New Indirect Measurement Procedure For Determining The Regulation Characteristics Of The Synchronous Machine

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***Abstract*- The paper presents a new, indirect method of measurement, for determining the characteristics of the regulation of synchronous machines with salient poles. The method is based on the measurement results in the no-load and short circuit conditions. The difference in comparison to the existing similar methods is, according to the authors, in determining the characteristics of regulation at different loads in the original way. This method takes into account the influence of the change in the flux leakage of the field windings depending on the excitation currents in the original way. This leads to the fact that, according to the proposed procedure, the indirectly obtained regulation characteristics will be much more accurate and reliable compared to the results obtained by the previous similar indirect procedures.**

***Index Terms* - synchronous machines, testing, measurements, regulation characteristics, no-load condition, short circuit condition, load current, excitation current.**

I. FOREWORD

Determing the reliable value of the excitation current I_f at synchronous machines has great significance not only because of the correct choices of the regulator but also because of determing the real value of the power losses in the excitation windings. The last statement has important role with the indirect determing of the efficiency η of the big synchronous generators.

By regulation characteristic we consider the changes in the excitation current of the synchronous machines I_f which depends on the load currents I_s at the constant nominal voltage U_n at different power factors $(\cos\varphi)$ which are also constant. Most accurately we can obtain these values $I_f=f(I_s)$ with direct current measurements in different load conditions, but such measurements last long. Besides, this the direct measuremets of the synchronous generators with large rated powers are mostly unachievable with the existing equipment in the available test laboratoties of the manufacturers Because of that, the manufacturers of the electric machines in such cases use indirect measurement methods for determing the regulation characteristic which are more achievable and definitely need to be the constituing part of the test protocol. It's taken by default that indirectly obtained characteristics $I_f=f(I_s)$ need to be maximally matching with the characteristics that could be obtained with the direct measurement method.

In literature „Testing the electric machines“ from different authors we can find a description of the different methods for indirect determination of the characteristics of the regulation of synchronous machines with salient poles. All indirect methods are based on the results of measurement in the generator no-load condition, on the results of measurements in a stabilized generator short circuit and, if necessary, on the results of additional measurements in order to determine the stator winding lekage reactance X_s. For indirect determination of the regulation characteristics of the synchronous machine we need to have the following data from the results of the stated standard measurements:

A. No-Load Characteristic

This characteristic represents a change in the value of the induced phase voltages ~~in the~~ U_e depending on the value of the excitation current I_{f0} at the constant speed of rotation n_n. The general shape of the no-load characteristics $U_e=f(I_{f0})$ of synchronous generators is graphically depicted in *Fig. 1.1*

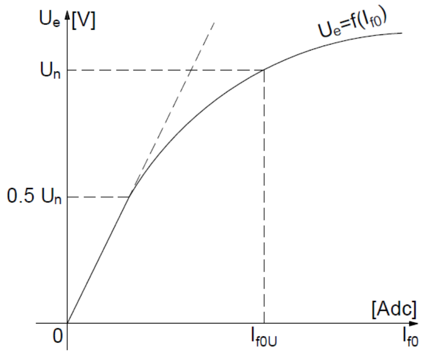


Fig.1.1 General characteristic of the no-load condition of the synchronous machine

It can be noticed that the induced U_e voltage in the initial part of the no-load characteristic practically grows linearly with the increase of the excitation current I_{f0}. Due to this, the initial part of this characteristic in the range of induced voltages $0<U_{e\%}<50\%$ can be analytically presented with the linear equation which passes through the origin of the coordinate system. Above about 50% of the induced voltages the $U_e=f(I_{f0})$ characteristics begin to increase more and more to the apices. Due to such non-linearity, this part of the characteristics should be represented by a polynomial. In the described way we arrive at the fitted function of the no-load characteristics which will be the basis in later analytical considerations.

