Evaluation of electromagnetic disturbances injected in high voltage networks by large electrical installations

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Abstract: - In the actual technological context, continuous improvement of the evaluation of the electromagnetic disturbances injected by the large electrical end users and the distribution system topology into high voltage networks is highly necessary. In this case, the power quality really means the voltage quality.
The disturbances phenomena occurring in the high voltage network due to some important 110 kV and 220 kV and users behaviour could have different aspects that must be examined.
The paper discusses means of identification for the disturbances mentioned above, using measurements in electric 400kV-220kV-110kV substations in Romania and identification of their real level. The measurements point out several incidents. A very important issue regarding the cumulative effect of these disturbances, the harmonic resonant level combined with the network faults, will be emphasized in this paper.

Key-Words: power quality, transients, interruptions, harmonics, line to ground faults, monitoring.

1. Introduction

This paper analyzes the disturbance phenomena within the high voltage networks, more specifically within substation areas with different voltage levels (400 kV-220 kV-110 kV). This becomes an important issue when important end users are connected to 110 kV and 220 kV bus-bars.
The disturbance phenomena analysis that can be conducted in a power system include the voltage and current which can be evaluated by magnitude of supply voltage, flicker, voltage dips and swell, voltage interruptions, transient overvoltages, supply voltage unbalance, voltage and current harmonics, voltage interharmonics, mains signalling on the supply voltage, voltage rapid changes.
The electromagnetic disturbances that will be analyzed here can be included in the concept of 'power quality". This concept applies to a wide variety of electromagnetic disturbances phenomena on the power systems and includes a multitude of individual type of power system disturbances. Using this concept, all the issues mentioned above will benefit by a system approach rather than handling them as individual problems.
A survey of some perturbations generated by important electrical installations belonging to the end users is necessary in order to avoid some unpleasant events. Some of these events can also be predicted, and the conditions which promote such unpleasant events can be specified. This is the case of a harmonic resonant in PCC due to a network fault.
In some situations, the flagging concept can be applied, while in other situations several simultaneous incidents may appear and their identification becomes a complex operation. This is the case of a no concordance between the voltage and current waveform due to an unknown large starting installation.
There are two possibilities to achieve power quality analysis: off-line and on-line analysis. The off-line power quality analysis, as term suggests, is performed off-line at the central processing location. On the other hand, the on-line data analysis is performed with the instrument itself for immediate information disseminations.

2. Measurements techniques to evaluate the troubleshooting emerged from MV into HV system

The disturbance phenomena that appear in the power systems may have different causes and also different possible solutions. In order to investigate the power quality some general steps are required, according with [4] and described in figure 1.
Power quality monitoring is the process of gathering, analysis and interpretation of raw measurement data into useful information.

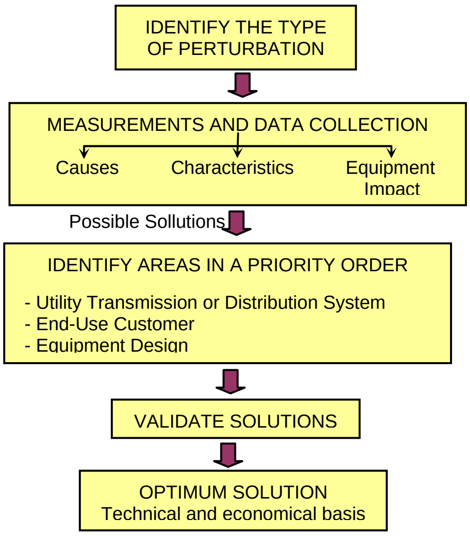


Fig. 1 Steps for power quality evaluation

This process is carried out by continuous measurement of voltage and current over an extended period of time. The recent advances in signal processing have made possible the design and implementation of intelligent systems for the analysis of raw data and transforming it into useful information.

Many advanced power quality monitoring systems are equipped with either off-line or on-line intelligent system to evaluate disturbances and system conditions as well as to draw conclusions about the cause of the problem or even predict problems before they occur.

