Testing of electrical parameters at direct start-up of a synchronous motor of 4650 kW/6 kV

E Răduca, C Hațiegan, M Molnar, D Anghel, M D Stroia and G Liuba

"Eftimie Murgu" University of Reșița, Electrical Engineering Department, Piața Traian Vuia 1-4, Reșița, 320085, Romania

E-mail: e.raduca@uem.ro

Abstract. The paper presents parameter testing in the transitory process of direct start-up of a synchronous motor of 4650kW/6kV used in actuating of natural gas compressors from storing stations. The electric drive motor is of synchronous type with rotational excitation and the actual operating conditions of it determine additional mechanical and electrical stresses, which can influence its performance. The asynchronous start-up mode assumed experimental determination of asynchronous start-up current values, asynchronous start-up time, excitation voltage and excitation current of exciter, voltage drop in stator winding. These experimental determinations were made using a dedicated data acquisition system. Graphical plotting was made and considered parameters were evaluated in continuous mode, then obtained values were compared with catalogue values, with conclusions being drawn for each case study.

1. Introduction

The paper presents the verification of the electrical parameters during the transient process of direct starting to the net of two synchronous motors with apparent poles of 4650 kW / 6 kV [1] used in the action of the compressors to compress the natural gas in a storage station.

The natural gas pressure storage stations are high risk installations and only through an adequate maintenance program can they be operated safely. The electric motors used to operate the compressors, as well as the other elements of the installation, must be checked periodically and the results obtained must be within the nominal parameters.

Regarding the electrical installation of the storage station, the technical status was determined for: synchronous electric motors of drive; reverse synchronous exciters; rotary excitation assemblies; automation cabinets for synchronous motors. These checks are carried out both before the start of the storage cycle and at the end of the cycle.

In the verification process, a dedicated data acquisition system was used, previously designed, and provided with the appropriate translators to reduce the high valuesof the voltages and currents from the installation to the accepted ones, in the range 0 - 10 volts.

2. Theoretical considerations regarding the direct network starting mode of a synchronous motor with apparent poles

We consider a three-phase synchronous machine with apparent poles, fed to a three-phase voltage system, [2-5] having the expressions:

$$u_a = U_n \cos t \tag{1}$$

$$u_b = U_n \cos\left(t - \frac{2\pi}{3}\right) \tag{2}$$

$$u_c = U_n \cos\left(t + \frac{2\pi}{3}\right) \tag{3}$$

The analysis of the phenomena that take place at the connection of the stator winding to the voltage source is done on the basis of the voltage equations, in the system of axes d, q:

$$U_d = r_s\, i_d + \frac{d\Psi_d}{dt} - \omega\Psi_q \tag{4}$$

$$U_q = r_s\, i_q + \frac{d\Psi_q}{dt} + \omega\Psi_d \tag{5}$$

$$U_f = r_f\, i_f + \frac{d\Psi_f}{dt} \tag{6}$$

where:
U_d, U_q, I_d, I_q are the voltages and currents of the equivalent windings of the axes d, q.
u_f, i_f are voltage and current from the excitation wrap
Ψ_d, Ψ_q are the components of the flows along the longitudinal and transverse axis respectively.
In the asynchronous engine start mode load angle θ, in relative units can be expressed by sliding s:

$$\theta = (1 - s)t + \theta_0 \tag{7}$$

In this case the angular speed will be:

$$\omega = \frac{d\theta}{dt} = 1 - s \tag{8}$$

and the voltage equations become:

$$U_d = \frac{d\Psi_d}{dt} - (1 - s)\Psi_q + r_s\, i_d \tag{9}$$

$$U_q = \frac{d\Psi_q}{dt} + (1 - s)\Psi_d + r_s\, i_q \tag{10}$$

$$U_f = \frac{d\Psi_f}{dt} + r_f\, i_f \tag{11}$$

When the excitation wrap is shorted during the start process, the voltage equations become:

$$\frac{d\Psi_d}{dt} - (1 - s)\Psi_q + r_s\, i_d = U_d \tag{12}$$

$$\frac{d\Psi_q}{dt} + (1 - s)\Psi_d + r_s\, i_q = U_q \tag{13}$$

$$\frac{d\Psi_f}{dt} + r_f\, i_f = 0 \tag{14}$$

Introducing representative phases $\underline{U_d}$, $\underline{U_q}$ whose real part is even the voltages u_d, u_q, namely:

$$U_d = R_e\left\{\underline{U_d}\right\} = U_n cos(st - \theta_0) \tag{15}$$

$$U_q = R_e\left\{\underline{U_q}\right\} = U_n sin(st - \theta_0) \tag{16}$$

The currents that are established in the stator and excitation winding are represented by the phasors $\underline{I_d}$, $\underline{I_q}$, $\underline{I_f}$ whose real part is the time functions i_d, i_q, i_f.

