The frequency characteristics of medium voltage distribution system impedances

Liviu Emil Petrean[*] , Mircea Horgoş[**], Olivian Chiver[***]
[*] Department of Electrical Engineering,
North University of Baia Mare, Faculty of Engineering,
Dr. Victor Babeş str., 62/A, 430083 Baia Mare, Romania,
E-Mail: petreanliviu@yahoo.com, [*], mhorgos@ubm.ro [**] , olich@ubm.ro [***]

Abstract *– In this paper we present the frequency characteristics of impedances involved in the electrical equivalent circuit of a large medium voltage distribution system. These impedances influence harmonics distortions propagation occurring due to the nonsinusoidal loads. We analyse the case of a 10 kV large urban distribution system which supplies industrial, commercial and residential customers. The influence of various parameters of the distribution network on the frequency characteristics are presented, in order to assess the interaction of harmonic distortion and distribution system network.*

Keywords: *frequency characteristics, harmonics distortions.*

I. INTRODUCTION

In recent times there have been considerable progress in the penetration of modern technology that uses power electronics. This led to the appearance of other nonlinear loads, which absorb nonsinusoidal large currents and create harmonic voltages throughout power system. These nonsinusoidal consumers produce poor power quality to both themselves and other consumers .

The purpose of harmonic analysis of electric networks is to determine the distribution of nonsinusoidal currents in the network. In harmonic analysis, the interaction between nonsinusoidal currents and network determined by the frequency characteristics of network impedances is extremely important. For a correct harmonic study eight basic rules [3] containing necessary to be met, one being that of that analysis are contained all the load substation fueled by the same transformer substation HV / MV. Usually it is considered that the analysis is good when taking into account 10-12 loads substation for a power feeder. In our case we considered a 10 kV medium voltage distribution system, with simplified equivalent electrical diagram shown in Fig.1. The equivalent circuit contains a number of n = 107 loads substations of 10/0.4 kV supplied by 36 feeder of 10 kV. There are 10 types of loads substations with power transformer rated in range 160 kVA - 2x1000 kVA.

