Modelling and Analysis of Power Systems Loads and Harmonic Flow Calculations

I. Kaşıkçı*, Member, IEEE.VDE, M. Darwish, Member, IEE, P. Mehta, Member, IEE
69469 Weinheim Ahornstr. 55, Germany*, Tel/Fax: 0049-6201-182301
E-mail: Ismail.Kasikci@rheinmain.af.mil
Brunel University,Department of Electrical and Electronics Engineering
Uxbridge, Middleesex, UB8 3PH UK, Brunel University UK

Abstract: This paper deals with the derivation of software models for low and medium voltage power systems, including distribution transformers and different loads with regard to the harmonics and power factor corrections. For this purpose, each element of the system is discussed and load models have been developed. The distribution substations can be supplied by medium or low voltage systems which require different solutions. The results presented in this paper are based on the calculation and measurements according to the IEC regulations.

I. INTRODUCTION

Harmonic loads have greatly increased during the past few years. The voltage and current waveforms are becoming more distorted. The various techniques proposed for harmonic elimination have mainly discussed the power circuit configurations and the control techniques. The process of modelling the filter performance in the power system also contributed to the analysis. However, very few papers of the surveyed literature analysed the load in order to specifically model it for reactive and/or harmonic compensation.

II. MODELLING AND ANALYSIS OF POWER LOADS

In reality, it is extremely difficult to model very complicated power distribution systems and to measure the frequency dependent network impedance which affects the values of the components.

The result presented in this paper is to give a better understanding of the harmonics in the power system using a software program to calculate harmonic power flow. A large medium and low voltage distribution power system are selected to demonstrate the application of this program. The harmonic current sources are investigated by measuring harmonics on the low and medium voltage side. The network impedances are determined and calculated based on the measurements at the point of common coupling (PCC). Fig.1 shows a general high, medium and low voltage power system with different loads and compensation methods. According to the Fig.1 the individual network impedance can be calculated and equivalent circuit for different orders and loads may be given (Fig.2).

Normally, the medium voltage impedance is superimposed to the low voltage power system with a transformer voltage ratio factor $(1/n^2)$ and the cable capacity must be taken into consideration. The harmonic impedances are mainly determined by the supply transformers as long as there is no resonance occurring in the power system. The basic data collection has been ascertained by harmonic measurement in the public power supply system.

In the following, a power flow program is developed to analyse the power quality and all possible system components and loads are discussed.

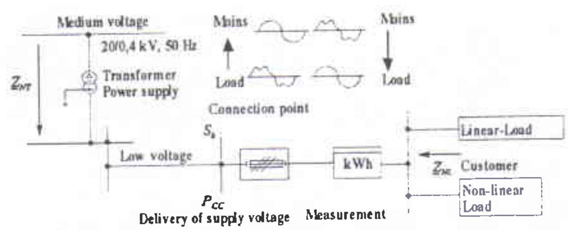

Fig 1 General power system plan for voltage and current harmonics (single line diagram)

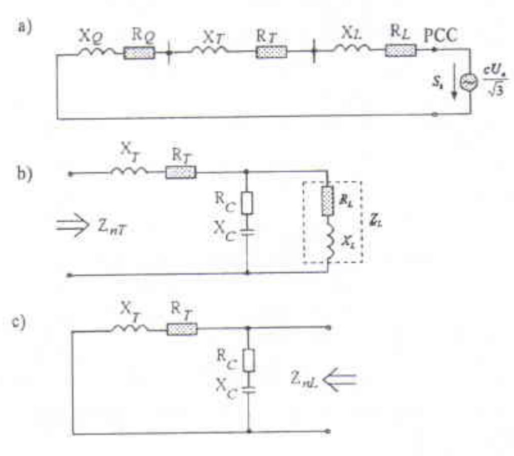

Fig 2. Modelling and equivalent circuits of electrical devices

a) equivalent interconnection of the positive network
b) equivalent circuit diagram seen from the transformer side
c) equivalent circuit diagram seen from the load side

The network impedance determines the magnitude of the harmonics. Therefore, it is important to find the impedance variations of each load. The models can be divided into four groups in the power system: residential, industry, rural and city, with different load characteristics such as T (transformers), R (resistors), C (capacitors) and S (series resonance) [1,2]. But, these groups can not be used for the simulation, because the simulation program and calculation time can be extremely large.

