

Software for computation of power losses in unbalanced and harmonic polluted industrial electric networks

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List of symbols

In this paper are used the following symbols:

ΔP_{line} – total active power losses on electric lines,

$\Delta P_{transf, w}$ – total active power losses on transformer windings,

$\Delta P_i, \Delta P_N$ – active power losses on line i ($i=1,2,3$) and neutral respectively,

$\Delta P_{p, i}, \Delta P_{s, i}$ – active power losses in every transformer phase, on primary, respectively secondary windings,

$\Delta P_{n, short_circuit}$ – nominal (tested) active power losses in transformer windings,

ΔP_{EC} – active power losses through eddy currents,

$R_{fk}, R_{p, fk}, R_{s, fk}$ – harmonic resistance, of line and transformer respectively,

$I_{i(N)}$ – rms. value of current on line i , and neutral respectively,

I_1 – rms. value of the fundamental current,

I_k – rms. value of range k harmonic current.

Abstract

The electromagnetic phenomena in the industrial electric power networks have reached a level of complexity so high that their accurate knowledge has imposed the developing of com-

plex software products, including expert systems, which can satisfy these expectations.

Particularly, the unbalanced and non-sinusoidal working conditions have a negative impact on both individual components of the electrical system and the whole system. The knowledge of distribution losses, which depend on the technical and operation characteristics of the electric network and on the distortion and unbalance degree of the current and/or voltage waveforms, is necessary in order to establish the network parameters and working state. Power losses calculus allows setting the electrical energy distribution cost, estimating the efficiency of the losses reduction solutions, etc.

Looking for computation of power losses in the industrial electric networks, taking into account the necessity of making complex mathematic calculations and considering the number of parameters that influence these power losses during an unbalanced and non-sinusoidal state, the authors have developed an original software tool which satisfies this goal, and quickly provides accurate results.

The paper presents this software, by describing its methodology and the mathematic equations that have been used to determine the electric power losses for radial electric networks working in unbalanced and harmonic polluted conditions.

Introduction

In our days, the electric power systems possess a unique working state, characterized by the existence of electromagnetic perturbations, which have a negative impact on the components of the electric systems. In the recent years the number of non-linear and single-phase loads, that introduce harmonic currents and unbalances and amplify the existing distorted regimes, has

grown alarming; as a result, in the distribution electric systems, the current and voltage waveforms have reached a very high level of distortion. The disturbing customer absorbs from the power supply more active and reactive power than it needs and puts out in the power system a part of them as harmonic or unbalance power (Cziker, 2004).

During the process of consumers supplying, it occurs losses in the generation, transmission and distribution stages. Depending on the structure of the power network, working conditions etc, the level of energy losses ranges between 10 % and 15 % from the energy produced by the power plants (Chindris, 2005). An important effect of the harmonic distortion and unbalance is the increase of power and energy losses in all elements of the power system.

The knowledge of power and energy losses is necessary to establish the network characteristics and working state, to set the electrical energy cost, to estimate the efficiency of the losses reduction solutions etc. Thus, the power engineers have to know the power losses of every component of the electric power system in the stage of design, development and operation.

In spite of the above-mentioned facts, the power designers calculate the power losses considering a sinusoidal balanced regime, and this approach can lead to under sizing of the network's elements, especially lines and cables. In the operation stage, it can generate many malfunctions or even failure of the entire power system.

In conclusion, in order to implement an accurate design of a power network, in concordance with its real working regime, and to obtain power losses close to reality, it is necessary to perform complex accurate calculations, to take into consideration many parameters. Thus, the authors have created a software program, named CPL, able to compute power losses in lines and transformers, considering a harmonic unbalanced regime.

Analytic support

Physically, the total power losses in any power system are the sum of the power losses located on:

- line conductors and windings of the transformers through Joule effect;

- the magnetic core of transformers, through eddy currents and hysteresis phenomenon;
- lines of 220 kV and higher rated voltage, through corona phenomenon;
- dielectric of the high voltage insulation (Eremia, 2006).

Only losses caused by eddy currents and Joule effect are considered in this paper. For a reasonable evaluation of power losses, the influence of non-sinusoidal and unbalance conditions in power networks is considered, under the following hypothesis:

- supply voltages are balanced and have sinusoidal waveforms;
- transformers windings resistances and inductances are equal for all three phases;
- transformers are not saturated.

Taking into account the unbalance of load currents, additional power losses appear in transformer windings through eddy currents and Joule effect. In a non-sinusoidal and unbalanced regime, the Fourier series expansion leads to unbalanced fundamental and harmonic currents systems; each of them can be decomposed in three symmetrical systems. Of special interest are triple harmonics, which add up in the neutral conductor of low voltage three-phase networks with Wye connection. Under these conditions, through each line conductor flow fundamental negative, positive and zero sequence currents and harmonic negative, positive and zero currents; through the neutral conductor flow only harmonic zero sequence currents (Chindris, 1999).

