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DISTURBANCES IN THE POWER SUPPLY NETWORK OF BUCHAREST SUBWAY SYSTEM (PART 1)

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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. Introduction

For the Bucharest Subway, the problems with the disturbances in the main power supply system exist. These problems were revealed once with the measurements made using oscilloscope Fluke installed at the dispatch point.

1.1. Subway substations connection to electric power network

Subway substations connection to the electric power network is made by:

a) High level short circuit currents due to strong loop network;

b) All transformers of 110 kV / MV (medium voltage) of power stations have the neutral connected to earth on 110 kV - so in the City of Bucharest is a homopolar current circulation with damaging effect on the reinforced concrete buildings;

c) On the side of medium voltage in the power network and consumers connected to the medium voltage (20 kV - for example, Bucharest Subway Line II) capacitive neutral displacement occurs, with the effect on telecommunication systems and closed circuit television;

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d) As in the power stations 110 kV / MV (for example IMGB), the short-circuit powers vary from power substation to power substation and within the same power substation from busbars to busbars, at National Power Dispatch we made short circuit calculation, in real terms, for the entire electric power network of the electrical company in the spring time. These results are needed to determine the interaction between electrical substations of the Subway system and electric power network. This interaction depends on the power level installed in the electrical company's power substations and short-circuits power at the point of connection;

e) Through the Subway system tunnel, the harmonic currents close and penetrate through transformers - power rectifier substations of Subway. They overlap with the currents through cable casings which connect the Subway system and the electrical company. In this way, a parasite movement occurs between Subway's power substations and the electrical company's power substations. In the electrical company power substations, power transformers are installed that supply the Subway system. They differ in number, power and short circuit voltage. The power transformers with different characteristics are connected in parallel for a short period, causing a loop current circulation among the power substations of the Subway system and the electrical company.

1.2. Features of subway train

a) Trains of the Subway system, depending on how they were constructed and maintained, have characteristics that differ from train to train;

b) Depending on how the subway train is driven (according to the driver mental state) the current shock varies, as well as the shock duration and voltage shocks - on the DC (direct current) side As a result, the energy consumption varies;

c) If the DC motors are not properly maintained and do not have anti-parasitic capacitors, the ignition phenomenon at the collector occurs. This causes stress on the train wagons and electromagnetic disturbances;

d) Depending on the sensor cleaning mode and the third metal track, sparks occur during the start.

1.3. Features of runway

a) Due to poor insulation of the runway along the tunnel in some areas, variable potentials type "hopping" occur;

b) Size and change of their variation were highlighted by measuring and recording the voltage drop on a portion of 500 m along the tunnel "U" shape – during the time when this portion was covered by a train in start-up;

c) As a new technical solution by recording with a Fluke oscilloscope installed at Dispatcher, the induced disturbances were observed in a telecommunications cable (e.g. closed loop circuit television). The cable was shorted to the ground by 75 Ω impedance equal to the characteristic impedance in the Subway system power substations. Following the trains position in the tunnel, it was found that areas with damaged insulation or careless construction of the runway can be highlighted;

d) There are areas where stray currents appear between the runway rails, e.g. level of 800 - 1200 A. That causes the phenomenon of "pinching". This is due to careless construction of the runway.

1.4. Features of Transformer - Rectifier Unit

a) In the point of connection in the MV power network (20 kV) of the Bucharest Subway system, whose feeds are made by very long cables, due to cable capacity, the resonant phenomena occur (oscillations of order of kHz), because of switching phenomena;

b) Because the electrical company's power network is over compensated (highly capacitive), placing capacitor batteries cause resonance (oscillation). The resonant frequency of oscillation depends on the ratio between the reactive power of capacitors and stray capacity over power short circuit. Also, according to this ratio the harmonic spectrum depends;

c) Because the degree of loading (current shock produced by the Subway system trains) varies rapidly and has duration of tens of seconds, the resonant frequency varies, as well as the degree of compensation, the degree of deformation of voltage at the point of connection and the voltage curve. The electric current registered on feeders depends on the relative power of the rectifier, the angle control, the network impedance, the inductance branch in parallel and the cable resistance;

d) For highlighting these phenomena, there were recorded voltage and current harmonics 3^{rd}, 5^{th}, 7^{th}, 9^{th}, 11^{th}, 13^{th} ... 31^{st} on the IMGB power substations' busbars;

e) These features vary from substation to substation and reveal any construction deviations (hidden defects of the equipment) and interaction among the metallic frame - rectifier - power transformers – the electrical company power network. When the measurements finished and conclusions drawn, the designer of the Subway system has decided to replace the universal rectifiers with thyristors;

f) These harmonics penetrate the close loop television equipment: monitors, coupling transformers, connecting cables, cameras;

g) Because of the rapid changes in the current when the subway train starts, it causes the magnetic field variation and voltage dips, the electric field harmonics at dispatcher were recorded and power electric laboratory, as well. It was found a similarity between the form of variation sizes and recorded ones;

h) During the start-up process, the voltage, current, active power, distorting power and apparent power were recorded simultaneously to see the influence of switching phenomena;

i) All such records have imposed the need for a data bank on industrial equipment applications - giving real-time behaviour. It appears the need to improve the runway insulation - which was carried out carelessly - and, as well, determination by an effective method of behaviour of electric power installations in a new section put into service:

- features of voltage - current in the subway train;
- voltage harmonics;
- variable potential along the tunnel;
- graph recording of disturbances submitted to telecommunication cables.

