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An analysis of the inverter overvoltage generated by the motor

***Abstract**. The overvoltage in the inverter that supplies the AC induction motor, which during the deceleration operates as a generator delivering current back into the inverter DC bus, has been investigated. The investigation was performed experimentally using a special test bench. The impact of the motor deceleration rate, motor load and initial rotation velocity, at which the deceleration starts, on the overvoltage was investigated and analyzed. The obtained results were employed for the development of the overvoltage fault protection of the inverter.*

Streszczenie.** W przekształtniku zasilającym silniki AC powstają przepięcia w czasie zwalniania silnika. Przeprowadzona badania tego zjawiska dla różnych: prędkości zwalniania, obciążeń silnika i prędkości obrotowej (**Analiza przepięć w przekształtniku zasilającym silnik)

Keywords: inverter, overvoltage, AC induction motor, motor deceleration.
Słowa kluczowe: przekształtnik, przepięcia, sinlik AC.

Introduction

The AC induction motor used in the variable speed drive based on the frequency converter can act as a generator under certain operating conditions. The inverter, which is the main block of the frequency converter, supplies the motor with the variable frequency variable amplitude three phase AC voltage. The motor rotation velocity is determined by the AC voltage frequency. If the frequency increases the motor accelerates, if it decreases – the motor decelerates. If the AC induction motor rotation velocity during the deceleration exceeds the synchronous velocity, it starts to operate as a generator delivering current back into the DC bus of the inverter through the transistors, which operate as switches of the inverter. Therefore, the capacitors of the DC bus are charged and voltage of the DC bus increases [1-3]. The maximal voltage value (overvoltage) depends on the motor deceleration rate, motor load and its inertness, capacitance of the DC bus capacitors and initial rotation velocity of the motor (rotation velocity, at which the deceleration starts). If the overvoltage of the DC bus exceeds the safe operation limits, the transistors of inverter switches, DC bus capacitors and other components used in the inverter can be damaged [3, 4]. Therefore, the problem of the overvoltage in the inverter, is topical [5]. There are lot of works, e.g. [6-9], dedicated to the investigation of the overvoltage in the inverter using simulation. However, during the frequency converter development process it is important to have accurate data, which can be obtained only experimentally. They are needed for the development of the overvoltage fault protection of the inverter.

The investigation technique

The investigation of the overvoltage in the inverter caused by the AC induction motor deceleration was performed using a special test bench. The block diagram and picture of the test bench are given in Figs.1 and 2. It includes the 4 kW AC induction motor fed from the inverter of the experimental example of the developed frequency converter. The motor drives the 5.5 kW DC generator, which acts as the motor load and is characterized by the relatively high inertness. The test bench includes the motor load torque and rotation velocity sensors and appropriate circuits for conversion of sensor signals to standard signals, which are used for measurement.