Based on these assumptions, the relationships presented in Table 1 were used for the calculation of power losses.

Software

CPL calculates the power losses in electric lines and transformers in three-phase, three and/or four wires, industrial electric networks working in non-sinusoidal and unbalanced conditions. The Borland C++ Builder visual environment was used for software developing. CPL has two parts: a friendly GUI (graphical user interface) and the operating modules, further presented on this chapter.

Table 1. Power losses in electric lines and transformers for different working states

Losses Working regime	Active power losses in electric lines [W]	Active power losses in transformers [W]
Sinusoidal and balanced	$\Delta P_{line} = 3 \cdot R_f \cdot I_1^2$	$P_{transf, w} = \Delta P_{n, short_circuit}$
Non-sinusoidal and balanced	$\Delta P_{line} = 3 \cdot (\sum R_{fk} \cdot I_k^2), k = \overline{1, N}$	$\Delta P_{transf, w} = 3 \cdot (\sum R_{p, fk} \cdot I_{p, k}^2 + \sum R_{s, fk} \cdot I_{s, k}^2) + \Delta P_{EC}, k = \overline{1, N}$
Sinusoidal and unbalanced	$\Delta P_{line} = (I_1^2 + I_2^2 + I_3^2) \cdot R_f + I_N^2 \cdot R_N$	$\Delta P_{transf, w} = (I_{x, 1}^2 + I_{x, 2}^2 + I_{x, 3}^2) \cdot R_x, x = p, s$
Non-sinusoidal and unbalanced	$\Delta P_{line} = \Delta P_1 + \Delta P_2 + \Delta P_3 + \Delta P_N$	$\Delta P_{transf, w} = \Delta P_{p, x} + \Delta P_{s, x} + \Delta P_{EC}, x = 1, 2, 3$

