On the Evaluation of Magnetic Saturation to the Asynchronous Machine
Călin Horia CHIOREANU
University “Politehnica” Timisoara, Physical Basis of Engineering, Timisoara, Romania

Keywords: Asynchronous machine, Magnetic saturation, Magnetization curve.

Abstract. In the paper is presented an analytical method for the determination of the magnetisation curve of the asynchronous machine. Obtaining the analytical shape reduces errors and allows to simplify the use of the magnetization curve in numerical applications for the evaluation of the machine's performance in any operating mode.

Introduction
The asynchronous machines are widely used today in small units for the generation of renewable energy, connected or not to a network. To study asynchronous machine operating as motor or generator, it is important to determine the magnetization curve of the machine and find the analytical approximations of the relationships with greater accuracy. Asynchronous motor is a nonlinear consumer who receives sinusoidal power from the grid voltage by fundamental. A part of the active power is used and the rest of the active power is charged in the network for other linear or nonlinear loads, through harmonics. The magnetization current is nonsinusoidal and the importance of harmonics is influenced by the saturation phenomena.

Evaluation of Magnetic Saturation to the Asynchronous Machine

Asynchronous Machine

In stationary operating regime, asynchronous machine equations can be written in the form:

\[ U_d = R_1 I_d - \omega_1 \Psi_q \]

\[ 0 = R_1 I_q + \omega_1 \Psi_d \]

\[ 0 = R_2 I_{dr} - s \omega_1 \Psi_{qr} \]

\[ 0 = R_2 I_{qr} + s \omega_1 \Psi_{dr} \]

\[ M_{elmg} = p_1 \left( I_q \Psi_d - I_d \Psi_{dr} \right) \]

Where \( s \) is the slip:

\[ s = \frac{\omega_1 - \omega}{\omega} \]

\( \omega \) being the angular rotor speed.

In complex, the equations of the two windings become:

\[ U_s = R_1 I_s + j \omega_1 \Psi_s \]

\[ 0 = R_2 I + j \omega_1 s \Psi_r \]

where
\[ U_s = U_d + jU_q \]
\[ I_s = I_d + jI_q \]
\[ I_r = I_{dr} + jI_{qr} \]
\[ \Psi_s = \Psi_d + j\Psi_q = \Psi_m + L_{12}I_s \]
\[ \Psi_r = \Psi_{dr} + j\Psi_{qr} = \Psi_m + L_{22}I_r \]
\[ \Psi_m = \Psi_{md} + j\Psi_{mq} \]
\[ \Psi_{md} = \frac{\Psi_m}{I_m}I_{md} \]
\[ \Psi_{mq} = \frac{\Psi_m}{I_m}I_{mq} \]

**Determination of the Magnetizing Curve**

If the asynchronous machine is driven by a synchronous motor with the same number of pairs of poles as asynchronous machine, the assembly operates at speed of synchronism and obtain the ideal no load operating mode.

![Figure 1. The vectorial chart at no load operating](image)

Because in this operating mode \( s=0, I_r=0 \) şi \( I_s=I_0 \), results:

\[ U_s = R_1I_0 + j\omega_1\Psi_s \]  

(6)

The vectorial chart corresponding to this equation is shown in Fig.1.

\[ \cos \phi_{10} = \frac{P_0}{2U_1I_0} \]  

(7)

angle \( \phi_{10} \) can be determined using the wattmeter. This can draw the statoric vector voltage \( U_s \). From voltage triangle results:

\[ \left(\omega_1\Psi_s\right)^2 = U_s^2 + \left(R_1I_0\right)^2 - 2U_sR_1I_0 \cos \phi_{10} \]

(8)

and so the stator magnetic flux is:
\[ \Psi_s = \frac{1}{\omega_1} \sqrt{U_s^2 + (R_1 I_0)^2 - 2U_s R_1 I_0 \cos \varphi_{10}} \]  

(9)

For different values of the terminals voltage, Pentru diferite valori ale tensiunii la borne, it may raise the dependence \( \Psi' = f(I_m) \) where stator flux is the sum of useful flux and leakage flux.

For the determination of the magnetizing flux \( \Psi_m \), it is necessary to estimate the stator leakage inductance \( L_{1\sigma} \). This can be achieved by serial connecting of the stator phases.

