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Analysis of the Power Supply Influence on the Universal Motor

Research paper

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Abstract: Due to their advantageous properties, universal motors are widely used in various applications and can be operated with both AC and DC voltage. Between main advantages of universal motors are their high starting torque, very compact design and high operating speed. In terms of the wide use of the universal motor, we want to analyze the impact of DC and AC power supply on the universal motor in this article. As part of the analysis, measurements were made of the influence of the AC/DC supply on the speed, torque, efficiency and electromagnetic radiation of the motor. At the end of the paper, the results of measurements on a universal motor with DC and AC power supply are presented.

Keywords: *measurement • analysis • power supply • universal motor*

1. Introduction

The universal motor, shown in Figure 1, is among the most widely used electric machines in household appliances and workshop hand tools due to their excellent control properties. The main advantage of these motors is not only its universal usage with AC but also with DC voltage.

In both cases, the motor speed is controlled by the magnitude of the supply voltage. The universal motor is also known as AC series motor or AC commutator motor. This motor consists of a stator with two concentrated excitation windings connected in series, a rotor with a winding, a commutator and two carbons. The stator and rotor windings are connected in series to the power supply voltage. The series connection of the stator and rotor windings is formed by contacts of commutator on rotor and two carbons.

Unlike a DC motor with external excitation, the universal motor powered by DC voltage does not have a constant speed. The speed of universal motor depends on the load allowed, and the motor torque decreases with speed. However, universal motors have a very high torque to weight ratio for all types of electric motors (Cros et al., 2004; Di Gerlando and Perini, 2013; Kanosh and Vinyi, 2009; Klug et al., 2004).

The main typical features of universal motors are the following:

- high speed, high efficiency and relatively low service life (continuous and long operation time is not recommended); and
- operation is on DC or single-phase AC voltage, while the operating power of the universal motor is from 50 to 1,000 W, and its speed is 10,000–20,000 rpm.

The universal motor is mainly used in applications that require a large starting torque and a small torque change during operation, high speed and a short operating time with a longer break. Some of the typical applications are as follows:

- home use: washing machine, mixer, juicer, fan, grinder, food processor, vacuum clean-er, etc.;
- hand power tools, garage door opening, water pump, compressor, table machine tools, etc.;
- personal care (massage machines, hair dryer, etc.); and
- office supplies: shredder, grater, etc.

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Fig. 1. Universal motor.

The task of this article is to compare the behaviour of a universal motor with DC and AC power supply thoroughly. Although similar studies already exist in this area (Jack et al., 2000), they only compare the partial characteristics and behaviour of a universal motor at different power supplies. In the articles of Davidson et al. (2001) and Bradley and Ismail (1991), there is, for example, the presented performance analysis of the universal motor, and the article (Garg, 2019) presents simulation comparison of the behaviour of the speed characteristics when universal motors are supplied with alternating or direct voltage. These published studies confirm our assumptions and our conclusions that by supplying the universal motor with DC voltage, we will achieve better operating characteristics of the universal motor. The main benefit of our study is a complex comparison of the characteristics of the universal motor in terms of the method of power supply, which is verified on a real motor used in practice.

2. Universal Motor Measurement

Since the universal motor can be supplied with AC and DC voltages, the goal of this work is to determine the effect of its power supply on the operating characteristics of the motor. The measurement results on the universal motor should provide a response as to which voltage (DC or AC) is more advantageous to use in the power supply of a universal motor. A universal motor from an Indesit washing machine with the following parameters was used for the measurement: U_N=220–240 V, I_N=3 A and P_N=300 W.

Figure 2 shows a measuring workstation for measuring on a universal motor.

During the measurement, the universal motor was connected to a dynamometer, which was used for loading of universal motor and at the same time to measure the motor torque and motor speed. A Fluke Norma 4000 Power Analyzer was used for measuring the voltage and current, as well as the harmonic analysis of the voltage taken from the network. The radiated intensity of the electromagnetic field was measured with a Matrix device type VX0100 with an external 62 mm antenna.

When powered by AC voltage, the universal motor was connected to a one-phase autotransformer. The connection scheme for AC power is shown in Figure 3. When powered with DC voltage, the universal motor was connected to a three-phase autotransformer, its output voltage being rectified by a three-phase uncontrolled bridge rectifier. The connection scheme for DC supply is shown in Figure 4.

