Modeling the mechanical and electrical characteristics of the synchronous motor

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Abstract. This paper presents the mechanical and electrical characteristics of the synchronous motor for variations of the required moment. It is presented the test configuration used to determine the mechanical and electrical characteristics of the synchronous motor. Engine torque modelling allows the shaft to be loaded with various resistive moments generated by an electromechanical brake. The presented characteristics highlight the mechanical characteristic of the synchronous motor, which does not depend on the resistant mechanical torque of the working machine during the technological process. There are presented the mechanical characteristics of the rotation speed depending on the variation of the resistant moment until the synchronism exit of the synchronous motor. The determination of these characteristics is dependent on the variation of the excitation current of the synchronous motor.

1. Introduction

For generating electricity in three-phase alternating current, the power plants use in most cases synchronous generators. Also, the synchronous machine has a wide spread both as synchronous motor and as synchronous compensator.

The study of the static and dynamic stability of the energy systems is indissolubly related to the behavior of synchronous and asynchronous machines. The impetuous increase of power installed in energy systems forced the deepening and modernization of synchronous machine theory, subsequently extended to the asynchronous machine, as well as other alternative current electrical machines. Particularly favorable has proved to be in this sense, for the analysis of the salient-pole synchronous machines functioning, „the theory of the two reactions” or the „Blondei — Park” theory. Lately, particular attention has been paid to the systematization of this theory, given the large number and variants of the equations that define the operation of the synchronous machine. [1]

The synchronous machine is characterized by the fact that the rotational speed \(n\) of the rotor is in constant ratio to the frequency of the network to which it is connected, and the inductive magnetic field is produced by a system of pairs of poles whose excitation winding is fed into continuous current. [2]

The operating mode of an electric machine is usually considered in relation to the active power. From this point of view, two regimes of the synchronous machine are distinguished: the generator regime and the motor regime. Generator and engine regimes are two aspects of the working regime. However, it is customary to emphasize these aspects because it affects certain linear dimensions of the machine elements. [3]
2. The synchronous motor
Compared to other electric motors, the synchronous motor has advantages in terms of non-load-dependent rotation speed, maintains constant speed, has a high efficiency and high power factor. [4]

A particular case of the engine regime is the compensator regime, in which the machine takes the necessary active power from the grid to cover its own losses and provides reactive power in the grid.

The main disadvantage of the synchronous motor is that it develops electromagnetic torque only at the synchronous speed and it also has a rigid mechanical feature until the resistive torque reaches the maximum torque value at which the engine exits from synchronism, [5]. Other drawbacks are related to the oscillations that may occur at sudden variations in load on the shaft.

The mechanical characteristic of the synchronous motor is linear because its velocity does not vary with the load on its shaft, the gradient of the feature being defined by the derivative of the angular velocity relative to the moment derivative and it is null.

3. Mechanical and electrical characteristics of the synchronous motor
The choice of an electrical motor for a specific application, the adjustment of the speed and its behavior at different torque values, can be made if we study their mechanical and electrical characteristics.

For obtaining the mechanical and electric characteristics of the motor it was used the standard shown in the THE STUDY OF THE SYNCHRONOUS MOTOR, C. CRISTEA I. STROE, Bulletin of the Transilvania University of Braşov • Vol. 10 (59) No. 2 – 2017, Series I: Engineering Sciences paper. This was used to simulate an increasing value of the torque.

The synchronous motor’s stator has a star configuration and is powered from a three-phase 400V line. The rotor is supplied with a voltage and a variable current through an excitation autotransformer. Their values are measured and monitored with the help of a digital multimeter. The servomotor feeds information to the controller which displays it via a dedicated software called ActiveServo. The connection of synchronous machine to the power grid is made with a switch, the voltage and excitation current are increased and variable resistive torque is applied [6].

For determining these characteristics, a complete system is used which includes a servomotor that communicates through the dedicated software ActiveServo. This system is able to apply different resistive torque values at the motor’s shaft. The requested reference torque values are enforced via the torque characteristic.

The servomotor is a self-cooled asynchronous motor, which allows the adjustment of the speed within a wide range of values, has a strong starting torque with protection, is monitored from a thermal point of view and also by the controller.

The controller allows the generation of the resistive torque imposed by the torque characteristic. By connecting it to a PC the system is capable of supplying very useful and complex data which characterises the studied motor’s parameters: voltages, currents, speed, torque and mechanical power. In addition it allows the application of resistive torques for multiple types of machines.

ActiveServo is the software which allows the recording and monitoring in time of the characteristics of the electrical machines. It also measures, computes and displays the varying electrical and mechanical quantities. In addition it has an integrated control system for the speed and torque. It is able to display the dependence between two quantities and also between one quantity and time. It allows the displaying of multiple characteristics, as well as exporting of graphs and measurement results [7].