Other attempts have been made to derive statistical load models of the circuits by their probability distribution [3]. For this reason, known and frequently occurred loads are considered in this work (Fig.3).

III. HARMONIC FLOW CALCULATIONS

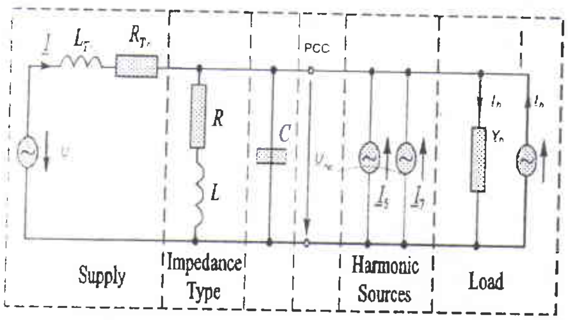

Fig.3. Equivalent circuit of different orders and loads

The harmonic current I_h is injected at the point of common coupling into the distribution system producing a voltage drop V_h on the frequency dependent harmonic impedance Z_h. Therefore, the bus bar impedance can be given as:

$$\underline{Z}_h = \frac{\underline{V}_h}{\underline{I}_h}. \quad (1)$$

- Transformer impedance

Generally, harmonics caused by a current source feeding, transformer and consumer impedance either in series for the low voltage system or in parallel for the medium voltage system. The transformer impedance Z_{rT} can be described by a rated power of S_{rT} and transformer short circuit voltage v_{kr} and ohmic voltage drop v_{Rr}

$$\underline{Z}_{rT} = \frac{V^2_s}{S_{rT}}\left(v_r + jv_x\right). \quad (2)$$

$$v_x = \sqrt{\left(v^2_{kr} - v^2_{Rr}\right)}. \quad (3)$$

Where v_x is the stray inductance of the transformer,

-Ohmic Loads:

Ohmic Load applies to the category of domestic and industry. The equivalent resistance R_L of the ohmic load can be calculated with the nominal supply voltage V_s and consumer power P_L (Fig.4).

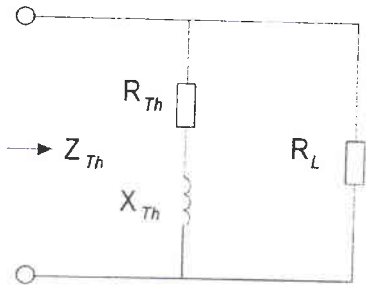

Fig.4. Equivalent circuit of ohmic load

$$R_L = \frac{V^2_s}{P_L}. \quad (4)$$

- Ohmic and inductive load (Motor)

The impedance of the asynchronous motor can be reproduced with rated I_{rM} and starting current I_a ratio $\frac{I_{rM}}{I_a}$ and motor rated power S_{rM} (Fig.5).

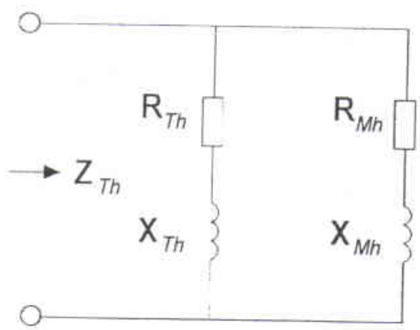

Fig.5. Equivalent circuit of ohmic and inductive load

$$\underline{Z}_{rM} = \frac{V^2_s}{S_{rM}}\frac{I_{rM}}{I_a}\left(\cos\varphi_a + j\sin\varphi_a\right). \quad (5)$$

- Ohmic,inductive and capacitive load (Capacitor)

Power system and facilities contain capacitors which affect the network impedance in such a way that resonance frequency f_r can be estimated in the system as (Fig.6).

$$f_r = \frac{1}{2\pi\sqrt{L\,C}} \geq \frac{1}{2\pi\sqrt{L_{T1}\,C}}. \qquad (6)$$