An important issue of monitoring is to establish the proper location. When power quality problems become evident, it is necessary to locate the monitors as close as possible to the equipment affected by those problems (figure 2).

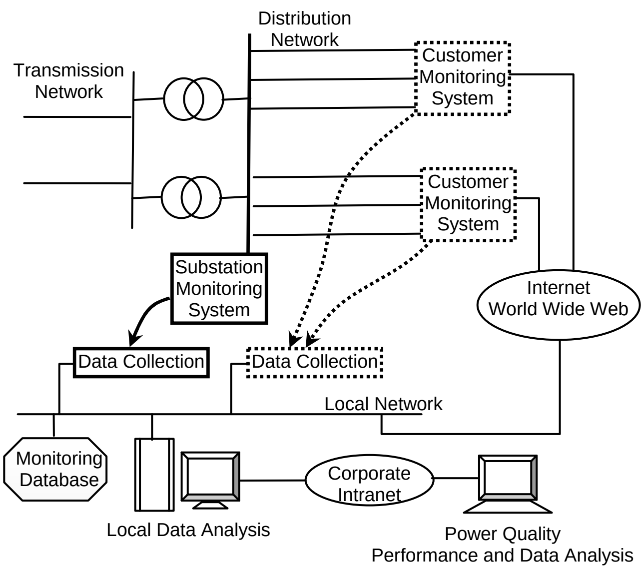


Fig. 2 A monitoring system located in the substation and on the end users sites

The substation operation regimes as well as the customer distribution line are monitored simultaneously by protective devices located on each side. The substation is important because it represents the PCC for most rms voltage variations.

Some monitor equipments can send the data over a telecommunication line to a central processing location for analysis and interpretation.

According to the CEI 61000-4-30/2000 [1,2], each parameter measured within a network node has two performance measurement classes, A and B. These are used to verify compliance with standards, and to establish the disturbing causes or for statistical survey application.

For class A performance measurements, intervals are aggregated over different time intervals, such as 150 cycles, 10 minutes or 2 hours. For class B performance measurements, the end user indicates these parameters.

The aggregation algorithm uses the square root of the mean squared input values. The „flagged" concept is used to avoid counting a single event more than once, given different parameters. This is used only for class A measurement performance.

2.1 Specified operating ranges for different parameters

Measurements for a specific voltage or current characteristic are adversely affected by application of a disturbing influence on the electrical input signal or on the instrument environment; for example, the measurement of voltage magnitude can be adversely affected by the voltage waveform. The following tables indicate the specified tolerance within their range of variation for different magnitudes.

Table 1 Specified operating range for class A performance

Parameter	Range
Frequency	42.5 Hz – 57.5 Hz
Voltage magnit. (steady state)	0 – 200 % $U_{declared}$
Flicker (P_{st})	0 - 20
Unbalance	0 – 5 %
Harmonics (THD)	Indicative values in IEC 6100-2-4
Interharmonics	Indicative values in IEC 6100-2-4
Mains signalling voltage	0 – 9% $U_{declared}$
Transient overvoltages	6 kV pk
Fast transients	4 kV pk

