STUDY OF INDUCTION MACHINE UNDER TRANSIENT DUTY AND STEADY-STATE AS SYNCHRONIZED MACHINE

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REZUMAT. In vederea analizei masinii asincrone trifazate in regim de masina sincrona (masina asincrona sincronizata MAS) se apeleaza la ecuatiile diferentiale de ordinul I exprimate numai ***în fluxuri totale si unghiul de rotatie***. Se obtine un sistem de 8 ecuatii care se refera: la cele 3 faze statorice, la cele 3 faze rotorice, (dintre care 2 sunt inseriate si sunt alimentate de la o sursa de curent continuu, constituind infasurarea de excitatie, iar cea de-a treia constituie infasurarea de amortizare, fiind conectata in scurtcircuit), la care se mai adauga 2 ecuatii de miscare. Această abordare permite obtinerea unor informatii directe-precise despre fenomenele care au loc în masina, inclusiv si despre directiile de actiune ale fluxurilor magnetice adică despre unghiul intern instantaneu. Pe baza acestor informatii se pot adopta strategii adecvate si lua decizii pertinente privind momentele favorabile ale cuplării înfăsurărilor la surse. Trebuie evitata situația de decrosare, de exemplu, cand se declansează un regim tranzitoriu electromecanic cu constantă de timp mare, care întârzie procesul cu o durată care poate fi egala cu dublul timpului necesar pornirii. Se insista asupra utilizarii hodografului fluxului rezultant rotoric ca instrument eficient, cu reale valente didactice în aprecierea comportarii masinii de inductie sincronizate in diverse regimuri: tranzitorii sau stationare.

Cuvinte cheie: motor asincron de putere mare, condiții de pornire speciale, două colivii rotorice, simulare MEF

ABSTRACT. For the analysis of the three-phase induction machine under synchronous operation (the so-called synchronized induction machine, SIM) one uses first order differential equations that contains nothing but ***total fluxes*** and ***rotation angle***. The resulted 8 equations system characterize the 3 stator phases, the 3 rotor phases (2 of them are series connected and fed from a DC source and the third is short-circuited and play the role of a damper winding) and the movement of the rotor (the last 2 equations). This approach allows the obtaining of direct and proper information about the intimate phenomena that take place inside the machine including the direction of magnetic fluxes, which leads to the instantaneous internal angle. On the basis of this information, one can adopt proper strategies concerning the most favourable moment for the connection of the windings to the supply sources. The pulling out must be avoided, for example when starts a transient duty with high time constant which delays the process with a length that may attain twice the value of the starting time. The hodograph of the resultant rotor flux is considered as a very effective tool, also for didactic purpose, that describe the behavior of the synchronized induction machine under different duties such as transients or steady state.

Keywords: high power induction motor, start-up constraints, two squirrel cages of distinct materials, FEM simulation

1. INTRODUCTION

A particular duty of the doubly-fed wound rotor three-phase induction machine [1, 2] refers to the so-called situation of *synchronized induction machine-SIM* [3] whose schematic diagram is presented in Fig. 1 [1]. The main characteristic of this operation mode consists in the fact that it put together the qualities of *induction machine* (safe starting with less expensive auxiliary devices, high starting torque) with the ones of the *synchronous machine* with electromagnetic excitation (operation with high power factor, sometimes even as synchronous compensator, constant speed, high pull-out torque, etc.). Due to these advantages, the SIM is used under motoring duty for high power applications, concerning constant speed and single direction of rotation such as pumps, fans, compressors and roller mills [2, 3, 4, 5, 6].

Coming back to the schematic diagram (Fig. 1), a SIM operates as follows. Initially, after connection to the mains of the three-phase stator winding by means of K1, the rotor winding is short-circuited (or connected to an auxiliary resistance) and the rotor starts and accelerates close to synchronous speed (K2 has the mobile contacts to the left side). Shortly after that, the mobile contacts of K2 are moved to the right side when the *cr* rotor phase is short-circuited and the other two phases, *ar* and *br* become series connected and fed from a DC source. After a few oscillations, the synchronizing torque that acts between the stator rotating field and the rotor (which has a constant magnetic field as a succession of magnetic poles on the perifery) pulls the rotor into synchronous speed.

