Igor VOLKOV, Sergii PODOLNYI

Institute of Electrodynamics of NAS of Ukraine

Requirements and new software for harmonic analysis in specialized nonlinear power systems

***Abstract**. The modern requirements of harmonic analysis software implementation for specialized nonlinear power systems are considered. The available software solutions for partially tasks fulfilling are analyzed. Approaches to the creation and development of perspective calculation program for mentioned task are showed.*

Streszczenie.** Rozpatrzono i przeanalizowano wymagania stawiane w zakresie specjalistycznych zastosowań analizy harmonicznej systemów elektroenergetycznych. Wykonano analizę dostępnych rozwiązań oprogramowania częściowo spełniających stawiane wymagania. Podano własne podejścia do tworzenia i rozwoju programów ukierunkowanych na rozwiązywanie zadań z zakresu analizy harmonicznej w systemach elektroenergetycznych. **(Oprogramowanie do analizy harmonicznej nieliniowych sieci elektroenergetycznych)

Keywords: Harmonic analysis, cluster calculations, the discrete schemes method.
Słowa kluczowe: Analiza harmoniczna, systemy elektroenergetyczne, obliczenia z podziałem na podukłady.

Introduction

There is the recommendation document for engineers dealing with electromagnetic compatibility in the construction and maintenance tasks of offshore and marine power systems «ABS (American Bureau of Shipping) Guidance Notes for Control of Harmonics in Electrical Power Systems» which specifies key requirements for the harmonic software analysis functionality working with the considered nonlinear power systems. The guidance assembled the experience of nonlinear power systems using and optimization. It describes the following basic criteria: the availability of a large nodes number for system units, the analysis of systems with amplitude and phase imbalance, resonance points frequency scanning, a large number of nonlinear models (6-puls, 12-puls, 18-puls, etc.), availability of different filters models, modeling the mixed (3 and 4 wire) electrical systems [1].

Analysis of existing software solutions such as ERACS, SOLV, Power Design Pro, ETAP, HI_WAVE and so on [2, 3], Showed that they can only partially satisfy the above requirements. There is a conceptual approach to the construction of most that software. The key idea was to create suitable tools for switchgear selecting problems, cables, transformers, etc., with accent on extensive line load using, on the contrary harmonic analysis stuff is solved by injecting of frequency-independent current sources as a rule i.e. the task was seen as minor.

For these reasons, the authors began to develop the harmonic analysis software in the first place for systems enriched by different nonlinear loads. The main concept is to build program as much as possible meets the mentioned requirements. That is the problem of electromagnetic compatibility – the primary task.

Software architecture

The basic components of software architecture for this problem are the implementation of the graphical kernel interface for the user (GUI) and mathematical parts.

Fig. 1 depicts the basic structural elements of the graphics core. It includes tools for diagrams drawing and editing, data saving and loading of the project, various forms of data format representation, displaying and exporting the numerical results, additional toolboxes for related problems solving, library navigation for the fast search real word electrical elements.

At present, most of these features implemented in the project (Fig. 2).

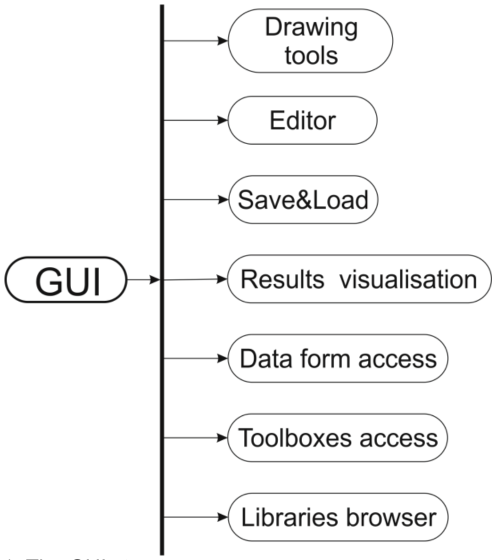
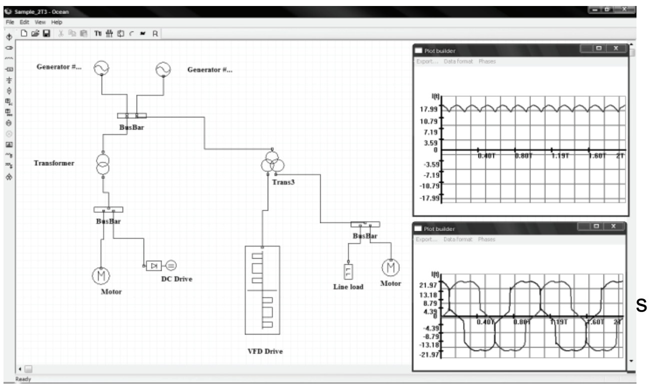