Table 2 Specified operating range for class B performance

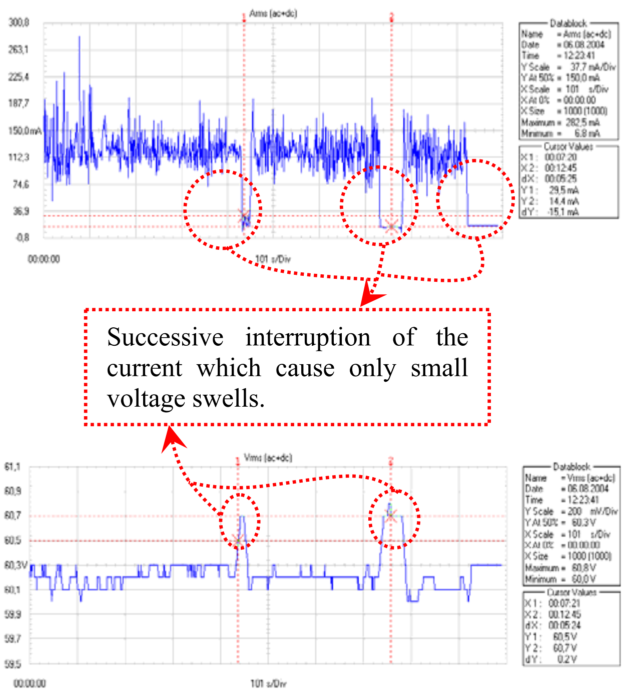
Parameter	Range
Frequency	42.5 Hz – 57.5 Hz
Voltage magnit. (steady state)	0 – 150% Udin
Unbalance	0 – 5%
Flicker (Pst)	0 - 4
Harmonics (THD)	Indicative values in IEC 6100-2-4
Interharmonics	Indicative values in IEC 6100-2-4
Mains signalling voltage	0 – 9% U_n

2.2 Statistical evaluation

The power quality statistics targets the compression of a large number of measurements in order to verify the compliance with contractual values, evaluation of the evolution during long periods of time and comparison between different networks during the same interval.
The number of values to be processed has to be representative, especially to calculate the percentile of 95% value [3].

3. Disturbances identified in Romanian substations (110 kV and 220 kV)

This section shows events and measurements recorded in Romanian substations (400 kV/220 kV/110 kV).
Figures 3-6 depicts the current and voltage waves: figure 3 and 6 are referring to 220 kV bus-bars, while figures 4 and 5 are referring to 220 kV bus-bars. It is obvious that for repeatable current interruptions, as shown in figure 6, the voltage swells at 110 kV substation are bigger in comparison with the data shown in figure 3 for 220 kV. The figure 6 also depicts a transient voltage.



U_{max} = 231.68 kV, U_{min} = 228.63 kV, ΔU = 0.69%

Fig. 3 The current and the voltage waves on a 16 minutes interval

Figure 4 points out rapid swells of the current in 110 kV line substations.
Figure 5 shows that current impulses can be produced by successive reconnections of the loads to the 110 kV bus-bars. In this case the voltage variations are not exceeding 6 % from the U_n.

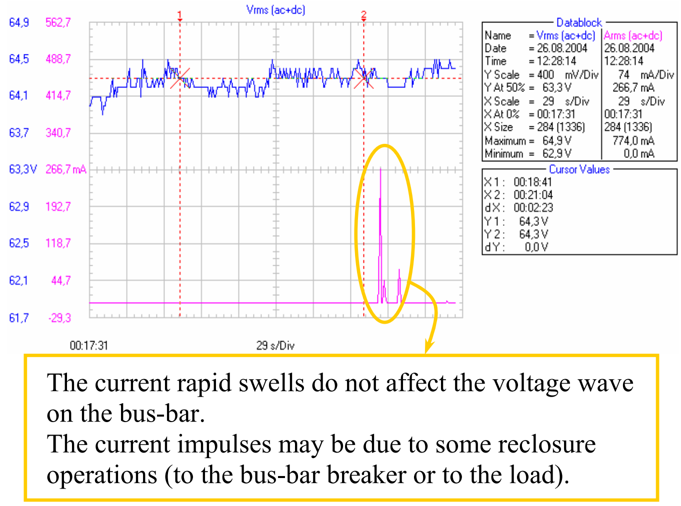
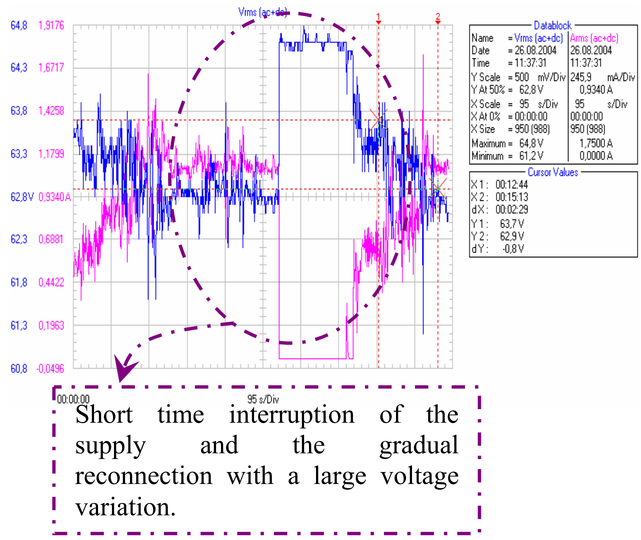