B. Continious Short-Circuit Characteristic

Under the short circuit characteristic, the synchronous machine implies changes in the value of the excitation current I_{fc}, depending on the fixed short-circuit current I_{sc} in the short-circuit stator rings at the constant rotational speed of the indicated value. In this operating condition, the magnetic induction in the air gap has a small value due to *(U=0)*. As a result, the main magnetic circuit of the generator is not saturated, which results in the short-circuit characteristic $I_{fc}=f(I_{sc})$ being a linear function, which in general can be represented as shown in *Fig. 1.2*

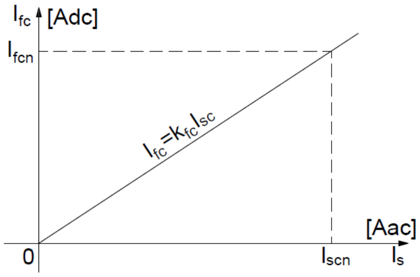


Fig.1.2 General shape of characteristic of the stabilized short-circuit run of synchronous machines

For purpose of later analytical considerations, it is desirable to present this characteristic with an equation as follows:

$$I_{fc}=k_{fc}I_{sc} \tag{1.1}$$

In equation (1.1), the multiplier k_{fc} represents the slope of curve of the equation, and I_{sc} is the value of the fixed short-circuit current in the armature due to the field current I_{fc} at the indicated rotational speed. In this case the slope of curve k_{fc} can be determined on the basis of only one measurement in the region of such an field current I_{fcn} which causes the short circuit of I_{scn} of the indicated value in the following way:

$$k_{fc}= I_{fcn}/ I_{scn} \tag{1.2}$$

It should be noted in particular that in practice these lines can intersect the abscissa slightly above zero due to the residual remanent magnetism. But this intersection point is variable due to variables. Therefore, in further consideration, this fact will not be taken into account.

C. Resistance And Leakage Reactance Of The Stator Windings

The values of the induced voltage E of synchronous generators in different load conditions can be determined starting from the value of the rated voltage U, adding the voltage drops on hot resistance R_s and on the leakage reactance of the stator winding X_s.

Measurement of the value of hot resistance R_s does not pose any problem since it is an integral part of standard measurements in order to determine the temperature of the stator winding temperature rise. A different case is with the measurement of the leakage reactance of the stator winding~~s~~ Xs. Its measurement is much more complex and is not an integral part of standard measurements. Therefore, in the ATB Sever test laboratory, with the indirect determination of the synchronous generator's regulation characteristics, for X_s, we use the values obtained from design calculation . In connection with this, we would like to emphasize in particular that the value of the leakage reactance X_s essentially has the same value as the Potier reactance ($X_s = X_p$). It follows that, in the absence of calculating the value of the leakage reactance, the measurement method for determining the Potier reactance X_p, as described in the literature [2] and [3], can also be used. This measurement process, however, is long lasting and unreliable.

For this reason, the authors of this paper suggest, instead of Potier's method, the measurement of the impedance of stator windings Z_{imp} with the pulled out rotor. This simple measurement can be carried out on a wound stator before mounting in standard measurements for the purpose of checking symmetry. The measurement procedure is as follows:

At the stator winding terminals, we connect such an U_{imp} voltage so that the current in them is equal to the rated current I_{sn}. The value of impedance of stator windings is then:

$$\mathrm{Z_{imp}}= U_{imp}/ I_{sn} \tag{1.3}$$

After that taking into account the measured resistance values R_s we calculate the total reactance of stator windings with the pulled out rotor according to the equation:

$$X_{imp}=\sqrt{Z_{imp}^2-R_s^2} \tag{1.4}$$

This reactance consists of two parts as follows:

$$X_{imp}=X_s+X_{m\phi} \tag{1.5}$$

The first component X_s originates from the leakage flux of the stator winding~~s~~, and the second component $X_{m\phi}$ of those fluxes of stator windings that are closed through the cavities of the rotor. The second component is not separately measurable. In the literature [2, 3, 4], [3], [6], we can find suitable analytic equations for determining it. Taking into account the required stator winding leakage reactance is:

$$X_s=X_{imp}-X_{m\phi} \tag{1.6}$$

In particular, we want to emphasize that according to the experience of the author, the values of the components X_s and $X_{m\phi}$ do not differ much ($X_s \approx X_{m\phi}$) and we will not make a big mistake if we use the leakage reactance in the calculation of the control characteristics according to the following approximate equation:

$$X_s \approx 0.5X_{imp} \tag{1.7}$$

II. THE EXISTING METHODS

In this chapter we will briefly describe the existing procedures that serve to indirectly determine the indicated value of the field current of the synchronous generators. Common to these procedures is that they are all described as graphic procedures. Authors of this paper have all processed these features in an analytical form. On the basis of the obtained analytical equations, the control characteristics for a wide range of load from an no-load to 125% of the rated load at different power factors in over-excited and under-excited operating conditions were calculated. After that, the obtained regulation characteristics were compared with the results of the corresponding direct measurements. The results of the comparison showed that all existing procedures have certain disadvantages. It has been shown that the control characteristics obtained with existing procedures throughout the range of operation deviate, in a greater or lesser extent, from the exact control characteristics determined by direct measurements. The aim of the authors in this paper was to point out the above deficiencies and to describe a new indirect method in which observed shortcomings were remedied.

We would like to note that in subsequent discussions of various procedures, we will limit the description to over-excited modes. It is assumed that the analytical equations obtained in this way will also be valid in under-excited modes, taking into account the angles of the power factor φ with negative signes (*sinφ* will have a negative sign).

A. The American Method

This procedure was first proposed by the American Electrical Engineering Society (AIEE). The description of the proposed graphic procedure for indirect determination of the rated value of the excitation current can be found in almost all the most important works in the field of synchronous machines. In this procedure, we need to know: the characteristic of the no-load, the short-circuit characteristic, and the resistance values of R_s, or the value of the stator winding leakage reactance X_s. The value of the induced voltage E at different load currents I_s with the given power factor $\cos\varphi$ can be determined on the basis of the vector diagram shown in Fig.2.1

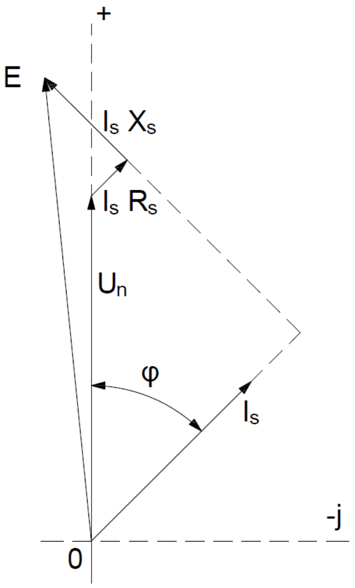


Fig.2.1 Vector-diagram of the loaded synchronous generator in an over-excited condition for determining E

Starting from this vector diagram for determining the values of induced voltage E with the indicated voltage U_n, we can write the following equation:

$$E = \sqrt{(U_n \cos\varphi + I_s R_s)^2 + (U_n \sin\varphi + I_s X_s)^2} \quad (2.1)$$

The principle of determining the excitation current of synchronous generators according to the American empirical procedure AIEE is shown in Fig.2.2 On the ordinate, the indication of the no-load in the appropriate scale is applied to the value of the indicated voltage U_n and the value of the calculated induced voltage E at the selected load current I_s with the selected power factor $\cos\varphi$. Then from the coordinate system center point O, we draw the straight line so that it coincides with the linear part of the no-load characteristic. The horizontal line drawn from the top of the voltage vector U_n intersects this line in point B. If we draw a line from this point downwards to the normal in relation to the abscissa, then the corresponding relation, the section $\overline{OA}$ is the part of the exciting current of the no-load $I_{f\delta}$ which belongs to the air gap at the rated voltage

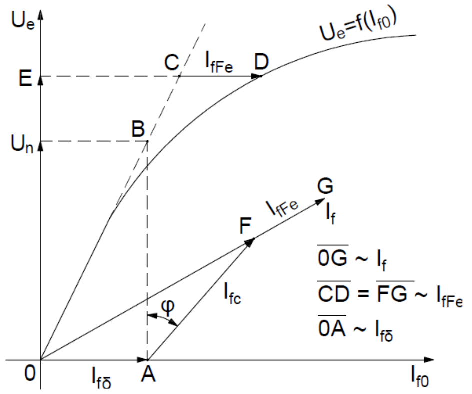


Fig.2.2 The American AIEE procedure for the indirect determination of the value of the excitation current of loaded synchronous generators