1.5. Behavior of switching equipment

a) Following the short-circuit test near and far in the IMGB substation, it was found that the high- speed circuit breakers behave normally and switching over voltages do not occur. Not exceed 18 kA < 30 kA – present value of guaranteed short-circuit;

b) After the short-circuit test near and far (stations Piata Sudului, Aparatorii Patriei) it was found that the high-speed breakers behave normally, but short-circuit currents of 29 kA appear, as well as switching over voltage of 1260 V > 850 V;

c) From the test of disconnecting and connecting the rectifier on DC and AC side when there is no train or train to start - it is found that the switching equipment behaves normally;

d) Recording DC voltage shows the presence of harmonic of 300 Hz produced by the hex phase rectifier.

1.6. Behaviour of Closed Circuit TV (CCTV) equipment

a) Electromagnetic disturbances of frequencies between 50 Hz-50 MHz penetrate all equipment of the subway system;

b) The strongest penetration is observed through the CCTV cable (double shielded cable) - because along the tunnel there are variable potentials and the cables do not meet the terms of the level of insulation - since it takes over as the variation of variable potentials along the tunnel;

c) In the CCTV cable, insulation breakthrough occurs, changes in insulation resistance and electrical resistance, as well;

d) Inductive coupling of screen with wire inside creates low impedance for the return current through the screen (the disruptive route);

e) Connecting the screen to earth (tunnel - with variable potentials) forces the disruptive current returns from the central wire through the screen.

1.7. Preliminary Conclusions

Using Fluke devices, in the work we have established new measurement methodologies, we checked them and realized measurement result analysis. They led to the following conclusions:

- Have established the precise conditions of operation of upgraded traction rectifier RSTM - 0825M;
- Have set the effect of electric traction substations of the electrical company’s power system. To define solutions for admission to the technical norms, there were determined the short-circuit currents and characteristics of the electrical company’s 110 kV / MV power network;
- Have defined technical solutions to framing into technical regulations for operation under deforming system and load shock throughout the Subway Line II;
- Have established the causes and nature of disturbances that occur in the closed circuit television system at the central dispatch of the Unirii 1 station. To diminishing that, the runway insulation needs to be improved, subway frame optimized and properly maintained as well.

2. General electromagnetic compatibility

2.1. Definitions

ELECTROMAGNETIC COMPATIBILITY is the condition in which the level of immunity to disturbances of any device on the system is higher than the level of disturbances to which the device is subjected in the system. Concept of electromagnetic compatibility refers to the system in which the device is used (TV monitor, TV room, TV cable), a device having the ability to be compatible in one system but not necessarily in another.

COMPATIBILITY LEVEL is the level of disturbance, less than or equal to the immunity of any undisturbed device in the system but equal to or greater than the disturbance level generated by the system disrupters.

NOMINAL COMPATIBILITY LEVEL is the estimated one under nominal conditions, with acceptable variations, e.g.: frequency, voltage and load.

CRITICAL LEVEL OF COMPATIBILITY is the level of the best advantageous conditions. It should be considered in emergency or rare events, in which case the protection and safety measures should be taken and enforced to prevent: human casualties, scraping, interruption of work and damage to equipment.

ELECTRIC IMMUNITY LEVEL of a device is defined as the maximum amount of disturbance that can be applied to, without losing its performance. The degrees of severity are:

- functional immunity level;
- failure immunity level;
- damage immunity level.

COMPATIBILITY MARGIN is defined as:

- difference in decibels between the level of immunity to disturbance of the device or system and level of disturbance to which it is subjected. Compatibility is the case of system or subsystem in which the margin in dB is positive;

- ratio between the level of immunity to disturbance of the device or system and level of disturbance to which it is subjected. Compatibility is the case of system or subsystem in which the ratio is bigger than 1.

INTERFERENCE lies in the effects due to disturbances, incompatible with achieving the performances required.

SUSCEPTIBILITY is the capacity of a device, apparatus or system with that responds to the unwanted energy of disturbances.

2.2. Disturbances

Disturbances may be manifested in the two forms:

- common mode interference or longitudinal interference, which consists in the appearance of a harmful energy relative to a common reference, usually weight, for both routes of signal or feeding;

- simple mode interference or normal or serial interference.

Harmful effects can be created by running resistance or mechanical movements that produces changes in capacity or by vibration of a current path in the magnetic field or by combined phenomena of electrical corrosion.

Line scanning of TVs, if not treated against disturbances, emits interference on 15,625 Hz and its harmonics.

2.3. Influences

In case of electrical installations of subway we have the voltage between 1 - 20 kV, on neighbouring wire telecommunication lines (CCTV cable), we have the following influences:

a) ELECTRIC INFLUENCE - effect of electric component of power line electric field (LE);
b) MAGNETIC INFLUENCE - effect of magnetic component of power line electric field;
c) RESISTIV COUPLING - effect of current passage through the ground of electrical installations.

Following the measurements and their processing it is determined the allowable limits and calculation conditions, as well as it is indicated the specific measures to reduce the effects of influences - for the protection of people, facilities and broadcasting against hazardous and harmful effects of these influences.

The works of protection against dangerous influences will be executed before putting into operation of the installations that make them necessary.

3. Closed circuit television (CCTV)

3.1. Introduction

Equipment of closed circuit television (CCTV) of Line II, sections 1 and 2. This is based on a draft prepared by the projection department of subway. It is used CCTV equipment on higher standards.

Based on the project, the CCTV installation consists in fig. 1. We have:

- signal generator (any of the cameras placed in stations IMGB Depot – Piata Unirii 2);
- transmission line (coaxial cable between stations and 7 cable corrections, placed by one in stations IMGB – Piata Unirii 2);
- output to the transmission line (at each station one Automatic Video Distributor, switching of coaxial line was done by remote control relays).

