Influence of the Unbalanced Voltage on Torque Pulsation for Induction Motor

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Abstract—One of the most applied electrical machines is Induction Motor (IM) with cage rotor. This type of motors has high starting current and torque value at the accelerating moment. Voltage drops in electrical nets are caused by high currents; therefore, it makes influence on the electrical energy users and electricity supply companies. Use of nowadays semiconductor devices can solve these disadvantages. Despite of the fact the frequency control devices are developing rapidly its application in industry is not so much. In several companies operating with induction motors, control devices are not installed. The aim of this work is to research influence of unbalanced voltage on IM torque. With the help of the program MATLAB Simulink a model which analyzed IM torque was created. In the work process this program was made for conveyors when the load is constant during the operation. At the end of this work, practical measurements are compared with the values obtained in software MATLAB Simulink.

I. INTRODUCTION

IM with cage rotor is the most widely used electrical machine. IM in engine mode can consume up to 60% of all the produced electrical energy [1]. These motors have several start-up methods [2], for example, direct, star-delta, autotransformer, soft and frequency converter. The first three methods are supplied by standard three-phase voltage. When motor is connected directly to the network, it makes high currents, torque fluctuations, and rotor run-time is quite less. For star-delta method, before switching stator is supplied with 58% (1/√3) of the rated voltage. As a result, the current and torque are reduced for 33.3%. Using the soft starters and frequency converters, supply voltage on the motor outputs is impulsive. These devices start-up time can be charged more.

The objective of the study is to overview torque transducer signal fluctuations when IM is connected to unbalanced power source.

Torque equation for IM is made of stored energy in magnetic linear system [3]. In particular, the stored energy is the sum of the self-inductance, of each windings times one half the square of its currents and all mutual inductance, each time the current in two windings coupled by the mutual inductance. The flux linkages, currents and energy stored are all expressed as function of electrical angular displacement.

Torque fluctuations depend on many factors like these: input voltage, symmetry of stator and rotor windings resistance, air gap equability, synchronous parasitic torque and rotor eccentricity, etc. This paper investigates the same motor, assuming that IM equivalent scheme parameters are constant and independent on the slip.

This book [4] discusses the electromagnetic torque dependence on the saturation and losses observation in the mathematical model. The author considers that the saturation and current losses are causing higher peaks, but obviously they produce lower torque and speed transients. However, when for higher-capacity motors with frequency control saturation moment is rising the torque is increasing. It may cause various damages for induction motor shaft.

From the literature [5] it can be concluded that the electromagnetic torque is determined as vector sum of stator current and flux linkages.

Measurement methods [6] which are based on acceleration experiments can be divided into two groups: differentiation method, which uses electrical, mechanical or graphical speed change characteristics and inertial method, which uses measurements from the motor acceleration. The first group usually is associated with simple torque measurement constructions, because they are unable to give precise measurements at short-time moments. In the second group there can be added torque sensors with complex design, for them some addition measurement devices should be used. Some of the most used torque measuring devices are strain gauges. These devices can provide accurate results despite the fact how fast the engine shaft is accelerating. In this research tensometer is used for torque measuring from the company SCAIME.

Fig. 1. Torque meter between IM and Powder break.

It is made of four tensometrical plates, at the input it is fed with 12V DCV, but at the output strain gauge is connected to the signal amplifier and filter. Manufacturing such type of torque measuring devices it is strictly important to take into account linearity of gain coefficient. At the output of these sensors the main harmonics values are high, they contain frequency range from 7 to 15kHz. Measuring the signal from the sensor output there could be observed noise.
II. ELECTROMAGNETIC TORQUE AFFECTING FACTORS FOR INDUCTION MOTOR

As mentioned previously, Induction Motor torque in mathematical model is expressed from mechanical energy changes as:

\[ dW_m = -T_e \left( \frac{2}{P} \right) d\Theta_e, \]  

where \( T_e \) - electromagnetic torque, \( P \) - the number of machine poles and \( \Theta_e \) - electrical angular displacement. However, the equations can be added with additional equivalent scheme values. If we look to the voltage asymmetries, then we should replace voltage with two components: forward and backward. Each stator phase may be replaced with two equivalent schemes. In backward sequence the frequency is 100(120) Hz and rotor resistance value in this case is greater. Inductance in backward order, on the contrary, is getting lower. Also respect that the core losses are especially lower than in the forward sequence scheme. Therefore, the torque equation consists of two components, 

\[ T_e = \frac{3R_s (I_{sr})^2}{s \omega} P + \frac{3R_b (I_{br})^2}{(2-s) \omega} P, \]  

where (f-forward and b-backward components) parameters transcription can be seen in [4] 175p.