The horizontal line drawn from the calculated value of the peak of the induced voltage vector at the selected load current I_s, intersects the straight line in point C, and the saturated part of the no-load characteristic in point D. The section $\overline{CD}$ represents the part of the excitation current I_{fFe} which belongs to the iron-part of the magnetic circuit. The needed value of the excitation current I_f in over-excited mode is determined as follows:

On the right side of the vertical $\overline{AB}$ from point A under angle φ we draw corresponding values of the short-circuit excitation currents I_{fc}. When determining its value, we can use the equation *(1.1)*, assuming that the load current is equal to the short-circuit current: $I_s=I_{sc}$. At the end, the excitation current $I_f \sim \overline{OC}$ at the given load current I_s we obtain in the way that the components $I_{f\delta}$ ~~i~~ and I_{fc} we summarize as vectors and on this sum in direction of resulting vector we add component I_{fFe}.

In an under-excited mode, the procedure is the same. The only difference is that in this case the values of the excitation current I_{fc} from point A at angle φ are applied to the left in relation to the vertical $\overline{AB}$. It is taken by default that the described procedure can be automated by use of a computer. In this case based on the fitted characteristic of the no-load and on the basis of the linear part equation and the characteristic for each current load the values of $I_{f\delta}$ and I_{fFe} are determined, and then from the short circuit characteristics and the corresponding value of the I_{fc} current. By applying these components for the determination of the excitation current I_f for different load currents I_s in the case of different factors of the $\cos\varphi$ force in over-excited condition, we can write the following equation:

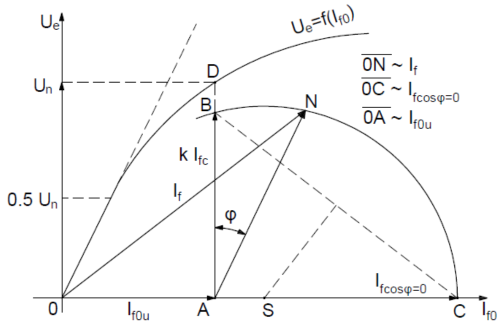
$$I_f = \sqrt{I_{f\delta}^2 + I_{fc}^2 + 2 I_{f\delta} I_{fc} \sin\varphi} + I_{fFe} \qquad (2.2)$$

According to the author's experience the american procedure gives acceptable results for load~~ed~~ condition at power factor $\cos\varphi=1$. Hovewer in over-excited condition, there are always measured less currents in relation to values obtained from direct measurements

B. Swedish Method

According to the designers of synchronous generators for the indirect determination of the indicated value of the field current I_{fn}, the method described in the Swedish regulations, which is in practice known as the "Swedish diagram", is mostly used. Here is necessary to have: the $U_e=f(I_{f0})$ characteristic, the short-circuit characteristic $I_{fc}=k_{fc}I_{sc}$, and the values of the field currents $I_{fcos\varphi}=0$ as a function of I_s from the direct measurement of the regulation parameters in the over-excited condition at the rated voltage U_n with the power factor $cos\varphi = 0$. The disadvantage of this semi-indirect process is that the existing equipment in the test station often does not allow direct measurement of the value of the excitation current $I_{fcos\varphi}=0$ with $cos\varphi=0$. Such situations may arise in cases where the indicated frequency of the generator does not correspond to the frequency of the available network. But a similar situation can also arise when testing large synchronous generators in which, due to over-rated currents I_s, the available equipment does not allow the direct measurements.

The principle of determining the excitation current I_f of the loaded synchronous generator according to the Swedish procedure is shown in Fig.2.3.



Figl.2.3 Swedish method for determing values of excitation current of loaded synchronous generators.