4. Mechanical and electrical characteristics depending on time for imposed increasing values of the engine torque value.
In the experimental determinations performed to study the characteristics, a synchronous motor with the following characteristics was used: \( P_n = 0.27\text{kW}, \quad I_n = 1.5\text{A}, \quad f = 50\text{Hz}, \quad n = 1500\text{rot/min}, \quad U_{\text{err}} = 20\text{Vcc}; \quad I_{\text{err}} = 4\text{A.} \) The excitation source generated a 20V DC voltage at a 3A excitation current.
For the synchronous engine studied, we will track the time dependence of the following dimensions: The intensity of the electric current in the rotor circuit $I[A]$; Engine torque $M[Nm]$; Speed $n[rpm]$.

The engine is brought to the synchronism speed for 5 values of the excitation current, between 0.5 and 3A with a step of 0.5 A. By programming we have imposed the following torque characteristic:

For 100 s we plotted the torque diagram so that for 1 step = 0.1Nm to start the engine braking from 5s to 95s. At this value the engine will be braked with 1.8 Nm.

![Torque diagram](image)

There are obtained the following characteristics:

**For $I_{\text{err}} = 0.5A$** The current intensity increases with the torque curve imposed up to 15s. After this value, as the speed changes, the value of the current increases unstable to 0.98A, after which at 0.82Nm the motor torque comes out of synchronism. The speed is kept constant for up to 15s at 0.3 Nm and then it is destabilized and at the value of 1356 rpm comes out of synchronism and the engine stops.

| $t$ [s] | $n$ [rpm] | $M$ [Nm] | $I$ [A] |
|-------|--------|--------|-------|
| 0     | 1499   | 0      | 0.46  |
| 5     | 1502   | 0.1    | 0.47  |
| 10    | 1500   | 0.19   | 0.49  |
| 15    | 1495   | 0.3    | 0.52  |
| 20    | 1356   | 0.4    | 0.64  |
| 25    | 1470   | 0.49   | 0.68  |
| 30    | 1310   | 0.6    | 0.69  |
| 35    | 1135   | 0.71   | 0.71  |
| 40    | 1132   | 0.82   | 0.98  |
| 45    | 498    | -0.21  | 0.03  |

![Characteristic representation $I_{\text{err}} = 0.5A$.](image)
Characteristic representation $I_{err} = 1\text{A}$.

| t[s] | n [rpm] | M [Nm] | I [A] |
|------|---------|--------|-------|
| 0    | 1506    | -0.01  | 0.37  |
| 5    | 1497    | 0.09   | 0.37  |
| 10   | 1503    | 0.19   | 0.38  |
| 15   | 1502    | 0.3    | 0.39  |
| 20   | 1500    | 0.41   | 0.40  |
| 25   | 1499    | 0.5    | 0.43  |
| 30   | 1499    | 0.6    | 0.45  |
| 35   | 1499    | 0.71   | 0.49  |
| 40   | 1498    | 0.8    | 0.54  |
| 45   | 1042    | 0.89   | 1.18  |
| 50   | 499     | -0.19  | 0.03  |

Values for $I_{err} = 1.5\text{A}$.

| t[s] | n [rpm] | M [Nm] | I [A] |
|------|---------|--------|-------|
| 0    | 1496    | 0      | 0.28  |
| 5    | 1506    | 0.08   | 0.28  |
| 10   | 1502    | 0.11   | 0.28  |
| 15   | 1501    | 0.2    | 0.28  |
| 20   | 1498    | 0.31   | 0.29  |
| 25   | 1499    | 0.5    | 0.33  |
| 30   | 1499    | 0.58   | 0.35  |
| 35   | 1498    | 0.71   | 0.37  |
| 40   | 1500    | 0.79   | 0.39  |
| 45   | 1500    | 0.89   | 0.42  |
| 50   | 1500    | 1.01   | 0.45  |
| 55   | 1501    | 1.11   | 0.50  |
| 60   | 1500    | 1.21   | 0.55  |
| 65   | 1496    | 1.31   | 0.64  |

Values for $I_{err} = 2\text{A}$.

| t[s] | n [rpm] | M [Nm] | I [A] |
|------|---------|--------|-------|
| 0    | 1492    | 0      | 0.19  |
| 10   | 1510    | 0.19   | 0.20  |
| 20   | 1507    | 0.4    | 0.22  |
| 30   | 1501    | 0.59   | 0.26  |
| 40   | 1500    | 0.81   | 0.31  |
| 50   | 1498    | 1      | 0.36  |
| 60   | 1499    | 1.19   | 0.43  |
| 70   | 1500    | 1.41   | 0.50  |
| 80   | 1502    | 1.61   | 0.63  |
| 90   | 1004    | 1.81   | 1.82  |
Table 5. Values for $I_{err} = 2.5A$

| t[s] | n [rpm] | M [Nm] | I [A] |
|------|---------|-------|------|
| 0    | 1498    | 0     | 0.14 |
| 10   | 1499    | 0.19  | 0.16 |
| 20   | 1498    | 0.39  | 0.18 |
| 30   | 1496    | 0.61  | 0.22 |
| 40   | 1499    | 0.81  | 0.26 |
| 50   | 1502    | 1     | 0.32 |
| 60   | 1502    | 1.2   | 0.37 |
| 70   | 1501    | 1.41  | 0.43 |
| 80   | 1501    | 1.61  | 0.50 |
| 90   | 1503    | 1.8   | 0.60 |

Figure 6. Characteristic representation $I_{err} = 2.5A$.