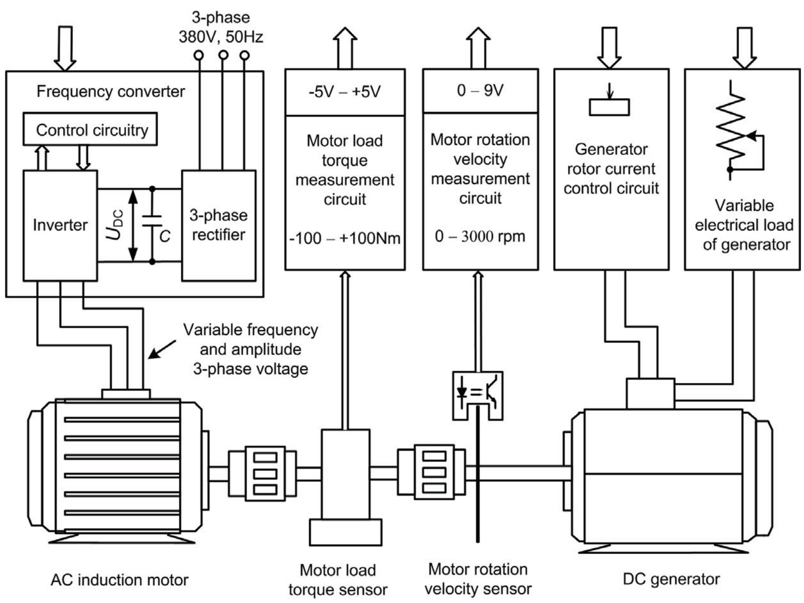

Fig. 1. The block diagram of the inverter overvoltage investigation test bench

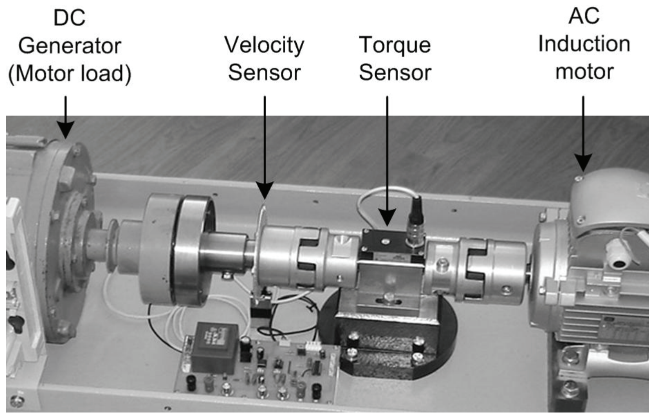

Fig.2. The test bench

The motor load torque is controlled by the variation of the DC generator rotor current and the generator electrical load. The transients of the inverter DC bus voltage (U_{DC}), motor load torque (M) and motor rotation velocity (V_r) have been investigated. The measurements of transients were provided using the Tektronix digital oscilloscope TPS2024.

The following investigation technique has been used. Firstly, the appropriate frequency (f_p) of the inverter output voltage and deceleration rate are preset and the motor is started. Secondly, the motor load torque is fixed by variation of the rotor current and electrical load of the DC generator. After this, the motor is stopped at the assigned deceleration rate and U_{DC}, M, V_r transients are measured. The motor deceleration rate (D) is expressed by the decrease rate of the frequency of the inverter output voltage, i.e. D has the Hz/s dimension.

The two situations can be observed during the motor deceleration when the motor acts as a generator and the DC bus capacitors are charged. The first situation is when the DC bus voltage spike does not reach the overvoltage fault protection trigger level, the second one – when the voltage spike reaches this level. In the first case the motor is stopped at the preset deceleration rate. However, if the overvoltage fault protection is triggered, the transistors of inverter switches are closed and the motor does not provide the energy to the DC bus. Therefore, the rise of the DC bus voltage is stopped, the motor is not decelerated by the inverter and, as a consequence, the motor deceleration becomes uncontrolled.

The examples of the transients of the U_{DC}, M and V_r for the case when the overvoltage fault protection is not triggered are presented in Fig. 3. It is seen that the motor deceleration causes the DC bus voltage spike and the motor load torque decreases and becomes negative during the deceleration. Additionally, the transient of the motor load torque has oscillations.

The DC bus voltage transient example for the case when the voltage spike reaches the overvoltage fault protection trigger level is given in Fig. 4. The rising edge steepness of the voltage spike in the analyzed case is about 1.5 V/ms. When the voltage reaches the fault protection trigger level, the transistors of inverter switches are closed by the protection circuit. Since the steepness of voltage spike is relatively low, the DC bus voltage practically is fixed at the value, which corresponds to the overvoltage fault protection trigger level even in the case when overvoltage fault protection circuit with the response time up to several hundreds of microseconds is employed. This fact allows us to use slow overvoltage protection circuit, i.e. circuit, witch has low sensitivity to electromagnetic disturbances produced by the inverter.