Horizontally from the coordinate center *O*, we apply the value of the no load field current I_{f0u} which belongs to the rated voltage U_n. To its end from point *A*, depending on the load current $I_s=I_{sc}$, the corresponding magnitudes of the short-circuit kI_{fc} with the peaks in point *B* are applied in the vertical direction. The coefficients of the increase in the short-circuit excitation currents *k* according to the proposal from the Swedish regulations need to have the following values:

k=1.1 for machines under 100 kVA
k=1.05 for machines from 100 to 1000 kVA
k=1.02 for machines above 1000 kVA

Then, horizontally from the coordinate center *O*, we apply the corresponding values of the field currents $I_{fcos\varphi=0}$ with the peaks at point *C*. From the middle of the section $\overline{BC}$ we withdraw its normal, which intersects the abscissa at the point *S*. This point represents the center of the circle passing through points *B* and *C*. After that we draw the line from point A that intersects the described circle at point N. According to the Swedish proposal of the required excitation current I_f corresponding to load currents I_s in different over-excited conditions will be represented by lengths $\overline{ON}$. It is assumed that when determining the excitation current in the under-excited conditions, the corresponding angles φ from point *A* should be drawn from the left side of the vertical line.

C. Hungarian Method

It is also interesting to mention the Hungarian process that has been used for decades by the Hungarian company GANZ. This approximately indirect method, for determining the excitation currents of synchronous machines with salient poles, is even simpler than the previously mentioned methods. According to the above mentioned procedures, this procedure is based on the characteristic of the no-load $U_e=f(I_{f0})$ and on the short-circuit characteristic $I_{fc}=k_{fc}I_{sc}$, but additionally we need to know the value of the reactance of stator windings X_{imp} with the pulled out rotor as defined in chapter 1.3.

This method, unlike the previous procedures, also takes into account the effect of increasing the main flux coverage of the field windings on the excitation current I_f due to the increase in the main flux in the over-excited conditions.

In order to compensate this effect, in this procedure, we calculate with larger values of the induced voltages E_h in relation to the value *E* according to equation *(2.1)* in the American method. The value of the induced voltage due to the resulting flux in the overexcited mode is determined according to the following equation:

$$E_h = \sqrt{(U_n \cos\varphi + I_s R_s)^2 + (U_n \sin\varphi + I_s X_{imp})^2} \quad (2.3)$$

It can be noticed that due to $X_{imp}>X_s$ at the same load current I_s in unloading conditions will be $E_h>E$. The principle of determining the excitation current of the I_f loaded synchronous generators with salient poles according to the Hungarian footprint is shown in *Fig. 2.4*.

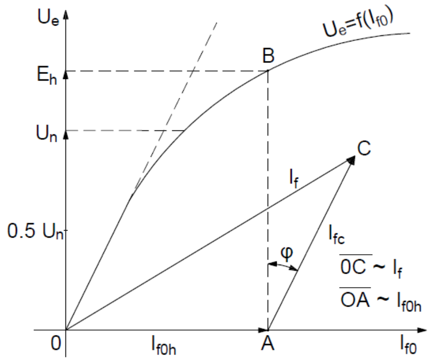


Fig.2.4 Hungarian procedure for the indirect determination of the value of the excitation current of loaded synchronous generators

The horizontal line withdrawn from the top of the induced voltage vector E_h intersects the empty path $U_e=f(I_{f0})$, at point *B*. From this point, we descend to the normal at abscissa to the point *A*, and on the basis of the resulting section, we determine the value of the no-load excitation current I_{foh}. After that, to the right (in the under-excited condition to the left) in relation to the vertical $\overline{AB}$ from point A at an angle φ the values of the short-circuit exciting currents I_{fc} are applied from the area of over-excited conditions.

The required excitation current is obtained as the vector sum of the components I_{f0h} and I_{fc} according to the following equation:

$$I_f = \sqrt{I_{foh}^2 + I_{fc}^2 + 2I_{foh}I_{fc}\sin\varphi} \qquad (2.4)$$

Otherwise, this procedure gives quite acceptable results in load conditions with $\cos\varphi=1$. But in the overexcited mode, with the same load currents, a much higher value is obtained, and in under-excited modes, the values of the exciting current are much lower than those from the direct measurements.