It is known, if the motor is supplied with unbalanced voltage IM consumes unbalanced currents. Therefore, at the rated slip (power) regime appears backward sequence braking torque and losses. These factors affect the efficiency, because magnetic and electrical losses are increasing. Voltage unbalance does not affect rotor circuit losses. However, most electricity suppliers companies are trying to deliver symmetrical voltage which is corresponding LVS standards to require +/-10% range.

III. EXPERIMENTAL STAND AND MEASUREMENTS

For the research the induction motor test workbench from company LEROY SOMMER was used. It consists of researched motor, torque sensor (SCAIME), powder break and tahogenerator. IM rated data: \( U_n=400V, I_n=3.4A, \eta=1425, \cos\varphi=0.843, f_n=50Hz, T_n=11Nm \), IM is connected in parallel to powder break. Powder break characteristic is able to provide constant torque for all speed ranges. Rotor rotational speed is measured from the DC tahogenerator. Torque meter is placed between IM and powder brake. Its operating principle is based on tensometrical sensor operation. Sensor input is connected to 12V DC supply voltage. It is supplied to strain gauges bridge, which consists of four sensitive tensometrical metal pellicles. Output signal is transported to MODMECA meter and then strengthened and filtered. The moment of inertia is determined from the speed characteristic when IM is connected directly to the network. Friction coefficient is calculated from motor mechanical losses at no-load.

![Fig. 2. Test stand for IM characteristics.](image)

![Fig. 3. Connection scheme for induction motor characteristics.](image)

### Table I

<table>
<thead>
<tr>
<th>Parameters</th>
<th>PU units</th>
<th>SI units</th>
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<td>( X_s )</td>
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<td>( X_m )</td>
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<td>( X_e )</td>
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<td>( R_e )</td>
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IV. ANALYSIS

Theoretical part of publication was made with the help of computer program MATLAB Simulink. In program Figure 4 demonstrates research principal scheme. Program is calculated IM mathematical model with differential equations, as was written in [8]. The differential equation was solved in stationary coordinate system. Unbalanced voltage value is selected 8% of the rated voltage.

The largest discrepancy appears in Figure 7, where IM was working in no load mode and was supplied with 8% unbalanced voltage. From the graph it is seen that the torque fluctuations have large frequency and amplitude differences.

In 6th Figure IM was loaded with half (5.5Nm) of the rated load. As shown, this load in network accounts 2% voltage unbalance therefore in Simulink the same unbalance was assigned. Unbalanced voltage causes unsymmetrical current in stator phases, in this case the stator magnetic flux remains elliptic form.

In Figure 8 represents practical measurements, when IM is connected to unbalanced voltage and under load applies great torque fluctuations. Also in this case there are differences between frequencies. Differences between amplitudes decreased.

In Figure 9 in mathematical model appears that from the first second till 2.5 second torque fluctuations amplitude do not depend on the load. But from real experimental measurements it is seen that load and voltage makes influences on the fluctuations.

V. CONCLUSION

Torque amplitude differences in no load mode with unbalanced voltage is explained by the inaccurate calculation algorithm choice, in program differential equations for IM equivalent circuit are calculated in direct sequence. In this
program for better results it is necessary to create separate algorithm or subprogramme, which will take into account backward sequence scheme. In no load regime it was observed that with unbalanced voltage speed fluctuations in mathematical model can reach greater values than synchronous speed. As a disadvantage in program MATLAB it may be noted that in IM mathematical model torque fluctuations are independent on the load value, but in the practical experiments torque variation depends on the given load and supply voltage. I would like to note that for MATLAB software user it creates additional difficulties. In introduction, Figure 1 demonstrated a torque measurement device. These devices have some disadvantages, for example, after long using period inside the device metallic dust appears and when torque device is connected to DC through the brushes it ensures transition resistance. It gives incorrect measurements.

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REFERENCES