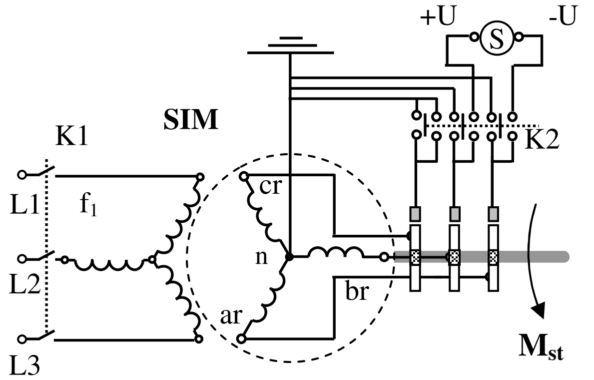

Fig. 1. Schematic diagram of synchronized induction machine.

Consequently, the machine becomes a synchronous motor, which is capable to drive a load machine. Lately, the electromechanical conversion of micro wind power plants uses frequently induction generators, which sometimes change their duty into synchronized induction generators (SIGs).

2. EQUATIONS OF THREE-PHASE INDUCTION MACHINE *IN TOTAL FLUXES*

The analysis of three-phase machine can be generally done (including unbalanced supply systems either for stator or rotor windings) by putting together the 6 equations of the electric circuits containing *nothing but total fluxes and voltages* and the 2 *movement-torque* balance equations where appears the electromagnetic torque (deduced from magnetic coenergy variation) and the rotation angle of the rotor, θ_R [2, 7]. Under *symbolic method*, one obtains a first order system with 8 equations, (1-8):

$$\overline{\psi}_{as}\left(\overline{s}+\nu_{st}\right)=\overline{u}_{as}-\nu_{sr}\left(\overline{\psi}_{bs}+\overline{\psi}_{cs}\right)+\frac{1}{3}\nu_{\sigma s}\cdot \cdot[\left(2\overline{\psi}_{ar}-\overline{\psi}_{br}-\overline{\psi}_{cr}\right)\cos\theta_R+\sqrt{3}\left(\overline{\psi}_{cr}-\overline{\psi}_{br}\right)\sin\theta_R] \tag{1}$$

$$\overline{\psi}_{bs}\left(\overline{s}+\nu_{st}\right)=\overline{u}_{bs}-\nu_{sr}\left(\overline{\psi}_{cs}+\overline{\psi}_{as}\right)+\frac{1}{3}\nu_{\sigma s}\cdot \cdot[\left(-\overline{\psi}_{ar}+2\overline{\psi}_{br}-\overline{\psi}_{cr}\right)\cos\theta_R+\sqrt{3}\left(\overline{\psi}_{ar}-\overline{\psi}_{cr}\right)\sin\theta_R] \tag{2}$$

$$\overline{\psi}_{cs}\left(\overline{s}+\nu_{st}\right)=\overline{u}_{cs}-\nu_{sr}\left(\overline{\psi}_{as}+\overline{\psi}_{bs}\right)+\frac{1}{3}\nu_{\sigma s}\cdot \cdot[\left(-\overline{\psi}_{ar}-\overline{\psi}_{br}+2\overline{\psi}_{cr}\right)\cos\theta_R+\sqrt{3}\left(\overline{\psi}_{br}-\overline{\psi}_{ar}\right)\sin\theta_R] \tag{3}$$

$$\overline{\psi}_{ar}\left(\overline{s}+\nu_{rt}\right)=\overline{u}_{ar}-\nu_{rs}\left(\overline{\psi}_{br}+\overline{\psi}_{cr}\right)+\frac{1}{3}\nu_{\sigma r}\cdot \cdot[\left(2\overline{\psi}_{as}-\overline{\psi}_{bs}-\overline{\psi}_{cs}\right)\cos\theta_R+\sqrt{3}\left(\overline{\psi}_{bs}-\overline{\psi}_{cs}\right)\sin\theta_R] \tag{4}$$