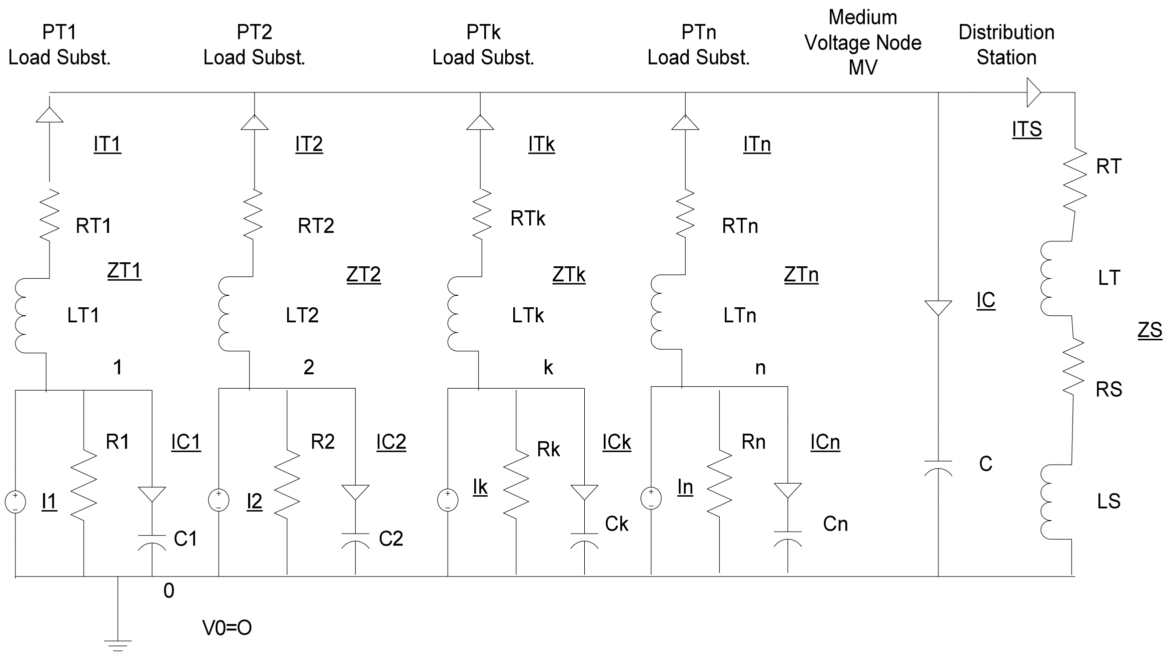

Fig. 1 Equivalent circuit of medium voltage distribution system

II. THE PARAMETERS OF EQUIVALENT ELECTRIC CIRCUIT

Loads substations of the distribution network can be classified into 10 groups according to the rated power and number of transformers of load substation: 2 loads substations of 160 kVA, 6 of 250 kVA, 55 of 400 kVA, 2 of 2x250 kVA, 21 of 630 kVA, 6 of 2x400 kVA, 3 of 1000 kVA, 6 of 2x630 kVA, 2 of 1600 kVA and 4 loads substations of 2x1000 kVA.

Each load substation PTk is modeled by the following electrical parameters: RTk, LTk equivalent resistance and inductance of the transformer (or transformers), resistance Rk corresponding to conventional load of the load substation and the capacitance Ck of capacitors bank for power factor improvement. In the study has been assumed that each tranformer is loaded on 50% of their nominal power. The values of Rk and Ck parameters depends on the loading of loads substation. Capacitances of the transformer windings are generally omitted for harmonic analysis of distribution systems. For nonlinear loads, modeling in the study was considered unit current source Ik(f) which is a function of frequency.

The power transformer 25 MVA, 110/11 kV of the distribution substation is represented by the resistance RT and inductance LT. The magnetizing branch in the transformer model is often omitted if the transformer is not considered a source of the harmonics. Capacitor C represents the capacitor bank of 10 kV condensers, 2.7 MVAr of distribution substation for power factor compensation. RS and LS is equivalent resistance and inductance of power system impedance. All electrical parameters of the scheme have been reported at 0.4 kV voltage level where there are nonsinusoidal loads. The parameters of 10 kV medium voltage lines were neglected.

III. FREQUENCY CHARACTERISTICS OF NETWORK IMPEDANCES

To analyze the frequency response of the distribution network, the equivalent impedances seen from the medium voltage node MV of the electric circuit and transfer impedances were calculated. Frequency spectrum was considered from 50 Hz to 2500 Hz, corresponding to harmonic analysis up to 50 harmonics order. The phasor values of impedances or admittances were calculated with known relations [5]; the inductive reactance XTk(f) = 2 π f LTk and capacitive susceptance Bk(f) = 2 π f Ck were considered as functions of frequency. In this study the frequency dependence of resistances was neglected.

In Fig. 2 we showed the frequency characteristics, i.e. the plots of the magnitude of the impedances versus frequency for a load substation of 1600 kVA: Zech_1600(f) - the network equivalent impedance seen by the current source of load substation, Zload_1600(f) - the equivalent impedance of the parallel connection between transformer impedance and the impedance of consumer (Rk and Ck parallel conection) of load substation, Zech_1600withoutC(f) - the equivalent impedance seen by the current source when the condenser in load substation is disconnected. The predominant influence of parallel connection of the load substation condenser Ck and transformer inductance LTk is observed.

Each load substation containing capacitors are characterized by the pair formed by transformer inductance Lk and Ck capacitance. Inductance Lk and capacitance Ck are connected in parallel to the current source of the load substation and in series to the medium voltage node MT.

Resistance Rk determines the broadness of the |Zech_1600(f)| and |Zload_1600(f)|| frequency characteristics (Rk resistance in parallel with Ck).

