DETERMINATION OF THE SOLENATION OF EXCITATION OF A SYNCHRONOUS GENERATORS, BY THE MATHEMATICS METHOD

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REZUMAT. În proiectarea generatoarelor sincrone, o importanţă semnificativă o are determinarea solenaţiei de excitaţie la sarcină nominală. Sursele bibliografice de specialitate [1], [2], indică determinarea acestei mărimi pe cale grafică. Valoarea determinată, în acest mod, nu reprezintă de fiecare dată valoarea exactă, depinzând de dibăcia proiectantului în construcţia grafică şi de corectitudinea construcţiilor grafice utilizate. Pentru a elimina acest inconvenient, am realizat un program de calcul matematic prin intermediul căruia, se determină foarte rapid şi corect valoarea solenaţiei de excitaţie.

Cuvinte cheie: caracteristică, solenaţie, calcul matematic.

ABSTRACT. In the designing of the sinchronous generator, a significant importance is the determining of the excitation solenation at the nominal load. The technical literature sources indicate the determination of this size with graphics construction. The value determined in this way is not always the exact value, depending on the designer's skill in graphic designing and the accuracy construction graphics used. To avoid this inconvenience, we developed a mathematical program through which, quickly and accurately, we determine the corect value of the excitation solenation.

Keywords: feature, solenation, mathematical calculation.

1. INTRODUCTION

In the category of renewable energy sources, established by CE, is the electricity produced in the MHC with less than 10 MW power [3].

The majority hydroelectric power plants are equipped with synchronous generators. They must meet user′s requirements for power, speed, operating mode (autonomous or connected to the network), but not every time these requirements can be met by large manufacturing companies, which typically have lower limited power. This is the reason why the authors of this paper have proposed optimal designing of a synchronous generator, designed to equip a small hydro. In doing this we faced with problems related to the excitation winding.

In the case of a synchronous generator designing, especially low-power, solenaţion excitation at rated load has a significant importance. At low power generators there is a risk of insufficient space for winding excitation is.

2. DETERMINATION OF THE EXCITATION AT RATED LOAD BY GRAPHICAL METHOD

The solenaţion excitation is determined after the construction of the partial characteristics of the synchronous generator, represented in Figure 1.

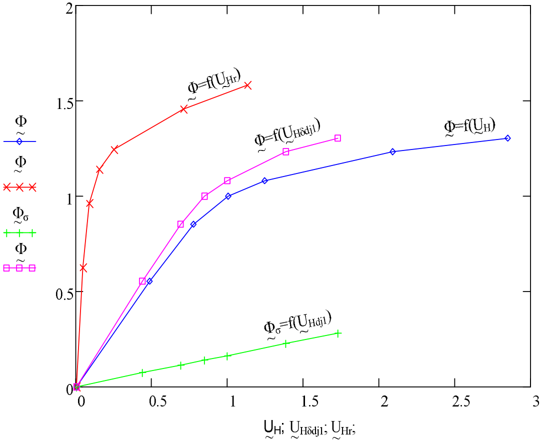

Fig. 1. The characteristics of the synchronous generator.

The partial magnetic characteristics are:

- the operation in no load, $\phi = f\left(U_H\right)$;
- of the stator, $\phi = f\left(U_{H\delta dj1}\right)$;
- of the rotor, $\phi = f\left(U_{Hr}\right)$;
- of the flow of dispersion between the poles, $\phi_\sigma = f\left(U_{H\delta dj1}\right)$.

The operation in no load characteristc, $\phi = f\left(U_H\right)$, represents at a different scale, the characteristic $U_e = f(I_E)$.

For the representation of the characteristics, all voltages and magnetic flux values are transformed into relative units (ur), and in Figures 1 and 2 these are symbolized with tilde.

