About the Vibrations that Occur in the Synchronous Motor on the Asynchronous Starting

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Abstract: In this paper is performed a study regarding the transient processes that occur in salient-pole wound-rotor synchronous machine into asynchronous starting regime. Both the transient starting regime (the moment when the stator winding is feed) and the synchronization respectively (when excitation winding is feed with DC voltage) are studied.

Keywords: vibration, asynchronous, starting, synchronous, motor.

1. INTRODUCTION

Although it has some advantages over asynchronous motor, the synchronous motor began to be used more widely only after the starting problem was solved.

It is known that this motor develops torque able to put in motion the rotor only if the rotor speed is synchronous speed. If the rotor speed is less than synchronous speed, the mean value of developed torque during a period is zero. This does not allow the movement of the rotor; it oscillates around of the resting position.

There are three known methods to starting this motor [1], [2]: starting with an auxiliary motor, starting in asynchronous mode, and synchronous start, using frequency converters that allow supplying the stator winding with voltage of very low frequency, with values close to zero.

In this paper, we will study the behavior of synchronous motor during its startup in asynchronous regime. During the startup process are two main transient regimes.

The first begins when the three-phase winding of the stator is supplied with voltage, and ends when the rotor speed approaches the maximum value in asynchronous regime (close to the synchronous speed).

The second transient regime starts when the excitation winding is supplied with DC voltage, and its duration is determined by several factors.

2. MATHEMATICAL MODEL

The mathematical model of salient-pole wound-rotor synchronous machine, written in the rotor reference frame (d-q axes), in the starting moment when excitation voltage is zero, is described by equations [3],

\[ \begin{align*}
\frac{du_d}{dt} &= \frac{R_d}{L_d} u_d + j\omega L_q u_q - \omega L_{dq} i_q - \omega L_{dq} i_d \\
\frac{du_q}{dt} &= \frac{R_q}{L_q} u_q + j\omega L_d u_d + \omega L_{dq} i_q + \omega L_{dq} i_d \\
o &= \frac{R_f}{L_f} e + \omega L_{fe} i_q + \omega L_{fe} i_d \\
n &= \frac{R_s}{L_s} i_d + \omega L_{ds} i_d + \omega L_{ds} i_q + \omega L_{ds} i_d + \omega L_{ds} i_q
\end{align*} \]  

(1)

where, \( R \) - is the winding resistance, \( i \) - is the winding current, \( \psi \) - is the magnetic flux, \( \omega = 2\pi f \) is the angular pulsation and the indices: \( s \) - for stator; \( d, q \), are for stator parameters in d-q axes; \( E \) - for excitation winding (in rotor); \( D, Q \), are for parameters of dumper winding (in rotor).

Of course, the magnetic fluxes can be written in terms of the corresponding inductances, and the system equations become,

\[ \begin{align*}
\frac{du_d}{dt} &= \frac{R_d}{L_d} u_d + L_{qo} \frac{di_d}{dt} + L_{do} \frac{di_d}{dt} - \omega L_{dq} i_q - \omega L_{dq} i_d \\
\frac{du_q}{dt} &= \frac{R_q}{L_q} u_q + L_{do} \frac{di_d}{dt} + L_{dq} \frac{di_d}{dt} + \omega L_{dq} i_q + \omega L_{dq} i_d \\
o &= \frac{R_f}{L_f} e + L_{fe} \frac{di_q}{dt} + L_{fe} \frac{di_d}{dt} \\
n &= \frac{R_s}{L_s} i_d + L_{ds} \frac{di_d}{dt} + L_{ds} \frac{di_d}{dt} + L_{ds} \frac{di_q}{dt} + L_{ds} \frac{di_d}{dt}
\end{align*} \]  

(2)

The \( \psi \) index correspond to the linkage flux between stator winding and rotor windings in d axe. Similarly \( \psi \) index correspond to the linkage flux between stator winding and rotor winding in q axe.

The motion equation, in case of three-phase machine, is as follows [4],

\[ \frac{3}{2} m_j \left( \psi_{d0} L_{q0} - \psi_{q0} L_{d0} \right) - \frac{1}{2} \frac{d\psi_{q0}}{dt} = \frac{1}{2} \frac{d\omega}{dt} \]

(3)

This equation can be written in terms of the inductances as,
Neglecting the phase resistance, from system equations 2, the relationships for computation the stator currents will result,

\[ i_d = \frac{u}{\omega L_d}, \quad i_q = \frac{u}{\omega L_q} \]  \hspace{3cm} (5)

where we have noted,

\[ L_d' = (L_d - L_{gh}) + \frac{1}{L_{gh} + \frac{1}{L_d} - \frac{1}{L_{2g}}} + \frac{1}{L_{2g} - L_{gh}} \]  \hspace{3cm} (6)

\[ L_q' = (L_q - L_{gh}) + \frac{1}{L_{gh} + \frac{1}{L_q} - \frac{1}{L_{2g}}} + \frac{1}{L_{2g} - L_{gh}} \]  \hspace{3cm} (7)

If excitation winding is also supplied, the presented mathematical model will change.

