

*power quality, power factor,  
efficiency, drive, induction motor*

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## **THE INFLUENCE OF POWER QUALITY OF THE MAINS ON OPERATION CHARACTERISTICS OF AN UNCONTROLLED AND CONTROLLED INDUCTION MOTOR**

The paper deals with the influence of power quality indices: the voltage distortion, the voltage unbalance and the voltage dip in the mains on operation characteristics of an induction motor directly fed from both the source and the frequency converter, and their comparing. There are mainly investigated energy characteristics as motor efficiency and motor power factor depending on the motor load in the paper. It is also shown that permitted power quality levels of both the voltage distortion and unbalance, especially in the case of the controlled drive, does not influence the induction motor operation characteristics a lot.

### 1. INTRODUCTION

Three-phase squirrel cage asynchronous motors, such as indispensable sources of power, are widely used in electrical drives, both non-adjustable and adjustable. Their large scale using and operation in many industrial applications are given by their simple construction, reliability, low maintenance and relatively low cost, but it is known that there is only one efficient method for controlling the induction motor speed without wasting energy – change of its operating frequency realized by using frequency converter implemented into structures of electrical drives abbreviated as VFD. These adjustable speed drives with induction motors and frequency converters are used in almost all technical applications where the speed control or excellent dynamic performance is required. However, energy savings of the VFD drives are associated with higher costs, drive complexity, negative influences on some motor parameters and problems related to the power quality and the electromagnetic compatibility [1].

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On the other hand, the ever increasing number and power of polluting loads (non-linear, time-variant loads, etc.) connected to distribution and industrial networks cause a significant distortion in the line current. Their overall power is no longer negligible with respect to the network power. This causes a deterioration of the voltage quality that may influence the other connected loads including electrical drives. Hence, the power quality in the mains is important for proper function and reliability of a device connected to them. It is described as a set of values of parameters [2], [3], from which we chose only some of them. We focused on the quality indices such as the total harmonic voltage distortion, the voltage unbalance factor and the voltage dip to experimentally verify their influence on energy characteristics of an uncontrolled and controlled induction motor drive, because voltage harmonics, non-symmetrical voltage components and voltage fluctuations have negatively impact on rotating machines [4], [5]. Namely, harmonics and negative/zero sequence components cause additional losses, the parasitic vibration and the torque and speed pulsation of the induction machine. However, their impact can be just eliminated by the  $LC$  filter in the DC – link of the VFD or adding an input filter in front of the VFD, so any disturbance on the supply line does not get transmitted to the motor side.

## 2. ENERGY MOTOR CHARACTERISTICS AND POWER QUALITY

More and more public attention is now being focused on reducing energy consumption [6]. From this point of view the energy ratios of the induction motor – the motor power factor and the motor efficiency and their dependencies on the motor load are very important. As it is stated above, the motor additional losses are associated with the power quality in the mains. Power quality factors defined in steady state, like the total harmonic distortion and the unbalance factor are based on the decomposition of an alternating, periodic, non-sinusoidal time function into the fundamental component and the harmonic component and decomposition of the three-phase unbalanced system into Fortescue's symmetrical components to distinguish useful and "harmful" part of delivered energy [7], [8]. Substituting these power quality factors into both mentioned motor characteristic we could get an impact of these factors on those characteristics which are multidimensional analytic functions. If we choose one from the factors as a parameter and the other parameters remain constant, then we can easily study investigated relationships both analytically and experimentally. Since our laboratory is equipped with a three-phase AC programmable power source, we focused on experimental measurement only. Thus, the values of power quality factors were set in a compliance with permitted levels given by standard [9] and the induction motor was loaded to obtain required motor characteristics.

The motor power factor at given loading was calculated using the single-phase definition. As the reference value, the average value (1) of phase power factors was taken into account

$$\lambda = \frac{1}{N} \sum_{i=1}^{N=3} \frac{P_i}{S_i}, \quad (1)$$

which is determined by the three-phase active powers  $P_i$  and apparent powers  $S_i$ . This is because the three-phase apparent power definition, on the contrary to the active one is not ambiguous in unbalanced three-phase system [8].