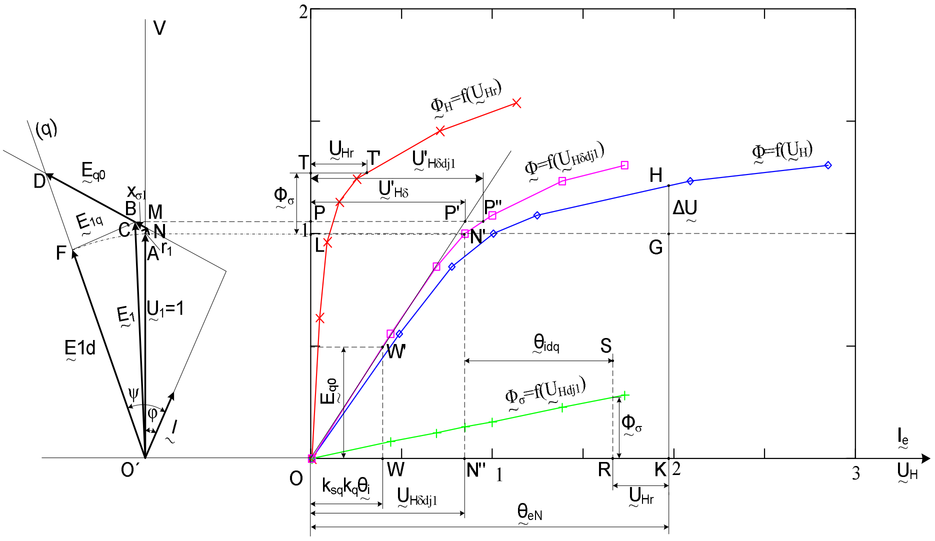

FIG. 2. The constructions necessary for the determination solenation excitation at rated load.

The excitation solenation at rated load is determined by graphics constructions related the high characteristics and presented in Fig. 1., construction that are presented in Fig. 2.

3. DETERMINATION OF THE EXCITATION SOLENATION AT RATED LOAD BY MATHEMATIC METHOD

Because of the errors which can occur in raising construction related graphics, the graphic method is not always an accurate method of showing the correct value of excitation solenation.

To eliminate this inconvenience, we developed a computer program using Mathcad software, through which, the excitation solenation at rated load can be determined more quickly and accurately.

Next we'll present in short the methods used to determine the analytical excitation solenation at rated load. The graphs used below, are conceived by us.

The magnetic air gap voltage, $U'_{H\delta}$, in relative units, is the relation between the magnetic air gap voltage, $U_{H\delta}$, at load operation and the magnetic voltage of the synchronous generator, U_{H0}, at no load operation, that is:

$$U'_{H\delta} = \frac{U_{H\delta}}{U_{H0}} \text{ [u.r.]} \qquad (1)$$

Depending on the magnetic air gap voltage, the corresponding flow, Φ', in relative units is determined (see Fig. 3).

Knowing the operating power factor of the generator, imposed by the designing theme, follows the angle φ in degree and φ_r in radians.

With this value of the angle φ_r, and knowing the resistance of the Indus phase, r_1 [u.r.], is calculated the large side U_{1a}, of the triangle, which is the other side U_1 respectively r_1, in relative units, Fig. 4., with the relation:

$$U_{1a} = \sqrt{U_1^2 + r_1^2 - 2\cdot U_1\cdot r_1\cdot\cos\left(\pi-\varphi_r\right)} \text{ [u.r.]} \qquad (2)$$

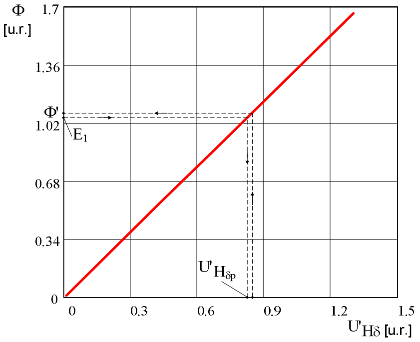

Fig.3. The variation of voltage flow depending on the the magnetic air gap.

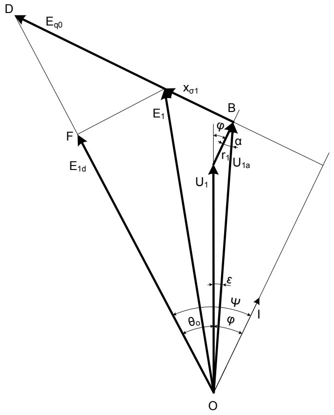

Fig.4. Explanations necessary of application the mathematical method.

We calculate the value of cosine angle α corresponding of it the segments sizes r_1 and U_{1a}.

$$\cos\alpha = \frac{r_1^2 + U_{1a}^2 - U_1^2}{2\cdot r_1\cdot U_{1a}} \qquad (3)$$

Calculating the angle ε, with the same program, for the particular case and if the value is below 1°, it can be neglected. Usually, the angle ε is neglected.

