DISTURBANCES IN THE POWER SUPPLY NETWORK OF BUCHAREST SUBWAY SYSTEM (PART 2)

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Rezumat. *În prezentul studiu este descrisă problema distorsiunilor apărute în rețeaua principală de alimentare a metroului București (sub pământ) cauza și acțiunile, la fel și măsurile luate pentru limitarea distorsiunilor produse. Toate acestea sunt reflectate în măsurătorile făcute utilizând osciloscopul Fluke instalat la punctul de dispecer, urmând a fi procesate.*

Abstract. *In the present study it is exposed the problem of disturbances in the main power supply of Bucharest Subway (underground) system, the cause and their action, as well as the measures taken to limit the disturbances produced. All this is reflected in the measurements made using oscilloscope Fluke installed at the dispatch point, following to be then processed.*

Keywords: power supply system, electromagnetic compatibility, disturbance, influence, disruptive voltages

1. Calculations and recommendations

1.1. Calculation of verifying compliance with limits

Verifying compliance with limits is done by Subway Co. for the following cases

Table 3. Compliance with limits

Nr.	Network and operation	Sizes that are calculated	
		Dangerous influences	**Perturbing influences**
1	Networks connected to the ground: a) normal regime - 220...250 kV -1...220 kV b) monophase grounding regime	I_C E, U_r	e_p, U_c e_p
2	Network isolated from the ground: a) simple monophase grounding b) double grounding -if 1>1,2 A/kV or t>10 min -if 1<1,2 A/kV and t<10 min	I_C E	e_p, U_c
3	Network of electric traction a) normal regime b) short-circuit regime	I_C, E, U_r E, U_r	e_p, U_c

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In addition to the sizes of the table, the voltages U_i, U_r will be calculated and their resultant when they act simultaneously.

The significance of size is:

- **I_C (capacitive current)** – alternating current that results from electric influence passing through the earth connection of a telecommunications circuit, for example, through the body of a person in contact with the circuit and earth;
- ***E* (longitudinal electromotive voltage)** - electromotive voltage produced by magnetic induction along a circuit thought to be composed of telecommunications conductor and earth;
- **U_r (resistive voltage)** - voltage in a telecommunications circuit (e.g. wire – ground voltage) due to increased of the potential of soil in the area of the ground installation;
- **U_i (inductive voltage)** - voltage in a telecommunications circuit (e.g. wire – ground voltage) resulting from the action of longitudinal electromotive voltage;
- **U_c (capacitive voltage)** - voltage to the ground of telecommunication circuit, resulting from the electric influence;
- **U_t (test voltage)** - AC voltage value of the dielectric insulation to the ground of the installation exposed to the effect of influences. When this element is a translating coil, U includes the primary – secondary insulation, too. When it is not otherwise specified, the values of voltages and currents of this standard are effective values.

1.2.Definitions

Residual voltage - voltage that remains in the installation of telecommunications while its protection works.

Power supply sector – of an electric traction line - the portion supplied from a single substation, in one direction.

If the traction line is supplied by the substations operating in parallel, it is considered that on the distance between two neighbouring substations there are two sections of supply, bounded by the principal sectioning point.

Electrical influence - permissible capacitive current through the body of a person considered as having a resistance of 3000 Ω, which is 15 mA.

1.3. Magnetic induction and inductive coupling

Allowable limits of the residual voltage from the magnetic induction and resistive coupling are given in the table below, where t is the time corresponding to the first stage of basic protection of electrical installation, including the self timing of the breaker.

Limits relate to the wire – earth voltage, and when there are devices that reduce voltages, limits refers to the residual voltage.

Table 4. Allowable limits of voltage depending of the circuit

Type of circuit	**Allowable limits of voltage [V] for:**			
	Electric line in normal regime	**Electric line under fault, when:**		
		$t < 0,3s$	$0,3 < t < 0,5s$	$0,5 < t < 3s$
Cable circuit with galvanic separation at ends	0,20 U_t	0,85 U_t	0,85 U_t	0,85 U_t
Cable circuit without galvanic separation at ends or airy	60	900	650	430

If there is a wire – earth voltage due to supply or other voltage acting simultaneously with the influences, the limit of 0,85 U_t is replaced by 0,85 $U_t – U_t$. If the case of the damage of material or equipment does not create danger for the people, the limit of 0,85 U_t is replaced by the limit $U_{î}$ and with the acceptance of interested parties; it shall be allowed higher values than U_i, if the protection would cost more than the damages.

In the technically and economically justified cases, the limit of 60 V in the table above, is replaced with a limit of 150 V, with the agreement of the parties concerned, if the normal operation of the equipment allows. In this case, the piece of equipment where voltage reaches more than 60 V will be marked.

When a cable is set with galvanic separation assemblies at the ends A and B, each of these assemblies will be applied the limit in the table above, provided that the B assembly is provided with gas protection at the ends or the voltage between the two assemblies should not exceed 85% of test voltage insulation between them. This provision also covers the case of entry into the common cable circuits from power substations.

In case of magnetic induction, it is calculated electromotive longitudinal electric voltage. If it exceeds the values specified above, the measures will be taken according the wire - earth voltage into these values.

When resistive voltage is applied to insulation and the risk for people can occur only at breaking insulation (for example: when cable passes near a pole grounding), the allowable limits are listed in the table above. This situation is valid for both circuits with the galvanic separation at ends and for those without this separation.

If a circuit is exposed simultaneously to a magnetic induction and resistive coupling, the limits in the table above and the recommendations above are applied to the resulting voltage.

1.4. Calculation of influences

Verify compliance with limits takes place for the cases of influence in networks connected to the ground, isolated from the ground and electric traction (previous tables), in which:

I_{P1} - current in the ground at mono phase current (residual current for compensation coil) relative to the network rated voltage

t_1 - time of elimination of the mono phase defect

e_p - electromotive voltage

Effects of magnetic induction are calculated for both air and underground lines. Effects of electrical influence (I_C, U_C and e_p's electric component) will be calculated only on the portions in which both lines are overhead. If the telecommunication line is the cable one, the effects of electrical influence of the air line will be calculated only if the cable has no metallic sheath or metallic screen connected to ground or no screen surrounding all conductors.