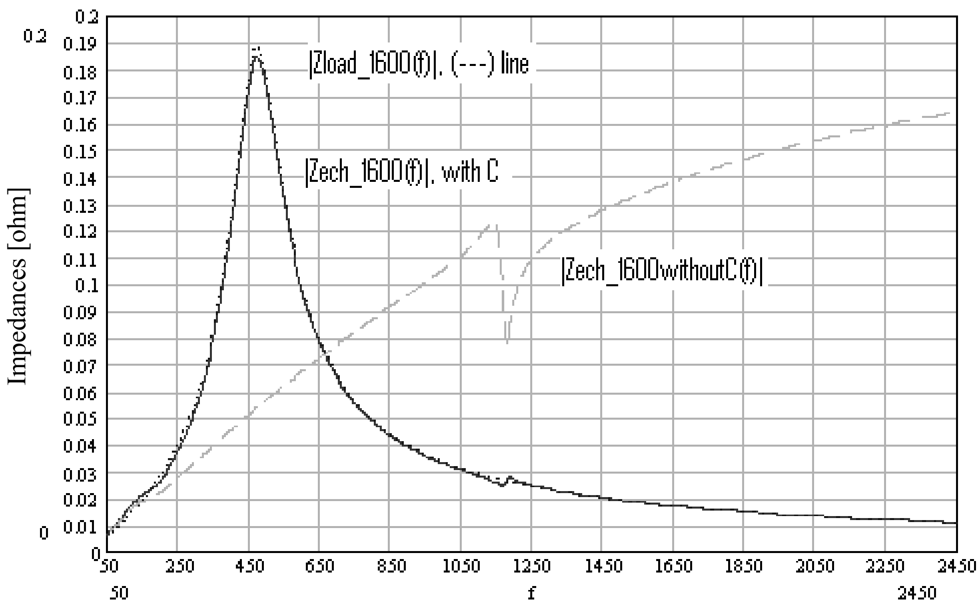

Fig. 2 Frequency characteristics of impedances for a 1600 kVA load substation. Frequency f [Hz].

As seen in Fig. 2, if the condenser of load substation is disconnected, the frequency characteristic is completely different. In the case of a 50% loading of load substations the values of parallel / series resonance frequencies are the following: fPT_160 = 612.7 Hz, fPT_250 = 462.5 Hz, fPT_400 = 460.5 Hz, fPT_2x250 = 487.5 Hz, fPT_630 = 471 Hz, fPT_2x400 = 475.7 Hz, fPT_1000 = 459.8 Hz, fPT_2x630 = 461.5 Hz, fPT_2x1000 = 459.8 Hz, fPT_1600 = 473.7 Hz,. These frequencies are determined by the value transformer (or transformers) inductance Lk and the capacitance Ck of condenser for power factor compensation of load substation (which dependents on reactive power consumption of the consumer, so the number of steps in the operation of the capacitor bank in load substation).

Distribution substation 110/10 kV together with the power system act as parallel connection between the capacitance C of 10 kV capacitor bank and equivalent inductance LT+LS of power transformer in series with power system. Resonance frequency of this circuit is 417 Hz. This value is visible in Fig. 3 in the frequency characteristic of impedance ZS (f) - the equivalent impedance of 110/11 kV distribution substation seen from the medium voltage node MV. As seen in Fig. 1, in relation to the medium voltage node MV load substations are all connected in parallel and then in parallel with the impedance of distribution substation ZS (f).

Equivalent impedance of all load substations connected in parallel with the distribution substation ZeloadsS (f) has a frequency characteristic (— line in Fig. 3) which has two maximum. One of these maximum is higher and has a value close to 1150 Hz (23 harmonics order) and the other has a less maximum value for a frequency close to the value of about 150 Hz. The importance of parallel and series LC connections is mentioned in literature [1, 2, 3] because the currents injected by nonlinear loads interact with network impedances to produce high harmonic voltages. In this case it is important to note that a substantially shift of resonance frequency appears due to the parallel connection between all loads substations and distribution substation. In order to identify the influence of the number of load substation connected in parallel with the distribution we calculate the frequency characteristics for a variable number of load substation. In Fig. 3 the frequency characteristics of the equivalent impedances seen from the medium voltage node MV are shown:

Ze_1_n_loadsS(f) – equivalent impedance of the parallel connection between the distribution station and one load substation of each type: 160 kVA, 250 kVA, …, 2x1000 kVA, totally 10 load substations,

Zeloads_1_630_400(f) – equivalent impedance of the parallel connection of the distribution substation and parallel connection of one 400 kVA load substation, one 630 kVA load substation and all other load substations, totally 33 load substations,

Zeloads_1_400(f) - equivalent impedance of the parallel connection of the distribution substation and parallel connection of one 400 kVA load substation and all other load substations, totally 53 substations,

Zeloads_1_630(f) – similar to the previous but one load substation of 630 kVA, totally 87.

There is a shift of resonance frequency of the equivalent impedances as the number of load substations connected in parallel with the distribution substation increase.

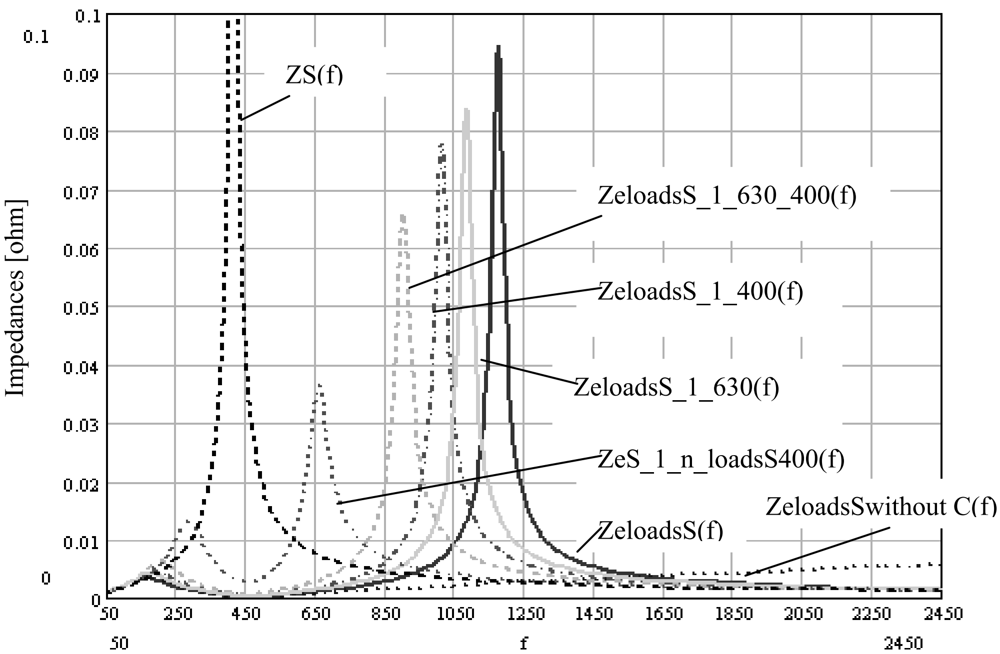

Fig. 3 Frequency characteristics of equivalent impedances seen from medium voltage node MV.