The segment length wich represents the resultant electromotors voltage, E_1, is calculated from the dispersion reactance of the stator winding value, $x_{\sigma 1}$ [u.r.], determined by designing, the segment U_{1a} and the angle α, with relation:

$$E_1 = \sqrt{U_{1a}^2 + x_{\sigma 1}^2 - 2 \cdot U_{1a} \cdot x_{\sigma 1} \cdot \cos\left(\alpha_r + \frac{\pi}{2}\right)} \text{ [u.r.]} \qquad (4)$$

For the value received by the resultant electromotors voltage, E_1, (which in relative units is equal to the flux Φ, all in relative units, which leads) in Fig. 3 is calculated the magnetic air gap voltage value, $U'_{H\delta p}$, in relative units, which is the length of segment PP' [u.r.], with the significance of Fig. 2.

Depending on the flux values Φ', resulted in the Fig. 3, for value $U'_{H\delta}$, calculated with the relation (1), and using the magnetic stator voltage, $U_{H\delta dj1}$, it was raised the graph in Fig. 5. With this graph, for the flux equal to E_1, it is determined the size of the stator magnetic voltage, $U'_{H\delta dj1}$, in relative units, equal to the length of segment PP''.

Now we calculate the ratio of saturation, r_{sat}, with the relation:

$$r_{sat} = \frac{U'_{H\delta dj1}}{U'_{H\delta p}} = \frac{PP''}{PP'} \qquad (5)$$

To quantify the weakening influence of the longitudinal field by the transverse field in Fig. 6 it is determined the coefficient k_1, (depending on the type of air gap under foot pole - constant or variable), which depends on the ratio of saturation [2].

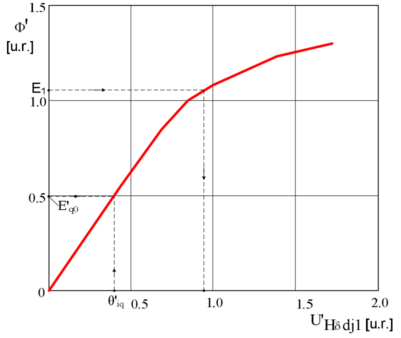

Fig.5. Variația fluxului în funcție de tensiunea magnetică a statorului.

To quantify the effects of saturation, it should be introduced the saturation coefficients after the longitudinal axis, k_{sd} and transversal, k_{sq}, in Fig. 6.

The coefficients k_d and k_q, and the solenation of the indus, θ_i, are known from the generator designing program, prior to this stage. With this the reaction solenation is calculated, in relative units, with the relation:

$$\theta'_i = \frac{\theta_i}{U_{H0}} \quad \text{[u.r.]} \qquad (6)$$

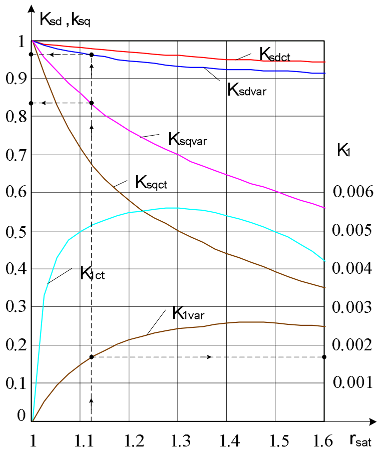

Fig.6. The variation of the coefficients k_1, k_{sd} şi k_{sq}

We calculated the transversal solenațion, taking into account the influence of magnetic saturation, with the relation:

$$\theta'_{iq} = \theta_i \cdot k_q \cdot k_{sq} \text{ [u.r.]} \qquad (7)$$

To this solenation, it corresponds the fictional electromotors voltage E'_{q0} [u.r.], from Fig. 5.

The segment OD (Fig. 4) results from the relation:

$$OD = \sqrt{U_{1a}^2 + \left(x_{\sigma 1} + E'_{q0}\right)^2 - 2 \cdot U_{1a} \cdot \left(x_{\sigma 1} + E'_{q0}\right) \cdot \cos\left(\alpha_r + \frac{\pi}{2}\right)} \qquad (8)$$

With the known data can be calculated $\cos \theta_0$, using relation:

$$\cos\theta_0 = \frac{OD^2 + U_{1a}^2 - \left(E'_{q0} + x_{\sigma 1}\right)^2}{2 \cdot OD \cdot U_{1a}} = 0{,}928 \qquad (9)$$

We calculate the angle θ_0 în grade, in degrees, respectively in radians and knowing the relation between angles Ψ, θ_0 and φ:

$$\Psi = \varphi + \theta_0 \qquad (10)$$

results the angle value ψ.