Fig. 4 The current and voltage variations on a 24 minutes interval



U_{max} = 123.46 kV, U_{min} = 116.6 kV, ΔU = 3.12%

Fig. 5 The current and voltage waves on a 16 minutes interval at the bus-bar station

In the areas **1** to **4** within the figure 7 there is no correlation between the current and voltage if there is a single load connected to the 110 kV bus-bar. The presence of additional loads which are supplied from the same bus-bars can be assumed.
Figures 8.a-c point out the supply voltage unbalance and in the same time emphasises different harmonic terms in all the three phases. This can be considered as a "flagged" record counting as the event is seen more than once, first for the voltage unbalance and second for the harmonic regime.

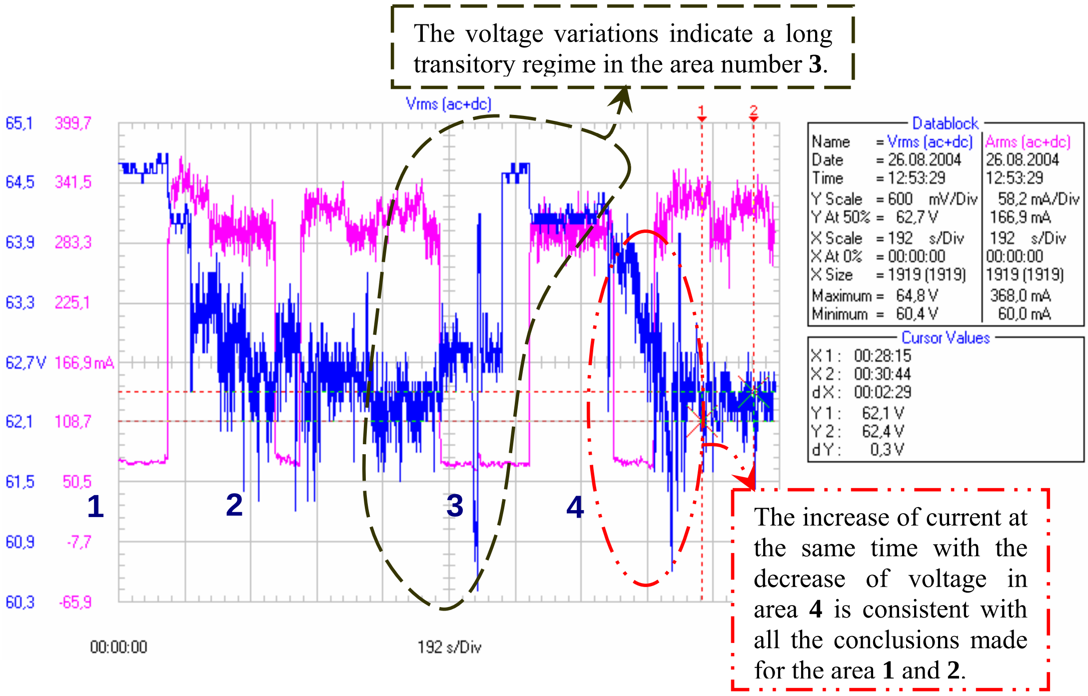


Fig. 7 Combined troubleshooting measured in Romanian substation

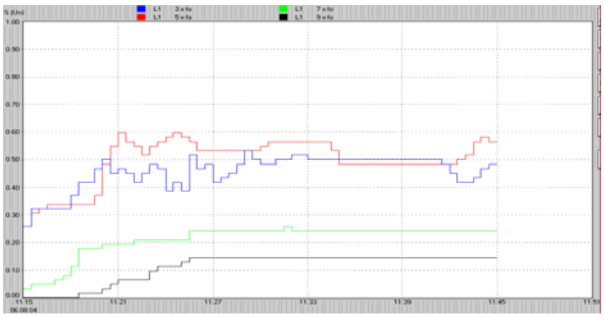


Fig. 8.a. Harmonic variation (h=3, 5, 7, 9) on phase A

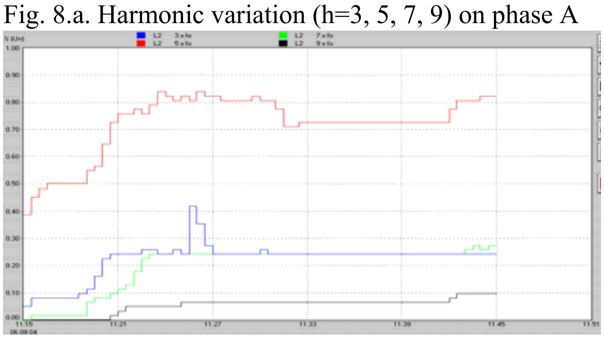


Fig. 8.b. Harmonic variation (h=3, 5, 7, 9) on phase B

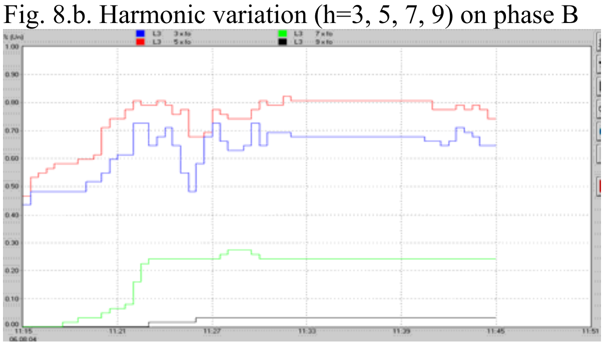


Fig. 8.c. Harmonic variation (h=3, 5, 7, 9) on phase C

Table 3.a

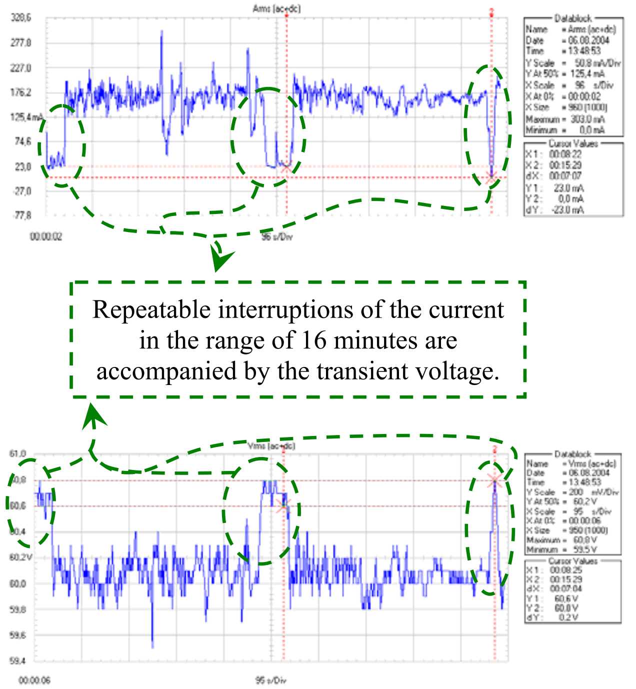
Harmonic order	Percent of fundamental [%]	
	max	**min**
3	0,53	0,27
5	0,60	0,31
7	0,26	0,04
9	0	0,14

Table 3.b

Harmonic order	Percent of fundamental [%]	
	max	**min**
3	0,42	0,06
5	0,82	0,38
7	0,28	0
9	0,09	0