$$\overline{\psi}_{br}\left(\overline{s}+\nu_{rt}\right)=\overline{u}_{br}-\nu_{rs}\left(\overline{\psi}_{cr}+\overline{\psi}_{ar}\right)+\frac{1}{3}\nu_{\sigma r}\cdot \cdot[\left(-\overline{\psi}_{as}+2\overline{\psi}_{bs}-\overline{\psi}_{cs}\right)\cos\theta_R+\sqrt{3}\left(\overline{\psi}_{cs}-\overline{\psi}_{as}\right)\sin\theta_R] \tag{5}$$

$$\overline{\psi}_{cr}\left(\overline{s}+\nu_{rt}\right)=0-\nu_{rs}\left(\overline{\psi}_{ar}+\overline{\psi}_{r}\right)+\frac{1}{3}\nu_{\sigma r}\cdot \cdot[\left(-\overline{\psi}_{as}-\overline{\psi}_{bs}+2\overline{\psi}_{cs}\right)\cos\theta_R+\sqrt{3}\left(\overline{\psi}_{as}-\overline{\psi}_{bs}\right)\sin\theta_R] \tag{6}$$

$$\dot{\theta}_R\left(\overline{s}+\frac{k_z}{J}\right)=\frac{p}{J}\left\langle\frac{-p\Lambda_3}{2}\{\sin\theta_R[\overline{\psi}_{as}(2\overline{\psi}_{ar}-\overline{\psi}_{br}-\overline{\psi}_{cr})+ +\overline{\psi}_{bs}(2\overline{\psi}_{br}-\overline{\psi}_{cr}-\overline{\psi}_{ar})+\overline{\psi}_{cs}(2\overline{\psi}_{cr}-\overline{\psi}_{ar}-\overline{\psi}_{br})]+ +\sqrt{3}\cos\theta_R[\overline{\psi}_{as}(\overline{\psi}_{br}-\overline{\psi}_{cr})+\overline{\psi}_{bs}(\overline{\psi}_{cr}-\overline{\psi}_{ar})+ +\overline{\psi}_{cs}(\overline{\psi}_{ar}-\overline{\psi}_{br})]\}-M_{st}\right\rangle \tag{7}$$

$$\frac{d\theta_R}{dt}=\dot{\theta}_R=\omega_R \tag{8}$$

The first 3 equations contain the values of the balanced supply voltages connected to the stator phases, that is $U_{asmax}=U_{bsmax}=U_{bsmax}=490V$, $\omega_s=314.1 rad/s$; u_{bs} - behind u_{as} with $2\pi/3$ *rad*. The *synchronized induction machine* has a particularity as concerns the rotor. The *cr* phase-voltage *is null*, $u_{cr}=0$, (this phase becomes a damper winding) and the other 2 phases are series connected and fed from a DC source with a voltage of (-40, +40)V.

3. THE SIMULATION STUDY OF THE SYNCHRONIZED INDUCTION MACHINE

For a three-phase machine with the following parameters (SI units): $R_s=R_r=2$; $L_{hs}=0.09$; $L_{\sigma s}=L_{\sigma r}=0.01$; $J=0.05$; $p=2$; $k_z=0.02$; $\omega_1=314.1$ one obtains the equation system:

$$\left(\overline{s}+135{,}5\right)\overline{\psi}_{as}=\overline{u}_{as}-32{,}26\left(\overline{\psi}_{bs}+\overline{\psi}_{cs}\right)+32{,}26\left(2\overline{\psi}_{ar}-\overline{\psi}_{br}-\overline{\psi}_{cr}\right)\cos\theta_R +55{,}88(\overline{\psi}_{cr}-\overline{\psi}_{br})\sin\theta_R$$

