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ADJUSTABLE SPEED ELECTRICAL DRIVES IMMUNITY TEST TO VOLTAGE DIPS AND SHORT INTERRUPTIONS

Odporność elektrycznych układów napędowych o regulowanej prędkości na zapady i krótkotrwałe zaniki napięcia

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Summary: **The immunity test results of adjustable speed electrical drives to voltage dips and short interruptions have been presented. Based on PN-EN 61000-4-11:1997 standard testing circuit has been built and three different converters have been tested. Some preliminary observation and general conclusions have been included in this paper.**

Strzeszczenie: **W artykule przedstawiono wyniki badań odporności układów napędowych o regulowanej prędkości na zapady i krótkotrwałe zaniki napięcia. Układ pomiarowy do badania odporności układów napędowych na zapady i zaniki krótkotrwałe zaniki napięcia wykonano zgodnie z normą PN-EN 61000-4-11:1997. Badaniom poddano trzy różne, jednofazowe i trójfazowe przekształtniki energoelektroniczne. Wstępne wyniki badań zamieszczono w artykule. Wykazano również niejednoznaczność kryteriów zawartych w obowiązujących normach.**

Keywords: electromagnetic compatibility, power quality, converters
Słowa kluczowe: kompatybilność elektromagnetyczna, jakość energii elektrycznej, przekształtniki energoelektroniczne, układy napędowe o regulowanej prędkości

1. INTRODUCTION

Adjustable voltage dips and short interruptions affect proper operations of converters. In extreme cases, they can cause total interruptions in drive operations. Depending on their application, such interruptions can cause minor to major financial losses.

Voltage dip is a sudden reduction of the voltage at a point in the electrical system. It is defined with help of two parameters: elapsed time and the value of dipped voltage.

A special example of voltage dip is power outage, which could be deemed voltage dip of less than 5% of the voltage supply. For practical purposes, it is designated as depth of dip (Δ U %), defined as:

$$\Delta U \ [\%] = \frac{Un - U}{Un} 100 \ \% \qquad (1)$$

where:
Un — nominal supply voltage;
U — dipped voltage value.

As a result of (1) the nominal dip value can fluctuate from 0 % ($U = U_n$) to 100 % ($U = 0$). For practical purposes, the dipped voltage value of 0 ÷ 10 (%) can be omitted as being the standardized admissible voltage dip as specified by the power provider [1].

The other parameter pertaining to voltage dips, apart from nominal dip amplitude, is the dip elapsed time. The standard [2] does not specify what elapsed time is appropriate for a given tested object, but only outlines a number of normalized time parameters, ranging from 0.5 of power voltage cycle to 50 cycles. The IEC Technical Groups (or CENELEC) should specify these values for standards for individual products or groups of products. Unfortunately, the adjustable speed electrical drive standard [3], does not delineate any values whatsoever.

Bearing in mind that adjustable speed electrical drives are installed typically in the industrial sector, it is assumed that their minimum immunity to voltage dips and short interruptions should not be lower than that of other machines of the same installation. Therefore, the values specified by the standard [4] have been taken as minimum immunity conformity criteria and given in Table 1.

Table 1. Conformity criteria for power drives application in industrial environments for voltage dips and short interruptions, according to [4]

Depth of dip ΔU (%)	Voltage dip elapsed time t_i (ms)	C
30	10	
60	100	
> 95	5000	

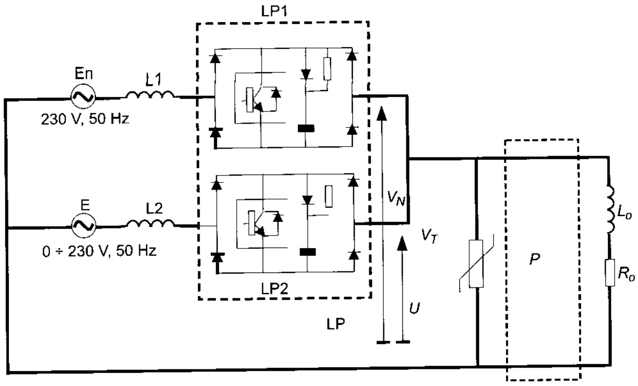

Fig. 1. Schematic of test instrumentation for voltage dips and short interruptions; where: E_n — nominal SEM; E — SEM decreased; P — inverter; L_o, R_o — load; LP — switch circuit