For the insulated network to the ground, cables comprising at least 66% of the total length, the value of 1.2 A/kV in previous tables is replaced with a value of 2 A/kV.

For the electrical network consisting entirely of jacketed lead or aluminium, disturbances will not be calculated:

a) if the network is isolated from the ground, no dangerous influence will be calculated;

b) if the network is connected to the ground, dangerous influences calculation will be made only when:

- electric and telecommunication cables are in the same ditch or channel for the length greater than 1 km;
- without being in the same ditch or channel, are at a distance less than 4 m over a length greater than 3 km.

For the transmission or distribution power network, the resistive voltage will be calculated for the grounding area of poles and power substations. For the electric traction networks, resistive voltage will be calculated for the grounding area of substations.

1.5. Calculation of capacitive current

For the circuits connected to the ground through the impedance of max. 1000 Ω, it is not necessary to calculate the capacitive current. For the circuits isolated from the ground, the capacitive current will be calculated considering the human body of zero resistance.

For the circuits connected to the ground through impedance $Z > 1000$ Ω, the capacitive current through a person's body will be determined by considering the human body resistance equal to 3000 Ω in parallel with impedance Z. The total current is calculated as for the isolated circuit from the ground. The capacitive current is calculated by considering the human body resistance equals zero.

1.6. Calculation of capacitive voltage

Calculation of capacitive voltage is necessary only when the impedance of the telecommunications circuit and earth is greater than 5000 Ω.

1.7. Calculation of longitudinal electromotive voltage

For the longitudinal electromotive voltage, the overall reducing effect of underground utilities (water, gas, etc.) will be considered as a reducing factor or taking the soil resistivity in cities and industrial areas, the value of 0.25 Ω, and in other areas with such networks, the value of 5 Ωm.

If you do not know specifically determined values for fault resistance, it will be taken up:

- 0 Ω for a fault on an electric traction line;
- 2 Ω plus grounding resistance for a fault in a power station;
- 15 Ω for a fault on a line with one or more protective conductors;
- 50 Ω for a fault on a three-phase line without protective conductor.

For calculation, it will be deemed that the faults on electrical lines occur as follows:

a) in the insulated neutral networks, a fault in the power station and the second at the opposite end of the proximity of telecommunication line;

b) in the grounded neutral network and the traction power networks, where the fault produces the largest longitudinal electromotive voltage;

c) in the networks comprising both cables and overhead lines, in one of the air portion of the network and / or the station;

d) in case of the longitudinal electromotive voltage, calculation is made to the composition of the inductive voltage and resistive voltage at the grounding that produces the resistive voltage.

Effects of load currents from the electric traction lines will be led according to the recommendations for the protection of people, materials and quality of transmissions, if other conditions of simultaneity of effects to the line were not determined.

If the telecommunications circuit is next to a single sector of supply, the calculation is made for the currents related to the maximum rail traffic in the area. It is considered that the locomotives are equally spaced and that one of them is at the end of the sector.

If the telecommunication circuit is next to the two sectors supplied in parallel, the calculation is made separately for each sector, for maximum traffic. For comparison with data limits, it will be retained the higher of the two values obtained.

In case of circuits only affected at middle third of the line between two substations, it will be deemed one of the substations is decommissioned and the other supplies both sectors in the same direction.

If the telecommunications circuit is next to the three sectors supplied in parallel, it will be considered:

- values E_1, E_2 and E_3 on the maximum traffic areas;
- difference $(E_1 + E_2) - 0{,}5E_3$ where E_1 şi E_3 are the electric voltages that have the same direction.

It will be kept the largest of these values.

If the telecommunications circuit is next to several sectors supplied in parallel (at least four entire sectors) it will be calculated:

- longitudinal electromotive voltages on sectors, at traction currents corresponding maximum traffic;
- value of their algebraic sum;
- values of longitudinal electromotive voltages induced by the current between substations, current due to unequal voltage on the substation bars.

If no other data, it shall be deemed the voltage difference between these substations is 10% of nominal voltage. The calculation is made separately for each distance between two neighbouring substations. It will be retained the highest of the values.

If the telecommunications circuit is next to the two sectors which have no phase voltages, it will be calculated:

- results at maximum traffic;
- vectorial sum of these results, taking into account the phase angle and power supply direction. The highest result will be kept.

For cases other than those specified above, it will be preceded on the same principles, taking into account:

- simultaneous effects of two neighbouring sectors supplied by the same phase decreases;
- is possible that the time when one of these sectors the traffic is up, the other to be reduced;
- when increasing the number of sectors that induces in a circuit, it increases the likelihood that effects correspond to a uniform traffic;
- effects of sectors supplied from different phases sum up vectorially.

If the risk does not concern people, but only material, equipment and telecommunications performance, the calculation is made according to the previously shown and the result will be multiplied by a factor of simultaneity, with values:

Table 5. Simultaneity factor for number of sectors

Number of sectors	Simultaneity factor, for the risk of:	
	damage	perturbation
Over 1	0,9	0,8
2	0,7	0,6
2	0,6	0,4

1.8.Calculation of resistive voltage

To calculate the resistive voltage, it shall be considered that the fault to the earth occurs at the grounding whose influence is calculated. For fault resistance, the following values are considered:

- 0 Ω for a fault on the electric traction line;
- 2 Ω plus grounding resistance, for a fault in a power substation;
- 15 Ω for a fault on a line provided with one or more protective conductors;
- 50 Ω for a fault on a three-phase line without protective conductors.

It will be considered the currents from all sources that supply the respective point, but only the portion that actually passes through the grounding.

Voltages U_i and U_r will be composed using formula $\sqrt{U_i^2 + U_r^2}$ unless it has been determined other phase angles than 90° between U_i and U_r. Electromotive voltage components will be summed based on the quadratic law, as well.

If a telecommunications line is in the vicinity of two or more electrical networks:

- consider the first that all networks are in the normal regime. It will be calculated influences for this system and influences of various lines and networks will sum in a vector;

- then consider the faulty network (each turn). Its influences will sum up vectorially with the influences of other networks under normal conditions.

Do not consider additional faults in two different networks. The effects of fault current from electric traction networks will be considered separately for each section bounded by two substations.

Calculations will be made considering that the line of telecommunications and its protective devices are in good conditions.