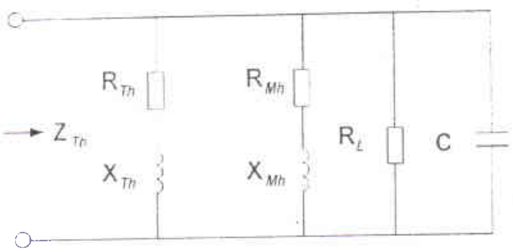

Fig.6. Equivalent circuit of ohmic, inductive and capacitive load

Further characteristics in Eq. 6 can be written as follows:

- Inductance L_{T1} with the short circuit power in the system S''_{kQ} is

$$L_{T1} = \frac{V^2_s}{\omega_1\, S''_{kQ}}. \qquad (7)$$

- then the capacitor C can be calculated with capacitive charging power Q_C

$$C = \frac{Q_C}{\omega_1\, V^2_s}. \qquad (8)$$

Then, the resonance frequency corresponding to the fundamental frequency f_1 gives:

$$\frac{f_r}{f_1} \approx \sqrt{\frac{S''_{kQ}}{Q_C}}. \qquad (9)$$

- Medium voltage power system

The occurrence of the resonance in the medium voltage power system is high, and all consumers, such as loads, capacitors of the facilities must be taken into account.

Therefore, the resonance can be given in the medium voltage system as (Fig.7):

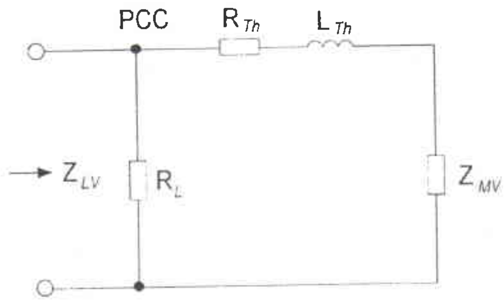

Fig.7. Equivalent circuit of medium voltage power system

$$\frac{f_r}{f_1} = \sqrt{\frac{S''_{kQr}}{Q_{MVC}}} \approx \frac{1}{V_s}\sqrt{\frac{\sqrt{3}V_s I''_k}{\omega_1\, C_E}}. \qquad (10)$$

and further the short circuit power of Eq. 10 for medium (MV) and low (LV) voltage results in

$$S''_{kQr} = S''_{kMV} + \sum\left[(1-k)\, S''_{kLV}\right]. \qquad (11)$$

provided that the distortion factor k=0 for f_{rLV} - f_{rMV} and k=1 for f_{rLV} . f_{rMV}

- Losses of the power system

The harmonic current is added to the real and reactive current then results in the power losses of the system.

$$P_{loss} = R\left(I^2{}_{real} + I^2{}_{reactive} + I^2{}_{harmonics}\right)$$

$$P_{loss} = R\,I^2\left[(g\cos\varphi_1)^2 + (g\sin\varphi_1)^2 + (1-g)^2\right]. \qquad (12)$$

where g is the fundamental oscillation contents.

- Earth leakage extinguishing

The magnitude of the earth remaining current I_{rem} is very important to distinguish from the earth fault current. It defines the value of the allowable earthing resistance. The earth remaining current can then be calculated by

$$\frac{I_{rem}}{I_{CE}} = \sqrt{\left(\frac{I_{1rem}}{I_{CE}}\right)^2 + \sum_h\left(\frac{I_h}{I_{CE}}\right)^2}. \qquad (13)$$

In the industry, capacitors and absorption circuits (filter) are installed to limit the harmonics which also influence the network impedance.

The characteristics of this filters can be evaluated as follows:

Capacitor C

$$C = \frac{Q}{\omega_0 V^2{}_s}. \tag{14}$$

Reactance X

$$X_v = -\frac{V^2{}_s\,\omega_0}{Q\omega} = -\frac{V^2{}_s}{Q\,v}. \tag{15}$$

Inductor L

$$L = \frac{1}{\omega^2{}_1 C} = \frac{f_0 V^2{}_s}{f^2{}_1\, 2\pi Q}. \tag{16}$$

Then the coil reactance gives

$$X_L = \omega L = \frac{h}{Q}\left(\frac{f^2{}_0 V^2{}_s}{f^2{}_1}\right). \tag{17}$$

The resistance

$$R = \frac{2\pi f_1 L}{Q_L} = \frac{f_0 V^2{}_s}{f_1 Q Q_L}. \tag{18}$$

IV. SIMULATION OF THE MODEL OF THE MODEL

The valid compatibility level for particular harmonic voltages in public low voltage (LV) and medium voltage (MV) system and the measured values are given in Tab.1. These values were put into the load harmonic model to investigate the power system.