Conformity criteria for inverters are delineated in standard [3] as:

Criterion B Admissible: self-reversible changes of characteristics and temporary changes of phase angle outside the scope of admissibility, temporary miscommunications not resulting in unintended drive switch-offs, temporary communications problems, temporary visible changes to information in the control panel.

Criterion C Admissible: irreversible switch-offs, changes to parameters, safety device start-up, loss of phase angle, loss of data and information. This criterion allows for fuse blows in the main commutation converters.

Taking advantage of testing potential of the Electromagnetic Compatibility Laboratory of the Gdansk Branch of the Electrotechnical Institute a series of tests has been run to examine immunity to voltage dips and short interruptions for a number of available adjustable speed electrical drives. The objective of this paper is to discuss the results of the aforementioned tests.

2. TEST PROCEDURE

The testing has been carried out for three measurement levels given in Table 1.

The elapsed time of dip has been gradually increased for each measurement level from the minimum value of 10 ms, in gradual increments of 10 ms until the switch-off of the tested object.

2.1. Schematic of test instrumentation for voltage dips and short interruptions

Figure 1 shows the schematic of the test instrumentation used for generating voltage dips for a given cycle.

The source of nominal power was power supply (630 kVA, 15/0.4 kV transformer), and the source of decreased voltage – a variable transformer of 0–760 V and 230 kVA. Given such power sources, the voltage scope of testing is restricted by IGBT transistor nominal voltage and diode voltage as shown in Figure 1. The lower of these two values is the diode nominal current of 32 A.

The dip generation set is controlled with help of a microprocessor controller which ensures synchronization or dip start-up at the voltage zero moment and qualifies dip elapsed time.

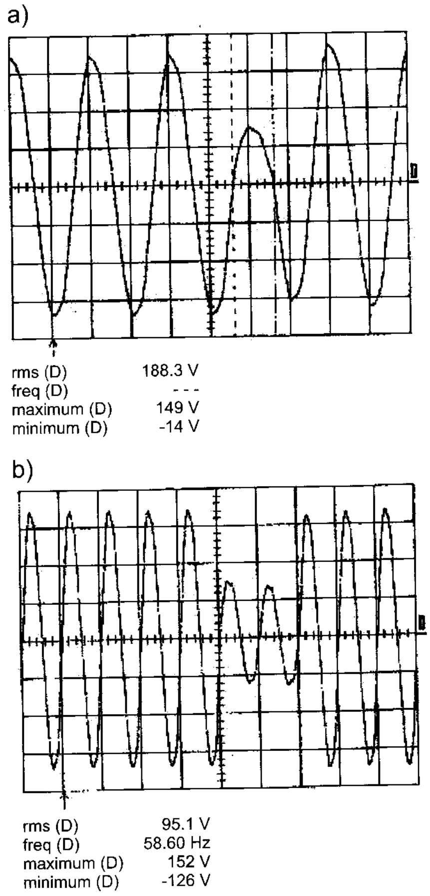

Fig. 2. Voltage time-waveform at ΔU = 60 (%); a) t_i = 10 (ms); b) t_i = 40 (ms)

Tri-phase dips occur in the same phase angle for all phases.

Figures 2, 3 and 4 show voltage time-waveforms for various voltage dips values ΔU and elapsed time Δt_i.

In case of voltage dips three-phase circuits, only one phase is synchronized, and the voltage dip for the other two appears in conjunction with the synchronized one.