The motor efficiency (2) was calculated from the definition used to the direct efficiency measurement

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}}, \quad (2)$$

where  $P_{\text{out}}$  is the mechanical output power and  $P_{\text{in}}$  is the active input electrical power of the motor.

### 3. EXPERIMENTAL RESULTS

Block diagram of the uncontrolled and controlled induction motor drive under test is depicted in Fig. 1. As can be seen, both drive arrangements were fed by the three-phase programmable power source. The controlled drive was equipped by the commercial frequency converter whose inverter switching frequency was adjusted to factory setting of 16 kHz. The mechanical load on the test motor was provided by a separately-excited DC motor drive which was controlled by a thyristor rectifier. The three-phase squirrel cage induction motor has these rated parameters:  $P_n = 4$  kW,  $I_n = 8.1$  A,  $V_n = 400$  V,  $f_n = 50$  Hz,  $n_n = 1440$  rpm,  $\eta_n = 86.6\%$  and it was connected in star.

Using the programmable source following conditions in the mains were simulated: the three-phase sinusoidal balanced system, the three-phase sinusoidal balanced system with the voltage dip value of 10%, the three-phase sinusoidal unbalanced system with the unbalance factor value of 2% and the three-phase non-sinusoidal system with the total harmonic distortion value of  $\text{THD}_V$  8%, in the legend of graphs denoted by symbols bal, dip, unbal and dist respectively.

Necessary digitized voltage, current, torque and velocity signals for computing of powers, according to (1), (2), were acquired by a 12-bit multi-channel measurement system based on two DAQ boards at the sampling rate of 156.25 kSa/s per channel. All voltages were measured by high precision isolation modules. Hall-effect transducers were used for accurate current measurement. Motor torque and velocity were obtained by a precision transducer. Bandwidths of all measured signals were limited by

signal conditioning modules to 30 kHz. All measurements have been performed in steady state.

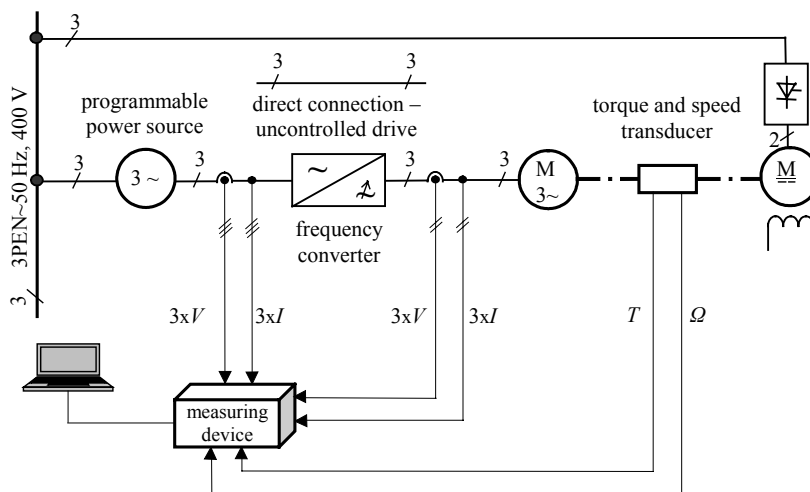


Fig. 1. Block diagram of tested electrical drives

Results of measurement of the uncontrolled drive are shown in Fig. 2 and Fig. 3. As can be seen from Fig. 2, the effectiveness employing of the delivered energy by the induction motor is higher both under the unbalance system and the voltage dip due to considerable changes of values in the numerator compared to those in the denominator of the equation (1). The harmonic distortion of the three-phase voltages doesn't have observable impact on the power factor characteristic, because the harmonic active and apparent power and their changes are small in values. Hence, the power factor graphs of the balanced sinusoidal and non-sinusoidal three-phase voltage system have practically the same shape.