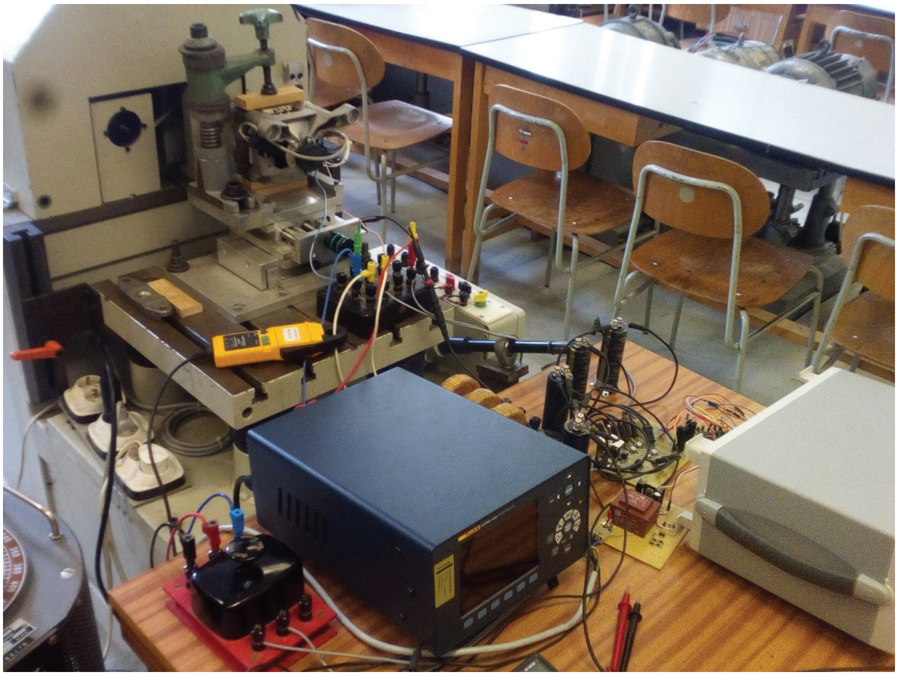

Fig. 2. Measuring workstation for universal motor.

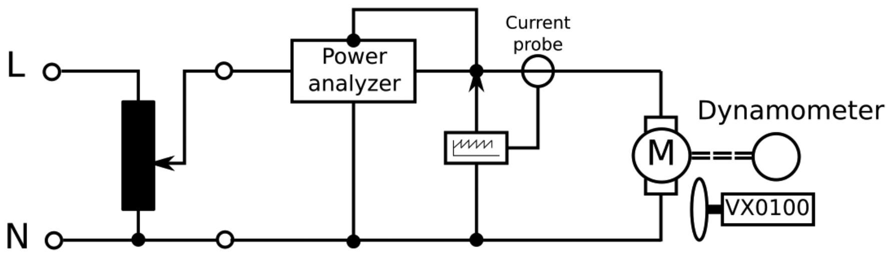

Fig. 3. Measurement connection scheme for AC supply.

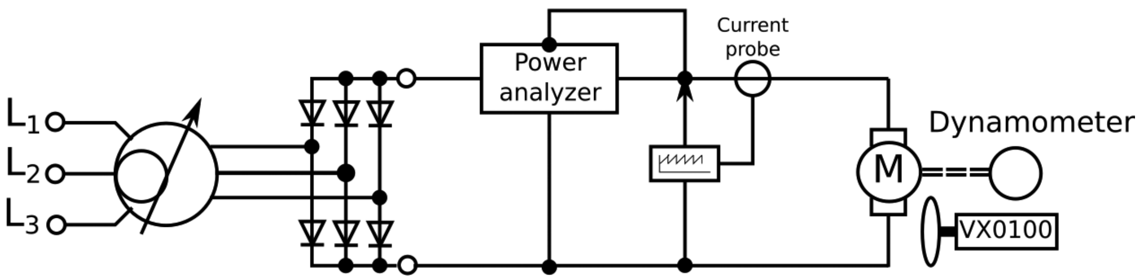

Fig. 4. Measurement connection scheme for DC supply.

3. Measurement Results on a Universal Motor

The values required for the construction of the speed and mechanical characteristics were measured for the individual power supply types, that is torque, current and motor speed at different supply voltages. Furthermore, the efficiency of the motor, electromagnetic radiation and, in the case of alternating power supply, higher harmonics were monitored. The results of individual measurements are shown in the following figures.