1.9.Recommendations

Networks connected to the ground and the traction ones will be provided with protective devices for automatic disconnection within 3sec when mono phase grounding occurs.

The timing of the first stage of basic protection may be greater than 1s only in justified cases.

Isolated networks from the ground in case of double grounding are provided with protective devices for automatic disconnection in max. 3 sec. In case of simple grounding they are provided with optical and acoustic signalling devices.

Simple groundings must be removed in maximum 10 minutes of their referral by the unit holding the telecommunications network.

Electrical and mechanical qualities of the facilities must comply with technical norms.

To cut the cost of protection of telecommunication lines, the design of electrical installations will examine the following possibilities:

a) choose a route away from the line of telecommunications;

b) reduce the soil grounding resistance;

c) decrease short-circuit currents, for example by:

- reducing the number of neutral points connected to earth, to the extent allowed by safety operation of facilities;
- sectioning of busbars;
- opening of loops.

d) fitting with fast switches and protective devices;

e) fitting of overhead lines with low resistance protection conductor, e.g. steel - aluminium;

f) cable line in urban areas.

In the electrified rail elements whose action by resistive coupling is not calculated, the telecommunication facilities are protected by using practical measurements, according to the official regulations on protection against the influences of electrified railways.

Under the new railway crossings, the cables will be installed in the insulated pipes, even no railway electrification is provided.

Protection against resistive voltages between sheath and earth of the same cable, as well as between two separate cable sheaths will be:

- in the public network by achieving symmetric potentials and grounding;

- cable-in work on power station and network portion of the public network by special measures in accordance with regulations on safety.

Some special measures may be taken into existing telecommunication facilities, we note:

a) reducing wire - earth voltage using protection devices with dilute gas to protect people and facilities;

b) sectioning of coil circuits translators, to protect people and facilities;

c) using translator coils with gas protection devices to protect people and facilities;

d) sectioning line with fuses;

e) earthen of a mid-point of the circuit to protect people and facilities;

f) using compressor – expander to reducing disturbances;

g) installation of current carrier systems to replace transmissions on disturbed vocal frequencies;

h) installation of additional receivers for increasing the allowable limit of psophometric voltages When the relatively good signal p differs from -7 dB, it is used to recalculate the limit or voltage psophometric;

i) restoring transposition with small step, to reduce disturbances, whether they are due to the loop effect.

2. Anti-perturbation solutions

2.1. Changes in CCTV products

Anti-perturbation solutions, which require changes in the CCTV products, target mainly automatic video distributor and cable correction as well and they are designed:

- adjustment of the distributor output in coaxial line;

- rejection of perturbation which penetrates the CCTV chain.

Automatic video distributor has output impedance of approximately 3 ... 50 Ω which is not adequate for the 75 Ω coaxial line output.

2.2. Changes in installations

Anti-perturbation solutions tailored to the level of concern:

- connection mode of external inter stations main signal cable (there are different types of signal cables);

- most convenient way of tying to the grounding belt of the inter stations cables depends on the "hopping" potential in the tunnel and the characteristics of tap to the electrical company's substations;

- disturbance rejection that closes through correcting devices, using isolating transformers, depends of cable coupling and cable – transformers;

- decoupling of CCTV from grounding belt using inductivities, depends of the construction of grounding belts and operating modes.

2.3. Solutions to improve CCTV image reception

In connection with the disturbance discerned on the image to be specified as follows:

- spectrum of the disturbance frequency is correlated with the frequency circuit tracks;
- increasing the level of disturbance is favoured by lower lighting (areas viewed by camera);
- improving quality of the inter station grounding belts allows strong rejection of these disturbances;
- using isolating transformers suitable for powering CCTV equipment at chain ends improves the transmission quality.

2.4.Deficiencies found

In the CCTV chain the following construction and maintenance deficiencies are:

- CCTV in station facilities do not have the equipment chassis connected to grounding belt (stations Tineretului, Eroii Revolutiei, Brancoveanu, Piata Sudului);

- power outlets (for CCTV equipment) whose the contact blades of ground are moved from normal position and no grounding of power equipment chassis (common failure in stations);

- at the video distributor, decreasing the frequency accuracy around 50 Hz excesses the value of (4 ... 6)% specified by the standard product;

- anti - perturbation solutions are not unique: solving the problem of electromagnetic compatibility of the Subway Line II, leads to new solutions, more efficient, for example: using optical fibres;

- in terms of susceptibility to disturbances of the camera, image quality played on the monitor is subject to quality illumination of the target area;

- change in the pattern of disturbances in the Subway system lead to changes in overall performances of the CCTV dispatcher system: e.g. quality of cable insulation and runway make it appears damage in image quality sent directly to the Subway system dispatcher monitor;

- disturbance generator was fully characterized allowing to determine the spectrum of disturbances in facilities function of these elements and to size anti perturbation measures, so as to ensure electromagnetic compatibility in any particular disturbance configuration of the system;

- have highlighted the operating modes of power circuits that cause voltages and currents disturbances and fluctuations;

- has made a comprehensive study of disturbances in the tunnel and technical areas of the subway to assess solutions, achieve and ensure electromagnetic compatibility for all installations in the entire Subway system Line II;

- distortions introduced by the cable manifests on the image reproduced at the reception by the loss of the fine details due to increased of mitigation on high frequency video spectrum and the appearance of the traces or defilement of the image because of the phase characteristic of the cables at low frequencies;

-coaxial cable introduces two types of distortions in the video frequency range:

- attenuation varies almost proportionally with $\sqrt{f}$ instead to remain constant;
- phase feature is the non-linear for frequencies below 1 MHz.

3. Analysis of measurements, conclusions and proposals for improvement

3.1. Introduction

To improve the design solutions to various types of installations, machinery, equipment and the whole subway system, the operating regime influences on the facilities, machinery, equipment and all Bucharest subway system have been examined.

3.2. Interaction Subway Company – electrical company

To determine the interaction (influence) of the electric traction substations on municipal electric power grid and to define solutions for admission to the provisions of the legislation in force relating to the operation in the deforming regime and under load shocks, the short-circuit currents in the electrical company's network were calculated. For these calculations, made for the real structure of electrical company, result that the electrical company's power grid, which is strongly looped and capacitive with power transformer neutrals connected to the earth, affects the Subway system by making earth currents (homopolar) and produces a capacitive displacement of neutral - with influence over telecommunication systems.