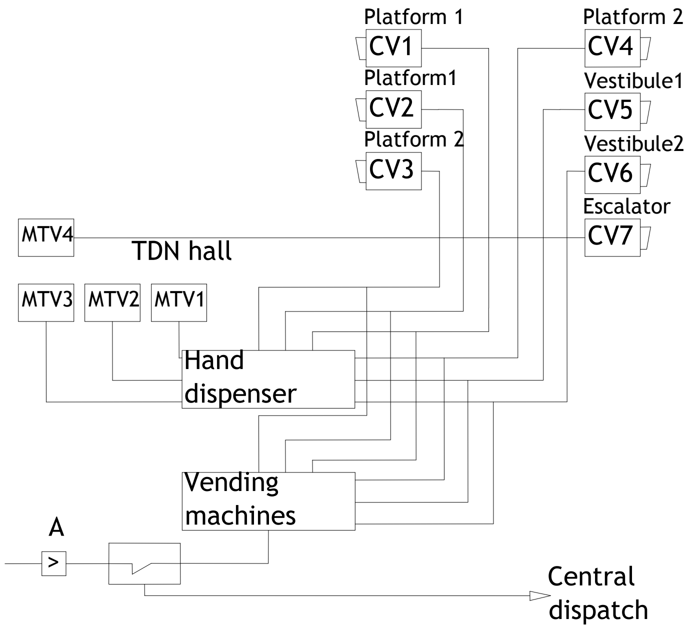

Fig. 1. Closed Circuit Television (CCTV).

3.2. Performance

Level of performance is as follows:

- CCTV installations in stations have a level of quality to the limit of acceptability for the image reproduced on local monitors;
- signal transmitted on the coaxial line from inter stations is highly disturbed and distorted on reception;
- image obtained after the first cable correction is strongly influenced by disturbance and has frequent non synchronization;
- image obtained after the second cable correction is totally out of synchronization and contains hardly detectable content.

3.3. Primary findings

CCTV installation on analysis indicates that the high density of electrical equipment, power supply configuration and underground tunnel signalization of the subway system produce significant interference and electromagnetic interactions. These cause adverse effect in functioning of the CCTV installation.

3.4. Disturbances

3.4.1. Sources of disturbances

After measurements, data were obtained on disturbances in the areas of disposing the CCTV equipment. Electrical influences can be classified as follows:

a) electromagnetic influences;
b) electrochemical influences.

Electromagnetic influences can be:

a1) low frequency electromagnetic influences (f <10 kHz);
a2) high frequency electromagnetic influences (f > 10 kHz).

Low frequency electromagnetic influences may have several causes, such as:

a1.1) current variation caused by the start of subway train (change in magnetic field);
a1.2) voltage variation caused by the start of subway train (change in electric field);
a1.3) ohmic connections of the current paths due to treatment of neutral Subway system Line I and in the electrical company's power supply that feeds the Subway power substations. Capacitive unbalance and neutral displacement influence the CCTV lines.

It was found that the frequency spectrum of disturbances is correlated with the system power supply frequency and operating frequency, as well. Disturbance intensity in the CCTV installations depends on the position of the subway in the underground tunnel and the motors operating mode on the train wagons (electric arc on collector, current shocks and voltage variations).

3.4.2. Ways of disturbance penetration

Regarding the penetration of disturbances in the CCTV facility, it was found by measurements; the disturbances penetrate through both coaxial signal line and the equipment (by electromagnetic influences). On the disturbance that penetrates the coaxial line, the measurements highlight a significant increase (over 10 times) the level of disturbance on the Subway Line II in relation to Subway Line I. The perturbation (distortion) introduced in the signal line, measured between IMGB Depot and Unirii 2 stations, and is correlated with the "hopping" potential levels. They are variable along the tunnel and approximately equal to the average of the latter. From measurements it was found that the disturbances level that penetrates the coaxial line is favoured by low insulation resistance of the coaxial cable between stations. This parameter shows large fluctuations over time. For example, the insulation resistance between the signal cable exterior armature to the ground belt between Piata Sudului and Constantin Brancoveanu stations varies between 400kΩ/1kV and 100MΩ/1kV. The minimum acceptable insulation resistance is considered to be at least 10MΩ/1kV (15MΩ/1kV).

Under these conditions the following situations are possible:

- CCTV signal cable has the screen interrupted or portions without screen (cable quality);
- CCTV cable grounding is not done properly.

Measurements made show that the "hopping" potentials on the tunnel and electromagnetic influences make impossible the idea of changing the arrangement of the tunnel coaxial lines to ensure a minimum acceptable of the insulation resistance.

Penetration of the disturbance in the CCTV installation takes place from electric power feeding and earth contact, as well. Assessment of the perturbation level in the feeding power network was done by measuring on all 20 kV busbars and general distribution panels (GDPs) in all stations of the entire Subway Line II. Also, measurements were made at TGDs in the Unirii 1 station: dispatch area, on the camera and monitors.

Grounding belt of CCTV installations in stations is heavily perturbed. Comparison of the segments of earth belt between stations shows, in terms of grounding of the disturbances, a critical sizing (for CCTV installations) and / or an untidy construction and / or inappropriate execution of grounding of the electrical equipment in Subway Line II and the CCTV system respectively. Interaction between the CCTV cable and grounding belt is so strong that, even with decoupling, disturbances are still very high.

3.4.3. Susceptibility to disturbances of CCTV chain

Regarding the susceptibility to disturbances of the CCTV chain and possibility of increasing immunity to disturbances, it was found that CCTV equipment is not qualified for operation under conditions of disturbances.

From this point of view, the standards of industry products mention, in the chapter of "environmental conditions", that the equipment is designed for operation in environments free from strong electromagnetic fields and disturbances.