Table 1. valid compatibility level (IEC 1000-2-2) and measured values of a industrial power system

Harmonic order v	Harmonic voltage in %	measured values LV	measured values MV
3	5.0	0.54	0.54
5	6.0	5.87	5.75
7	5.0	1.55	1.35
9	1.5	1.29	0.18
11	3.5	0.47	0.46
13	3	0.37	0.27

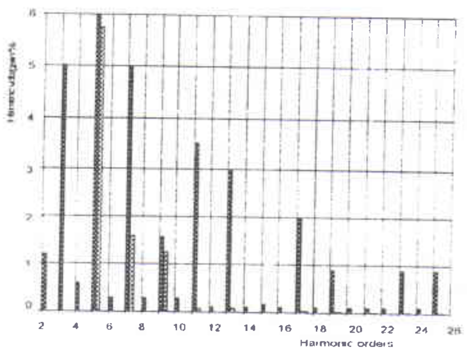

Figure 8. Comparison of the harmonic values

Fig. 8 presents a comparison of the compatibility level with the calculated harmonics.

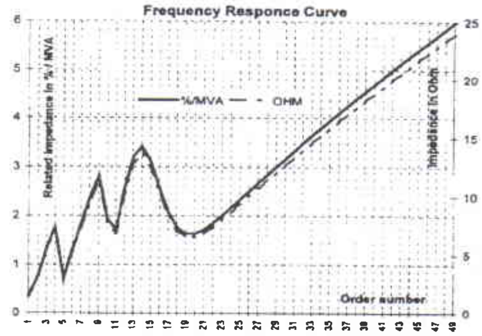

Figure 9. Simulation result

Fig. 9 shows the simulated curve and efficiency of the load modelling. The sufficient accuracy of this model has been checked up to 110 kV voltage level at 2x40 MVA transformer and 8000 MVA network short circuit power.

V. CONCLUSION

In reality, it is extremely difficult to model very complicated power distribution systems and to measure the frequency dependent network impedance which affects the values of the components.

The information presented in this paper is to give a better understanding of the harmonics in the power system using a software program to calculate harmonic power flow. A large medium and low voltage distribution power system was selected to demonstrate the application of this program. The harmonic current sources were investigated by measuring harmonics on the low and medium voltage side. The network impedance's were determined and calculated based on the measurements at the point of common coupling (PCC).

REFERENCES

[1] Technischer Bericht: "Harmonische in Nieder und Mittelspannungsnetzen." Nr. 1-280, Mai 1994. (German)

[2] FGH:" Oberschwingungsgehalt und Netzimpedanzen elektrischer Nieder- und Mittelspannungsnetze FGH." Technischer Bericht 1-268, 1988. (German)

[3] W. Mombauer, K.-H.Weck: Load modelling for harmonic flow calculations. ETEP Vol. 3.No.6. November/December 1993, pp 453-460.

BIOGRAPHY

Ismail Kasikci, born in Turkey, received two Dipl.- Ing. Degrees from University of Applied Sciences in Darmstadt Germany and the MPhil degree from Brunel University London.

He has been working as a professional electrical design engineer within the industry for the past 15 years. He is responsible for design and development of electrical power planning, including power distribution networks, transformer stations, protection and control of electrical systems.

He is also a Lecturer at Association of German Electrical Engineers (VDE). His special fields of interest are reactive power compensation and harmonics, design, protection and control of electrical power systems. Additionally, he reviews, proposes VDE and IEC regulations and standards. He is an author of three books in electrical engineering being published in 1999 in German and another three books in Turkish. He is a member of VDE and IEEE.