3.1. Speed characteristics of universal motor

Figures 5 and 6 show the speed characteristics of a universal motor at DC and AC supply voltages for different effective values of the supply voltage.

By comparing the waveforms of the characteristics in Figures 5 and 6, it can be seen that when the motor is supplied with AC voltage, the speed of the universal motor is slightly higher at a torque of 0.1 Nm, but decreases rapidly with the load when the motor is supplied by DC voltage.

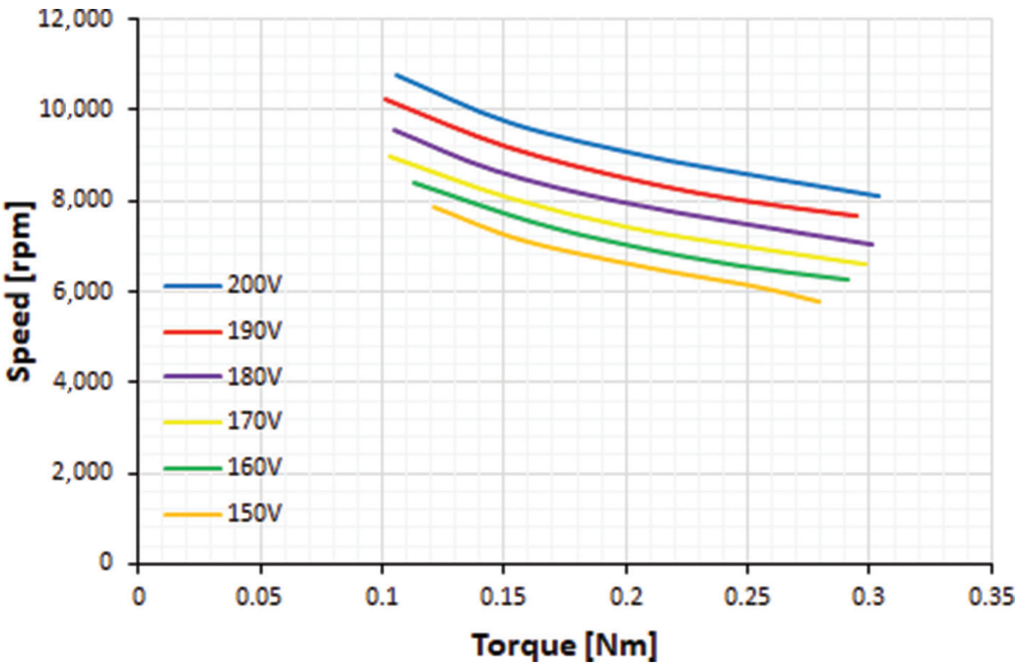

Fig. 5. Speed characteristic for DC supply of the universal motor.