Also the magnetic fluxes are presented by the phases:

$$\underline{\Psi_d} = \underline{X_d} \cdot \underline{I_d} \tag{17}$$

$$\underline{\Psi_q} = \underline{X_q} \cdot \underline{I_q} \tag{18}$$

where $\underline{X_d}$, $\underline{X_q}$ are the complex reactions after the axes d, q.

In the case of a symmetrical feeding system, can consider:

$$U_q = -jU_d \tag{19}$$

so that the voltage equations become:

$$\left(r_s + js\underline{X_d}\right) \cdot \underline{I_d} - (1 - s)X_q I_q = U_d \tag{20}$$

$$(1 - s)X_d I_d - \left(r_s + js\underline{X_q}\right) \cdot \underline{I_q} -= -jU_d \tag{21}$$

Resulting from the system of equations above, we finally obtain the expressions of the representative vectors of the stator currents after the two axes:

$$\underline{I_d} = \frac{\frac{r_s}{2s-1} + j\underline{X_q}}{\frac{r_s^2}{2s-1} - \underline{X_d}\underline{X_q} + j\frac{sr_s}{2s-1}\left(\underline{X_d} + \underline{X_q}\right)} \cdot \underline{U_d} \tag{22}$$

$$j\underline{I_q} = \frac{\frac{r_s}{2s-1} + j\underline{X_q}}{\frac{r_s^2}{2s-1} - \underline{X_d}\underline{X_q} + j\frac{sr_s}{2s-1}\left(\underline{X_d} + \underline{X_q}\right)} \cdot \underline{U_q} \tag{23}$$

It is observed that the analysis of component dependence $\underline{I_d}$ and $\underline{I_q}$ and the current as a function of sliding s, based on the relationships above is relatively complicated.

Considering that in high power machines, the stator winding resistance have very low values, it can be considered that the measure r_s is negligible in relation to the reactants $\underline{X_d}$, $\underline{X_q}$ and thus the calculation relations of currents are simplified and become:

$$I_d = \frac{U_d}{jX_d} \tag{24}$$

$$jI_q = \frac{U_d}{jX_q} \tag{25}$$

It is thus observed that the geometric place of the currents is the inverse of the geometric place of the reactants, according to Figure 1,[4].

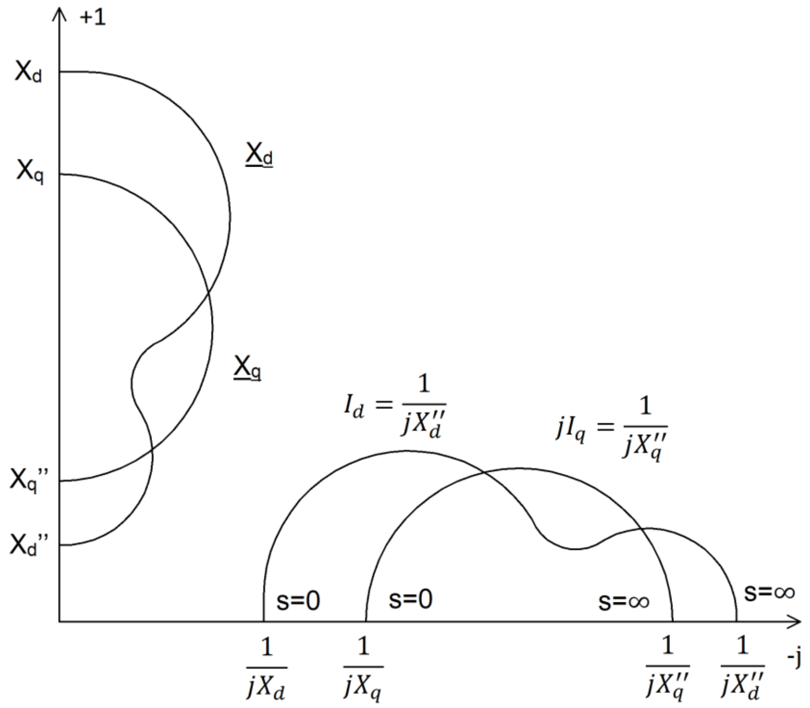

Figure 1. Geometric location of the reactants along the d and q axes
- X_d and X_q are the reactants of the voltage along the axis d respectively q
- X_d'' and X_q'' are the reactants on the transients along the axis d respectively q