It is not defined a level of immunity to disturbances introduced by electric supply, ground contact and parasitic coupling.

Products are aligned with the standards of radio interference in that such disturbances produced by equipment (and placed in the power supply or radiated from the field) do not exceed the level required by STAS, so do not disturb radio reception.

For example, isolation transformers which supply the CCTV installation on sections 1 and 2 of Subway Line II are inappropriate in terms of perturbation. That requires their replacement or duplication of isolation transformers.

It was found that the disturbance acquired by a corrector, is (5… 20)% higher than the disturbance taken by the integrated corrector in similar conditions.

3.4.4. Blocking Techniques

Regarding the possibility of applying techniques of "blocking of perturbed element to the operation of disruptors", we see that the operation of installation (continuous viewing of the image on the monitor) does not allow blocking image signal during the occurrence of disturbances caused by the start of the subway wagons.

Solutions of type of “resynchronization of perturbation" proves laborious, as well as they require testing and modifications. They would not fall in the attempt to operationally resolve the electromagnetic compatibility in the CCTV installation of Subway Line II.

Table 1. Measurements made by the team of specialists on Subway Line I

Nr.	**Signal (station /inter-station)**	**km**	**vault**	**Electro chemical potential [mV]**	**Lateral resistance (CR-PT) [Ω km]**	**Runway**	**Humidity**	**Note**
1.1.1	Depot Industriilor [B6A]	-	-	+59	3,16	concrete traverse	semi-dry	-
1.1.2	Corridor entrance	-	-	+96	3,16	concrete traverse	water infiltration	-
1.1.3	Tunnel entrance	-	1	+106	3,16	concrete traverse	water infiltration	-
1.1.4	[B3A]	-	105	+173	3,41	concrete traverse	water infiltration	-
1.1.5	[B5A]	-	305	+85	2,35	concrete traverse	semi-dry	-
1.1.6	-	-	415	+123	3,16	concrete traverse	semi-dry	-

1.1.7	[X]	-	503	+142	2,70	concrete traverse	dry	-
1.1.8	[XP1]	-	615	+81	2,35	concrete traverse	dry	-
1.1.9	[XP2]	-	750	+159	1,78	concrete traverse	water infiltration	-
1.1.10	Industriilor	-	-	+85	2,0	concrete traverse	dry	-
1.1.11	[B1]	-	190	+126	2,35	concrete traverse	water infiltration	-
1.1.12	[B3]	6,564	455	+212	6,24	concrete traverse	dry	-
1.1.13	[B5]	-	675	+206	5,27	concrete traverse	dry	-
1.1.14	Pacii-[X]	-	880	+228	1,64	concrete traverse	dry	-
1.1.15	Pacii-[X]	-	-	+146	0,29	concrete traverse	dry	-
1.1.16	[B1]	-	267	+308	2,35	concrete traverse	semi-dry	-
1.1.17	[B3]	-	645	+265	7,17	concrete traverse	semi-dry	-
1.1.18	[B5]	-	1015	+251	6,82	concrete traverse	wet	-
1.1.19	[B7]	-	1395	+247	5,27	concrete traverse	wet	-
1.1.20	[B9]	-	1772	+305	2,35	concrete traverse	water infiltration	-
1.1.21	Armata Poporului-[X]	-	1970	+143	2,13	concrete traverse	water infiltration	-
1.1.22	Armata Poporului-[X1]	-	-	+45	2,35	concrete traverse	dry	-
1.1.23	[B1]	-	1380	+300	2,0	concrete traverse	wet	-
1.1.24	[B3]	-	1010	+267	2,0	concrete traverse	wet	-
1.1.25	[B5]	-	635	+282	1,64	concrete traverse	wet	-
1.1.26	[B7]	-	270	+149	1,52	concrete traverse	wet	-
1.1.27	Politehnica-[X]	-	52	+150	0,88	concrete traverse	wet	-
1.1.28	Politehnica-[X1]	-	800	-39	0,36	concrete traverse	wet	-
1.1.29	[B1]	-	590	+42	2.13	concrete traverse	wet	-
1.1.30	[B3]	-	280	+83	3,16	concrete traverse	wet	-
1.1.31	-	-	145	+130	3,61	wood traverse	wet	-

1.1.32	Ventilation unit switch	-	-	-289	2,13	wood traverse	water infiltration	-
1.1.33	[B5]	-	-	-66	2,0	concrete traverse	dry	-
1.1.34	[B7]	-	-	+3	2,0	wood traverse	dry	corridor
1.1.35	Eroilor-[XM]	-	-	-72	1,52	wood traverse	dry	corridor
1.1.36	Eroilor-[X1]	-	-	-40	2,13	wood traverse	dry	corridor
1.1.37	[B1]	2,949	-	-60	2,0	wood traverse	dry	corridor
1.1.38	[B3]	3,170	-	-60	3,41	wood traverse	dry	corridor
1.1.39	[B5]	-	-	-60	4,67	wood traverse	dry	corridor
1.1.40	Izvor-[X]	3,705	-	-150	6,24	wood traverse	dry	corridor
1.1.41	Izvor-[X1]	3,900	-	-90	6,27	wood traverse	dry	corridor
1.1.42	[B1]	4,300	-	-120	6,24	wood traverse	dry	corridor
1.1.43	[B3]	4,482	-	-138	7,17	wood traverse	dry	corridor
1.1.44	[B5]	4,803	-	+20	3,41	wood traverse	dry	corridor
1.1.45	Piaţa Unirii-[X]	4,97	-	-30	4,67	wood traverse	dry	corridor
1.1.46	Piaţa Unirii-[X1]	5,272	-	-40	1,64	wood traverse	water infiltration	corridor
1.1.47	[B1]	5,451	-	-	3,88	wood traverse	dry	corridor
1.1.48	-	5,638	-	-48	4,67	wood traverse	dry	corridor
1.1.49	[B3]-ventilation unit	5,762	-	-70	6,50	wood traverse	dry	corridor
1.1.50	[B5]	-	-	-15	6,24	wood traverse	dry	corridor
1.1.51	[B7]	6,379	-	-	5,93	wood traverse	dry	corridor
1.1.52	Timpuri Noi-[X]	6,540	-	-20	-	wood traverse	dry	corridor
1.1.53	Timpuri Noi-[X1]	6,866	-	-75	3,41	concrete traverse	dry	corridor
1.1.54	[B5]	7,540	-	+30	-	concrete traverse	dry	corridor
1.1.55	[B7]	-	-	+10	6,24	concrete traverse	semi-dry	corridor
1.1.56	Mihai Bravu-[X]	8,010	-	+85	2,35	concrete traverse	dry	corridor