$$\left(\overline{s}+135{,}5\right)\overline{\psi}_{bs}=\overline{u}_{bs}-32{,}26\left(\overline{\psi}_{cs}+\overline{\psi}_{as}\right)+32{,}26\left(2\overline{\psi}_{br}-\overline{\psi}_{cr}-\overline{\psi}_{ar}\right)\cos\theta_R +55{,}88(\overline{\psi}_{ar}-\overline{\psi}_{cr})\sin\theta_R$$

$$\left(\overline{s}+135{,}5\right)\overline{\psi}_{cs}=\overline{u}_{cs}-32{,}26\left(\overline{\psi}_{as}+\overline{\psi}_{bs}\right)+32{,}26\left(2\overline{\psi}_{cr}-\overline{\psi}_{ar}-\overline{\psi}_{br}\right)\cos\theta_R +55{,}88(\overline{\psi}_{br}-\overline{\psi}_{ar})\sin\theta_R$$

$$\left(\overline{s}+135{,}5\right)\overline{\psi}_{ar}=\overline{u}_{ar}-32{,}26\left(\overline{\psi}_{br}+\overline{\psi}_{cr}\right)+32{,}26\left(2\overline{\psi}_{as}-\overline{\psi}_{bs}-\overline{\psi}_{cs}\right)\cos\theta_R +55{,}88(\overline{\psi}_{bs}-\overline{\psi}_{cs})\sin\theta_R$$

$$\left(\overline{s}+135{,}5\right)\overline{\psi}_{br}=\overline{u}_{br}-32{,}26\left(\overline{\psi}_{cr}+\overline{\psi}_{ar}\right)+32{,}26\left(2\overline{\psi}_{bs}-\overline{\psi}_{cs}-\overline{\psi}_{as}\right)\cos\theta_R +55{,}88(\overline{\psi}_{cs}-\overline{\psi}_{as})\sin\theta_R$$

$$\left(\overline{s}+135{,}5\right)\overline{\psi}_{cr}=\overline{u}_{cr}-32{,}26\left(\overline{\psi}_{ar}+\overline{\psi}_{br}\right)+32{,}26\left(2\overline{\psi}_{cs}-\overline{\psi}_{as}-\overline{\psi}_{bs}\right)\cos\theta_R +55{,}88(\overline{\psi}_{as}-\overline{\psi}_{bs})\sin\theta_R$$

$$\dot{\theta}_R\left(\bar{s}+0{,}4\right)=(40)\Big\langle-(32{,}26)\Big\{\sin\theta_R\Big[\overline{\psi}_{as}\left(2\overline{\psi}_{ar}-\overline{\psi}_{br}-\overline{\psi}_{cr}\right)+\overline{\psi}_{bs}\cdot$$
$$\cdot\left(2\overline{\psi}_{br}-\overline{\psi}_{cr}-\overline{\psi}_{ar}\right)+\overline{\psi}_{cs}\left(2\overline{\psi}_{cr}-\overline{\psi}_{ar}-\overline{\psi}_{br}\right)\Big]+\sqrt{3}\cos\theta_R\cdot$$
$$\cdot\Big[\overline{\psi}_{as}\left(\overline{\psi}_{br}-\overline{\psi}_{cr}\right)+\overline{\psi}_{bs}\left(\overline{\psi}_{cr}-\overline{\psi}_{ar}\right)+\overline{\psi}_{cs}\left(\overline{\psi}_{ar}-\overline{\psi}_{br}\right)\Big]\Big\}-M_{st}\Big\rangle$$

$$\theta_R=\omega_R\frac{1}{s}$$

On the basis of these equations, the structural diagram in Matlab-Simulink environment has been carried out and numerous simulations were performed. A few representative ones are presented as follows.

Two distinct cases will be discussed concerning the operation as synchronized induction generator (SIG).

a) DAGS1 case. This case used the mathematical model described by the equation system (1-8) and the parameter values presented above. The schematic diagram corresponds to Fig. 1. Initially, the mobile contacts are placed to the left position and K1 is switched on. The machine starts at no-load, as induction motor, developing a small torque, linear variable with speed, necessary for frictions. The start-up process takes less then 0.2 sec. The variations of the electromagnetic torque and of the angular velocity are presented in Fig. 2 and Fig. 3, respectively. The electromagnetic torque value gets around 3Nm and the angular velocity comes near synchronous speed, ≈157rad/s.