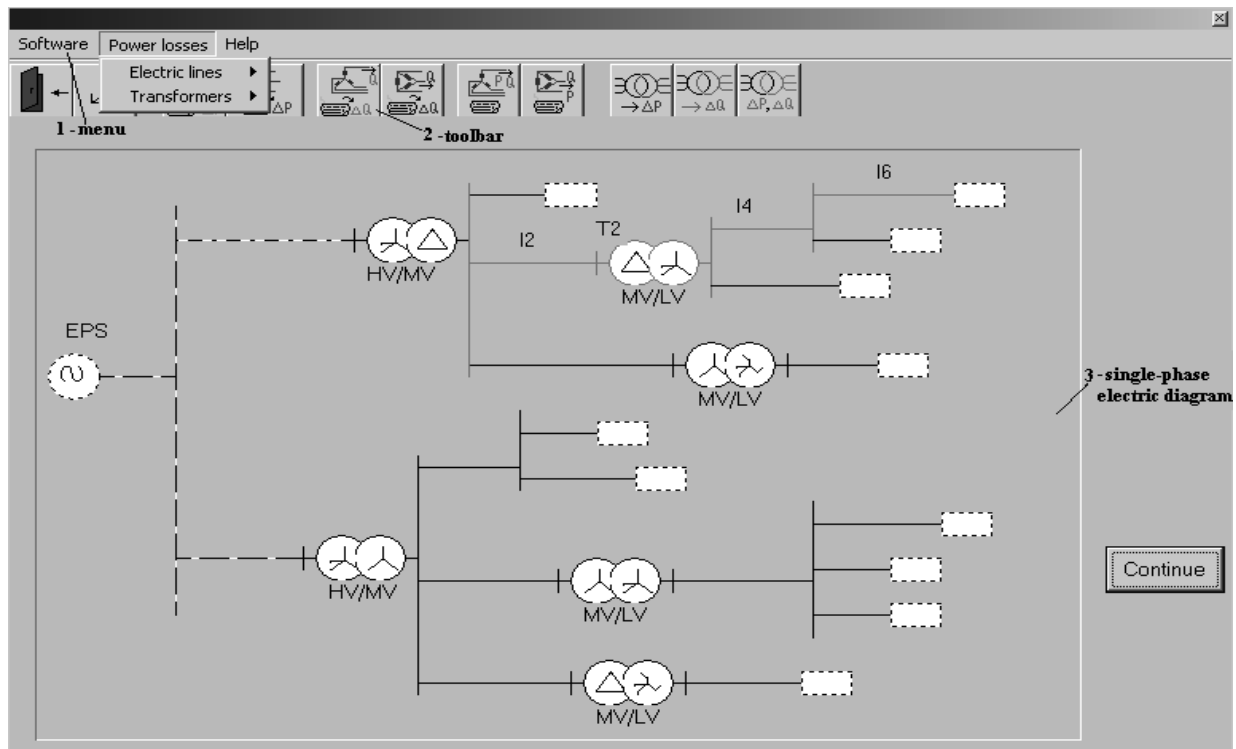


Figure 1. GUI, Main window

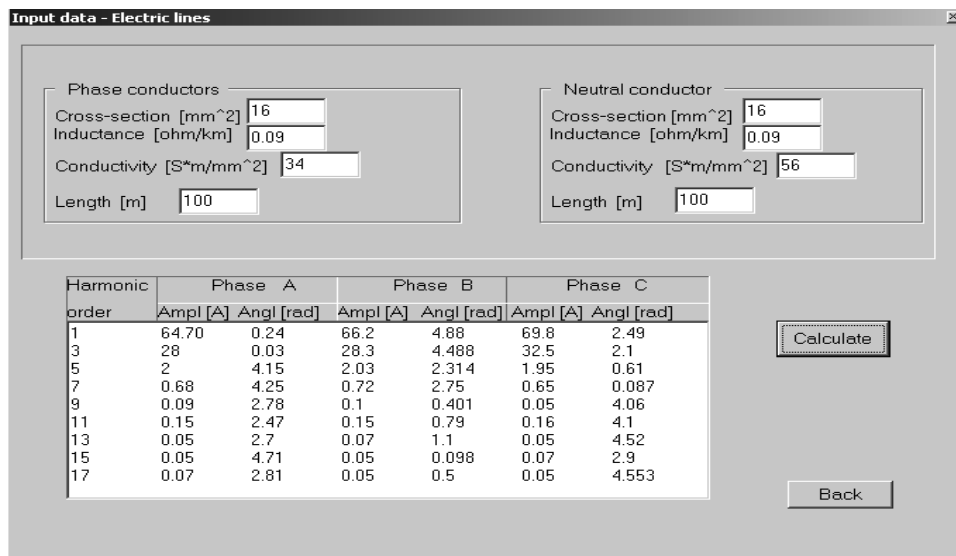


Figure 2. Auxiliary window: input data for calculation of active and reactive power losses in electric lines

GRAPHIC USER INTERFACE

The graphic user interface represents the component of the software with which the user comes in contact. Through it, the user introduces the input data and obtains the output data. CPL's GUI consists of one main window, presented in Figure 1, and several auxiliary windows.

The main window contains a menu bar (1); a toolbar (2) and a one-line electric distribution network diagram (3). The menu bar has three fields: Software, Power losses, with two sub-fields (Electric lines and Transformers), and Help.

By accessing the field Power losses, the user can get both active and reactive power losses for only one power element: electric line or transformer.

The toolbar contains shortcut buttons to some auxiliary input data windows. As in the case of the menu, using toolbar's shortcuts, the user can determine power losses only for a distinct power element, but besides he can get active and reactive power losses separately. If the user wants to obtain power losses for more than one element, he can use the one-line electric diagram (Figure 1, 3).

The dialog windows, represented by auxiliary windows, allow to introduce input data and to display results. Figure 2 presents an example of an input data window.

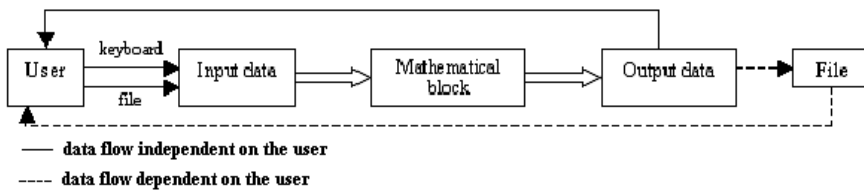


Figure 3. CPL's working principle block diagram.

Table 2. Input data for electric lines power losses.

Number of conductors Power's type	Electric networks without neutral	Electric networks with neutral
Active power	<ul style="list-style-type: none"> - phase conductor cross-section [mm²]; - conductor conductivity [m/Ωmm²]; - conductor length [m]; - rms value of harmonic currents [A]; - harmonic currents's angles [rad]. 	<ul style="list-style-type: none"> - phase and neutral conductor cross-section [mm²]; - conductor conductivity [m/Ωmm²]; - conductor length [m]; - rms value of harmonic currents [A]; - harmonic currents's angles [rad].
Reactive power	<ul style="list-style-type: none"> - phase conductor inductance [Ω/km]; - conductor length [m]; - rms value of harmonic currents [A]; - harmonic currents's phase [rad]. 	<ul style="list-style-type: none"> - phase and neutral conductor inductance [Ω/km]; - conductor length [m]; - rms value of harmonic currents [A]; - harmonic currents's phase [rad].