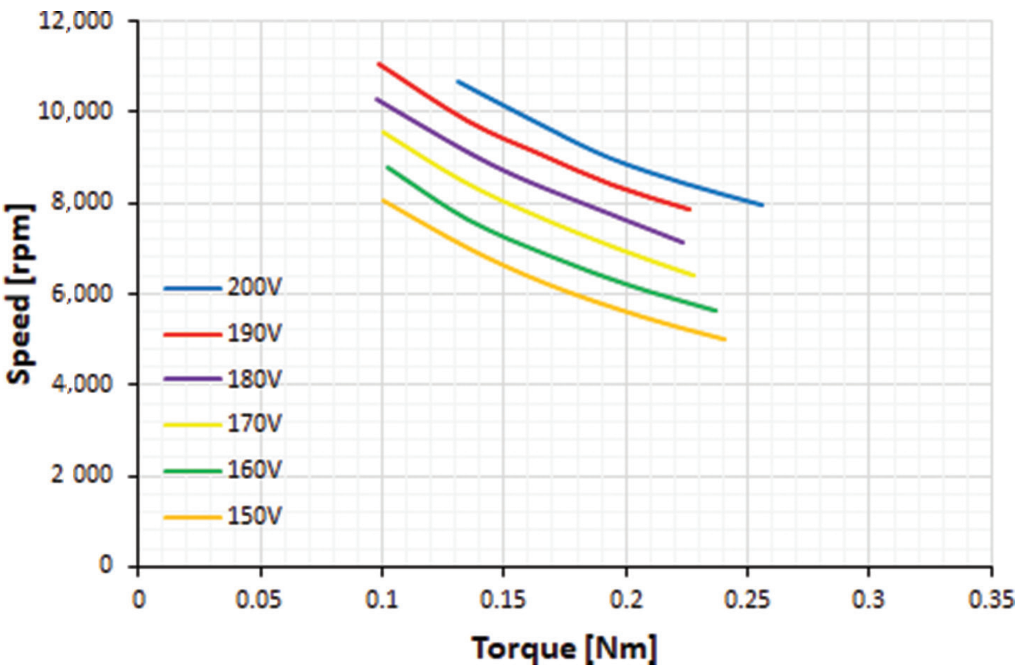

Fig. 6. Speed characteristic for AC supply of the universal motor.

3.2. Torque characteristics of universal motor

Figures 7 and 8 show the torque characteristics of a universal motor at DC and AC supply voltages.

As can be seen from the individual waveforms, the universal motor achieves a higher torque value when supplied with DC voltage than when supplied with AC voltage at the same value of the armature current.

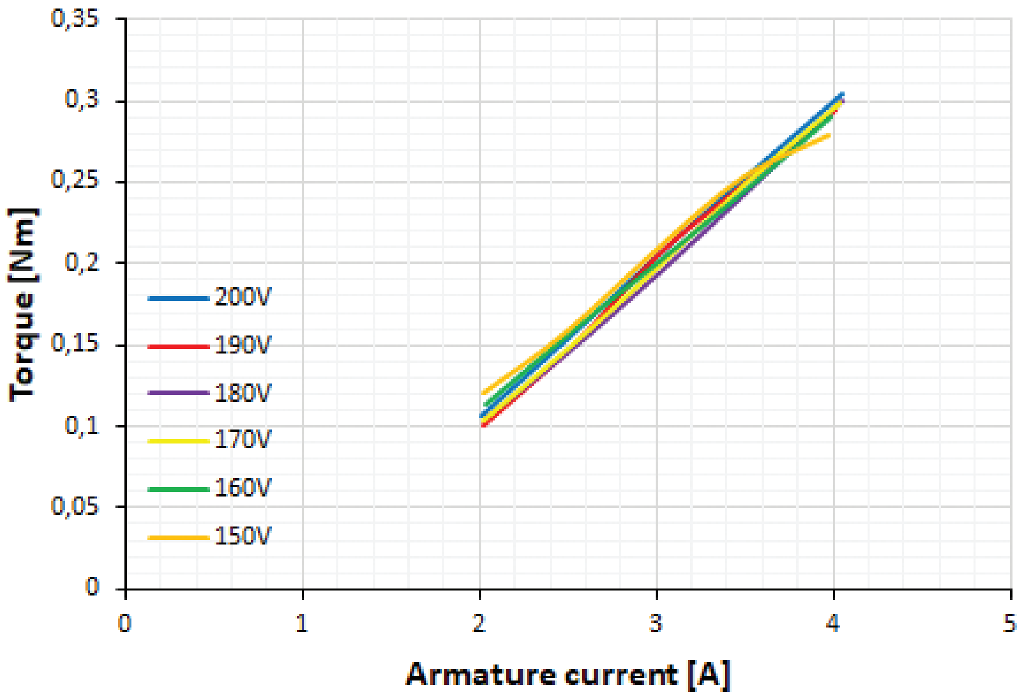

Fig. 7. Torque characteristic for DC supply of the universal motor.