3. Checking electrical parameters of 4650 kW / 6 kV synchronous motors direct network start-up

For each of the 2 engines noted below M1 and M2 respectively, [1], the parameters that characterize the asynchronous start regime were checked, [6]:
- the values of the asynchronous starting current;
- asynchronous start time;
- the value of the voltage and the excitation current of the exciter;
- the voltage drop from the stator winding.

The values of these parameters must be within certain limits imposed by the technical documentation. The results of the engine tests are given in the following figures

From the recordings made, the following values characterizing the asynchronous engine M1 start-up process are shown, [1],:

Network voltage: 6150 V
Engine voltage: 5050 V

Start-up current: 3080 A
Excitation current: 0,11 A
Excitation voltage: 1,1 V
Start time: 3,0 sec.

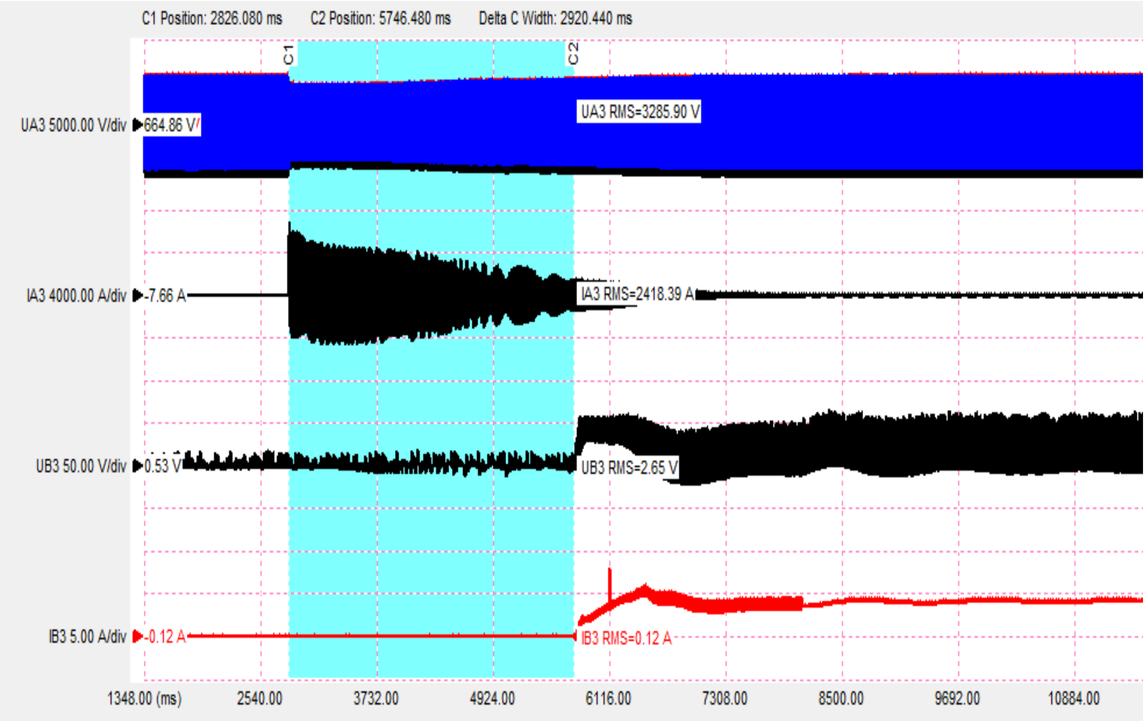

Figure 2. The asynchronous regime of direct network start-up of M1

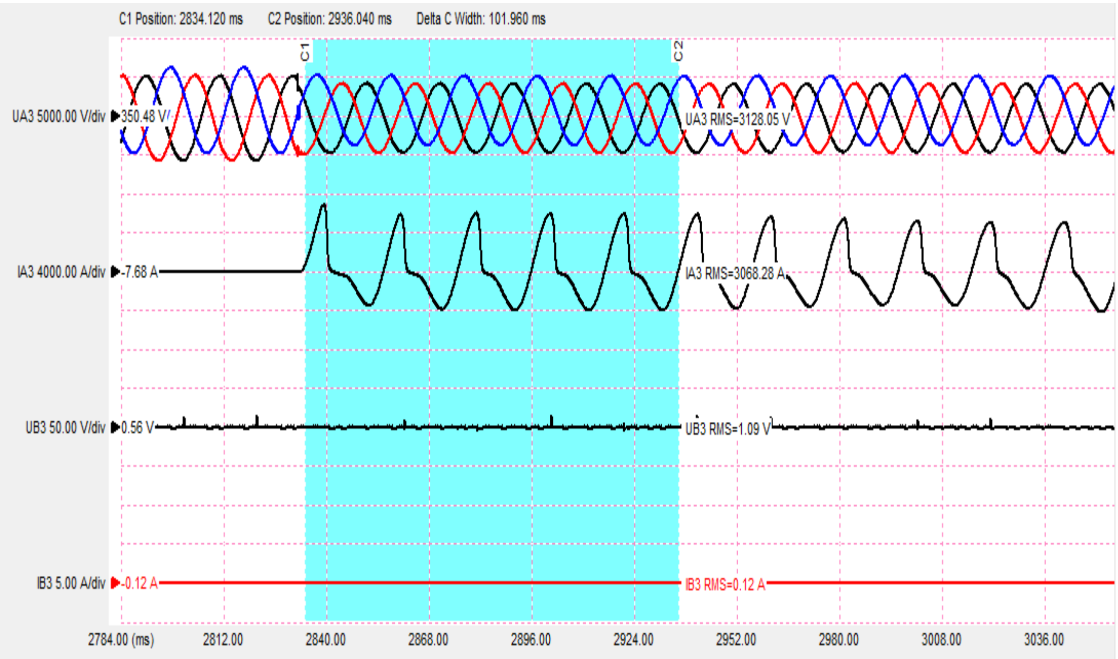