Because the stator three phases are equal and offset with 120° in space, Deoarece cele trei faze statorice sunt egale şi decalate cu 120° în spaţiu, the amount of useful flux from the three phases is zero, so:

\[ U_1 = I_1 \left( 3R_1 + 3j\omega_1 L_{1\sigma} \right) \]  

(10)

where it obtain the leakage inductance:

\[ L_{1\sigma} = \frac{1}{\omega_1} \sqrt{\left( \frac{U_1}{3I_1} \right)^2 - R_1^2} \]  

(11)

Figure 2. Determination uf the useful flux \( \Psi_m \)

After the determination of stator leakage inductance \( L_{1\sigma} \), It can obtain useful flux \( \Psi_m \):

\[ \Psi_m = \Psi_s - L_{1\sigma} L_m \]  

(12)

Because the determination of \( \Psi_m \) on the basis of the vector diagrams for each voltage at its terminals, can induce errors, it is more advantageous use of analytical methods.

From Fig. 2 results:

\[ \Psi_m^2 = \sqrt{\Psi_s^2 + \left( L_{1\sigma} I_0 \right)^2 - 2 \Psi_s L_{1\sigma} I_0 \cos \alpha} \]  

(13)

and in accordance with the relations between the angles:

\[ \Psi_m^2 = \sqrt{\Psi_s^2 + \left( L_{1\sigma} I_0 \right)^2 - 2 \Psi_s L_{1\sigma} I_0 \sin \beta} \]  

(14)

\[ U_s^2 = \left( \omega \Psi_s \right)^2 + \left( R_1 I_0 \right)^2 + 2 \omega \Psi_s R_1 I_0 \cos \beta \]  

(15)
\[ \sin \beta = \sqrt{1 - \cos \beta} \]  
\[ (16) \]

It may obtain such analytical flux dependence \( \Psi_m \) on the magnetising current \( I_m \), on the basis of laboratory samples at the ideal no load operating mode of asynchronous machine.

For different voltages at the terminals It may be calculated the useful flux from the machine at the ideal no load operating mode and may raise magnetization curve \( \Psi_m = f(I_m) \) both in the unsaturated and in the saturated area.

For the most exact approximation of the magnetization characteristic, we looked for approximation relations of different forms, which could be compatible with the equations of machine, written in according to the syntax of programming environment Scientific Work Place and who should assure a best overlapping to the real curve, without even complicating uselessly the equation system. A very good overlapping was obtained, on fields, with the help of second degree equation:

\[ \Psi_m = a + bI_m + cI_m^2 \]  
\[ (17) \]

**Experimental Results**

The experiments were done on an asynchronous motor made by “Electromotor S.A.” Timișoara, of the type AT 112. The label data of the used machine are: \( P_n = 4 \) [kW]; \( U_n = 380/220 \) [V]; \( I_n = 8.55/14.9 \) [A]; connection Y/Δ; \( n_n = 1450 \) [rpm]; \( \cos \phi_n = 0.84 \).

The magnetization characteristic has been experimentally called, from an synchronous speed test, by modifying the supply voltage between 0 and 400 [V].

Analytical expressions of approximation polynomial, on overlapped fields, were the following:

\[ \Psi_m = 1.4412 \times 10^{-2} + 0.2304I_m - 9.2537 \times 10^{-2} I_m^2 \]  
\[ \text{for } 0 \leq I_m \leq 5 \text{ A} \]

\[ \Psi_m = 0.13773 + 0.19918I_m - 9.6078 \times 10^{-3} I_m^2 \]  
\[ \text{for } 5 \leq I_m \leq 9 \text{ A} \]

\[ \Psi_m = 0.956 + 2.4667 \times 10^{-2} I_m - 2.3605 \times 10^{-3} I_m^2 \]  
\[ \text{for } 9 \leq I_m \leq 14 \text{ A} \]

Figure 3. Magnetization curves.
Conclusions
For a fine tune modeling of the machine operation, in addition to the determination with greater accuracy of the machine parameters, magnetic circuit analysis is required upon saturation, without which the asynchronous machine may not operate. In the paper it opted for the approximation of the magnetic dependence În lucrare s-a optat pentru aproximarea caracteristicii magnetice on areas, by the second degree polynomial approximation, solution which has not been found in the bibliography and that has proved correct and easy-to-use during of the mathematical and numerical manipulations. The polynomial approximation, were determined on the basis of the experimental magnetization curve, resulting in a good concordance between the experimental and theoretical characteristics.

References