3.3. Voltage - current characteristics of wagons

Since the operating regimes are influenced by the Subway wagons, for different trains of Subway, the voltage–current characteristics were recorded in the Aparatorii Patriei station for both directions. These characteristics depend on the construction, maintenance and management mode of the Subway wagons and highlights the fact that current shocks occur (they are associated with changes in magnetic field) and voltage dips (they are associated with changes in the electric field).

Depending on how the subway wagons are run, the energy consumption varies, so the problem of optimal driving of subway train must be taken into account.

3.4. Voltage harmonics in power substations of Subway system

It records the time variation of voltage harmonics 3, 5, 7, 9, 11, 13 on the 20 kV busbars and 380 V general distribution panels on IMGB Depot – Pipera Line.

3.4.1. Placing on technical norms of harmonic voltages on 20kV

Hexaphase rectifier is characterized by the following harmonic currents:

$$\frac{I_1}{I_1}=1;\frac{I_5}{I_1}=0{,}01;\frac{I_7}{I_1}=0{,}14;\frac{I_9}{I_1}=0{,}091;\frac{I_{11}}{I_1}=0{,}077;\frac{I_{13}}{I_1}=0{,}053$$

Harmonic voltages at the point of connection of the rectifier should not exceed the following: U = 20 kV (voltage between phases).

$$\frac{U_1}{U_1}=1;\frac{U_3}{U_1}=0{,}01;\frac{U_5}{U_1}=0{,}025;\frac{U_7}{U_1}=0{,}025;\frac{U_9}{U_1}=0{,}01;\frac{U_{11}}{U_1}=0{,}015;\frac{U_{13}}{U_1}=0{,}015;$$

$$\frac{\sum U_{imp}}{U_1}=0{,}01;\frac{\sum U_{par}}{U_1}=0{,}006;$$

To compare with recordings made on the 20 kV power station busbars of IMGB Depot - Pipera Line, they should not exceed the values:

$$18 \text{ kV} < U < 1{,}10 \cdot 20 = 22 \text{ kV long run}$$

$$0{,}9\,U_n < U_n < 1{,}1\,U_n$$

$$U_3 < 0{,}2 \text{ kV} = 200 \text{ V} : \left(U_{3mas} < \frac{200}{200} = 1 \text{ V} \right)$$

$$U_5 < 0{,}5 \text{ kV} = 500 \text{ V} : \left(U_{5mas} < \frac{500}{200} = 2{,}5 \text{ V} \right)$$

$$U_7 < 0{,}5 \text{ kV} = 500 \text{ V} : \left(U_{7mas} < \frac{500}{200} = 2{,}5 \text{ V} \right)$$

$$U_9 < 0{,}2 \text{ kV} = 200 \text{ V} : \left(U_{9mas} < \frac{200}{200} = 1 \text{ V} \right)$$

$$U_{11} < 0{,}3 \text{ kV} = 300 \text{ V} : \left(U_{11mas} < \frac{300}{200} = 1{,}5 \text{ V} \right)$$

$$U_{13} < 0{,}3 \text{ kV} = 300 \text{ V} : \left(U_{13mas} < \frac{300}{200} = 1{,}5 \text{ V} \right)$$

$$\sum U_{imp} < 0{,}2 \text{ kV} = 200 \text{ V} : \left(\sum U_{mas} < \frac{200}{200} = 1 \text{ V} \right)$$

$$\sum U_{par} < 01{,}20 \text{ kV} = 120 \text{ V} : \left(\sum U_{mas} < \frac{120}{200} = 0{,}6 \text{ V} \right)$$

Transforming ratio is: $\frac{20000[\text{V}]}{100[\text{V}]} = 200$. It is observed that these values are exceeded when subway trains start.

3.4.2. Placing on technical norms of harmonic voltages of 380 V

Harmonic voltages in low voltage network (general distribution panels) U = 0.380 kV stations IMGB Depot - Pipera and Unirii 1 for which U satisfies the following conditions:

$$0{,}3439 \text{ kV} = 0{,}95 \cdot 0{,}380 \text{ kV} \le U_1 \le 1{,}05 \cdot 0{,}380 \text{ kV} = 0{,}399 \text{ kV}$$

$$0{,}3439 \text{ kV} \le U_1 \le 0{,}399 \text{ kV}$$

must not exeed the following values:

$$\frac{U_1}{U_1}=1;\frac{U_3}{U_1}=0{,}0085;\frac{U_5}{U_1}=0{,}0065;\frac{U_7}{U_1}=0{,}006;\frac{U_9}{U_1}=0{,}004;\frac{U_{11}}{U_1}=0{,}004;\frac{U_{13}}{U_1}=0{,}003;$$

$$\frac{\sum U_{imp}}{U_1}=0{,}0025;\frac{\sum U_{par}}{U_1}=0{,}002;$$

Transforming ratio is: $\frac{380[\mathrm{V}]}{380[\mathrm{V}]}=1$

$$U_{smas}<3{,}23[\mathrm{V}]$$
$$U_{5mas}<2{,}63[\mathrm{V}]$$
$$U_{7mas}<2{,}28[\mathrm{V}]$$
$$U_{9mas}<1{,}40[\mathrm{V}]$$
$$U_{11mas}<1{,}40[\mathrm{V}]$$
$$U_{13mas}<1{,}14[\mathrm{V}]$$
$$\sum U_{imp}<0{,}95[\mathrm{V}]$$
$$\sum U_{par}<0{,}76[\mathrm{V}]$$

3.5. Voltage and current harmonics during starting

To determine the deforming regime and cyclic character of electric charge, the measurements of voltage harmonics 3, 5, 7, 9, 11, 13 were performed during of 24 hours for each harmonic. These records reveal deviations from the quality of electric equipment and construction of Bucharest Subway system.

3.6. Harmonic voltage in dispatcher, monitor and camera

To highlight the electromagnetic influences on the CCTV system, there were determined over 24 hours, the voltage harmonics on the electric panels serving subway dispatcher of the Unirii 1 station. Be noted that these harmonics penetrate the monitor protection system (voltage harmonics measured in monitor), as well as camera protection system (voltage harmonics measured in cameras).

