NON TRANSIENT PROCESS AT THE OSCILATIONS WITH LARGE AMPLITUDES

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Abstract **– In the case of the analyze of the transient process with the considering the speed of rotor constant, the system of the equations, wrote in the two axis theory, which describe the operation of the machine, is linear and it could be obtain analytical solutions. Much complicated is the study of the behavior of the synchronous machine at variable speed. This paper presents the conditions in which this is realizable for some cases important in practice. One of those is the study of the non stationary process at the high amplitude.**

Keywords: *synchronous machine, non stationary process, oscillations with large amplitude.*

1. INTRODUCTION

With a disturbance of the stationary regime of a synchronous machine, considered connected to a powerful network of tension, accompanied with mechanical oscillations by high amplitudes of the rotor, the simplified assumptions, which must lead to the linear equations in the theory of the two axes, could not be used.

To analyze the processes have to use the numerical integration of those, employing the electronics of calculation.

In the particulars cases or with assumptions simplifiers extensively are obtaining also analytical solutions, important especially because are explained the factors which are conditioning the transient process considered and their weight. In the particulars cases or in assumptions extensive simplifier are obtaining also analytical solutions, important especially because are explain the factors which are conditioning the transient process considered and their weight.

Thus, in the areas uppermost interesting in practice of the rotating near with the synchronous (for the unexpected variation of load, at the synchronizing with the network or at the losses of the synchronism), in the machine's equation could be neglected, in a first approximation, the voltages of transformation $\frac{d\psi_d}{dt}, \frac{d\psi_q}{dt}$ and the voltages on the resistances of the stator's winding $R_s I_d, R_s I_q$ in rapport with the voltages of rotation: $\frac{d\beta_B}{dt}\psi_d, \frac{d\beta_B}{dt}\psi_q$, so it considers:

$$u_d \cong \frac{d\beta_B}{dt}\psi_q, u_q \cong -\frac{d\beta_B}{dt}\psi_d .$$

There are neglected also the components of over-transient of the currents of stator's which, anyway, are decreasing quickly comparing with the period of the mechanical oscillations (time constants are in average in the range of 0,03-0,06s) and doesn't influenced essentially the electromechanical torque. The simplification introduced is used currently in the problems of dynamical stability, [10], [11].

2. FORMULATION OF THE MATHEMATICAL PROBLEM

In the enunciated conditions, the system of equations, which is describing the behavior of a machine with salient poles, when the positive sense for the windings of the stator is the same with the source, it obtains the form:

$$\begin{aligned} u_d &= \frac{d\beta_B}{dt}\psi_q, & \psi_d &= L_d i_d + L_{dh} i_E \\ u_q &= -\frac{d\beta_B}{dt}\psi_d, & \psi_d &= L_q i_q \\ u_E &= R_E i_E + \frac{d\psi_E}{dt}, & \psi_E &= L_E i_E + L_{dh} i_d \\ M_m - M &= \frac{J}{P}\frac{d^2\beta_B}{dt^2}, & M &= \frac{3}{2}p\left(\psi_q i_d - \psi_d i_q\right) \end{aligned} \tag{1}$$

System (1) is nonlinear and it is hard to solve.

Taking account, follow up, results that in the presence of the small oscillations:

$$\beta_B = \omega_1 t + \vartheta_0 + \Delta\vartheta(t) \tag{2}$$

and if, it is considering, according with the assumption, that the slide s is small, results $\omega \cong \omega_1$ and

$$u_d = -\sqrt{2}U\sin\vartheta_0 \cong \omega_1\psi_q, u_q = -\sqrt{2}U\cos\vartheta_0 \cong -\omega_1\psi_d . \tag{3}$$