According to Fig. 3, the efficiency characteristics of the uncontrolled drive are significantly affected by the power quality in the mains from roughly 60% loading of the tested induction motor. Decrease of the efficiency, at the rated motor load, is about 0.3% both for the voltage dip and the total harmonic voltage distortion, and for the voltage unbalance is higher than 1%.

As it has been shown in [6], [10], the efficiency decrease in dependence on both the voltage distortion level and the voltage unbalance level can be approximated by the linear function in the range of their maximum permitted levels [9]. Parameters of the lines, the slope and the y-shift depend on the motor load. Particularly values of the slopes at given loading don't differ in values a lot, so the dependence of the efficiency decrease can be quite good described by one collective value of the slope in the range 60%–100% of motor load. The slope has the negative value of  $-0.046 \pm 0.007$  onto 1% of

the total harmonic voltage distortion and the value of  $-0.158 \pm 0.008$  onto 1% of the voltage unbalance factor for the motor under test.

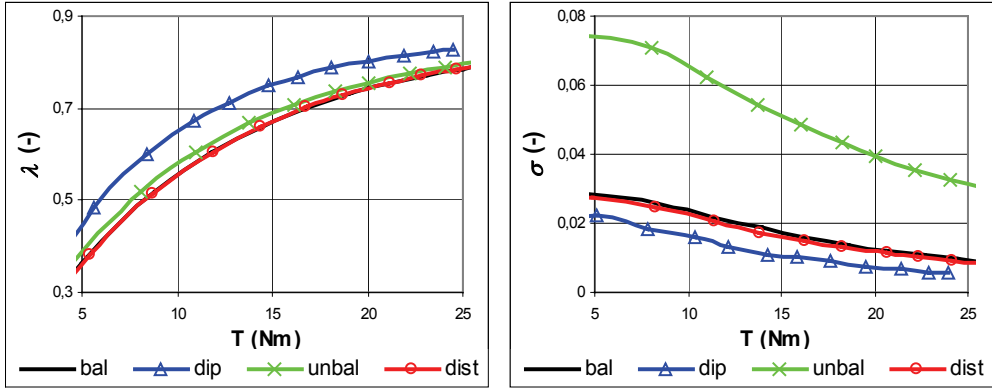


Fig. 2. The average power factor characteristics of the uncontrolled drive and the standard deviation of the phase power factors; maximum permitted level quality indices; the output source frequency of 50 Hz

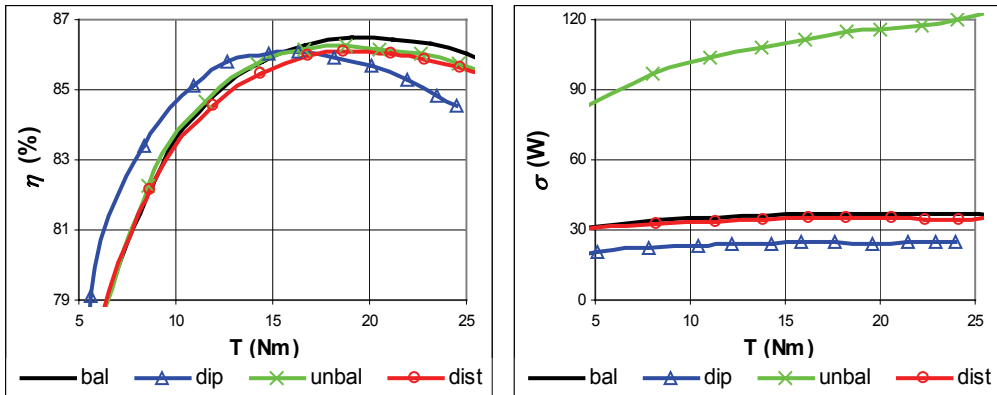


Fig. 3. The efficiency characteristics of the uncontrolled drive, the standard deviation of the active phase powers; maximum permitted level quality indices; the output source frequency of 50 Hz

Results of measurement of the controlled drive are shown in Fig. 4 and Fig. 5. As can be seen by comparing the average power factor characteristic in Fig. 2 with that in Fig. 4 they differ only a little bit. However, influence of power quality indices on them can be observed in details on the graphs of the standard deviation. These graphs clearly show that the DC – link of the VFD effectively eliminates disturbances in the mains and minimizes their impact on the induction motor.