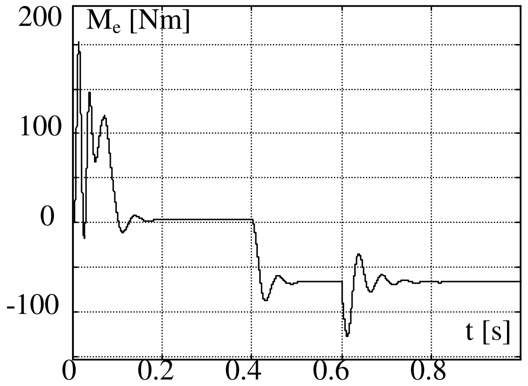

Fig. 2. *M_e =f(t)* for a SIG with torque enforcement of -70 Nm at the moment t_1=0.4 s and put under excitation at the moment t_2=0.6s.

At the moment t_1=0.4sec., a load torque of -70 Nm is applied and the machine becomes a SIG. The value of the speed rises with a few percents over synchronous one, the slip and developed electromagnetic torque become both negative. The stator active power changes its sign.

At the moment t_2=0.6sec., K2 moves the mobile contacts to the right position. Consequently, two rotor phases are series connected and fed from a DC source (U_{ar}=-40V, U_{br}=+40V). They become *excitation winding*. The third rotor phase stays short-circuited (U_{cr}=0) and becomes *damping winding* for the machine that operates as *non salient pole synchronous machine*.

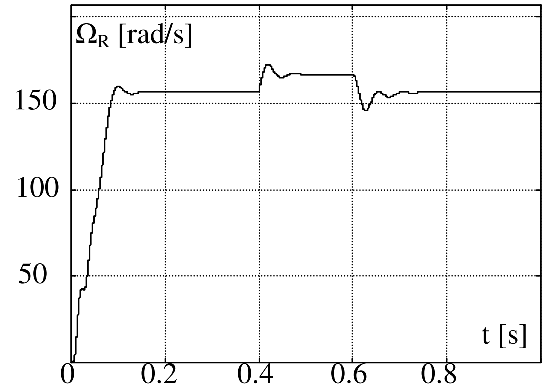

Fig. 3. *Ω_R=f(t)* for a SIG with torque enforcement of -70 Nm at the moment t_1=0.4 s and put under excitation at the moment t_2=0.6s.

Now, the electromagnetic torque determines a deceleration of the rotor and after a few oscillations the speed reaches the synchronous value. Further, the machine operates as synchronized induction generator connected to the mains.

Fig. 4 presents the *dynamic characteristic.* The operation is described by the points order: A(start-up) – M(the last transit through maximum starting torque value) – S1(cuasi-synchronism as no-load motoring duty) – S(induction generator) – S2(synchronized induction generator).

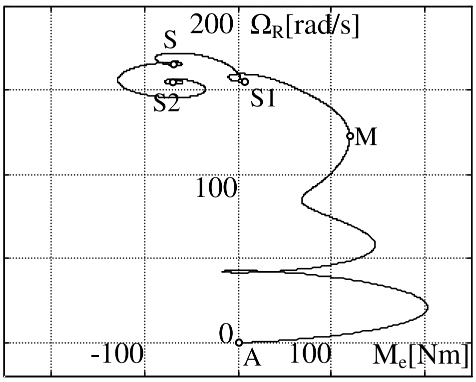

Fig. 4. Dynamic characteristic *Ω_R=f(M_e)* for a SIG with torque enforcement of -70 Nm at the moment t_1=0.4s and put under excitation at the moment t_2=0.6s.

Fig. 5 shows the hodograph of the resultant rotor flux. Initially, the flux is null and corresponds to the A point. Than, during start-up, the rotor flux rises and tracks a limit value (over-synchronism – speed overshoot – S1’ point) than goes to S1 and the rotor gets the synchronism as no-load motoring duty.