Table 3.c

Harmonic order	Percent of fundamental [%]	
	max	**min**
3	0,73	0,43
5	0,82	0,47
7	0,28	0
9	0,04	0



$U_{max} = 231.68$ kV, $U_{min} = 226.73$ kV, $\Delta U = 1{,}13\%$

Fig.6 The current and voltage variations on a 16 minutes interval

4. The simultaneously effect of disturbances phenomena

4.1 Resonance conditions

Applying the method of symmetrical components on a three-phase network under line to ground fault conditions depicted in figure 9, an analysis through the circuit, may be done [4].

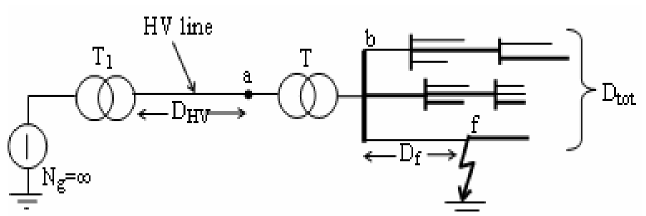


Fig.9 Schematic representation of distribution system

The possible resonance conditions, which could occur in a distribution system, for a given harmonic h, are given by

$$\mathrm{Im}\left[\overline{Z}_{ep}(h)+\overline{Z}_{en}(h)+2\overline{Z}_{f}(h)+\overline{Z}_{0}\right]=0 \qquad (1)$$

where

$\overline{Z}_{ep}(h)$ and $\overline{Z}_{en}(h)$ represent, at the positive and negative sequence respectively, the equivalent harmonic impedance of the system, including the linear loads, transformer T and HV system, at he bus-bar *b*;

$\overline{Z}_{f}(h)$ is the positive and negative impedance of the line between *b* and fault section *f*;

$\overline{Z}_{0}(h)$ is the zero sequence impedance at the fault section.

The resonance conditions in correspondence to a harmonic order *h* may give rise to a considerably high harmonic fault current.

Introducing the parameters $\gamma = \dfrac{D_c}{D_{tot}}$ and $\xi_0 = \dfrac{c_{oc}}{c_{oa}}$

where D_{tot} - overall length of the MV network; D_c - total length of the cable lines of the MV network; c_{oa} – average zero sequence per unit of length capacitance of MV overhead lines; c_{oc} – average zero sequence per unit of length capacitance of MV cable lines.

The impedance may be expressed

$$\mathrm{Im}\left[\overline{Z}_0(h)\right] = -\frac{1}{\omega \cdot c_{oa} \cdot h \cdot D_{tot}\left[(\xi_0 - 1)\cdot\gamma + 1\right]} \qquad (2)$$

4.2 The case of an electrical substation in Romania

The study of resonance phenomena in the case of harmonic line to ground fault existence in the MV network, which may influence the functioning conditions of the HV system have been realised for an electrical substation within the Romania network (400/110 kV) depicted in the following figure [5,6].

The computed values of "critical" distance D_f^* as a function of the overall length of the MV network D_{tot} and γ (the rapport between the length of cable lines and D_{tot}) for the 20 kV network connected to the substation with two transformers were represented in the following curves.

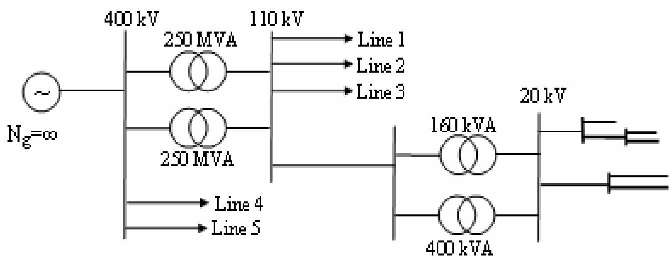


Fig.10 Electrical substation of Romania - 400/110 kV

Making a comparative analysis using the values from the tables the effect of the HV system becomes obvious. The "critical" distance D_f^* is much varying with the rapport γ (for h=7 and γ=0.1 will result the reduction to the half of D_f^* in the same situation where h=5).