Fig.1. The GUI structure

The GUI does not impose restrictions on the system dimension, besides allows you to create electrically unconnected power systems and allows operating both electrical and auxiliary elements.



s of software

Fig..2 The GUI implementation

Mathematical kernel

The kernel mathematical structure is shown on Fig. 3. It includes the following main elements: the main builder of the graph-matrix, choosing of an analysis method and ones implementation, optimized matrix calculations, each elements parameters calculation, data post-processing.

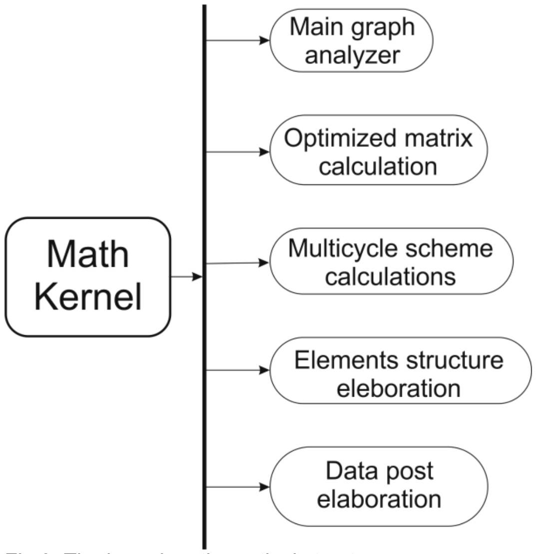


Fig.3. The kernel mathematical structure

Obviously, the most common method for transient process calculation is the space-state method. There are several stages int this method. It includes state-space equations formation, state-space differential equations approximation by difference equations, obtaining numerical solution of difference equations at each moment of the simulated time. This calculation sequence is effective for circuits with a small number of reactive and non-linear elements. The state-space equation of such circuits can be formed manually or in computer by relatively simple algorithms. Thus the accuracy of the resulting decision will only be affected by the chosen method of numerical integration. There is not calculation of the state-space equations formating for circuits with a great number of reactive elements and multipolar nonlinear elements. As a rule one should develop a new formating method for each new complex circuit and it's fairly difficult task. Therefore, the computer calculation of complex circuits should prefer simple way that is forming the equations by the most easily and universal procedure.

Therefore as the basic electrical calculation method was chosen the discrete schemes method. It includes the following steps: differential equations approximation of each single circuit element by the difference equation, obtained difference equation become represented as the active resistive subcircuits, the whole circuit is builder with replacements, there are only current or voltage sources and resistive elements, for simple replaced circuit is performed calculation by arbitrary electrical method. In order to determine the instant variable values in every simulating time points performs each element parameters recalculating in these moments of time according to a chosen numerical method.