The enforcement of a load torque of -70 Nm (t_1=0.4 sec.) determines the curve S1-S on the hodograph that coresponds to over-syncronism generator duty.

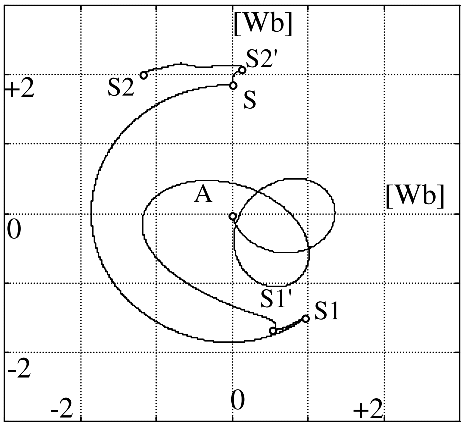

Fig. 5. Resultant rotor for a SIG with torque enforcement of -70 Nm at the moment t_1=0.4 s and put under excitation at the moment t_2=0.6s.

The induction generator is then DC energized, at the moment t_2=0.6 sec. and the magnetic flux, the rotor flux particularly, suddenly increases. The machine becomes a synchonized generator and the hodograph tracks the S-S2'-S2 sector. The operation point lays in S2 as long as the load remains unmodified. A deeper investigation of the hodograph movement reveals the followings:

- i) for *subsynchronous* speeds, the hodograph tracks *anti-clockwise* (positive) spirals which are similar to transient duty but they become circles for steady-state. This behavior describes the *induction motor* duty (Fig. 5 – sector A-S1 excepting the narrow area that corresponds to the over-speed before S1' point);

- ii) for *oversynchronous* speeds, the hodograph tracks *clockwise* (negative) spirals which are similar to transient duty but they become circles for steady-state. This behavior describes the *induction generator* duty (Fig. 5 – sector S1-S plus the narrow area that corresponds to the over-speed before S1' point;

- iii) for *synchronous* speeds, at steady-state and constant load, the hodograph becomes a point and the machine operates as *synchronized induction generator* (Fig. 5 – point S2).

The synchronization process (sector S-S2'-S2, Fig. 5) is accompanied by ocillations of the speed, of total fluxes of both rotor and stator and of the torque values. The movement of the hodograph is also esentially influenced by the moment when the rotor windings are connected to the DC source. More precisely, at the end of the transient duty, an internal angle will exist between the resultant rotor flux and the resultant stator flux. This angle depends on load degree and has a certain but constant value. Since, at the connection moment, the rotor position (and the rotor flux position too) is aleatory then the *synchronization* process (with all the accompanying events) depends on the initial moment of the transitory process. Consequently, the machine may operate from a duty to another (and the hodograph rotates toward both directions – damped oscillations) until it reaches the steady-state point operation, which corresponds to the load degree.

The manner used in writing the equations (using as quantities the applied voltages, total magnetic fluxes and rotation angle) allows a deep analysis, which is very useful for didactic purposes but also for the study of transient duties that are specific to induction machines, including the unbalanced operation such as SIG [2]. To justify this statement, a second study case is presented as follows.

b) Case DAGS2. The symmetric three-phase machine (the same parameters as in the previous case) with perfect symmetry both in stator and rotor (which is short-circuited) is connected to the mains (t_0=0) and starts as a no-load induction motor. The electromagnetic torque, M_e, has significant values (Fig. 6) and after a few oscillations, the torque reaches a low value (≈3Nm), which corresponds to frictions.