DC current from excitation winding produces a rotating field, which induces in the stator winding, currents that overlap existing ones. By neglecting the stator resistance, these currents can be calculated with relations,

\[ i_d' = \frac{u_d}{\omega L_d'}, \quad i_q' = 0 \]  \hspace{3cm} (8)

If not neglect the stator winding resistance, the relations expressing the winding currents are more complex.

3. MEASUREMENTS AND RESULTS

The transient currents that occur in stator winding when it is supplied with voltage were registered by a Fluke 435 apparatus, which allow these types of records in inrush mode, Fig. 1.

Also was recorded the transient current which occur in excitation winding when the stator winding is supplied and when it is supplied with DC voltage respectively.

The automation scheme of starting and synchronization, and also the places where the currents were recorded, are shown in Fig. 2.

The specialty literature suggest that during operation in asynchronous regime, the excitation winding must be connected to a resistance whose value to be 7 ... 10 times the resistance of the winding.

In our case the resistance of excitation winding is approximately 11 Ω. The value of resistance in series with the excitation winding was 90 Ω in the first case and then 190 Ω. The motor power is 5kW, nominal voltage 400V, nominal stator winding current 7.2A and 3000 RPM.

The main role of this resistance is to limit the induced voltage and the current, in excitation winding during the starting regime. Usually, the voltage can reach values of tens of kV.

The performed measurements show that, in studied case, the starting current in stator winding is not influenced by the fact that the value of series resistance was twice initial value. This is because the cage of rotor is the one that imposes the starting current.

The value of this current is in all cases about two times the nominal value Fig. 3.
The difference between the different values of excitation winding current is due rather to salient poles rotor position relatively to the stator magnetic field position at starting. However, we note that the current values in excitation winding are generally lower when series resistance is greater.

Another goal of the study was to observe the influence of the voltage value applied to the excitation winding, at synchronization, on the
currents in stator winding and excitation winding respectively, and of course, if the motor is affected mechanically, i.e. if there are vibrations. In our case the excitation winding voltage in nominal regime is 24Vcc.

Records obtained for different excitation voltages are shown in Fig. 6 for the stator winding currents and Fig. 7 for the excitation winding current.

![Fig. 6 The currents in stator winding at synchronization](image)

a) DC voltage, 10 V  
b) DC voltage is 15V (synchronization around the time 16s)

c) DC voltage, 20V  
d) DC voltage, 24V (synchronization around the time 16s)

e) DC voltage is 30 V  
f) DC voltage is 40V (synchronization around the time 16s)
Examining the records we can draw some important conclusions. To obtain a more fine synchronization, both in terms of stator winding currents but also in terms of the current in excitation winding, is recommended that the synchronization to be done in inductive regime. Thus, for the studied model, in all cases when voltage applied on the excitation winding was lower than the nominal value, the synchronization was fine. The stator winding currents decreased at synchronization and the current in excitation winding had a minor jump, then its value becomes constant.

Starting from the nominal value of voltage and as it grew, the synchronization was less fine. At nominal voltage, the stator winding currents...
decrease again at synchronization, but the current in the excitation winding has a high jump and oscillates for a long time. The current oscillations are accompanied by the rotor oscillations, the motor making a big noise.

When the voltage is higher than the nominal value, the stator winding currents and the excitation winding current made significant leaps at synchronization, their oscillations are amplified in time and it is necessary to change the voltage value. Also, rotor oscillations are very significant, the vibrations increase significantly and noise is very loud.

4. CONCLUSIONS

Next, some general conclusions on the asynchronous starting of synchronous motor will be presented. Series resistance with excitation winding is required to reduce the voltage across excitation winding and, also, the current through this winding.

The stator winding currents are imposed mainly by the rotor cage.

A fine synchronization is obtained, if the voltage applied to the excitation winding is lower than the nominal value, the regime being inductive one. In this case, the motor vibrations do not occur, the machine operates smoothly.

If the voltage is higher than the nominal value when the excitation winding is supplied, the stator winding currents and excitation winding current made very important leaps.

These leaps are accompanied by significant oscillations of the currents, and these can increase in time, or not longer depreciate. During these oscillations, motor noise is very high, and vibrations are also very important.

REFERENCES

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