For $I_{err} = 1A$ The current intensity increases with the torque curve imposed up to 40s. After this value, as the speed changes, the value of the current increases unstable to 1.18A, after which at 0.89Nm the motor torque comes out of synchronism. The speed is kept constant for up to 40s at 0.8 Nm and then it is destabilized and at the value of 1042 rpm comes out of synchronism and the engine stops.

For $I_{err} = 1.5A$ The current intensity increases with the torque curve imposed to 65s. After this value, because the speed is destabilizing, the value of the current increases unstably to 0.64A, after which at 1.31Nm motor torque comes out of synchronism. The speed remains constant until 65s at 1.21 Nm after which it is destabilized and at 1496 rpm it comes out of synchronism and the engine stops.

For $I_{err} = 2A$ The current intensity increases with the torque curve imposed to 85s. After this value, because the speed is destabilizing, the value of the current increases unstably to 0.63A, after which at 1.61Nm the motor torque comes out of synchronism. The speed remains constant for up to 85s at 1.61 Nm after which it is destabilized and at 1004 rpm comes out of synchronism and the engine stops.

For $I_{err} = 2.5A$ The current intensity increases with the torque curve up to 92s. After this value, because the speed is destabilized, the value of the current increases unstably to 0.6A and then at 1.8 Nm the motor torque comes out of synchronism. The speed remains constant to 92s at 1.8 Nm after which it is destabilized and at 1491 rpm comes out of synchronism and the engine stops.

Table 6. Values for $I_{err} = 3A$

| t[s] | n [rpm] | M [Nm] | I [A] |
|------|---------|-------|------|
| 0    | 1498    | 0.01  | 0.09 |
| 10   | 1491    | 0.19  | 0.11 |
| 20   | 1493    | 0.39  | 0.14 |
| 30   | 1504    | 0.6   | 0.18 |
| 40   | 1504    | 0.81  | 0.24 |
| 50   | 1502    | 0.89  | 0.26 |
| 60   | 1502    | 1.2   | 0.35 |
| 70   | 1504    | 1.38  | 0.42 |
| 80   | 1501    | 1.58  | 0.48 |
| 90   | 1497    | 1.81  | 0.54 |

Figure 7. Characteristic representation $I_{err} = 3A$.
For $I_{err} = 3$A The current intensity increases with the torque curve imposed to 94s. After this value, because the speed is destabilizing, the value of the current increases unstably to 0.55A and then at 1.81 Nm the motor torque comes out of synchronism. The speed remains constant for up to 94s at 1.81 Nm after which it is destabilized and at 1498 rpm comes out of synchronism and the engine stops.

5. Conclusions

To improve the mechanical and electrical characteristics depending on time for required increasing values of the torque motor value it has been used an imposed torque diagram in which the engine is driven at synchronism speed for 5 values of the excitation current, between 0.5 and 3A, so that for 100s we plotted the torque diagram for 1 step = 0.1Nm to start the engine braking from 5s to 95s, at this value the engine being braked with 1.8 Nm. For the synchronous motor we studied, we tracked the time dependence of the following dimensions: The intensity of the electric current in the rotor circuit $I$[A]; Engine torque $M$[Nm]; Speed $n$[rpm]

Analyzing the current intensity value in the rotor circuit we notice that it decreases for increasing values of the excitation current. If for $I_{err} = 0.5$A the maximum current value at detaching is 0.98A, for the value $I_{err} = 3$A the motor is detached at the value of 0.54A. The same as with torque characteristics analysis, from the previous graphics we notice that although as the torque continues to increase, the motor speed remains constant at 1500 rpm until it reaches a value outside of the range of synchronism. It is noticed that at $I_{err} = 0.5$A the motor is disconnected after 45 seconds at 0.89 Nm, while at the maximum value studied for $I_{err} = 3$A the motor is disconnected at 95 seconds at 1.81 Nm. The graphics indicate that for a synchronous motor the value of the excitation current is very important for keeping the constant speed according to the torque value. The value outside of the range of synchronism is closely related to the maximum torque value but also to the excitation current value.

By adjusting the excitation current value of the synchronous motor, we can control the exit from the synchronism condition at mechanical torque shocks at the shaft. Based on this premise we can continue experimental research on the synchronous machine when it operates in generator regime.

6. References

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