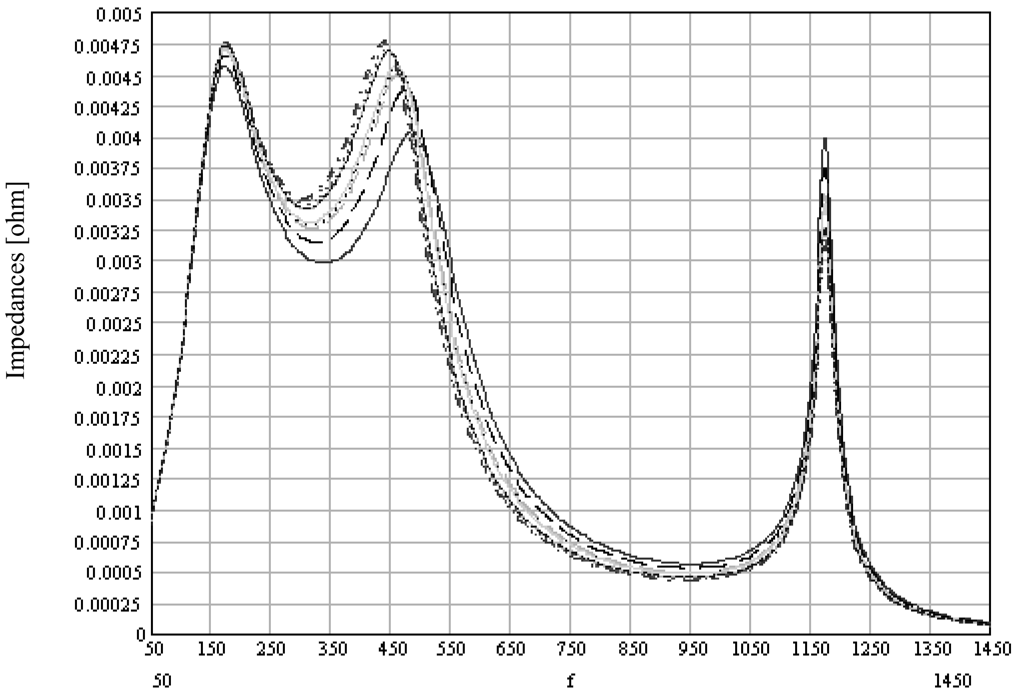

Fig. 4 Frequency characteristics of transfer impedances between nodes of 160, 250, 400, 2x250, 630, 2x400, 1000, 2x630 and 2x100 kVA loads substations and the current source located in a load substation of 1600 kVA.

In Fig. 4 we show the frequency characteristics of transfer impedances between nodes of loads substations and the current source located in a load substation of 1600 kVA. Frequency characteristics shown in Fig. 4 show the possibility of propagating of the harmonic currents from a load substation (1600 kVA) to the loads substations connected to the same distribution substation when the frequency of harmonics currents coincides with the resonance frequency of transfer impedances.

III. CONCLUSIONS

The study of the frequency characteristics of a distribution system impedances containing a large number of load substations put the following highlights:

1. Each load substation containing capacitors for power factor improvement has an inductance Lk and capacity Ck. They constitute a parallel resonant circuit to the current source of load substation and a series resonant circuit to the network.

2. Frequency characteristic of equivalent impedance seen from the current source of load substation is determined by the parallel connection of inductance Lk of the transformer and capacitance Ck of load substation capacitor. This fact is due to high value of parallel connections impedance versus equivalent impedance of the other load substations connected in parallel with the distribution substation.

3. The value of resonance frequency of a parallel connection between the capacitor bank and power transformer of the distribution substation is not directly visible in the frequency charcteristics of transfer impedances. This is because of the phenomenon of frequency shift towards higher values of resonance frequency of the parallel connection between distribution substation and load substations.

4. Common resonance frequency of the parallel connection of load substation (Ck and LTk series connection) presents a shift towards lower values.

REFERENCES

[1] J. Arrillaga, N. R. Watson, *Power System Harmonics*, Second Edition, John Wiley & Sons, 2003.

[2] J. K. Das – *Power System Analysis, Short-Circuit Load Flow and Harmonics*, Marcel Dekker, Inc., 2000.

[3] M. Grady, – *Understanding Power System Harmonics*, Dept. Of Electrical & Computer Engineering, Univ. of Texas at Austin, www.ece.utexas.edu/~grady.

[4] L. E. Petrean, M. Horgoş, et all. "*Some aspects regarding harmonics distortions propagation in power distribution system*" Carpathian Journal on Electrical Engineering, Vol. 2, nr. 1 , 2008, ISSN 1843-7583 North University of Baia Mare, Romania.

[5] C. Şora, *Bazele electrotehnicii*, Editura didactică şi pedagogică, Bucureşti, 1982.