Figure 3. Waveform of the electrical quantities in asynchronous regime of M1

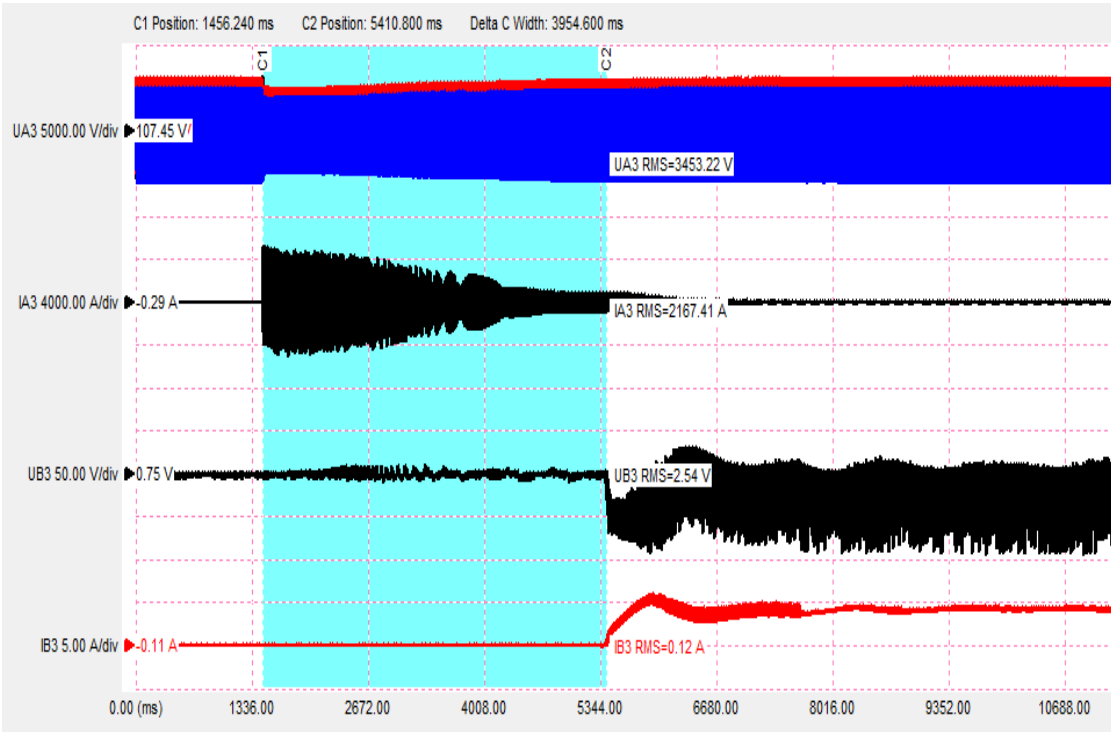

Figure 4. The asynchronous regime of direct network start-up of M2

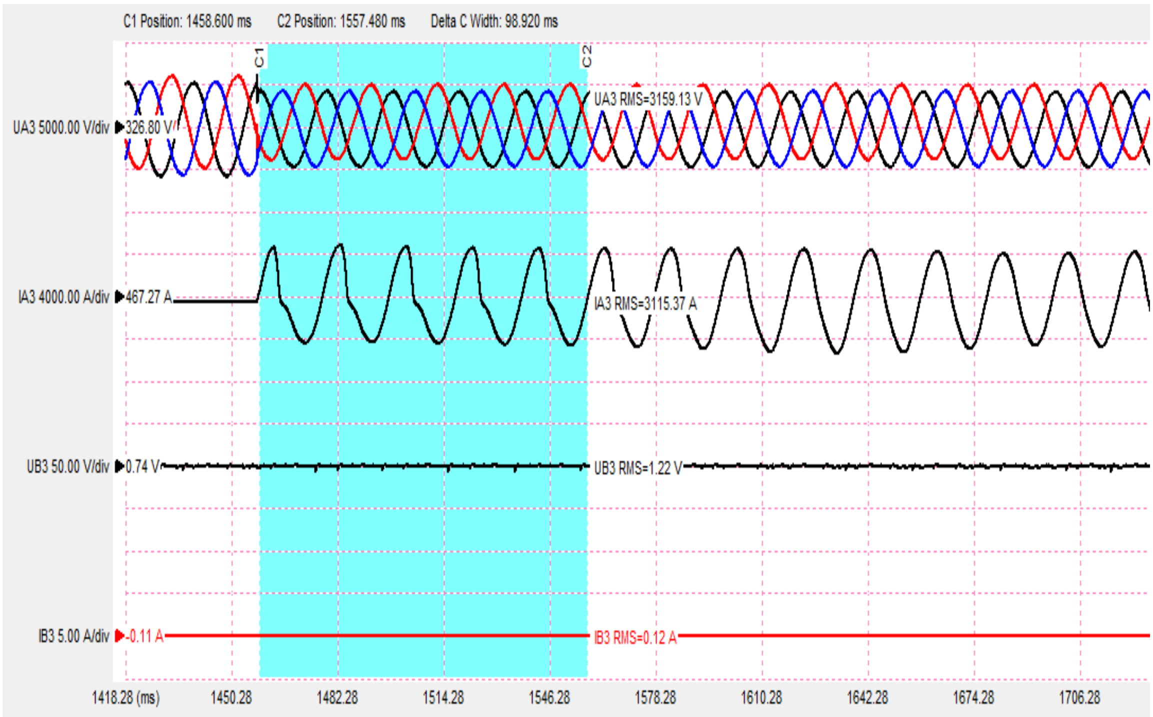

Figure 5. Waveform of the electrical quantities in the asynchronous regime of M2

From the recordings made, the following values characterizing the asynchronous engine M2 start-up process are shown [1].

Network voltage: 6130 V
Engine voltage: 5010 V
Start-up current: 3110 A
Excitation current: 0,13 A
Excitation voltage: 1,3 V
Start time: 3,2 sec.

From the analysis of the behaviour of the motors in the transient process [5] of direct starting to the network of the synchronous motors of 4650kW the following results:

- the voltage drop in the asynchronous running mode is on average:

ΔU=1110=18.21%

- asynchronous start time, is on average:

tpa=3.1 sec.

4. Conclusions

In the asynchronous mode, the motor is characterized by a power factor φ <0.7, at a stator current having a maximum value around $5I_n$. In this mode the supply voltage drops to around 5kV.

During the asynchronous regime, the continuous component is practically zero. It is observed that the electric quantities in the stator both the current and the voltage are perfectly sinusoidal and the sizes in the rotor have a shape close to the continuous component.

The use of a complex, dedicated, precise verification system allowed the results to be obtained continuously, graphically and as a consequence, the correctness of the measurement verdicts was ensured.

From the recordings made it can be seen that in all cases, the starting regime passed in good conditions, without finding the activation of any protection.

On the basis of the obtained values, it was checked the correlation of the actuation times of the protection relays in the automation cabinet of the equipment and where it was considered fine aids were made.

References

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