Electrical system elements replacing by the two-pole resistive and active network allows securing the circuit topology and allows applying all known methods for DC-circuit complex electrical analysis. The difference equation based on the Euler implicit method for both replaced inductance and capacitance are following:

(1)
$$x_{n+1} = x_n + h \cdot f(n+1) \Rightarrow$$
$$i_{L,n+1} = \frac{h}{L} \cdot u_{L,n+1} + i_{L,n};$$
$$i_{C,n+1} = \frac{C}{L} \cdot u_{C,n+1} - \frac{C}{L} \cdot u_{C,n}.$$

For the mass of electrical circuits matrix equations eigenvalues specific feature exited. The eigenvalues located on complex plane left side, but in quite arbitrary manner. Therefore, integration of these equations reasonably implement by methods with the stability region including the entire complex plane left side, such as the implicit Euler method or the trapezoids. Such methods are A-stable. That is, using (1) is sufficient to satisfy the stability conditions. Certainly, there should be the correct choice of integration step h.

Another important advantage of the discrete schemes method is the possibility of macromodels using relative to two-pole network elements. Macromodel elements allow decreasing equations order by combining several basic elements in an equivalent two-pole network.

As the main method for determining the instantaneous values of both voltages and currents the topological method of nodal potentials is used [4]:

(2) $U_0 = -(A\,Y\,A)^{-1} A(J + Y\,E)$

where: A – incidence matrix, Y – diagonal conductance matrix, J,E – currents and voltage vectors.

By separating circuits segments on 3-wire and 4-wire systems we can automatically fill the cells of incidence A-matrix with the elements incidence submatrixes Ai for each of the possible options. At the stage of A-matrix formation elements connection is verified. There is a simple criterion. If the circuit segment includes some elements with only 3-wire topology exited the segment assumed as 3-wire and all primary undefined topology elements in this pool inherit 3-wire properties. For the circuit segments of the 4-wire structure is the same. 3-wire and 4-wire elements can not be present within a single network pool, but generally it could take a place in different circuit segments within a single scheme.

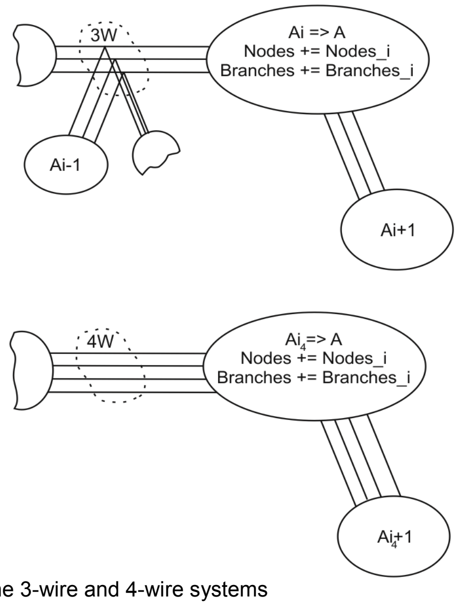


Fig. 4. The 3-wire and 4-wire systems

Although this method isn't without a several shortcomings (absence of conductivity matrix for an ideal transformer, specific problems with mutual inductance, etc.), but such approach provides several advantages. Quasi-linear feature of the discrete schemes method in which transformers are included, with the correct graph-matrix nodes numeration transforms A-matrix in matrix with cluster structure (Fig. 5).

$$\begin{pmatrix} [A_{seg1}] & [\quad 0 \quad] \\ [\quad 0 \quad] & [A_{segJ}] \end{pmatrix}$$

Fig 5. Structure of A-Matrix

Cluster structure allows to split the problem of finding the inverse matrix into subtasks of individual inverse matrices determination for each cluster with smaller dimensions, and for linear clusters (e.g. the EMF with liner filter connected with nonlinear load through transformer) inverse matrix need to be calculated just one time. That is, by analyzing a set of input items belonging under criterion linear/nonlinear, during calculations preprocessing performing clusters classification and for liner clusters expression (AYA) -1 is calculated only once for a constant simulation step.