1.1.57	Mihai Bravu-[X1]-gate AC	-	-	-180	0,26	wood traverse	dry	corridor
1.1.58	[B1]	-	-	+20	-	wood traverse	dry	-
1.1.59	[B3]	-	218	+4	-	concrete traverse	dry	-
1.1.60	[B5]	-	540	+20	-	concrete traverse	dry	-
1.1.61	[B7]	-	838	-10	-	concrete traverse	dry	-
1.1.62	Dristor-[X]	-	20	-166	0,35	concrete traverse	-	oil spots
1.1.63	Dristor-[X1]	-	180	+9	-	concrete traverse	dry	-
1.1.64	[B1]	-	193	-50	-	concrete traverse	dry	-
1.1.65	[B3]	-	494	+50	-	concrete traverse	dry	-
1.1.66	[B5]	-	692	+10	-	concrete traverse	watery spots	messy corrosion on track shoe
1.1.67	[B7]	-	1056	+27	-	concrete traverse	-	-
1.1.68	Nicolae Grigorescu-[X]	-	1390	-43	-	concrete traverse	wet	-
1.1.69	Nicolae Grigorescu-[X1]	-	1535	-50	4,15	concrete traverse	dry	-
1.1.70	[B5]	-	600	-180	5,58	concrete traverse	dry	-
1.1.71	Titan[X]/ AC	-	-	+190/-90	2,51	concrete traverse	dry	-
1.1.72	Titan-[X1]	-	-	-90	3,16	concrete traverse	wet	-
1.1.73	[B1]	-	194	-110	2,35	concrete traverse	wet	-
1.1.74	[B3]	-	485	-190	2,35	concrete traverse	dry	-
1.1.75	[B5]	-	763	+74	3,41	concrete traverse	wet	-
1.1.76	Costin Georgian-[X]	-	961	-94	1,52	concrete traverse	dry	-
1.1.77	Costin Georgian-[X1]	-	-	+10	1,41	concrete traverse	dry	-
1.1.78	[B1]	-	1010	+100	3,16	concrete traverse	dry	-
1.1.79	[B3]	-	750	+115	3,61	concrete traverse	dry	-

1.1.80	[B5]	-	490	-190	2,35	concrete traverse	dry	-
1.1.81	[B7]	-	270	-80	1,30	concrete traverse	water infiltration	-
1.1.82	Republica-[X]	-	70	+110	9,35	concrete traverse	semi-dry	-
1.1.83	Republica-[X1]	-	-	-90	2,70	concrete traverse	dry	-

4. Disruptive Voltages on Power Supply

4.1. Admissible limits

Disruptive voltages on the AC supply terminals of the wire telecommunications shall not exceed the limits:

Table 2. Disruptive voltages on the DC terminals and the transmission lines terminals

Frequency [MHz]	Permissible limits [dB]
0,15...0,50	66
0,50...5,00	60
5,00...30,00	66

Disruptive voltages on the DC terminals and the transmission lines terminals should not exceed the limits above, plus 30 dB.
Disturbing field must not exceed 46 dB (0 dB = 1 µV / m) in the frequency range of 30 ... 300 MHz at measuring distance of 3 m.

4.2. Disturbances

An electric converter (rectifier - inverter) disturbs other systems via the common cable for connection to the grounding bar.

Let's be a CCTV system coupled on the same grounding route, with a length of 10 m, to an electric converter that switches currents of 20A in about 4 µs.

It follows a galvanic coupling disturbing voltage on the grounding wire: (grounding connection inductance is about 1µH per cm length).

$$|\Delta U| = L\frac{\Delta I}{\Delta T} \text{ and}$$

$$|\Delta U| = 100V$$

If it switches 50A in 0.5 µs, with fast commuting elements. Disturbances caused by the electric converter in the electric network overlap disturbances by grounding connection.

On switching currents of hundreds or thousands of amperes, the presence of parasitic and distributed inductances and capacitances create resonance and reflections phenomena. In this situation, surges of order of kilovolt can develop.

Capacitive coupling is its own disturbances by voltages, disruptive sources having low impedance.

Inductive coupling is its own disturbances by currents, acts as a power source connected in series with the input of disrupted circuit.

Disturbances may occur in an infinite number of forms, as frequency spectrum. Harmonic voltages depend on the load impedance, disturbance source impedance and impedance of power supply.

Devices with non-linear behaviour generate disruptive voltages of different frequencies (harmonics are generated of applied voltage and produce high frequencies that may disturb).

If simultaneously at least two voltages of different frequencies apply to a non-linear device, inter-modulation distortion components appear, including non-harmonic components, because the combination of harmonic components.