Inside the subway dispatcher, using an antenna, the voltage harmonics (electric field) were measured but also in the electricity lab.

3.7. Variables potentials along tunnel

Defects in construction of the tunnel and running route are detected by the "hopping" potentials that appear along the tunnels of subway from Piata Unirii 2 –

IMGB Depot stations. These "hopping" potentials are due to insulation defects and are detected at the train crossing through areas with poor insulation.

3.8. Method of calculation of electromagnetic influences

Capacitive displacement of neutral - caused by the electrical company's power grid, variable potentials in the subway's tunnels, power system characteristics that cause current harmonics (whole network - rectifier) and subway trains all cause electromagnetic disturbances.

3.9. Disturbances in CCTV cable

Using the oscilloscope with memory, the disturbances have been viewed on the CCTV cable between dispatcher Unirii 1 and the Subway stations: IMGB Depot, stations IMGB, Aparatorii Patriei, Piata Sudului, Brancoveanu, Eroii Revolutiei, Tineretului, Unirii 2, Universitate.

There is a correlation between the disturbances in the CCTV cable – and the "hopping" potential caused by the insulation and construction irregularities in achieving the tunnel and the runway. It is recommended that in future such measurements be made to highlight constructive infringements of the tunnel insulation and running routs.

3.10. Causes of disturbances

Disturbances in the CCTV system - Subway occur due to sudden changes of current and voltage in the alternating or direct current circuits. In this case, in the circuits of electrical devices and circuits connected to these devices, the currents with a very large frequency spectrum (that can include any frequency up to 50 MHz) are produced. A source of electromagnetic influences is the hexaphase rectifiers. These influences have frequencies which represent multiple the primary source frequency. Disturbances enter the CCTV system through the earth (tunnel) connection or main supply.

3.11. Measurements for determining effects of converters

Measurements for determining the effects of converters (rectifiers, inverters) at the Bucharest Subway Company were designed in this paper for two purposes:

a) comparing the results with technical norms:

- EP 142/80 – Technical norms on combating the flicker effect;
- EP 143/80 – Technical norms on limiting the distorting regime.

b) raising characteristics ρ, $Q = f(I)$ of converter for calculating the optimal operating points and providing the necessary sizing of compensation installations of the converters, which are distorting consumers.

Issues raised by converters on the supply network are function of the ratio of short - circuit $\frac{Q_{SC.system}}{Q_{SC.mutator}}$, and the amplification of some current harmonics depends on the resonant frequency of the network, as well.

3.12. Deforming regime - method of limitation

To prevent deforming regime, characterized by levels of parameters beyond the limits allowed by the norms - PE 143/80 - should be taken into account the possibilities of application the following measures:

a) selecting of devices to be characterized by a low current harmonic level generated;
b) preferential location in terms of power supply network in the area of high short-circuit power;
c) increase the number of the rectifier's pulses;
d) increase the short - circuit impedance of the deforming device.

Regardless of the specific of the deforming consumer need for the design stage:

1) determine the deforming regime parameters. Evaluation of the harmonic voltages level and the voltage distortion factor is done by knowing the harmonic currents (indicated by the manufacturer of the device or measured in similar facilities) and harmonic impedances of the regional power network.
2) examine the possibility of occurrence of the resonance phenomenon.

DEFORMING REGIME is due to the operation in the alternating current networks of the deforming apparatus. According to Academician Professor Constantin Budeanu, they can be divided into devices that are the cause of the initial production of deforming regime (converters, iron core reactances, etc.) and devices that are powered by the deforming currents, enhance this strain. So, for a deforming regime to exist, at least one of the network parameters is not linear or a signal applied to the network must be non sinusoidal.

3.13. Effects of deforming regime

Taking into account the consequences of deforming regime, they are:

-raising the line losses and increasing the apparent power of receivers, thus reducing the power factor and efficiency;
-resonance phenomena in the power networks and consumers;
-disruption of the telecommunication lines by the harmonic currents;
-deformation voltages of the networks through the power failure caused by the current harmonics;
-errors of measurement on measuring devices.

3.14. Special measurements of power

We determined by using the PQD meter, made in the point of common connection, the network reaction:

- APPARENT POWER S characterizing the presence of instantaneous powers in terms of restraint facilities, the losses due to transmission power, etc.;
- ACTIVE POWER P that defines a system of instantaneous power, permanent and having an average finite value over a voltage half period;
- REACTIVE POWER Q that defines a state created by the alternative instant power with a zero mean value, caused by the intrinsic variation of electromagnetic energy transmitted with a non-zero mean value;
- ELEMENTARY DEFORMING POWER D corresponding instantaneous alternative power with a zero mean value, because of changes in the energy transmitted, the average value is also zero. It should be noted that the instantaneous deforming power not always due to intrinsic electromagnetic variation deflection wave voltage and current that may cause certain harmonic amplitudes increase, leading to resonance phenomena of voltage or current.

Variation of these powers is given in the range 0 ... *t*.

3.15. Methods to reduce deforming regime

As in a deforming regime the effects of an inductive receiver cannot be compensated using a capacitive receptor and vice versa, from measurements on Subway Line II have found ways of reducing the network reactance by installing converters that decrease the amplitudes of the current harmonics.

To reduce harmonics of the mains supply, it is required to choose a rectifier with a higher number of pulses, but for economic reasons this is not always possible. Since the network parameters play a role in the LC filters failure, these situations were not taken into account. For the operating procedure $\alpha \neq 0$ and $\beta \neq 0$ that may act on the power factor by switching. Taking into account the results obtained, it is necessary systematizing of converters for the electric traction and consideration of the power network reaction (*P, Q, D, S,* power factor), on load variation, to install converters through their construction have deforming regime diminished.

3.16. Measurements on switching regimes in case of short-circuit or normal operation

The measurements of the currents and voltages in case of short-circuit in the Stefan cel Mare substation that emphasizes the normal operation of electromagnetic equipment is presented here. Also, in this station, the measurements of the currents and voltages have made on the DC and AC sides on disconnecting rectifier under load and no load.