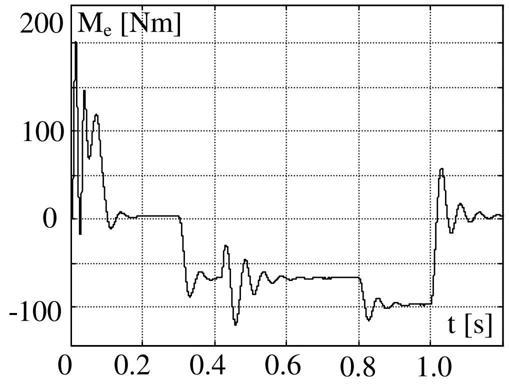

Fig. 6. *M_e =f(t)* for a SIG with no-load start-up, torque enforcement of -70 Nm at the moment t_1=0.3s, put under excitation at the moment t_2=0.42s, a second torque enforcement of -30Nm at the moment t_3=0.8s, and complete unload at the moment t_4=1s.

The speed increases rapidly in approx. 0.1 sec. (gets over synchronism) and then goes to a value close to synchronism, Fig. 7.

On the dynamic mechanical characteristic, Fig. 8, the representative point A starts from zero and tracks the sector A-M-As0, close to synchronism.

The hodograph of resultant rotor flux starts from A, Fig. 9, and tracks some anti-clockwise repetitional cycles (sector A-M-S0'-As0, see the arrows), excepting a narrow sector by the SO' point (*overshoot* process).

- At the moment *t_1=0.3sec,* the induction machine operation switches to *generating duty* by applying an opposed torque of -70 Nm. This fact determines a response of the electromagnetic torque, which oscillates around this value. The slip turns to a negative value and the speed reaches oversynchronous values. On the dynamic mechanical characteristic, Fig. 8, the representative point tracks from As0 to S1 after a few oscillations. The hodograph of the resultant rotor flux, Fig. 9, tracks the sector As0-S1 in anti-clockwise direction (oversynchronism).

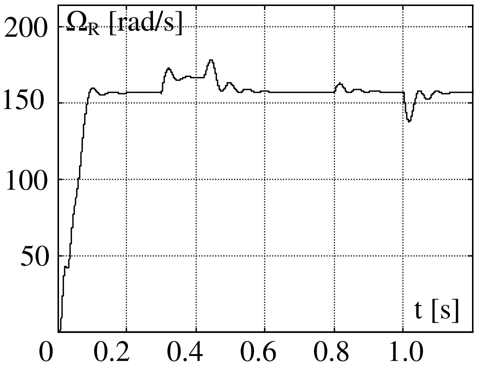

Fig. 7. $\Omega_R=f(t)$ for a SIG with no-load start-up, torque enforcement of -70 Nm at the moment t_1=0.3s, put under excitation at the moment t_2=0.42s, a second torque enforcement of -30Nm at the moment t_3=0.8s, and complete unload at the moment t_4=1s.

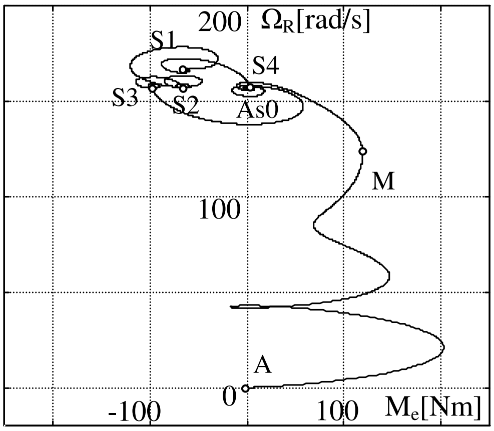

Fig. 8. $\Omega_R=f(M_e)$ for a SIG with no-load start-up, torque enforcement of -70 Nm at the moment t_1=0.3s, put under excitation at the moment t_2=0.42s, a second torque enforcement of -30Nm at the moment t_3=0.8s, and complete unload at the moment t_4=1s.

- At the moment t_2=0.42sec, the machine is connected to the DC source (the series-connected *br* and *cr* rotor phases are fed with *Uebr=40V, Uecr=-40V*, while the *ar* phase remains short-circuited, *Uear=0V).* The machine operation turns to synchronous generator duty when the load torque keeps constant to 70 Nm but the speed has the synchronism value. There are some torques that oscillate around this value and get over the rotor. On the dynamic mechanical characteristic, the representative point tracks from S1 to S2 after a few oscillations, Fig. 8. The hodograph of resultant rotor flux tracks the sector S1-S2 in anti-clockwise direction and settles down to S2 point, Fig. 9.