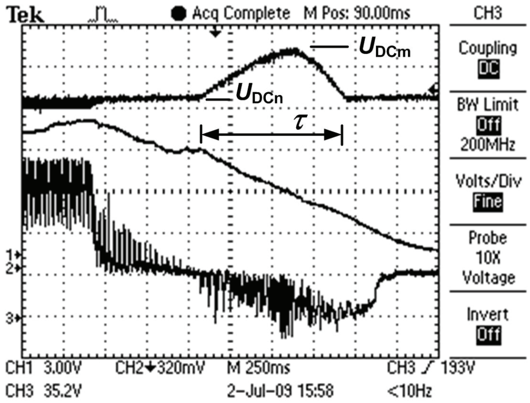

Fig.3. The U_{DC} (upper curve, it has been measured using the 1/3 voltage divider, therefore 1div ~ 100V), V_r (middle curve, 1div ~ 1000rpm) and M (bottom curve, 1div ~ 6Nm) transients caused by the motor deceleration at D=16.7Hz/s and capacitance of the DC bus capacitor C=470μF. U_{DCn}≈ 540V

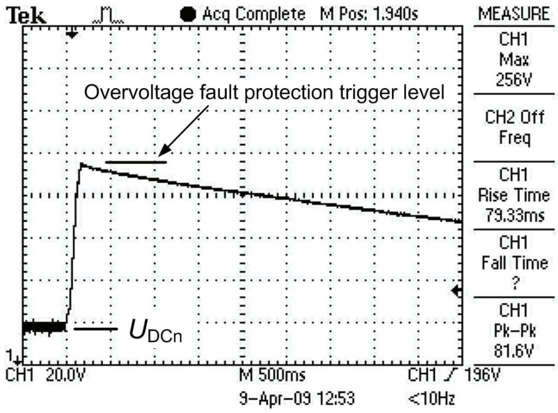

Fig.4. The U_{DC} transient caused by the motor deceleration at M=6.5Nm, D=25Hz/s, f_p=50Hz and C=880μF. The case when the voltage spike reaches the overvoltage fault protection trigger level. U_{DC} has been measured using the 1/3 voltage divider, therefore 1div ~ 60V

The shape of the falling edge of the voltage spike (Fig. 4) is determined by the slow discharge of the DC bus capacitors by the frequency converter circuitry, which is fed from the DC bus voltage.

The inverter overvoltage investigation results

The investigation was accomplished at various motor load torques for the different motor deceleration rate and initial motor rotation velocity, at which the deceleration starts. The results were obtained for DC bus capacitor capacitances C = 470 and 880 μF. During the investigation the duration of U_{DC} spike (τ) and the maximal U_{DC} value U_{DCm} (overvoltage) (Fig. 3) were estimated. The results are presented in Figs. 5–7. The overvoltage depends on the motor load – it decreases if the motor load increases. This can be explained by the fact that the motor even during the deceleration supplies the energy to the load and only the excess energy of the motor is supplied to the DC bus. It is seen that the overvoltage increases when the motor deceleration rate and initial rotation velocity (initial inverter output voltage frequency) increase (Figs. 5 and 6). The increment of the capacitance of the DC bus capacitors allows us to reduce the overvoltage. However, the overvoltage decrement is slight even imperceptible (compare the dependences given in Fig. 5 with the corresponding dependences presented in Fig. 6). This can be explained by the fact that the capacitor voltage is proportional to the square root of energy (E) used for the capacitor charge. Knowing the nominal DC bus voltage U_{DCn} (in the analyzed case U_{DCn}≈540V), the DC bus capacitance C and the amount of energy, which is supplied by the motor to the DC bus during the motor deceleration, the DC bus voltage can be calculated using a well known equation $U_{DC}=[(2E/C) + U^2_{DCn}]^{1/2}$, where E is expressed in Joules, C – in Farads and the voltage − in Volts.