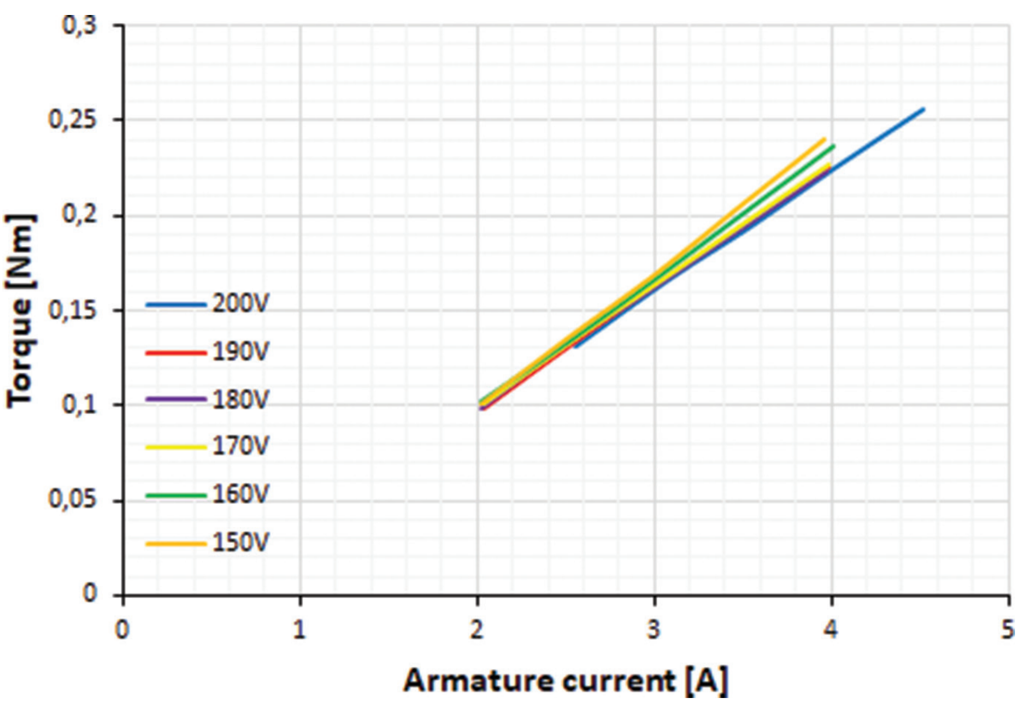

Fig. 8. Torque characteristic for AC supply of the universal motor.

3.3. Efficiency characteristics of universal motor

Figures 9 and 10 show the efficiency characteristics of a universal motor at DC and AC power supplies. It can be seen from the above that the efficiency of a universal motor supplied with alternating voltage decreases slightly with increasing armature current, while at a direct voltage, it remains at approximately the same value.

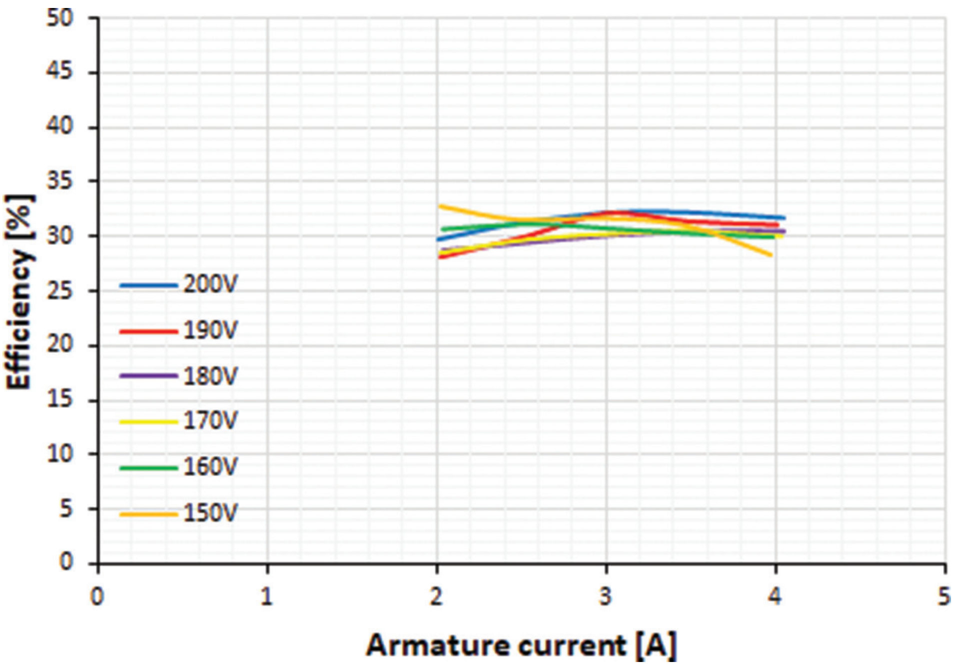

Fig. 9. Efficiency characteristic for DC supply of the universal motor.