So, you may experience disruptive voltages from the sums and differences of input voltage harmonic frequencies.

4.3. Parameters of disruptive voltages

Key parameters of a disruptive voltage are:

- peak-voltage;
- front-velocity, proportional to "richness" of harmonic spectrum $\left(\frac{d\mu}{dt}\right)$;
- disturbance „energy" $\int \mu dt$ (on the reference impedance);
- time interval of peak level or length of time that the level of disturbance exceeds the reference limits.

Proper functioning of electrical equipment, in terms of disturbances in the network, implies not to be affected by:

- voltage interruption not exceeding 10 ms, except electric power circuits;
- voltage drop not exceeding 0.5 s and 15% of nominal supply voltage;
- voltage peaks not exceeding 1.5 ms, with values below 200% of nominal line to line root square voltage.

Industrial electrical disturbances have a very broad spectrum. The spectral richness exceeds 50 MHz with a given energy concentration around 100 kHz ... 150 kHz, and in the low frequencies, as well.

At low frequencies, up to 5 ... 10 kHz, the disruptive levels are determined by the harmonic frequency of 50 Hz and combinations thereof.

In the industry there are large peak voltages of several kilovolts.

For disturbances including over 30 ... 35 kHz frequencies, the parasites can be considered like impulses.

Disruptive voltage distribution function on a network can be assessed by the relationship:

$$F(U) = 1 - e^{-\lambda \Delta U} \qquad \text{where } \Delta U = U_M - U_0$$

U_M = disturbance amplitude in impulses

U_0 = threshold device for measuring disturbances

Long-term disturbances are characterized by area (V_s) described by:

$$s = \Delta U_{parazit} \cdot \tau_{parazit} \qquad \text{where: } \tau_{parazit} = \text{disturbance time lengh}$$

Capacitive coupling is one of the main routes of penetration of disturbances in the Subway CCTV system.

4.4. Minimizing of parasitic voltages

Parasitic voltage in CCTV system (disturbed) can be minimized if it is reduced:

- pulsation, by reducing the perturbing spectrum, equivalent to mitigate wave abrupt fronts;
- input resistance of the receiver by:
  - reduction of the value of input impedance to the limit accepted by the operational diagram and consumers;
  - reduction selectively of the input impedance with the frequency by filtration.
- disruptive voltage generator by:
  1. separation and sorting routes;
  2. reduction of the level of disturbing element.
- value of parasite coupling capacity.

Capacitive coupling is shown by the disrupted voltage (CCTV system).

$\underline{U}_{pr} = j\omega C_k R_{ip} \underline{U}$ where: C_k = coupling capacity

R_{ip} = input impedance of disturbed element

In fig. 2, the disruptive coupling is presented function of the coupling impedance $\underline{Z}_C$ and disturbed route impedance $\underline{Z}_N$

$\underline{Z}_C$ = coupling impedance

$\underline{Z}_N$ = characteristic impedance of the route subject to disturbance

4.5. Comments

1. - coupling impedance $|\underline{Z}_C|$ is higher;

   - CCTV cable characteristic impedance $\underline{Z}_N$ is: $Z_N = Z_C = 75 + 4[\Omega]$.

2. - 1 m of coaxial cable provides [75 pF/m];

   - 1 cm of grounding route determines [1nH];

   - mutual inductance between two wires of 100 mm long, spaced at 2 mm, is about 20 nH.

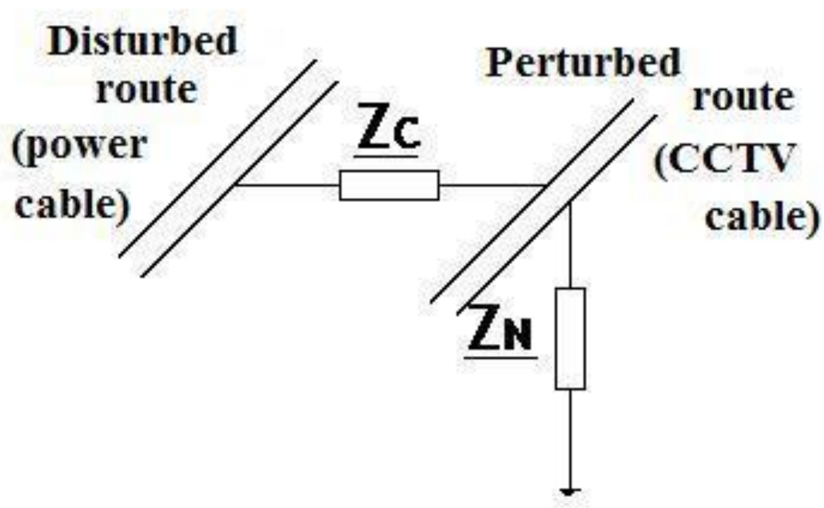

Fig. 2. Disruptive coupling function of the coupling impedance and disturbed route impedance.

4.6. Disruptive voltages on CCTV transmission cable

Disruptive measurement results:

4.6.1. CCTV cable (perturbed route): Dispatcher Unirii station - IMGB Depot

$\underline{U}_{PR}$ = disruptive voltage on CCTV cable (receptor)

$\underline{U}_{P}$ = disruptive voltage

$$\underline{U}_{PR} = \frac{Z_N}{Z_N + Z_C} \cdot U$$

$\underline{U}_{PR} = 60$ mV (statistic)

$$\underline{U}_{p} = \left(1 + \frac{75}{|\underline{Z}_N|}\right) \cdot 60$$

$\underline{U}_{PR} = 120$ mV (rare)

$$\underline{U}_{p} = \left(1 + \frac{75}{|\underline{Z}_N|}\right) \cdot 120$$

$\underline{U}_{PR} = 30$ mV

$\underline{U}_{PR} = 40$ mV

$\underline{U}_{PR} = 70$ mV

$\underline{U}_{PR} = 200$ mV (on decoupling)

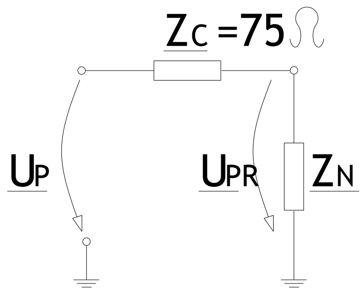

Fig. 3. CCTV cable (disturbed route): Dispatch Unirii station – IMGB Depot.