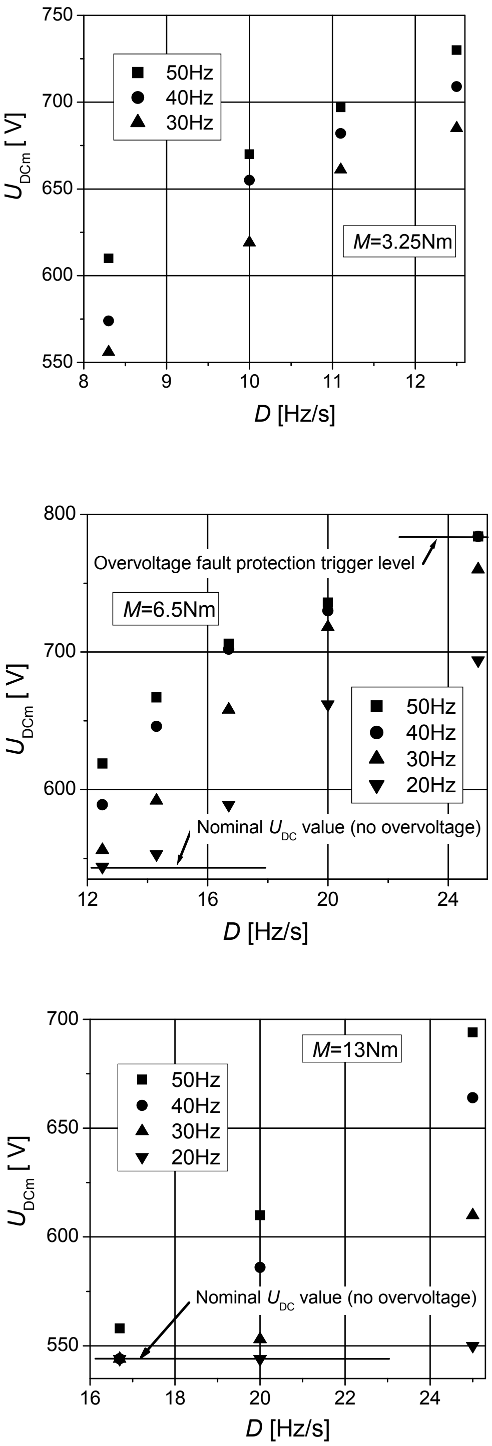

Fig.5. The dependences of the inverter DC bus overvoltage on the deceleration rate of the motor for various motor load torques and motor initial rotation velocities (initial inverter output voltage frequencies) for the case when C=470 μF. Initial inverter output voltage frequency f_p=50 Hz corresponds to V_r ≈2800rpm, f_p=40 Hz – to V_r ≈2200rpm, f_p=30 Hz – to V_r ≈1700rpm and f_p=20 Hz – to V_r ≈1100rpm)

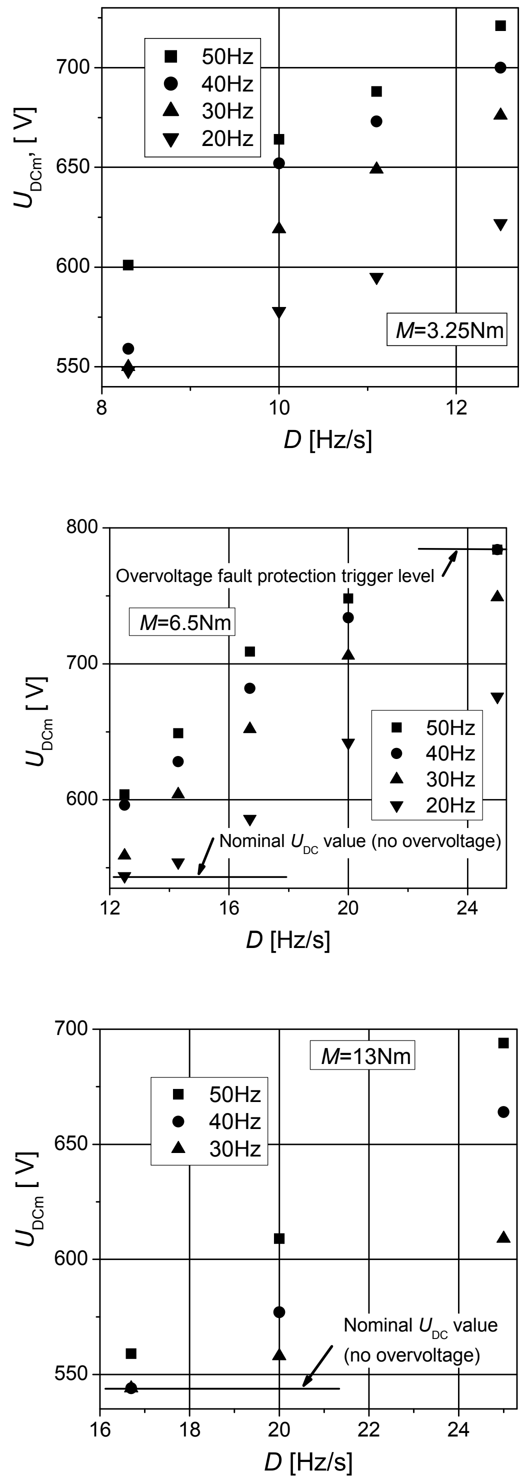

Fig.6. The dependences of the inverter DC bus overvoltage on the deceleration rate of the motor for various motor load torques and motor initial rotation velocities (initial inverter output voltage frequencies) for the case when C=880 μF