The segment FD in Figure 4, is:

$$FD = E'_{q0} \cdot \sin \Psi_r \text{ [u.r.]} \qquad (11)$$

The resulted electromotors voltage, E'_{1d}, after the axis d, corresponds to the segment $OF=OD-FD$

In Fig. 5, to this voltage corresponds a magnetic air gap and stator voltage, $U'_{H\delta dj1}$. For comparison, this should be ON" segment in Fig. 2.

The solenation of reaction of the indus, θ'_{idq}, which takes into consideration the demagnetization effect of both components (longitudinal and transversal), in case who air gap under foot pole is variable, is computed with the relation [1]:

$$\theta'_{idq} = \theta'_{iq} \cdot \sin \Psi_r + k_1 \cdot r_{sat} \cdot \frac{\tau}{\delta_M} \cdot \theta'_i \cdot \cos \Psi_r \qquad (12)$$

The Sum of magnetic voltages (solenation) $U'_{H\delta dj1}$ and θ'_{idq}, constitutes the magnetomotive voltage $U'_{H\delta dj1\sigma}$:

To this magnetomotive voltage corresponds, in Fig. 7, the dispersion flux, Φ'_σ , the inductor at the nominal load operation.

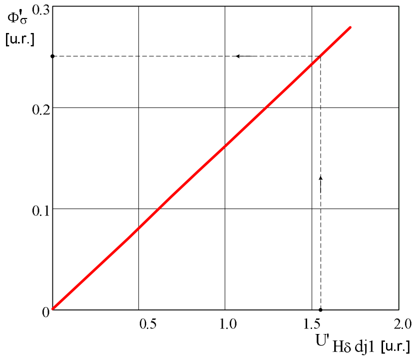

Fig.7. The variation of dispersion flux depending on the the stator magnetic voltage.

We calculate the sum of sizes reported E'_{1d} and Φ'_σ, resulting the flux reported Φ'_H, which determines the inductor solenation corresponding to the resulted electromotors voltage. This size corresponds to the OT segment in Figure 2.

$$\Phi'_H = E'_{1d} + \Phi'_\sigma \quad [\text{u.r.}] \qquad (13)$$

To this flux corresponds the inductor solenation U'_{Hr}, in Fig. 8.

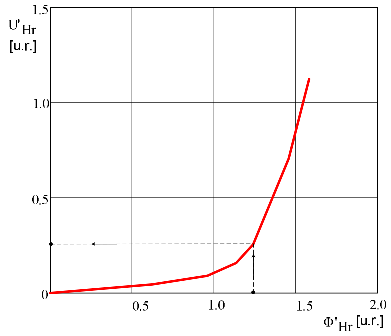

Fig.8. The variation flux depending of the inductor voltage magnetic.

The sum sizes $U'_{H\delta dj1\sigma}$ and U'_{Hr} constitutes the solenation excitation $\theta'eN$, at full load:

$$\theta'_{eN} = U'_{H\delta dj1\sigma} + U'_{Hr} \quad [\text{u.r.}] \qquad (14)$$

This is the size of resulted by applying the mathematical method.

From Figure 9, for the nominal solenaţion excitation θ'_{eN}, results the polar electromotors voltage, U'_{eE} (U'_0):

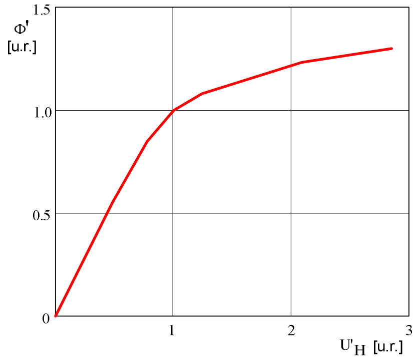

Fig.9. Variation of flux depending of the magnetic voltage

The voltage drop from no-load to full load operation is calculated with the relation:

$$\Delta U = \frac{U'_0 - U_1}{U_1} \qquad (15)$$

5. CONCLUSIONS

The presented method, althoung follows the graphical method steps, does not use any measuring segments but it calculates with mathematical relations, each size that occurs in determining solenaţion excitation at full load.

The characteristics used, being represented by the MathCad program, allow determining the exact sizes necessary by the interpolation functions.

The presented method can be applied for any power of the synchronous generator, introducing the equation of its nominal data.

The mathematical method is entirely written in MathCad software, and it can run without the intervention of the designer, if there are the characteristics listed in Chapter 2, and the result is displayed instantaneously.

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