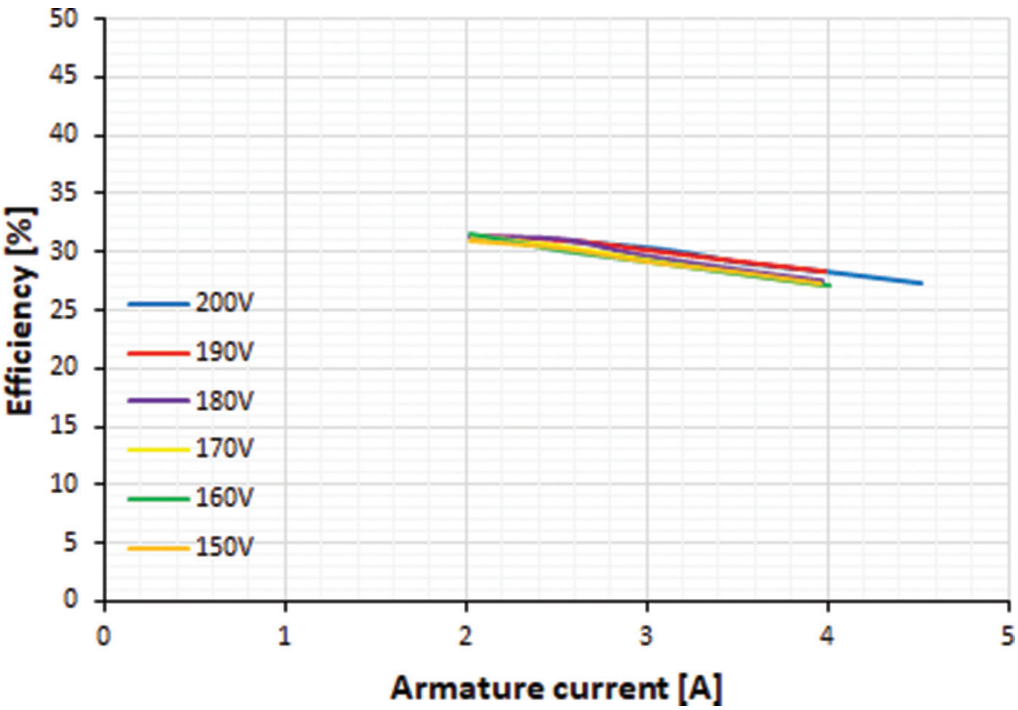

Fig. 10. Efficiency characteristic for AC supply of the universal motor.

3.4. Electromagnetic radiation and higher voltage harmonics

Figures 11 and 12 show the intensities of the electromagnetic field near a universal motor at DC and AC power supplies, which has been loaded with a current of 2A and 3A, respectively.

The intensity of the electromagnetic field was measure with a Matrix type VX0100 with an external 62 mm antenna, while the device was place in close proximity to the universal motor commutator.

The comparison of the magnetic field intensity was made for currents 2A (motor current at minimum load) and 3A (nominal motor current). There were no significant changes in the magnitude of the magnetic field intensity

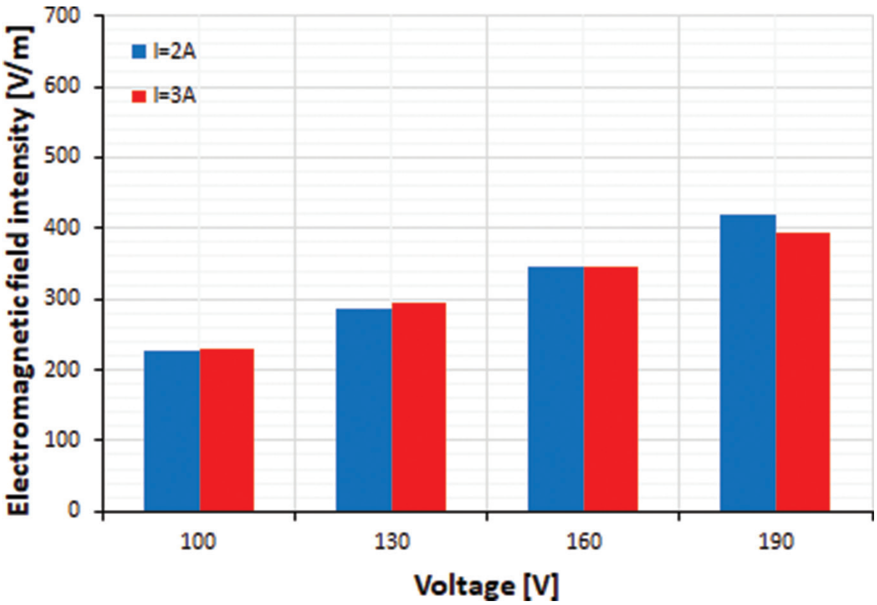

Fig. 11. Electromagnetic field intensities at DC supply.