The transients currents appeared in the rotor only in the winding of field and taking account that the time constant is

high T_E (order of seconds), they are so, that could be used the principal of the constant flux ψ_E, a significant time on the mechanical oscillations period.
If the current i_E is eliminated in equations (1) for the fluxes of longitudinal ax, result:

$$\psi_d = \left(L_d - \frac{L_{dh}^2}{L_E} \right) i_d + \frac{L_{dh}}{L_E} \psi_E$$

and taking account of §9 [1], results

$$\psi_d = L_d^{'} i_d + \frac{L_{dh}}{L_E} \psi_E .$$

System (1) takes the simplified form (4):

$$\begin{aligned} u_d &= -\sqrt{2}U \sin \vartheta_0 = \omega_1 \psi_q, & \psi_q &= L_q i_q \\ u_q &= -\sqrt{2}U \cos \vartheta_0 = -\omega_1 \psi_d, & \psi_d &= L_d^{'} i_d + \frac{L_{dh}}{L_E} \psi_E \\ M_m - M &= \frac{J}{P} \frac{d^2 \vartheta_0}{dt^2}, & M &= \frac{3}{2} p \left(\psi_q i_d - \psi_d i_q \right) \end{aligned} \quad (4)$$

and allow the following interpretations with practical concern.
In this conditions, for each ϑ_0 correspond currents i_d, i_q, i_E constants, well specified; currents of the stator winding of the machine hasn't, in fact, a periodical components and hereby they are sinusoidal.
It is known [4], [12] that the equation of voltages in the stationary synchronous regime is

$$\begin{aligned} \underline{U} &= -R_S \underline{I} - jX_d \underline{I}_d - jX_q \underline{I}_q + \underline{U}_{eE}; \\ \underline{U}_{eE} &= -j\omega_1 \underline{\psi}_E . \end{aligned} \quad (5)$$

At the considered variation of the phase voltages, and of the currents with the shape:

$$\begin{aligned} i_A &= \sqrt{2} I \sin(\omega_1 t - \varphi), \\ i_B &= \sqrt{2} I \sin\left(\omega_1 t - \varphi - \frac{2\pi}{3} \right); \\ i_C &= \sqrt{2} I \sin\left(\omega_1 t - \varphi - \frac{4\pi}{3} \right) \end{aligned}$$

applying (3) and it is obtaining:

$$i_d = -\sqrt{2} I \sin(\varphi + \vartheta_0), i_q = -\sqrt{2} I \cos(\varphi + \vartheta_0). \quad (6)$$

It is evidenced ψ_E in the equations of voltages and for ψ_d, ψ_q given by relations like (4) and (6) is obtains:

$$\underline{U} = -R_S \underline{I} - j\omega L_d^{'} \underline{I}_d - j\omega L_q \underline{I}_q - j\omega \frac{L_{dh}}{L_E} \underline{\psi}_E \text{, or}$$

$$\underline{U} = -R_S \underline{I} - jX_d^{'} \underline{I}_d - jX_q \underline{I}_q + \underline{U}_{eE}^{'}; \underline{U}_{eE}^{'} = -j\omega \frac{L_{dh}}{L_E} \underline{\psi}_E \quad (7)$$

in which $\underline{I} = \underline{I}_d + \underline{I}_q$, with the same validity as (5).
In relation (7), with the considering of U'_{eE} = ct, the equation of voltage, called also dynamical equation of voltages, is true also for the symmetrical transient currents of the windings of stator which are established, according with the foregoing assumptions, at high oscillations of the synchronous machine. The suitable diagram of phasors is the dynamical phasors diagram (figure 1).
Is observed that, relative of those established in stationary regime, in dynamical regime U_{eE} is replaced with U'_{eE} and X_d with X_{fd}.

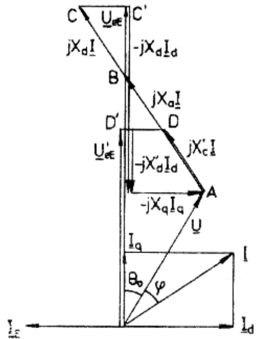

Figure 1: Dynamical phasors diagram

For a total image is interesting to follow the geometrical place of the current I of a machine connected at a network of voltage U at $U_{eE}^{'} = ct$.
Is proceeding as in [4]. Current $\underline{I}$ is given by the equation:

$$\begin{aligned} \underline{I} &= j\frac{U}{X_d^{'}} + \left(\frac{1}{X_q} - \frac{1}{X_d^{'}} \right) U \sin \vartheta_0 e^{j\vartheta_0} - j\frac{U_{eE}^{'}}{X_d^{'}} e^{j\vartheta_0} \\ &= \underline{A}^{'} + B^{'}(\vartheta_0) e^{j\vartheta_0} + \underline{C}^{'} e^{j\vartheta_0} \end{aligned} \quad (8)$$

where,

$$\underline{A}' = j\frac{U}{X_d^{'}}, B'(\vartheta_0) = \left(\frac{1}{X_q} - \frac{1}{X_d^{'}} \right) U \sin \vartheta_0, \underline{C}^{'} = -j\frac{U_{eE}^{'}}{X_d^{'}} .$$

The geometrical place, look for $\underline{I}$ in the complex plan at the variation of ϑ_0, in the hypotheses of the conservation of the flux of the winding of field, is the curve (I') and represent the snail of Pascal (fig. 2).