3.17. Analysis of measurement on switching regimes in stations Stefan cel Mare and Gara de Nord

Here it was determined: the maximum short-circuit current, liquidation time of short-circuit, maximum voltage levels, service voltage of 820 VDC, over voltages, current slope at t = 0 sec., current value at which the electric arc occurs (open contacts), opening time of contacts, time adjustment (time at which the breaker reaches the adjustment value), proper time of the breaker.

From oscillograms result calculation parameters (maximum short-circuit current and time constant of the circuit) to supply the short-circuit of one (two) rectifier(s), depending on the distance from the short-circuit site (fig. 6).

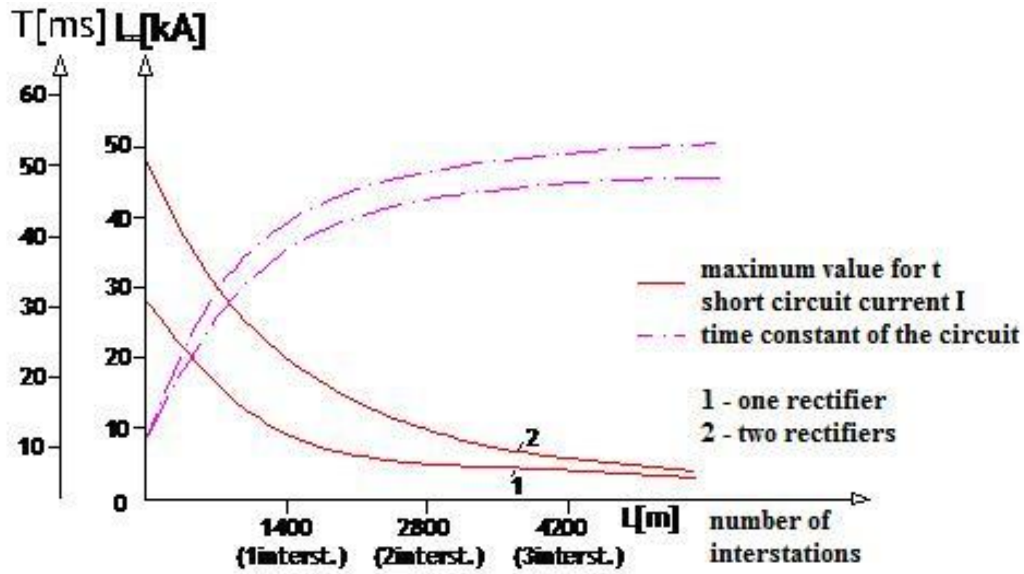

Fig. 6. Calculation parameters (the maximum short-circuit current and time constant of the circuit) to supply the short-circuit of one (two) rectifier(s), depending on the distance from the short-circuit.

Supply scheme for the subway line assumes in each substation two busbars of +825 V, supplied by one rectifier. Each busbar supplies through two cables (left–right) adjacent intersections (fig. 7).

In figure 8 is presented the variation of the short-circuit current through the breakers A2 and B2, inter station 1400 m and in figure 9 is presented the variation of the short-circuit current through the breakers C1 and D1, inter station 1400 m. Variation of the short-circuit current through A2 and B2 breakers, inter station 700 m, is shown in figure 10 and the variation of the short-circuit current through the breakers C1 and D1.

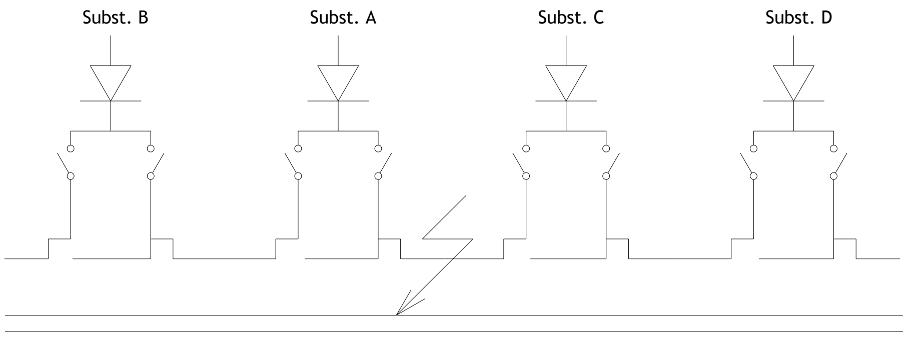

Fig. 7. Supply scheme for the subway line studied

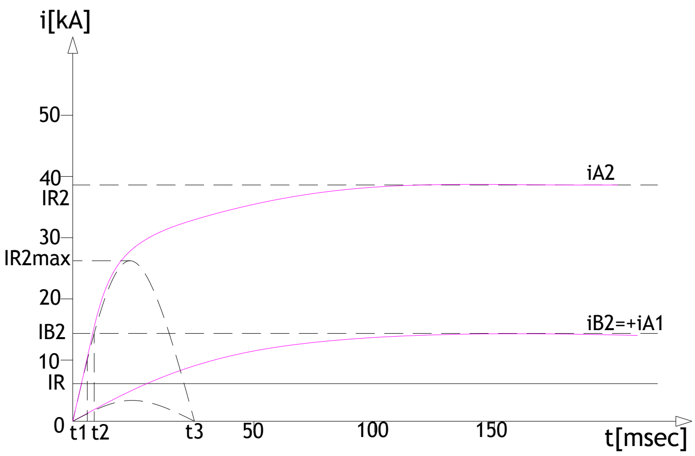

Fig. 8. Variation of the short-circuit current through the breakers A2 and B2, inter station 1400 m.

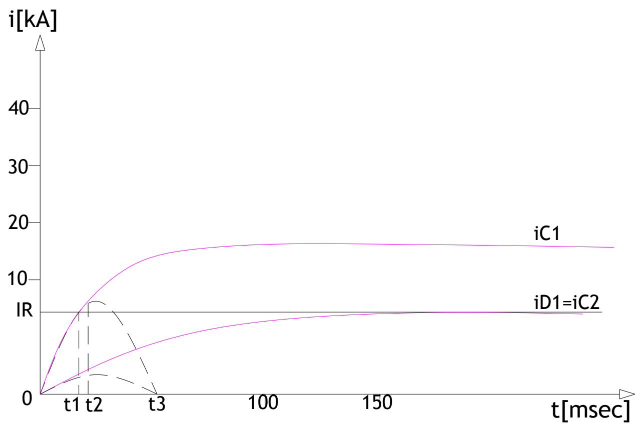

Fig. 9. Variation of the short-circuit current through the breakers C1 and D1, inter station 1400 m.