For example, if U_{DCn} =540V and the energy of 27.7 Joules is supplied to the 470μF DC bus capacitor, it is charged according to the given equation up to U_{DC}= 650V. If the capacitance is increased up to 880 μF (by the 87%), the calculated voltage at the same amount of energy U_{DC}= 595V, i.e. theoretically the voltage in the analyzed situation should decrease by 7.5% only.

The investigation of the U_{DC} spike duration (Fig. 7) shows that it decreases when the motor initial rotation velocity (initial inverter output voltage frequency) decreases. However, the dependence of the spike duration on the deceleration rate is not monotonic. It has a peak, at which the spike duration reaches the maximal value. The location of the peak depends on the motor load. It is seen (Fig. 7) that in the analyzed case the dependences have the peak at D=10Hz/s if the motor load is 3.25Nm, and at D=17Hz/s when the motor load is 6.5Nm.

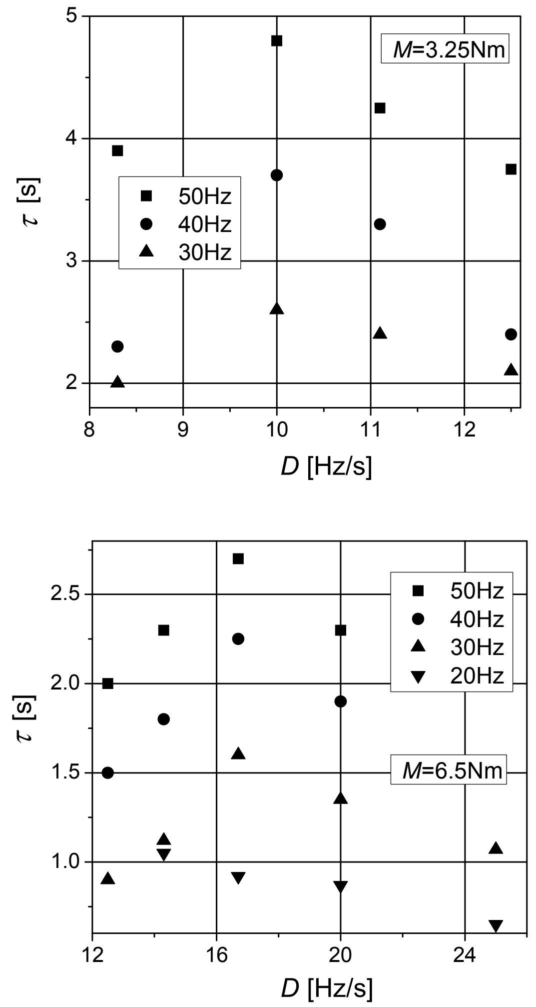

Fig.7. The dependences of the inverter DC bus voltage spike duration on the deceleration rate of the motor for various motor load torques and motor initial rotation velocities for the case when C=470 μF

Conclusions

1. The rising edge steepness of the voltage spike caused by the motor deceleration is relatively low (about 1.5 V/ms). Therefore, the slow and, as a consequence, insensitive to electromagnetic disturbances overvoltage protection circuit with the response time up to several hundreds of microseconds can be employed.

2. The duration of the inverter DC bus voltage spike caused by the motor deceleration decreases when the motor initial rotation velocity decreases.

3. The dependence of the spike duration on the deceleration rate is not monotonic. It has a peak, at which the spike duration reaches the maximal value. The location of the peak depends on the motor load.

4. The increment of the capacitance of the inverter DC bus capacitors allows us to reduce the overvoltage slightly.

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