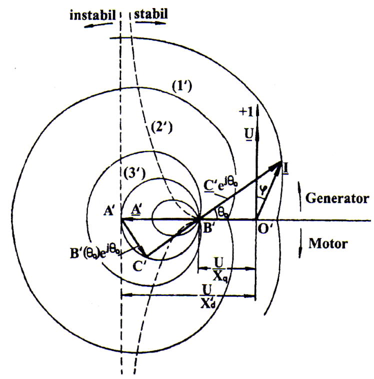

Figure 2: Diagram of current of the synchronous machine with salient poles at $U_{eE}^{'} = ct$.

In figure 2 was traced the curves (1'), some of them double circular, for much values of U'_{eE}. At $U'_{eE} = 0$ there are reduced of the circle (3'). The curve $(2')$, the place of points with maximal ordinate of curves $(1')$, asymptote to the perpendicular in A' on $O'A'$, is separated the areas of the stabile operation by those of the non stable operation at U'_{eE} = ct. It is observed the important which are obtained for I and the capacity of overload.

The shape different of the curves (l') towards those from [4] obtained conform (5) derive from $X_d<X_q$.

In figure 3 for the current I from the stationary regime is corresponded the electromagnetic voltage U_{eE} proportional with C and electromagnetic voltage U'_{eE} proportional with C'. To the slowly variation of ϑ_0 the place of I is the snail of Pascal (1) definite in [4], at the rapid variation of ϑ_0 (thus is used the principle of the constant flux of the winding of field), the geometrical place is the curve $(1')$ specified in figure 2.

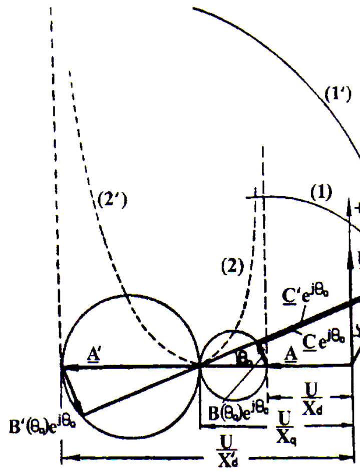

Figure 3. Geometrical place of I at $U_{eE} = ct$ and $U'_{eE} = ct$

To retain that the electromagnetic voltage U'_{eE} is conditioned by the electromagnetic voltage U_{eE} and the internal angle from the stationary regime is anterior for the mechanical oscillation. In figure 2 were traced, to be compared, also the curves (2), $(2')$ which are for separate the areas of static stability (at U_{eE}= ct.) respective of stability at U'_{eE} =ct.

The calculus of the *dynamic electromagnetic torque* at U'_{eE} = ct. from (4) is expanded as in [4] and is obtain

$$M = \frac{pm}{\omega}\left[\frac{UU'_{eE}}{X'_d}\sin\vartheta_0 - \frac{U^2}{2}\left(\frac{1}{X_q} - \frac{1}{X'_d}\right)\sin 2\vartheta_0\right]. \quad (9)$$

Representation of $M = f(\vartheta_0)$ is giving in figure 4. Because of $X'_d < X_d$, the amplitude of the principal component $M' = \frac{pm}{\omega}\frac{UU'_{eE}}{X'_d}$ is important. It is observed that because of $X'_d < X_q$, the component $M'' = \frac{pm}{\omega}\frac{U^2}{2}\left(\frac{1}{X'_d} - \frac{1}{X_q}\right)\sin 2\vartheta_0$, conditioned by the magnetical and electrical non symmetry of the machine, is opposite of its corresponding component in stationary regime.

