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Two-speed Synchronous Generator for Special Purposes

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Abstract. This paper deals with basic performances of a design of a two-pole three-phase 40MVA synchronous generator. The generator is designed to test three-phase and single-phase high power transformers aimed to work within 50 Hz and 60 Hz network frequency. This means that the generator will operate at two nominal speeds, at 3000 rpm and 3600 rpm, with nominal power of 40 Mvar induction load when rating with symmetrical three-phase load. The additional requirements relate to constant operation with two-phase 25 MVA load and single-phase 13.5 MVA load, since for testing single-phase and special transformers phase connection you like will be used.

In the course of designing, special attention was paid to correct dimensioning of the damper rotor winding as well as to the geometry of stator windings, rotor and air gap, which in the end will produce minimum voltage wave distortion, i.e. generator voltage wave shape with harmonious content less than 1% (as it was demanded).

Two-pole turbogenerators are machines that already exist in the market in predefined typical power rates, whose values are primarily determined by the type and power of a turbine. Thus IEC 60034-3 with IEC 60034-1 additionally prescribes standard parameters for these generators, such as power factor, permitted deviation of voltage and frequency, alterations of output power depending on parameters of the primary cooling medium and similar. Two-pole generator 40 MVA which is installed in the testing facility of a transformer plant should have satisfied the special operation conditions determined by requirements for testing of transformers prescribed by IEC 60076-1 and IEC 60076-6 standards. Generator which shall be a part of equipment of the testing facility must satisfied performance such as two rated rotation speeds, voltage waveform distortion not higher than 1% (5% according IEC 60034-1), operation with unbalanced load with low vibrations on both speeds and noise level of max 90dB(A). Additional requirements were high number of starts and operation condition in wide temperature range.

In order to obtain power regulation, the generator is driven by an induction motor powered through frequency regulator.

In order to power generator with a full inductive load of 40 Mvar a field magnetomotive force (MMF) of a standard three phase generator of approximately 60 MVA is needed in case the power factor is within the range of usual 0.8-0.85 (IEC 60034-3). Also, due to the permanent asymmetric operation with the power of 25 MVA the generator had to be designed with an inverse component of 36% nominal current. At standard generator this requirement ranges from the prescribed 8% (IEC 60034-1) to usually demanded 10%. Due to the existence of the inverse field that, in respect to rotor, moves with a double speed in the opposite direction, electrical currents will be induced in the rotor. Requirement for operation with a high inverse component of the stator current therefore additionally increases the rotor load.

Loading the field winding will be the highest in the working regime with a nominal three-phase load and lower speed (40 MVA, 3000 rpm). At higher speed (3600 rpm) a weaker electro-magnetic field is needed for inducing nominal voltage. In cases of properly designed and optimized generators the difference of the field MMF

is somewhat higher than 20%, which affects a saturation of the magnetic circuit.

In case of an asymmetric work electric circuits close to air-gap and electric circuits of a damping winding are taken into consideration. An operation of the machine with a permanent asymmetric load may be secured only with a proper dimensioning of the damping winding. The impact of two speeds on electrical loading the damper winding is considered through changes in the value of the synchronous reactance (Fig.1.).

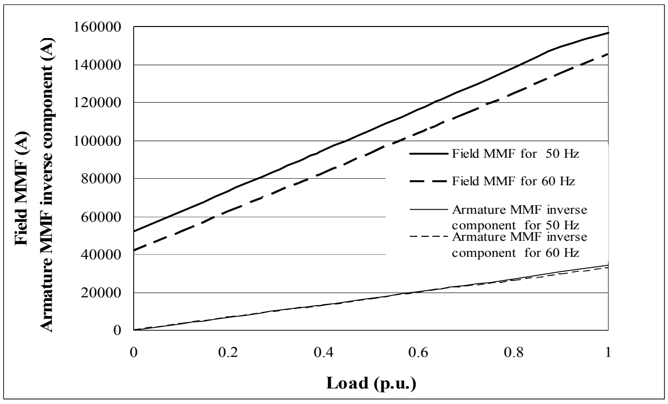

Fig. 1. Field MMF and inverse component of armature MMF at generator speeds of 3000 rpm and 3600 rpm

We may use classic calculations for calculation of harmonics in the field of air-gap and its elimination with a sufficient accuracy. At the generator with a stator winding connected in triangle, dividing number of slots N_r and number of winding slots N_w in ratio 3:2 was selected. Thus in MMS of field winding harmonics of triple frequency order (3rd, 9th, 15th etc.) are eliminated.