4.6.2. CCTV cable (perturbed route): Dispatcher Unirii station – IMGB 1

$\underline{U}_{PR} = 40\ \text{mV}$: (Train on starting in Tineretului – Eroii Revolutiei)

$\underline{U}_{PR} = 50\ \text{mV}$: (Tain on starting in Eroii Revolutiei – Brancoveanu)

$\underline{U}_{PR} = -60\ \text{mV}$: (Train on starting in Brancoveanu – Eroii Revolutiei)

$\underline{U}_{PR} => 40\ \text{mV}$: (Train on starting in Brancoveanu – Piata Sudului)

$\underline{U}_{PR} = 55\ \text{mV}$: (Train on starting in Piata Sudului – Aparatorii Patriei)

$\underline{U}_{PR} = 30\ \text{mV}$: (Train on starting in Aparatorii Patriei – IMGB 1)

$\underline{U}_{PR} = -30\ \text{mV}$: (Train on starting in IMGB 1 – Aparatorii Patriei)

$\underline{U}_{PR} = -50\ \text{mV}$: (Train on starting in Aparatorii Patriei – Piata Sudului)

4.6.3. CCTV cable (perturbed route): Dispatcher Unirii station – Piaţa Sudului

$\underline{U}_{PR} = 20\ \text{mV}$: (Basic level with no train on starting)

$\underline{U}_{PR} = 30\ \text{mV}$: (Train on starting in IMGB – Aparatorii Patriei)

$\underline{U}_{PR} = 20\ \text{mV}$: (Train on starting in Aparatorii Patriei – Piata Sudului)

$\underline{U}_{PR} = 30...40\ \text{mV}$: (Train on starting in Piata Sudului – Aparatorii Patriei)

$\underline{U}_{PR} = 25\ \text{mV}$: (Train on starting in Tineretului)

$\underline{U}_{PR} = 25\ \text{mV}$: (Train on starting in Piata Sudului)

$\underline{U}_{PR} = -30\ \text{mV}$: (Train on starting in IMGB – Piata Sudului)

$\underline{U}_{PR} = 35...40\ \text{mV}$: (Train on starting in Tineretului – Unirii)

4.6.4. CCTV cable (perturbed route): Dispatcher Unirii station – Brancoveanu

$\underline{U}_{PR} = 20\ \text{mV}$: (Train on starting in Eroii Revolutiei – Unirii)

$\underline{U}_{PR} = 20\ \text{mV}$: (Train on starting in Brancoveanu – Unirii)

$\underline{U}_{PR} = 20\ \text{mV}$: (Train on starting in Unirii – IMGB)

$\underline{U}_{PR} = 30\ \text{mV}$: (Train on starting in Unirii – Depot)

$\underline{U}_{PR} = 30\ \text{mV}$: (Train on starting in Tineretului – Unirii)

5. Capacitive unbalance, neutral displacement, influence of CCTV – Subway system

5.1. Influence of system

Electric (power) cable lines (ECL), regardless of the treatment of neutral, influence CCTV cables because of the electromagnetic field.

Influences depend on the nominal voltage of electric cable lines (20 kV), distances of ECL and CCTV cables.

Electromagnetic influences depend on the current value of grounding, treatment of neutral and homopolar current component (e.g. Harmonics of order $3k$ = 3, 6, 9, 12, ...).

Unbalance exists even at normal operating regime on the non-transposed lines. Unbalance current is much smaller than the single-phase short circuit if ECL has the neutral grounded.

Influences on telecommunications lines have two aspects: the risk of accident and disturbances.

In term of risk of accident – the measures that are expected to avoid the induction of hazardous voltages in case of short-circuits, are usually sufficient for lower currents.

In terms of disturbance - the effects of short - circuit currents, that takes very little time, are not normally taken into account, but only in special cases.

For disturbances, the asymmetry currents are important under normal operating regime or grounding currents regime, when the ECL operates longer under grounding currents regime.

5.2. Neutral displacement

Any movement of the neutral results in the appearance of a homopolar voltage.

This voltage V is due to existence of a transversal admittance:

Y_A, Y_B, Y_C different on the three phases:

$$V_A = V + U_A$$
$$V_B = V + U_B$$
$$V_C = V + U_C$$

These admittances are determined by the capacities of phases from the ground.

For a fully transposed line, for which capacities from the ground are equal, then:

$$U_N = -V = \frac{U_A Y_A + U_B Y_B + U_C Y_C}{Y_A + Y_B + Y_C}$$

and if the neutral circuit has Y admittance:

$$U = -V = \frac{U_A Y_A + U_B Y_B + U_C Y_C}{Y_A + Y_B + Y_C + Y_K}$$

and so, there is no neutral displacement, then $V = 0$.

5.3. Capacitive unbalance

To determine the currents passing through capacities from the ground and returning through the ground (if the homopolar circuit admittance is infinite), the equivalent circuit can be determined either in the form of a voltage equivalent equal to the neutral displacement voltage in series with the capacitive admittances either as an injected current.