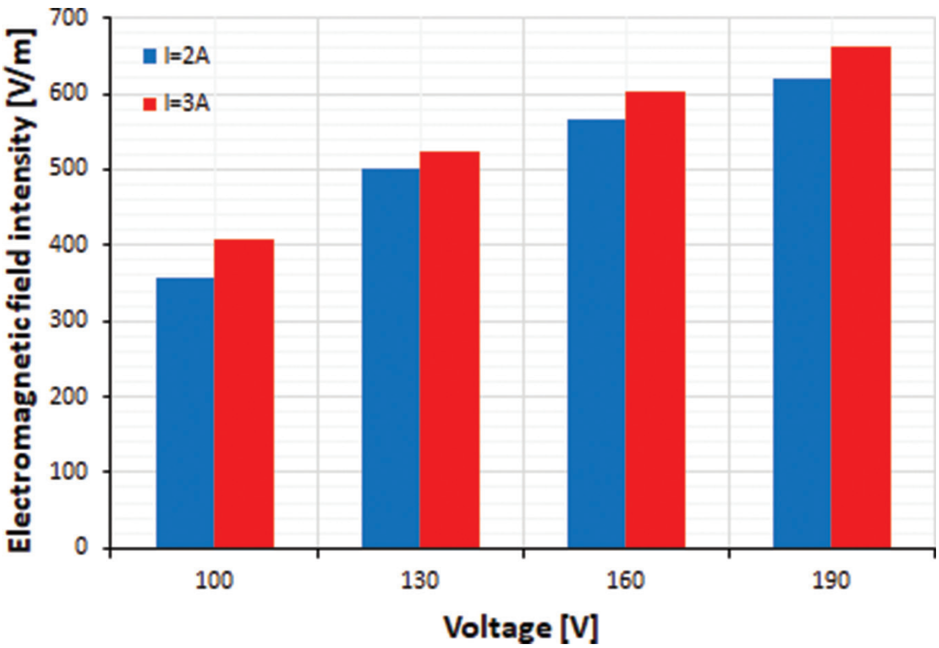

Fig. 12. Electromagnetic field intensities at AC supply.

within this interval. The magnitude of the intensity of the electromagnetic field was influenced by the AC or DC power supply (DC current was not fully smoothed, because we get DC voltage from the AC supply voltage that was rectified only by a non-controlled rectifier). As can be seen from the presented results of the electromagnetic field intensity, the interference around the universal motor, which was supplied with DC voltage, is significantly lower than with the universal motor supplied with AC voltage.

Figures 13 and 14 show the higher harmonic components of the AC supply at 3A and 2A as measured by a Fluke Norma 4000 Power Analyzer.