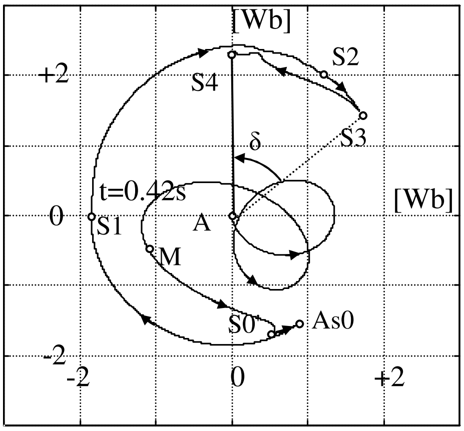

Fig. 9. Rotor flux for a SIG with no-load start-up, torque enforcement of -70 Nm at the moment t_1=0.3s, put under excitation at the moment t_2=0.42s, a second torque enforcement of -30Nm at the moment t_3=0.8s, and complete unload at the moment t_4=1s.

- At the moment t_3=0.8sec, the already excited machine gets a sudden additional torque enforcement of -30Nm (the total load torque is now of -100Nm but lower then pull-out value). The speed tends to advance over synchronous value but after a few oscillations it returns to synchronism. The one effect of this torque enforcement is the *alteration of the internal angle.* There are also oscillations of the electromagnetic torque. In Fig. 8, the operation point tracks from S2 to S3 after a few oscillations. The hodograph of the resultant rotor flux tracks the sector S2-S3 in anti-clockwise direction and settles down to S3 point, Fig. 9. This rotation of the hodograph proves the alteration of the *internal angle* due to load modification.

- At the moment t_4=1s, the machine is *suddenly unloaded,* by applying a positive load torque of 100Nm (the total torque value becomes zero). The machine operates at no-load and the speed tends to decrease under synchronous value but after a few oscillations it returns to synchronism. The one notable effect is the *decrease of the internal angle* to a value very close to zero, $\delta \approx 0$. There are also oscillations of the electromagnetic torque around its cuasi-null value, Fig. 8. The representative point tracks from S3 to S4 point after a few oscillations. The hodograph of the resultant rotor flux tracks the sector S3-S4, in clockwise direction and settles down to S4≡As0 point, Fig. 9. This *rotation* of the hodograph equates the alteration of internal angle due to the load of 100Nm (from -100Nm to 0Nm). The internal angle, δ, can be so established as the angle between the radii AS3 and AS4, Fig. 9.

The internal angle corresponding to the load of -70 Nm can be expressed as the angle betwee the radii AS2 and AS4, or for any other load one should plot the *angular characteristic* of the induction machine under *synchronized induction generator* duty.

4. CONCLUSIONS

✓ The mathematical model "*in total fluxes*" allows an easy analysis of the induction machines but also of synchronous machines for any duty.

✓ The mathematical model called *"in total fluxes"* is based on the equations of the electric circuits, which derive from *induced voltage* law. The recommended form of this law is $\dot{\Psi}_j = -v_j \Psi_j + u_j(t)$ and has as variable quantities the total *magnetic* fluxes and the *electric* voltages. The parameters, which characterize each machine, are present inside the factors v_j.

✓ The unitary approach for both induction and synchronous machines (with electromagnetic excitation) put in view particular phenomena, which are specific to these machines with *double feeding*. It is mainly about the oscillations of the mechanical and electromagnetic quantities.

✓ The simulations of the AC machines (asynchronous and synchronous one), which are based on the equations where nothing but *total fluxes* and *rotation angle* are present, allow a deep analysis upon the directions of magnetic fluxes and further upon the *instantaneous internal angle.*

✓ The information provided by these simulations can suggest proper strategies concerning the right moments for the connection of the windings to the supply sources. The obtained results prove that any *pulling out process* determines an *electromechanical transient duty* with high time constant, which may delay the process with a two times higer duration.

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