For this problems class the structure of matrix (AYA)^(-1) is symmetric with positive determinant, so to speed up finding the inverse matrix the Holetskyi method of LLT decomposition is used. In addition, for clusters with nonlinear structures symmetry feature allows to simplify finding the AYA-matrix by means of triangular matrix elements reflexing relative to diagonal, besides the triangular matrix elements are calculated according to (3):

(3) $$M(i,j) = \sum_{k=1}^{K} A(i,k) \cdot Y(k,k) \cdot A(j,k)$$

where: K– cluster size.

For "heavy" systems, i.e. systems with many nodes and branches clusterisation will allow to easily separate CPU load between individual cores if multicore systems are available, or to design LAN-calculation extention. Implemented algorithm, if necessary, allows using of different depth models with required electric circuits elements detailing.

In order to properly build the A-matrix, the forming preprocessing stage should correctly in automatic way to number circuit nodes. The connecting nodes actually is zero resistance lines, distribution busbars and idealized switches. This procedure is divided into two stages. The first phase unites ideal nodes representation into a single hub (such as ideal lines connected with zero resistance distribution busbars), i.e. Node (J) $\in$ {Node (j1), Node (j2) ... Node (jN)}. The second phase formes global topological single-line connection matrix. Based on this matrix it performs elements renumbering in order to obtain correct clustering structure with the help of graph theory methods.

Table 1. Global topology

	Elem(1)	Elem(2)	Elem(3)	--------	Elem(E)
Node(1)	1	1	2	--------	0
Node(2)	0	1	0	--------	2
--------	--------	--------	--------	--------	--------
Node(N)	0	0	0	--------	2

If a direct connection between nodes and elements is existed it is indicated by "1" in the case of connection absence - "0". Connection with the value "2" indicates that this node will be used for clusterisation, i.e. element is some type of transformer. An example of this procedure is shown on Fig. 6. Nodes numeration within a cluster does not matter.

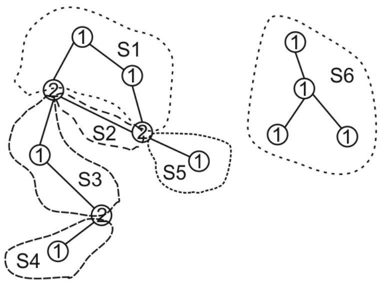


Fig 6. Global sorting structure

At a present time, the program has got the basic linear elements: generators, reactors, LC-filters, cable lines, line load, induction motor, 2 and 3 winding transformers with standard configurations of primary and secondary windings. Among the nonlinear elements are following presented: DC-motors, frequency-controlled motors in RC-equivalent circuit loading (VFD), spectral power sources.

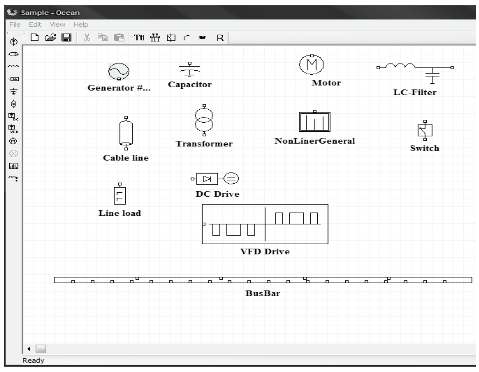


Fig 7. Example of element list

In the near future, advanced computational program core will able to solve a number of related problems such as: optimization of reactors parameters, filters, checking compliance with the electromagnetic compatibility standard IEEE 519, etc.

REFERENCES

[1] www.eagle.org
[2] www.easypower.com
[3] www.ecmweb.com/products/electric_focus_power_quality_3
[4] Демирчан К., Нейман Л., Теоретические основы электротехники. – СПб.:Питер, 2006.

Authors: *DSc., prof., corresponding member NAS of Ukraine* Igor Volkov, Institute of Electrodynamics NAS, *av. Peremogy 56, Kyiv, E-mail:*i.volkov@kv.ukrtel.net; *Ph.D., Sergii Podolnyi,* Institute of Electrodynamics NAS, *av. Peremogy 56, Kyiv E-mail:*dgp@ukr.net.