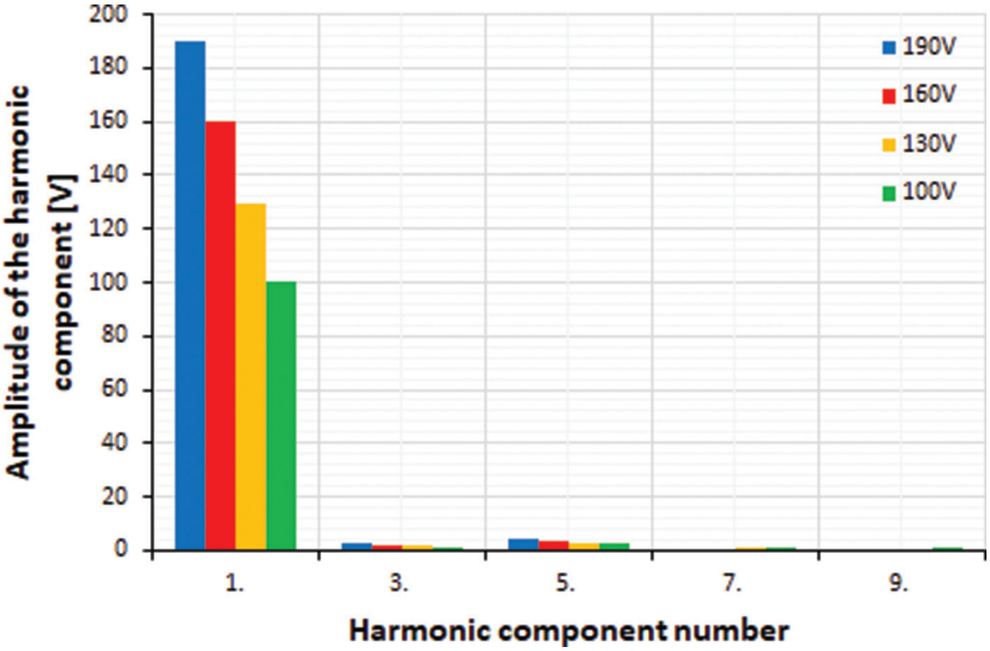

Fig. 13. Higher voltage harmonics with AC supply of the universal motor at a current of 3A.

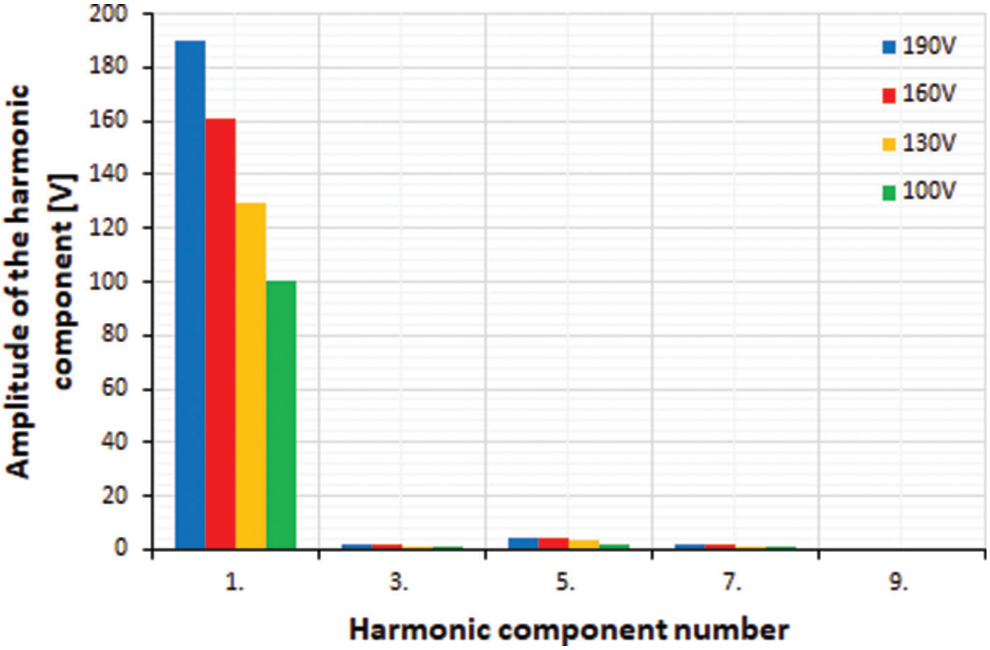

Fig. 14. Higher voltage harmonics with AC supply of the universal motor at a current of 2A.

4. Conclusion

Universal motors are widely used especially in home appliances for their advantageous properties. Since the universal motor is supplied with either AC or DC voltage, we wanted to present the influence of the universal motor supply to its output characteristics and to the supply network in this article. As part of the measurement, the effect of the power supply was tested on a universal motor used in the Indesit washing machine, and its speed characteristics, torque characteristics, the effect of the power supply on the motor efficiency, and electromagnetic radiation were monitored. As can be seen from the presented results in all measurements, we measured better operating characteristics when supplying the universal motor by DC voltage.

Comparing the individual speed characteristics, we found that the speed of the universal motor at DC voltage is approximately 0.8% lower than at AC power on average, but around the operating point, which corresponds to a current of 3A, the motor speed is about 1.35% higher when motor is powered by DC voltage. For the other monitored parameters, that is for the torque characteristic, the measurement of the efficiency of the universal motor, and the measurement of the radiated electromagnetic intensity, the results were clearly in favour of the DC supply of the motor. The universal motor had on average 13% more torque at DC power supply, 3.45% more efficiency than AC power supply, and the magnitude of the electromagnetic field radiation was on average 40% higher at AC power than at DC power voltage.

Based on these measurements, we can state that by using a simple uncontrolled rectifier when supplying the universal motor from the AC network, the operating characteristics of the motor will be better than when supplying directly by AC voltage.

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