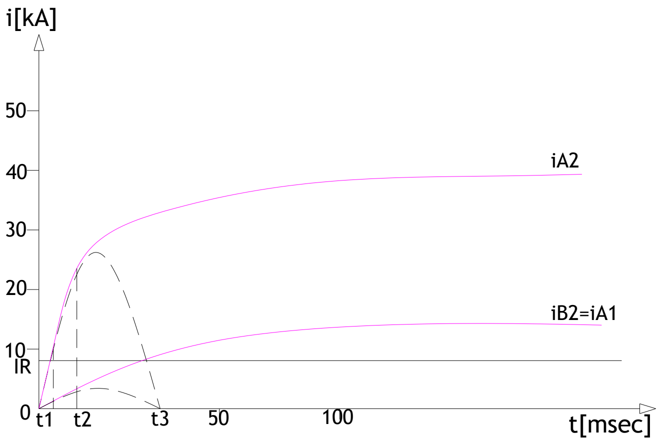

Fig. 10. Variation of the short-circuit current through the breakers A2 and B2, inter station 700 m.

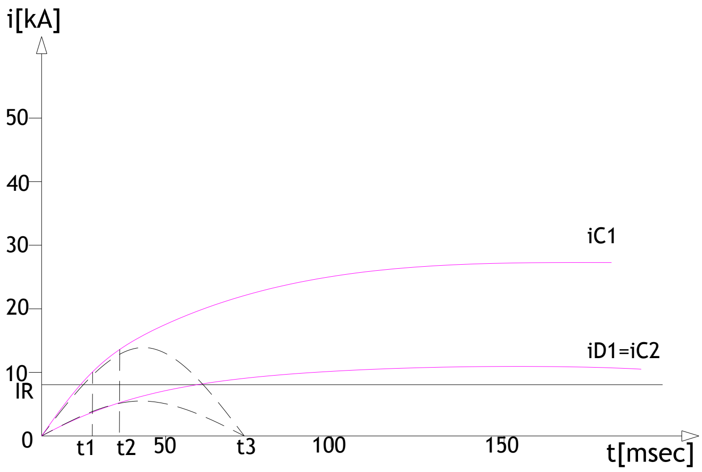

Fig. 11. Variation of the short-circuit current through the breakers C1 and D1, inter station 700 m.

4. Conclusions

There are mutual disturbances between the power electronic equipment and electrical networks (the electrical company's AC networks and subway company's DC networks).

Current shape used by rectifiers (harmonics) depends on the rectifier assembly and absorbed current variation by the train wagons.

Theoretically, the currents in line (to network) contain only frequency harmonics of $(kp \pm 1) \cdot f_1$ and DC voltage contains only frequency harmonics of: $k \cdot p \cdot f_1 \quad [k = 1, 2, 3 ... p = pulsation]; \quad f_1 = 50 \text{ Hz}$.

Practically, the tolerated deviations from the theoretical sinusoidal shape and symmetry of voltages (to network) lead to appearance of harmonics of the theoretical value ought to be zero.

For some apparently symmetrical coupling ways, asymmetrical switching can lead to harmonics who's the theoretical value should be zero. Current harmonics are characterized by the fact that their amplitude decreases rapidly. Since the fundamental current is 95% and current harmonics are effectively 5% of current. As a fact the current harmonics cause losses in the mains supply, transformers and electrical machines.

Harmonics resulting from current form lead to deformation of the network voltage according to the network harmonic impedance, which is often difficult to determine. Voltage harmonics cause disturbance to other electrical receivers. Inductive voltage drop reduces the higher harmonics. Switching causes to the supply network voltage, pinches and beaks (due to temporary short - circuits) and produces changes in the phase angle and reactive power. At some point, the amplitude of the pinch (beak) depends on the ratio: total inductance per phase / upstream inductance per phase. High frequency oscillations caused by switching are sudden voltage jumps which occur at the beginning and especially at the end of commutation.

Reaction of the power grid, in the point of connection of the rectifier, is characterized by: changes in voltage, current imbalance, voltage deforming, frequency variation, instantaneous disappearance of part or all of a phase, instantaneous disappearance of part or all of the phases (interruption and restoration), incompatibility among several networks, propagation of high frequency disturbances.

There is mutual disturbance between electric motors of the trains and AC and DC power networks. In the electric motors of the trains, parasitic forces and vibration of the stator appear which depend on the quality of the terminal voltage.

International standards require that telephonic harmonic factor (THF) of the engine goes no further than 1.5%. Variation in time of the voltage on terminals, so the THF factor, may be determined by the Fourier analysis of curves of the polar field and wiring factors of the corresponding stator wiring. Like any flexible structure, the electric machine stator has natural frequencies with different characteristic shapes.

Parasitic forces act on the stator core, such as radial and tangential directions. Change of the mechanical structure of the motor stator leads to reducing the vibration. Design steps can be taken to move the natural frequencies and to avoid the maximum forces. This will ensure that the oscillation amplitudes will be reduced even from the design stage.

4.1. Measurements and their interpretation

Measurement of the dispersion currents of the tunnel was made by using the method of measurement of the potential drops along the tunnel.

Potential drops on about 500 m long tunnel (under current circulation area of the train, when the train is a distance of 500 m from the station) should be no larger than 100 mV. Bur positive and negative peaks were found above these values.

Measurements were made of lateral resistance of ballast to determine areas and weak points of insulation. Insulation resistance of the runway to the structure must be maintained at values of 5 ÷ 10 Ω km, but not less than 1 Ω km.

Because the voltage drop in the U runway and low insulation resistance (ballast resistance) of the runway to the concrete structure of the tunnel, a part of the traction current turns back to the traction substation (to the point of negative cable connection to the runway) through the reinforced concrete structure of the tunnel and hardware placed in the tunnel. This causes electromagnetic incompatibility, as well influence of CCTV, telecommunications and corrosion in the tunnel.