III. DESCRIPTION OF THE NEW METHOD

The aim of the author is to eliminate all those shortcomings that were observed during the application of the existing procedures described in the previous chapter. The starting point was the American method in which the authors introduced significant corrections. According to the above mentioned indirect methods, this procedure is based on the no-load characteristic $U_e=f(I_{f0})$ and on the short-circuit characteristic $I_{fc}=k_{fc}I_{sc}$. The principle for determining the excitation current of synchronous generators according to the new procedure is shown in *Fig. 3.1*

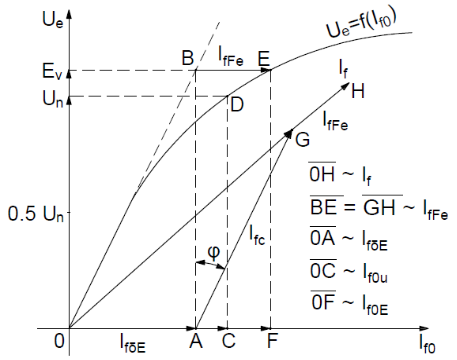


Fig. 3.1. The new procedure for the indirect determination of the value of the excitation current of loaded synchronous generators

In the new procedure in relation to the American procedure, two significant corrections were introduced:

- The first difference is that the parts of the excitation current which belong to the air gap in the new process are determined on the basis of the induced voltage of E_v, and not on the basis of the indicated voltage U_n, as was the case with the American procedure. It follows that due to the $E_v>U_n$ and the components of the excitation currents belonging to the air gap in the new procedure, they will have a higher value than the value in the American method $I_{f\delta E}>I_{f\delta}$.

- Another difference is that in order to take into account the increase in the value of the excitation current due to the increase in the leakage flux of the field winding at different loads, in the new procedure the induced voltage of E_v is determined with fictive increased voltage drops according to the following equation:

$$E_v = \sqrt{(U_n\cos\varphi + vI_sR_s)^2 + (U_n\sin\varphi + vI_sX_s)^2} \qquad (3.1)$$

In equation (3.1) the letter v denotes the coefficient of fictive increase in voltage drops at different loads. The value of this coefficient of magnification ranges within the limits of $0.95<v<1.4$. Higher values are due to higher induced voltages in over-excited modes and lesser values to lesser induced voltages in under-excited modes.

The methods for determining these coefficients will be discussed later.

The principle of determining the excitation current I_f of loaded synchronous generators with salient poles in over-excited conditions under the new procedure is as follows:

In the first iteration with the selected load current I_s with the corresponding factor $\cos\varphi$, assuming $v=1$, using the equation (3.1), we calculate the initial value of the induced voltage of E_v, and its value is applied to the ordinate with the characteristic of the no-load. The horizontal line drawn from the top of the vector E_v intersects the extension of the linear part of that characteristic in point B, and the characteristic itself in point E. If we drop a normal from point B relative to the abscissa, then in the appropriate dimension, the cutoff $\overline{OA}$ abscissa is the part of the excitation current of the no-load mode $I_{f\delta E}$, which belongs to the air gap at the calculated induced voltage E_v. The cutoff $\overline{BE}$ represents part of the current I_{fFe} which belongs to the iron parto of the magnetic circuit. The following procedures in order to determine the excitation currents I_f that belong to different load currents I_s in the case of over-excited conditions are the following:

On the right side of the vertical $\overline{AB}$ from point A at angle φ we apply the appropriate values of the exciting short-circuit currents I_{fc} assuming that $I_s=I_{sc}$. In the end, the required excitation current I_f for a given load current I_s according to Fig. 3.1 is obtained by adding the components $I_{f\delta E}$ and I_{fc} to the vector and adding to their sum in the direction of the resultant vector the I_{fFe} component. It follows from that, that for determining the value of the excitation current I_f we can write the following equation:

$$I_f = \sqrt{I_{f\delta E}^2 + I_{fc}^2 + 2I_{f\delta E}I_{fc}\sin\varphi} + I_{fFe} \qquad (3.2)$$

Note: In under-excited conditions in the upper equation, $\sin\varphi$ should have a negative sign.