Table 3. Input data for transformers power losses

Calculus Transformers	Aproximate	Advanced
3-Phase transformers	<ul style="list-style-type: none"> - nominal rating [kVA]; - primary, secondary nominal voltages [kV]; - primary, secondary connections; - cooling system, constructive type; - tested short-circuit power losses [kW], voltage [%]; - rms values [A] and phases [rad] of harmonic currents; - load power [kW]. 	<ul style="list-style-type: none"> - nominal rating [kVA]; - primary, secondary nominal voltages [kV]; - primary, secondary connections; - cooling system, constructive type; - tested short-circuit power losses [kW], voltage [%]; - short-circuit voltage [%]; - rms values [A] and phases [rad] of harmonic currents; - load power [kW]; - windings characteristics: conductor cross-section, conductivity, coil's breadth etc.

OPERATING MODULES

Figure 3 shows the working diagram of the software product: (1) the input data are read from a source file or from the adequate auxiliary window, (2) the read values are processed, and (3) the output data are posted on the desktop through the right auxiliary window. The user can save the input and output data in a report file, where are introduced more results than are showed on the desktop: for instance, power losses in the neutral conductor (if exists).

For a better knowledge and understanding of the quantities used as input data, Table 2 and Table 3 present these data for electric lines and for transformers, respectively.

After the software processes the input data, the power losses produced by the active power and/or reactive power flow are calculated according to the relationships indicated in Table 1, and displayed in a dedicated auxiliary window. When the user exits CPL, he is asked if he wants to save the input data and the obtained results (output data).

The mathematical block diagram – Figure 4, shows the working algorithm of the proposed software. Inside the software, the input data are divided into line's and transformer's input data, and than these values are used to calculate the power losses chosen by user.

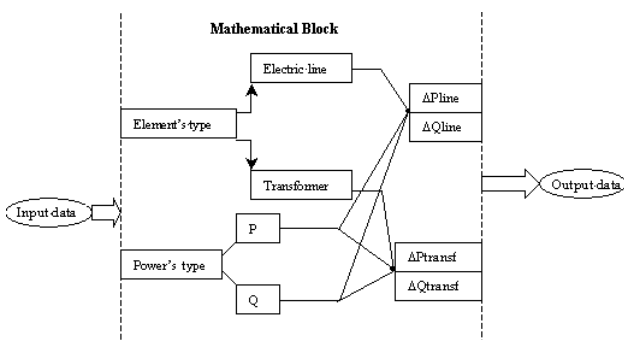


Figure 4. Block diagram of CPL's mathematical block.

Conclusions

The paper presents an original software product, named CPL, created in Borland C++ Builder visual environment; it helps to calculate power losses in unbalanced and harmonic polluted industrial distribution power networks.

Because the computation of power losses in unbalanced and non-sinusoidal regime requires complicated mathematical relationships, the use of CPL decreases the timework and offers several advantages: the great number of input data, values more correct for the power losses and the possibility of working with complex electric power networks.

Acknowledgments

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References

- [Chen, 1995] – Chen T.H. Evaluation of line loss under load unbalance using the complex unbalance factor, IEE Proc.-Gener.Transm.Distrib., Vol.142, No.2, March 1995, pag. 173 – 178.
- [Chindris, 1999] – Chindris M., Unbalanced Power Systems under Non-Sinusoidal Conditions, Socrates Course, Universitat Politecnica de Catalunya, Barcelona, Spain, March 1999.
- [Chindris, 2005] – Chindris M., Cziker A., Determinarea pierderilor suplimentare de putere în reele electrice de J.T. funcționând în regim nesimetric și nesinusoidal, CEE 2005, Sesiunea 1 – Calitatea energiei electrice – Aspecte teoretice și reglementări.
- [Cziker, 2004] – Cziker A., Chindris M. Considerații privind pierderile de putere în rețelele de distribuție reale de exploatare. Simpozion Internațional de Eficiență Energetică, Cluj-Napoca 2004.
- [Mendes, 1990] – Mendes A., Duphil N., Harmonics: A supply authority view. Collection des notes internes de la Direction des Etudes et Recherches. Note interne 93NR00019.
- [Tugulea, 1987] - Țugulea A., Golovanov Carmen. Efecte energetice ale regimurilor nesimetrice și deformante ale sistemelor electroenergetice. Posibilități de măsurare, ENERG, vol. III, București, Editura Tehnică, 1987.
- [Cioc, 1989] – Cioc I., Vlad I., Calota G. Transformatorul electric: construcție, teorie, proiectare, fabricare, exploatare, Scrisul romanesc, Craiova 1989.
- [Jeziński, 1966] – Jeziński E. s.a. Transformatoare electrice, construcție și proiectare. Editura tehnică, București 1966.
- [Eremia, 2006] – Eremia M. Electric power systems. Volume I Electric networks. Editura Academiei Române, Bucharest 2006.