Parameters of a generator in a certain operation regime are analytically calculated using generator equivalent circuits for the two axes – direct (*d-axis*) and quadrature (*q-axis*) (Fig.2. and Fig.3.). After the selection of main dimensions an accurate calculation of the flux density in the air-gap is obtained by Finite Element Method.

The stator damper winding impedance network is similar to the rotor damper winding network, shown in Fig. 4. and Fig. 5. For equated system of matrix equations:

$$\left.\begin{aligned} 0 &= \mathbf{R}_k \mathbf{i}_k + \frac{d\boldsymbol{\psi}_k}{dt} \\ \boldsymbol{\psi}_k &= \mathbf{L}_k \mathbf{i}_k + \mathbf{L}_{kf} \mathbf{i}_f \end{aligned}\right\} \qquad (1)$$

we may not determine the flux ψ_k in a current loop between two bars of the damper winding that close angles β_k and β_{k+1} due to the fact that the flux density weave (B) close to the damper winding is unknown.

Building in the damping winding enables construction of a machine of external dimensions, equal to those of a typical 40MVA generator. An adjusted rotor, designed for high inverse loads, is placed in the machine. The obtained generator characteristics confirm proper dimensioning. The measured values of heating confirm the calculated current of the inverse regime of operation and currents of damper windings. The effect of building in a stator damper winding is especially significant. This paper discusses how to select and optimize dimensions of a two-speed two-pole generator designed for special working conditions such as facilities in which energy transformers of highest power are tested. Calculation results and measured values will be also given in the article.

The generator is installed in the EFACEC Laboratory in Porto, Portugal.

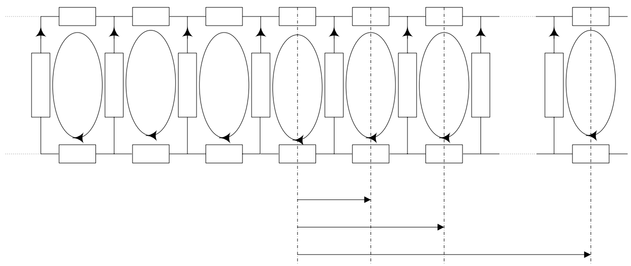

Fig. 2. Rotor damper winding impedance network

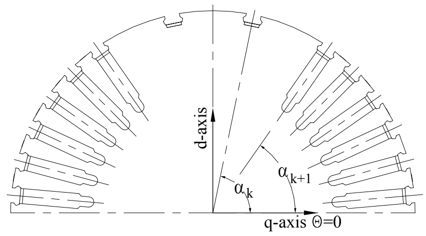

Fig. 3. Rotor cross-section with damper bar angular position

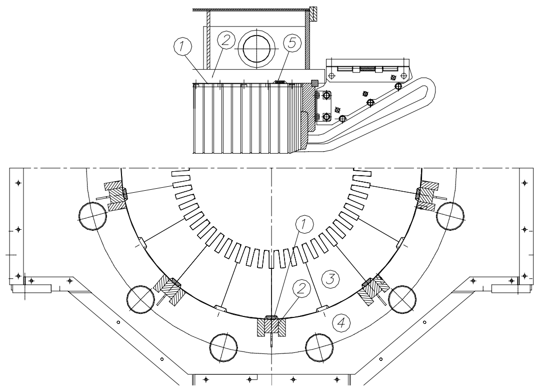

Fig. 4. Geometry of stator damper winding
a) longitudinal half-section, b) cross half-section,
1- dovetail bar, 2 – frame steel bar, 3 – stator yoke, 4 – frame, 5 – end ring.

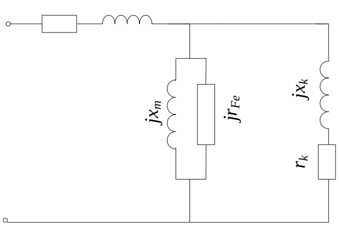

Fig. 5. Equivalent circuit of stator damper winding