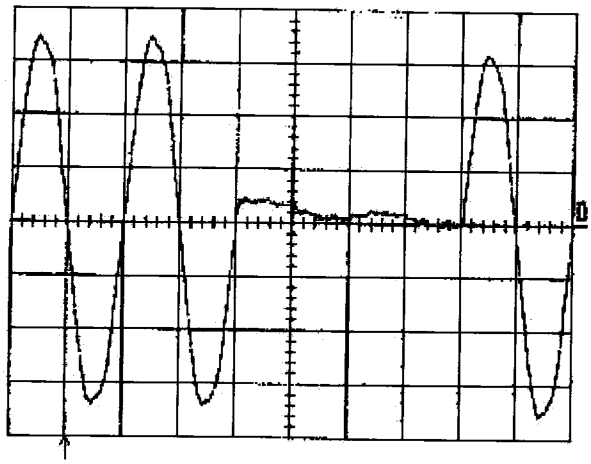

Fig. 3. Voltage time-waveform at $\Delta U > 95$ (%) and $t_i = 40$ (ms)

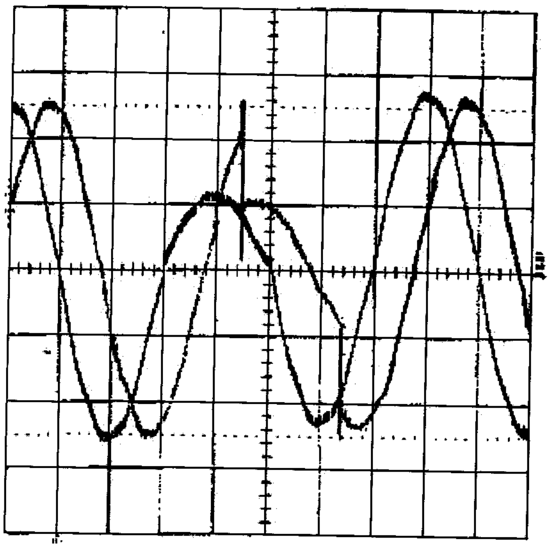

Fig. 4. Voltage time-waveform in two-phase circuits at $\Delta U = 60$ (%) and $t_i = 10$ (ms)

2.2. Testing unit

Testing of inverters immunity to voltage dips has been carried out in a circuit shown in Fig. 5.

The circuit shown in Fig. 5 meets the requirements relating to the methodology of testing and measurements as presented in standard [2].

2.3. Equipment under test

The testing has been carried out in three adjustable speed drives. Two of them are designed to be fed from three-phase voltage, and one – from single-phase voltage. They were assigned X, Y and Z symbols.

The basic parameters of the tested converters are given in Table 2. All converters are equipped with an LCD panel.

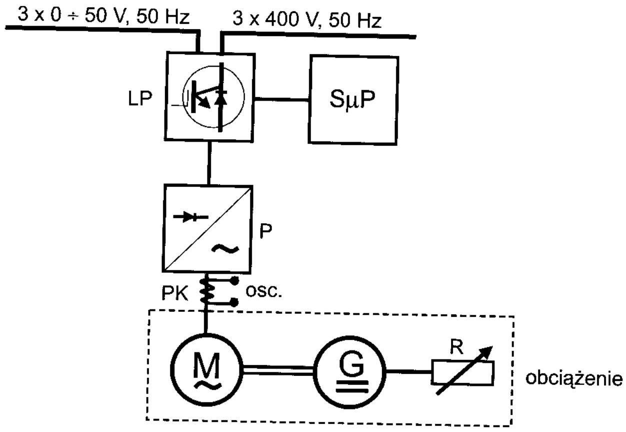

Fig. 5. Testing unit circuit, where: LP — switching circuit; SμP —microprocessor controller; P — converter under test; PK — current probe; M — three-phase inductive drive; G — DC generator

2.4. Execution of the test

As an evaluation criteria for the tested drive and at the same time the converter, has been the waveform of the registered load voltage. Additional information was available from messages specifying type of converter operations interference shown in display panels. The voltage measurement was made with the current transducer 301X of Pearson (USA) of a permanent linear convertion ratio of 0,01 V/1 A, top admissible voltage of 50 kA and working frequency bandwidth of 100 MHz.

The registered drive voltage waveform and known time and placement of the voltage dip enable evaluation of drive functions and analysis of root causes of potential intermissions in drive operations.