Similar conclusions can be made after comparing the efficiency characteristics and the standard deviations of the active phase powers in Fig. 3 and Fig. 5. This compari-

son demonstrates the positive effect of the frequency converter and its control on the efficiency characteristics. However, considering the overall efficiency of the controlled drive under test is up to 4.5% lower.

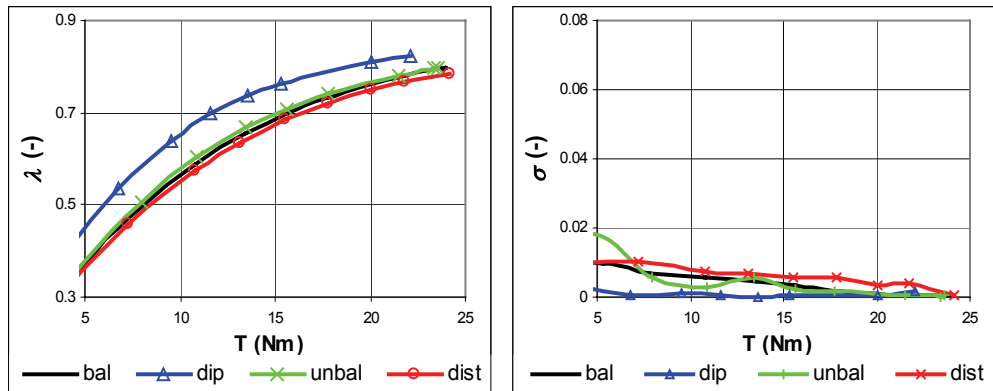


Fig. 4. The average power factor characteristics of the controlled drive and the standard deviation of the phase power factors; maximum permitted level quality indices; the output converter frequency of 50 Hz

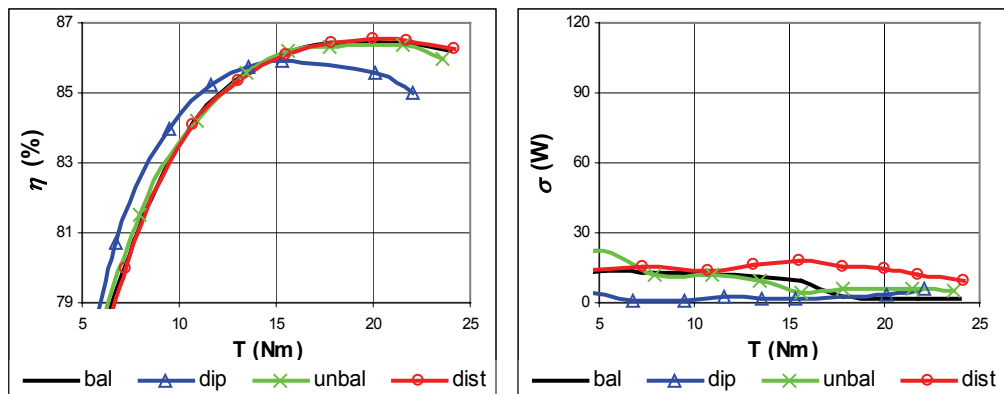


Fig. 5. The efficiency characteristics of the controlled drive and the standard deviation of the active phase powers; maximum permitted level quality indices; the output converter frequency of 50 Hz

#### 4. CONCLUSIONS

This paper has been focused on the assessment of power quality influence on the energy characteristic both the uncontrolled and controlled induction motor drive rated at 4 kW. Experimental measurements have been shown that from investigated power quality indices the voltage dip most affects the energy characteristics of the induction

motor and that the maximum permitted standard levels of both the voltage distortion and unbalance in the mains don't significantly affect these, especially in the case of the controlled drive due to its DC – link whose filtering effect is illustrated by the graphs of the standard deviations of both the phase power factors and active powers.

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