Equation (5.2) can be written in the form:

$$\underline{I}_N = \underline{U}_N\left(\underline{Y}_A + \underline{Y}_B + \underline{Y}_C\right) = \sum_{k=A,B,C} \underline{U}_K \underline{Y}_K$$

From this relationship, the capacitive unbalance current I in the normal regime is determined, calculating *U*, *I*. This has the same value like the current determined by neutral displacement voltage, applied to the admittance equal to the sum of the capacitive admittances.

In a three-phase power line, the capacities between conductors and between conductors and earth cause a capacitive consumption.

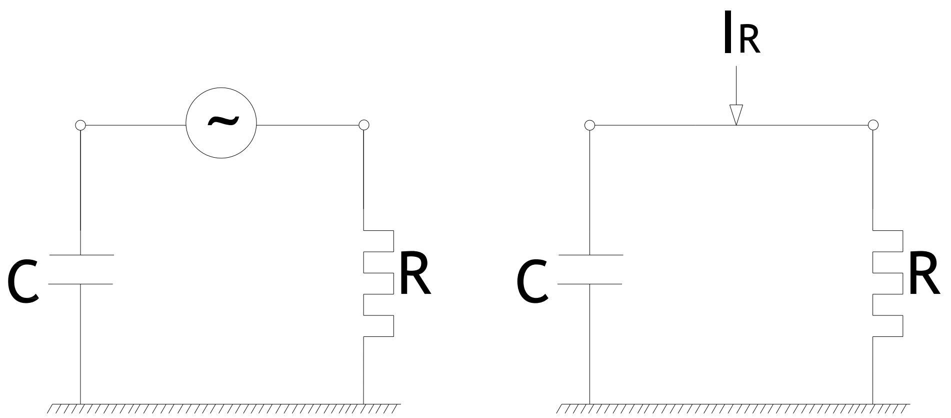

Fig. 4. Equivalent circuits for determining the capacitive currents returning through the earth.

Average values of capacitances C and C_0 are:

$$C = 2{,}3 \cdot 10^{-9} \text{ F/km}$$

$$C_0 = 4 \cdot 10^{-9} \text{ F/km}$$

These capacities are combined in a balanced regime into a service capacity of value:

$$C_S = C + 3C_0$$

$$C_S = 10{,}9 \cdot 10^{-9} \text{ F/km}$$

Symmetrical capacitive current (average value) in the normal regime, with line to line voltage U is:

$$I = \frac{U[\text{kV}]}{\sqrt{3}} \cdot \omega \cdot C_S \cdot 10^{-9} \ [\text{A/(kV} \cdot 100 \text{ km)}]$$

$$I = \frac{U[\text{kV}]}{\sqrt{3}} \cdot 314 \cdot 10.9 \cdot 10^{-9} \ [\text{A/(kV} \cdot 100 \text{ km)}] = 0.2 \ [\text{A/(kV} \cdot 100 \text{ km)}]$$

For Subway Line II, U = 20 kV:

$$I = \frac{U\left[\text{kV}\right]}{\sqrt{3}} \cdot \omega \cdot C_S = 4\left[\text{A} / 100 \text{ km}\right] =$$

$$= 20 \cdot 0{,}2 \ [\text{A/100km}] = 4 \ [\text{A/100km}] = 4000 \ [\text{mA/100km}] = 40 \ [\text{mA/km}]$$

In case of grounding of a phase, a returning path is created for the capacitive currents passing through C.

The neutral displacement in this case has the value of the phase voltage $V = U$ and get the grounding current:

$$I_P = 3 \cdot U \cdot j \cdot \omega \cdot C_0 = \sqrt{3} \cdot U\left[\text{kV}\right] \cdot 314 \cdot 4 \cdot 10^{-6} = 0{,}22\left[\text{A/(kV} \cdot 100 \text{ km)}\right]$$

$$I_P = 21\left[\text{mA/km}\right]$$

For a soil resistivity of 10^4 Ωcm, the value of mutual inductance between the lines of force (homopolar circuit) and telecommunications line (CCTV), considering the return through the earth, is about 0.25 Ω/km.

On a parallelism of 10 km and a phase short - circuit current of 1 kA, the voltage induced in the telecommunication line is 10×1000×0.25 = 2500 V/kA.

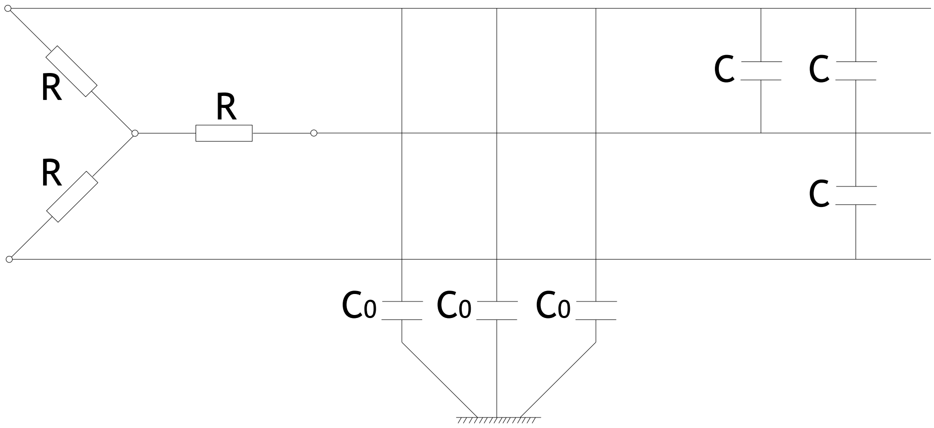

Fig. 5. Capacities of a three phase power line.

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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