Figure 6 shows sample oscillographs obtained for the drive with converter Z.

Oscillograhs have been obtained as a result of the following working environment of the testing equipment:

— Voltage dips in three phases;
— Depth of voltage dips ΔU>95 %;
— Set drive operating frequency f_s = 10 Hz;
— Converter load voltage I_o = 0,8 A;

The following parameters have been tested for impact of voltage dips and short interruptions on adjustable drives:

— frequency;
— load current of circuit-controlled drive.

Table 2. Basic parameters of tested converters.

No	Characteristic values	Converter X	Converter Y	Converter Z
1.	Main voltage[V]	230	3 x 400	3 x 380
2.	Drive power [kW]	1,1	7,5	5,5
3.	Output current [A]	5,0	16,0	11,0
4.	Frequency bandwidth [Hz]	0,5 ÷ 300	0,5 ÷ 360	0 ÷ 200

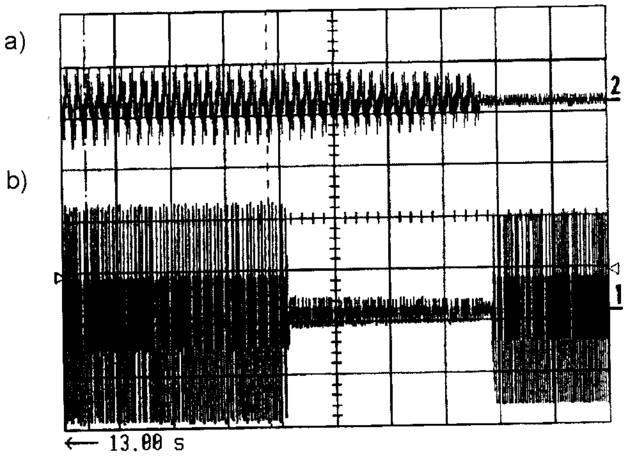

Fig. 6. Voltage and drive load oscillographs of converter Z; where: a) main voltage waveform, b) drive current waveform

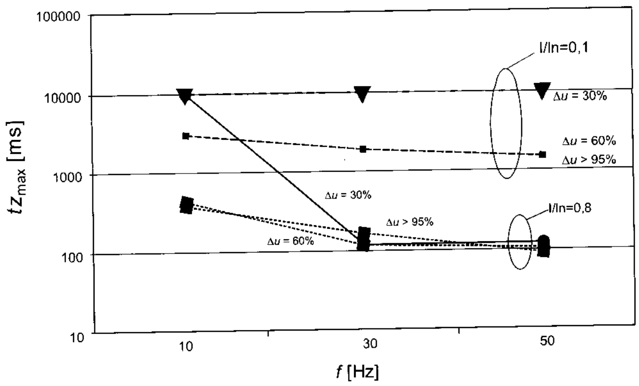

Fig. 8. Correlation of $ti_{max} = g(f)$ for converter Y at various values of ΔU and I/In

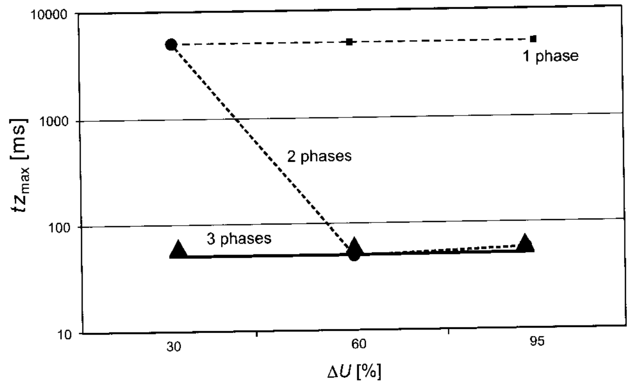

Fig. 9. Correlation of $t_{max} = f(\Delta U)$ for converter Y at I/In = const and f = 50 (Hz)

3. TESTS RESULTS

Test results are outlined in Figures 7 ÷ 10.