We would like to point out in particular that the excitation currents I_f in no-load conditions with the same load current I_s derived from the first iteration *($v=1$)* will have higher values (due to $I_{f\delta E}> I_{f\delta}$) in relation to the values from the American method. The values of the excitation currents I_f in the over-excited conditions, besides this increase, they do not reach the true values obtained from direct measurements.

Therefore, in the new procedure, the authors propose a continuation with fictitiously increased induced voltages of E_v, with the fact that in the second iteration, the coefficient of fictitious increase in voltage drops in different loads is determined based on the results from the first iteration. For this purpose, using the right values of the induced voltage E from the first iteration from the fitted empty path $U_e=f(I_{f0})$, we read the associated excitation currents $I_{f0E}=I_{f0}(E)$ and the value of the no-load $I_{f0U}=I_{f0}(U_n)$ at the indicated voltage. Thereafter, the coefficient of fictive increase of drops v in at different load currents I_s is determined according to the following equation:

$$v= I_{f0E} / I_{f0U}=OF/OC \qquad (3.3)$$

In the continuation of the second iteration we determine the fictitious induced voltages of the E_v on the basis of the equation (3.1), whereas for the coefficients v we use the calculated values from the first iteration according to the equation (3.3). Then, using the same procedure as for the first iteration, we determine the true values of the regulation characteristic $I_f=f(I_s)$ true value for the different load currents I_s with the different values of the power factor $cos\varphi$ in the over-excited and, if necessary, in the under-excited conditions.

IV. APPLICATION EXAMPLE

An example of the application of the new indirect measurement procedure for determining the control characteristic $I_f=f(I_s)$ will be shown on a specific synchronous generator produced by the ATB SEVER plant with the following indicated data:

-Generator type: GSOTE 400 Lk-6
-Apparent power: S=600 kVA
-Power factor: cosφ=0.8 ind
-Voltage: U=690 V
-Connection: Y
-Current: I_s=502 Aac
-Frequency: f=50Hz
-Rotation speed: n=1000 min^{-1}
-Excitation voltage: U_f=100.6 Vdc
-Excitation current: I_f=68 Adc
-Leakage reactance of the stator windings: $X_s=0.0689\Omega$
-Stator reactance without the rotor: $X_{imp}=1.41\Omega$

In addition to the above mentioned data, the following characteristics have been applied in the indirect procedures for determining the control characteristics from the previous measurements:
-The characteristic of the no-load $U=f(I_{f0})$, which is shown in *Fig. 4.1*

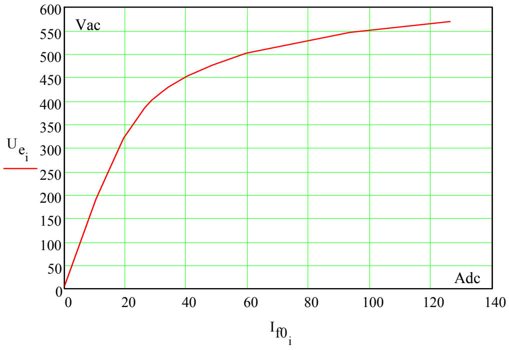


Fig.4.1 No-load characteristic (measurement result)

-Short-circuit characteristic $I_{fc}=k_{fc}I_{sc}$, which is shown on *Fig. 4.2*

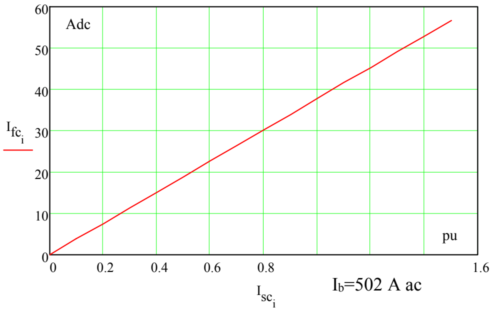


Fig.4.2 Short-circuit characteristic(measurement result)

This characteristic can be shown using the straight-line equation. The slope of curve of this line in this case has value: k_{fc}=0.07527

