the synchronous machine loses its synchronism. The synchronism lose occurs much faster when the torque variation is higher. The continuous increasing of the θ load angle and the overshooting of the limit value (approximate π) proves the synchronous machine's synchronism lose issue.
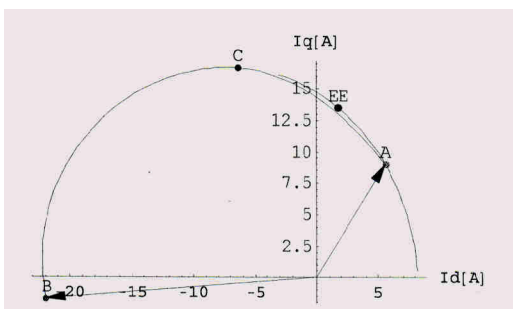

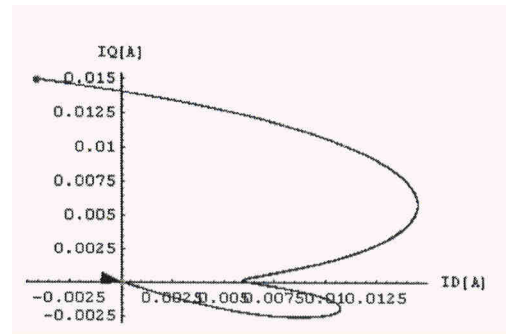Figure 5. The phase portrait of the stator current attached to the steady state regime current.

Figure 6. The phase portrait of the amortization currents.

5. CONCLUSIONS

At a $\Delta M > MEE - Mrez$, the synchronous machine becomes unsynchronized and there are occurring the following phenomena: the stator current increases its value continuously in dynamic regime; the amortization currents are no longer at zero value; the current's phase portraits have the final point located at the unsynchronized region; the load angle increases over the limit value and the electromagnetic torque becomes equal to zero; the rotor speed drops continuously and is unable to reestablish the synchronous speed. [5]

As an overall conclusion, the dynamic stability means the maintaining of the machine's nominal functioning even after significant and fast load variations, the dynamic stability being a characteristic to fast functioning regimes.

References

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