Figure 7 shows maximum values of dip elapsed time t_i resulting in switch-off of inverter Y, depending on its set frequency, at the depth of dip of > 95 % and inverter load I/I_n of ca 60 %.

The situation shown in figure 7 indicates the decrease of maximum dip elapsed time causing converter switch-off (ti) with the increase of converter frequency (at constant ΔU and load).

Figure 8 shows the impact of converter load volume, understood as the relation between main voltage I to nominal voltage In, and the maximum voltage dip elapsed time causing automatic switch-off of the converter. With increasing load voltage the maximum dip elapsed time causing automatic switch-off decreases. The same is true for depth of dip (at I/In = const). With increasing ΔU, the maximum dip elapsed time ti decreases.

Figure 9 shows the correlation between the maximum dip elapsed time causing automatic switch-off of triple-phase converter with constant load and constant maximum frequency of 50 (Hz). Decrease of the maximum elapsed time tz depends strongly on the place of dip occurrence in the three-phase network (with dips occurring in one, two or three phases at the same time). With a given maximum operational frequency (50 Hz), the impact of the depth of dip ΔU could not have been observed for dips occurring in one or three phases of voltage at the same time. There have been significant differences to be seen for dips occurring in two phases.

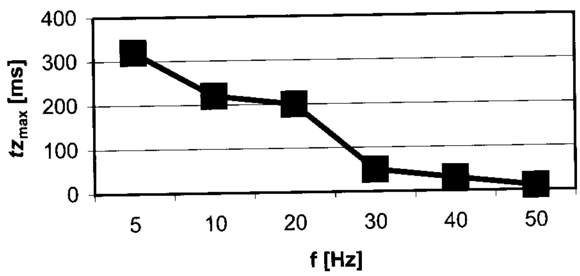

Fig. 7. Co-dependency of $ti_{max} = g(f)$ for converter Y at ΔU > 95 % and I/In ≈ 0,6

During all testing the display panels showed four types of messages specifying causes of automatic switch-offs:

- Overcurrent in power part of converter in normal operation,
- Overcurrent in power part of converter in acceleration mode,
- Voltage overshoot. As a result of generator operations the converter output voltage was switched off.
- Voltage too low. With too low constant voltage the operations of electronic circuits were interrupted.

4. CONCLUSIONS

Since the aforementioned converter testing results pertaining to objects from two manufacturers and encompassing only three available items should be viewed as preliminary. Therefore no generalizations as to the observed behavioral patterns for this group of converters. At the same time it is possible to present the following observations:

1. Adjustable speed electrical drives immunity to voltage dips and short interruptions is dependent upon: the set frequency of rotating motor speed, load volume and type of dip (one, two or three phase).
2. Load has essential impact on immunity of drives. The critical value is ca 80% of the maximum load, above which the immunity drops considerably.
3. There is a direct correlation between immunity of drives to voltage dips and the set of rotating motor speed. The closer to the nominal frequency, the lower immunity.

Based on the testing carried out so far, in order to answer the question whether drives have appropriate immunity to dips, from the standpoint of end users, one has to find answers first to the following preliminary questions:

1. Do the indirect depth of voltage dips and associated elapsed times as specified by the standard [2] are representative for the actual parameters of industrial installations?
2. Are the evaluation criteria specified by the standard [3] precise enough?

According to the standard [3], the depth of dip > 95 % entails a 5 sec elapsed time. It is not however clear whether within this time-frame the drive MUST or CAN switch off. From the vantage point of security and co-ordination of operations of other devices powered without the use of drives, criterion C should be excluded by definition.

5. REFERENCES

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2. PN-EN 61000-4-11:1997 *Electromagnetic compatibility (EMC) Part 4: Testing and measuring techniques. Section 11: Voltage dips, short interruptions and voltage variations immunity tests.*
3. PN-EN 61800-3:1999 *Adjustable speed electrical power drive systems – Part 3: EMC product standard including specific test methods.*
4. PN-EN 50082-2:1997 *Electromagnetic compatibi-lity. Generic immunity standard. Part 2: Industrial environment.*

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