From the curves depicted in figure 11 and figure 12 it is obvious that the "critical" distance decreases when the harmonic order is higher. Another important aspect is the smaller distance of the resonance phenomena to the electrical substation by the increase of the parameter γ.

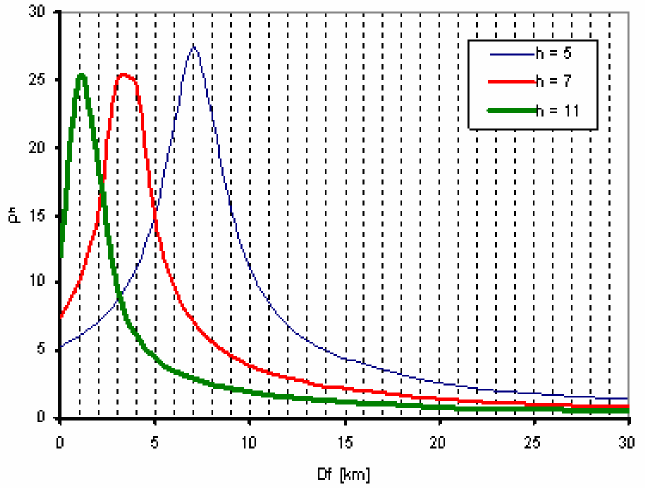


Fig.11 The dependence ρ_h (D_f) for: h_{res}=5; D_{tot}=150 km; γ=0.5

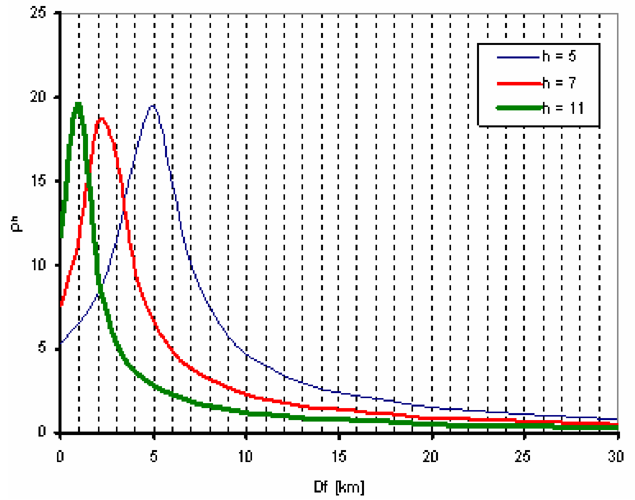


Fig.12 The dependence ρ_h (D_f) for: h_{res}=5; D_{tot}=150 km; γ=0.7

5. Conclusions

A lot of measurements were made during 2004 to determine different aspects of power quality on the 220 kV and 110 kV bus-bars which belong to large Romanian substations.

The analysis type of the measurements performed was in part on-line and on the other part off-line. The off-line measurements are used to establish the perturbation categories.

The measurements are made using class A performance parameters, as discussed in this paper, and help us draw the following conclusions:

1. The measured values are within the range recommended by [1, 2] from the point of view of voltage parameters, as well as of its harmonic regime;
2. The influence of the short-circuit power S_{sc} at the bus-bars; the disturbances on 220 kV are per unit smaller than those of 110 kV;
3. A typical voltage variation is recorded in figure 7. This situation points out how useful is the signature for troubleshooting problems throughout electrical network including customer's installations to identify and locate the source of a power quality of event and to select an accurate solution;
4. Transient regimes of connecting and disconnecting in our recordings are frequently present;
5. The cumulative effect of the disturbances, such as the harmonic resonant level in PCC combined with the network faults will increase the electrical stress.

6. Acknowledgements

The authors gratefully acknowledge colleagues from Power Quality Laboratory for the complete technical support needed to obtain the measurements. We also gratefully acknowledge C.N.T.E.E "Transelectrica" S.A for having made available the measurements in Romanian substations.

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