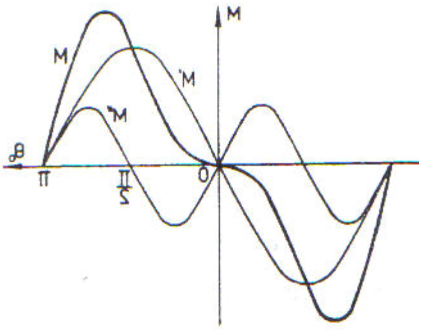

Figure 4. Torque of the salient synchronous machine at U'_{eE} = ct

Relation (9) is suggested that in the expression of the dynamic torque is interfered a component in function of $2\vartheta_0$ also at the machine with full poles which in the stationary regime has $X_d=X_q$.

Those presented upper could be used to analyze the dynamic stability of the synchronous machine. During of the first oscillations must be considered the characteristics $M(\vartheta_0)$ defined by (9). Electromagnetic voltage U'_{eE} is considered that from the stationary regime anterior of the perturbation. Resulted that *can't be establish only a mechanical dynamic characteristic*, its shape being conditioned from the dates of the stationary regime.

4. CONCLUSIONS

Must be observed that, on the damping of the oscillations induced by the sudden variation of the load of the machine, are reducing also the transient currents from the winding of field and the mechanical characteristics in succession which are obtained, tend for that the stationary regime.

So, can appear the circumstance, which for the considered load shock, didn't obtain finally a synchronous operation, not but that on the dynamical characteristic the condition of stability is satisfied.

Observed that for the process in which s varying quickly in large limits, established upper, aren't in concordance with the reality and can be induce important errors. Must be retaining the circumstance in which the network of voltage isn't strong. In this case, the mechanical oscillations of the rotor, which are traduced through the oscillations of the electrical power at the connecting terminal, produced determinates the variation of the voltage of the network in amplitude and in frequency, which in determinate conditions (of resonance) caused the continuous increase of the rotor's oscillations till the loss of the synchronism. Also, an important variation of the amplitude of the voltage of network has non favorite effects on the connected machines on those bars.

Also, the others synchronous generators which are operating coupled to the considered network can enter in oscillations and can lose the synchronism. So, through the amplification of the process, the network's voltage could decrease to zeros. This major no advantage is sensible reduced in the powerful network, where the shocks of power produced by a starting process or by an operated on variable torque of a synchronous machine, even of great power, didn't appeared dangerous.

References

[1]. Campeanu, A., Introducere în dinamica maşinilor electrice de curent alternativ, EDITURA Academiei Române, 1998.

[2]. Bodefeld, Th., Sequenz, H., *Elektrische Maschinen.* Wien 6 Auflage, Springer Verlag, 1962.

[3]. Bonfert, K., *Betriebsverhalten der Synchronmaschine.* Berlin, Springer Verlag, 1962.

[4]. Campeanu, A., Masini electrice. Probleme fundamnetale, speciale si de functionare optimal^. *Craiova, Edit. Scrisul Romanesc, 1988.*

[5]. Campeanu *A.,* Uber eine besondere Betriebsweise des Ruckarbeitsbetriebes van Synchronomaschinen. *A.f.E. 61, 1979.*

[6]. Campeanu, A., Asupra cuplului componentei aperiodice a curentului statoric al masinii sincrone. *Bul. st. si tehn. I.P.T.* ***105,*** *15, 1970.*

[7]. Campeanu, A., Contributii la studiul unui regim de recuperare al masinii sincrone. *St. si Cerc, de Energ. si Electrot, 23, 4, 1973.*

[8]. Campeanu*, A.,* The Transient Electromechanical Oscillations of the Synchronous Machine in a Special Case. *Brasov, OPTIM '98, 1998.*

[9]. Campeanu*, A.,* Stabilitatea staticd a masinii sincrone in regim de recuperare. *Electrotehnica, 11, 1971.*

[10]. *Kazovski, E.,* Perehodnie protest v elektriskih masinan peremennovo toka. *Moskva, Leningrad, Izd. Akademii nauk SSSR, 1962.*

[11]. Sipailov, G.A., ş.a., Electriceskie masini. Moskva, Vîsşaia şkola, 1987.

[12]. *Dordea, T.,* Maşini electrice. *Bucureşti, Editura Didactică şi Pedagogică, 1977.*