Measurements, samples and tests, to verify the technical characteristics of the Subway system Line III, were made, as well as for the 3rd runway rail.

To accurately assess the influences that the electrical traction produces on the neighbouring installations, it is necessary to determine the distributed electric parameters of electrical power supply to the train wagons. These measurements were carried out under practical conditions of the sitting of the 3rd runway rail, running track and positive and negative cables. The results are heavily influenced by the 3rd runway rail insulation and the runway as well.

Electromagnetic disturbances occurring in the CCTV system arise due to sudden changes of AC and DC voltages and currents. Removal of disturbances, at source and binding circuits, is achieved by following methods:

-avoidance the cause that produces disturbances (e.g. reduction of the DC machine collector fire);

-electromagnetic shielding and disturbance removal that spreads to the networks directly related to the source by using filters;

Over voltages that appear in the remote control, signal and measure cables on subway are determined by:

- switching the power supply sources from the load to the idle;
- capacitive load of the lines (cables are essentially electric capacities);
- wrong handling of the connection or disconnection devices of lines;
- earth currents;
- resonance phenomenon.

Switching the supply transformers of the underground remote control, signal and measure cables (TTS) causes directly dangerous increase of the voltages that have the effect of weakening or destroying electrical insulation. To combat them should:

- be known technical terms in which that occurs;
- be taken technical measures of protection;
- remove the causes producing over voltages.

Over voltages occurrence in the remote, signal measure cables caused by the existence of the capacitive currents in these lines is under certain conditions, can create, by reducing the inductive currents, dangerous surges in adverse effects on electrical insulation.

4.2. Over currents, causes and effects

Transport of electricity in a remote control, signal and measure line is subject to the existence in that line of a maximum current that cannot be exceeded. When the current exceeds this value, an over current arises in this line determined by:

- absorption currents of receivers in the system;
- short-circuits;
- earth currents.

Absorption currents of the electric receivers, both AC and DC currents, exceed nominal currents that move in electrical line and subway traction lines creating premises of the initial start of developing over currents. Short-circuits are common faults in the subway traction lines caused by touching two conductors which have a potential difference.

Earth currents produce appreciable over currents as due to a defect in the cable insulation or wires breaking inside cables. In this last situation one of the conductors becomes grounded or all the cable wires become grounded. In both cases, dangerous over currents arise producing cable insulation deterioration. Over currents, in particular due to short-circuits, produce faults in the remote control, signal and measure underground cables even in the short time until the circuit breakers trip off due to heat by the Joule – Lenz effect. Besides melting conductors (the most endangered are aluminium ones) over currents can cause burning insulating and protective coatings of the cables. The subway remote control, signal and measure cables must be protected against electromagnetic influence of the power lines. If in the electromagnetic field of a conductors system is another conductors system, the effect of variation of the electromagnetic field of the first conductors system creates in the second system, voltage and current disturbances that disturb the proper functioning of remote control, signal and measure lines. Technically, it is sufficient, to limit induction produced by the high voltage to certain values, such as the remote control, signal and measure cables can achieve a virtually non-deformable signals transmission.

4.3. Proposals

Permissible limits of the dangerous induction. There are two different kinds of dangerous inductions:

a) induction during the breakdown regime of symmetrical power transmission lines with neutral connected to earth or isolate when the longitudinal electromagnetic forces or load current appear in the remote control, signal and measure lines, shortly, only during the breakdown and disappear when disconnecting the damaged line;

b) induction during the normal regime of power transmission lines operating in asymmetrical regime, when the longitudinal electromotive forces or load current in the remote control, signal and measure lines persist for a long time, while inducing lines work. Because there are two types of dangerous induction, two acceptable limits have been set.

High voltage power lines at subway may influence the signals transmitted on remote control, signal and measure lines. Industrial frequency currents disturb the transmission of signals, since the frequency is close to the industrial frequency current. Harmonic components of currents and voltages influence the remote control, signal and measure cables and, as well as the transmission of signals on cable phone line.

Because the influence of power lines on the remote control, signal and measure cables do not produce unacceptable disturbances, the design directives should be applied.

There is an interaction between power circuits of the Bucharest Subway Company, trams and Electrical Company. Interaction issues and electromagnetic compatibility can be addressed taking into account all these influences.

Circumstances in which the interference signal is largely caused by incompatibility between the weak current measurement technique and intense current measurement technique. This imposes measurements to limit dangerous voltages.

Manner of occurrence of the interface is due to:

- current i, of power circuit, which produces an alternating magnetic flux Φ_1, determining passing a current through the coaxial cable screen;
- variable magnetic flux Φ_2, produced by currents passing through close conductors, which causes a current passing through the coaxial cable screen;
- electromotive voltage e_1 causes an interference signal due to the fact that an alternating current passing through the device casing
- due to capacity between the central conductor and cable screen as imperfect screen provided by braided metallic screen is signal interference;

- behaviour of the simple - shielded coaxial cable is better at small cable (Φ_3, 5÷5,3) for frequencies above 1 MHz;
- behaviour of the double-shielded coaxial cable is better for frequencies below 100 kHz;

In order to eliminate the interference, the following technical measures are taken into account:

- shielded isolation transformer, with minimal capacity between primary and secondary winding;
- filtering cells placed between the shielded transformers and metering device;
- shielded coil for making measurements in the heavy currents and high voltage with rapid variations.

In current practice, the shielded systems can be divided into the following:

- frequency range 1 kHz – 1 MHz. Electric field lines are short-circuited by the conductive surface of metallic sheets and as a result screening in the electric field, in this frequency range, is practically perfect. Shielding against the magnetic field is given by the permeability and wall thickness of the coil.

- frequency range 1 MHz – 100 MHz. Because of the discontinuities in windows, doors, no longer can count on a short-circuiting the electric field lines. Shielding effectiveness decreases with the increasing frequency in this range. Magnetic shielding is limited.

- frequency range > 100 MHz. Interference wave can be considered plane. Depreciation of the plane wave, because of the skin effect, depends only on a good electrical conductivity of surface material used in screening.

Following measurements, it was decided to implement the fibre optic communication.

NOTE: ***This study it was realised when the stations had another name. In the present, some stations have another name only. For concordance, it was kept the name of the station from the date when the study it was realised.***

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