A. Results And Comparison

Since synchronous generators are in most cases ordered for work in over-excited conditions, consideration will primarily be given to this area. The regulation characteristics besides the display with the indicated power factor $cos\varphi_n = cos\varphi_n$ will also be shown for cases with the power factor $cos\varphi_n = 0$ and $cos\varphi_n = 1$. The characteristics of the regulation $I_f = f\ (I_s)$ of the synchronous generator with the specified power factor obtained on the basis of direct measurements are shown in *Fig. 4.3*

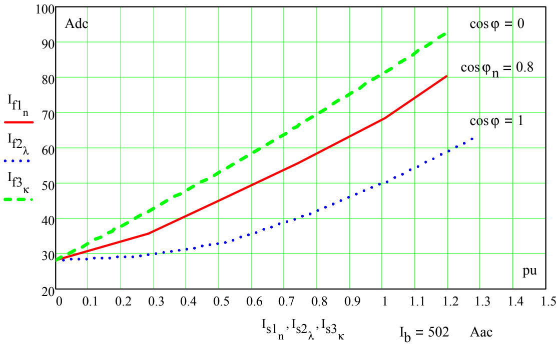


Fig. 4.3 The regulation characteristics obtained based on direct measurements (over-excited mode)

Considering direct measurements these characteristics we can take as accurate and they will be base for future consideration for comparison with regulation characteristics obtained with indirect methods.

The regulation characteristics for the shown synchronous generator are obtained based on suggested indirect method and are shown on *Fig 4.4*:

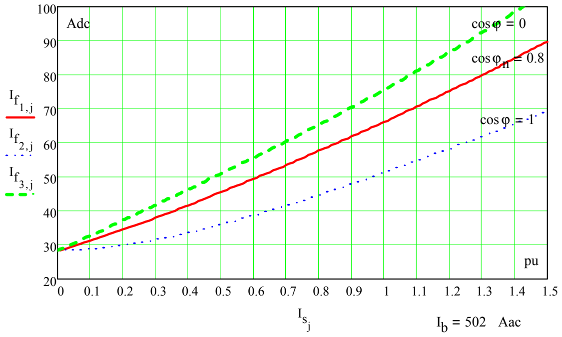


Fig. 4.4 Regulation characteristics obtained based on new indirect measurement method

It can be noted that the regulation characteristics according to the proposed indirect procedure at all power factors are very well in agreement with the regulation characteristics according to *Fig.4.3*.

The comparative values of the excitation currents which, according to the result of the application of the existing indirect methods, belong to the rated load current I_s*=502Aac* for different power factors are given in Table *Fig.4.5*.

Based on the table, we can conclude that in relation to the exact values from the direct measurements in terms of the field currents at the indicated loads, the most accurate results are the new indirect method and the semi-indirect Swedish method.

Rated current	*I_{sn} = 502 Aac*		
Power factor	*cosφ_n=0.8*	*cosφ=1*	*cosφ=0*
Direct measurement *I_f [Adc]*	67.5	50.0	80.5
New method ***I_f [Adc]***	**66.2**	**51.2**	**76.0**
American method *I_f [Adc]*	63.6	50.9	70.8
Swedish method *I_f [Adc]*	67.4	48.7	80.5
Hungarian method *I_f [Adc]*	69.7	48.6	85.2

Fig.4.5 Table of rated values of excitation currents obtained based on different measurement methods

V. CONCLUSION

Based on the facts presented in the previous chapters, it can be noted that in the new indirect procedure for determining the excitation currents of synchronous machines, all the defects that were found by the authors in the existing similar indirect procedures were noticed. For this reason, the indirect procedure proposed by the authors is proposed for use in all those cases where the available test station does not have the appropriate equipment for direct measurement of excitation currents and the efficiencies.

Such cases can occur with high-voltage synchronous generators due to excessive power, due to the unapropriate rated voltages and due to the unapropriate frequency in relation to the available network. But similar cases may arise even when the test station does not have the appropriate loading generating machines for the purpose of measuring measurements of excitation currents and the efficiency in different load modes.

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