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ADAPTIVE DIGITAL MODEL OF SIGNAL PROPAGATION PROCESSES IN LONG LINES AND BRANCHING PL- NETWORK

On the basis of Heavyside telegrapher's equations digital model of high frequency signals propagation in branch tree-like energy supply network of multistory multifunctional building has been developed. The technique of model adaptation to the variations of sources and receivers of signals location has been suggested. The developed model provides the possibility to select the location of sources, receivers and relay stations of high frequency signals from the point of view of reliability and error probability performance of information network.

Key words: *model, signal, network, source, receiver, two-terminal network, tree-terminal device, graph.*

Introduction

Modern period of development of automation integrated systems is characterized by considerable growth of the demand for automated control systems of buildings (ACSB) and multifunctional constructions (ACSMC).

The concept of similar systems construction is based on integration in a single engineering system main life-support systems of the building (electric energy supply, lighting, heat supply, microclimate, etc.). The characteristic feature of modern multistory buildings and multifunctional constructions from the point of view of management, control, measurement and account of energy resources is that their space is in a complex manner divided into local spaces of the users (LSU) among numerous judicial and private persons – tenats or owners of these areas. Each such local space must be informationally integrated in a single system of building automation. Unlike principle engineering life-support systems, location of which does not change in time, the structure of building space division into numerous local spaces of users (LSU) is dynamic. It undergoes constant changes due to changes of rent contracts and contracts of building purchase. Changes of the structure of building space division into numerous LSU leads to changes in the topology of ACSB and ACSMC. In these conditions conventional wire communication channels turn out to be inefficient. Changes of the topology of wire systems require additional expenditures for buying cables and conducting materials and additional civil engineering and installation works. And probably, already installed networks will never be used and the expenses for their installation will not be recouped.

Three popular wireless technologies Wi-Fi, ZigBee and EnOcean [1,2,3] are efficient in buildings, having few floors and as local subsystems inside separate premises. Reinforced concrete floors are serious obstacles for wide application of these technologies in the systems of automation of multistory buildings.

In this connection, Power Line technologies become very interesting for creation of information channel of ACSB and ACSMC, because these technologies use for signal transmission the network of electric supply. Solutions in the sphere of information transfer along high voltage lines without branching on the section of high voltage signal passage are known and well studied [4, 5]. Regarding the application of PL-technologies in conditions of branching networks of energy supply of multifunctional buildings, individual study of the conditions of high voltage signals passage, taking into account shunting action of loads and numerous branchings should be performed. The aim of these studies is determination of high frequency signal parameters in different points of the given energy supply network at the preset location of signal source. Methodology of construction of topological structure of the network for information transmission in energy supply circuits of the building must be based on the result of such studies.

Due to the spreading of PL-technologies in various projects of ACSB and ACSMC the problem of creation of universal adaptive digital model of high-frequency signals propagation processes in branching tree-like network of energy supply of multistory, multifunctional building becomes urgent. The given study is aimed at solution of this problem. Characteristic feature of the suggested solution consists in original methodology of construction of object-oriented digital models of tree-like PL-networks of two types of unified functional modules and in the mechanism of automatic readjustment of the model structure in the process of the change of high frequency signals sources locations. Without having a claim on completeness and accuracy of processes description of signals in PL-networks transmission, the suggested model enables to simplify considerably and optimize their design.

Modeling of signals propagation process in tree-like networks by means of counter information flows

Electromagnetic process of signal propagation in the line with distributed parameters is described by the so-called Heavyside telegrapher's equations

$$\frac{\partial u}{\partial l} = -L\frac{\partial i}{\partial t} - iR,$$
$$\frac{\partial i}{\partial l} = -C\frac{\partial u}{\partial t} - uG,$$

(1)

where $i(l,t)$ - current in the line, $u(l,t)$ - voltage between direct (phase) and return (zero) wires of the line, R, L, C - linear resistances, inductance and capacitance of the line, correspondingly, G - linear conductance of insulation between direct and return wires.

Following Heavyside, the line with distribution parameters is modeled by the chaine of elementary two-ports. Each two-port is the model of infinitely small section of the line, where distributive parameters are set by linear values: capacitance, inductance and active resistance. Taking into account the characteristic

features of electric supply networks of buildings, we will make some assumptions.

1) While construction the model of the elementary section, we will neglect the impedance of the return wire (dead grounded neutral of distributive network) approximately considering the potential of neutral wire (multiply grounded) everywhere to be equal zero. As a result of this assumption, sections of the network in the first approximation can be presented by the elementary three- terminal devices , as it is shown in Fig. 1.

2) Taking into account comparatively small length of the sections of electric energy supply (approximately several scores of meters) we may neglect the conductance of insulation between the wires of the line.

3) Taking into consideration the fact, that on 100 kHz frequencies, the signal wavelength $\lambda = \dfrac{2\pi}{\omega}(LC)^{-1/2}$ in energy supply network has the order $10^2 \dots 10^3\,\mathrm{m}$, exceeding the length of sections between the points of its branching, we may neglect signal distortions, as a result of wave reflection.

Schematic representation of line model, taking into account the suggested assumptions, is shown in Fig. 1.
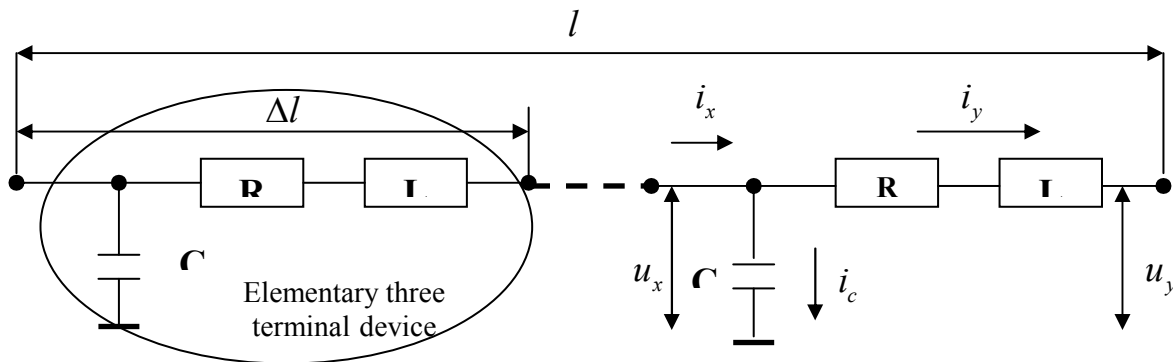

Fig. 1. Line of signal propagation, composed of elementary three terminal device

Replacing the approximately infinite small increment of the line by its finite small section, we transform telegrapher's equation in partial derivatives to the form of finitely-differential equations, describing elementary tree-terminal device as functional module, transforming the vector of input variables of $\left[u_x(t), i_x(t)\right]$ into the vector of output variables $\left[u_y(t), i_y(t)\right]$

$$u_y = u_x - i_y R\Delta l - L\Delta l \frac{di_y}{dt},$$

$$i_y = i_x - C\Delta l \frac{du_x}{dt}.$$

(2)

These equations are obtained from (1) by replacing $\dfrac{\partial}{\partial l}u(l,t) = \dfrac{u_y(t) - u_x(t)}{\Delta l}$ and

$\frac{\partial}{\partial l} i(l,t) = \frac{i_y(t) - i_x(t)}{\Delta l}$. Such replacement does not introduce considerable distortions in the picture of signal propagation, if the ratio of the length $\lambda = \frac{2\pi}{\omega}(LC)^{-1/2}$ of elementary section of the line Δl to the length of the wave, propagation along it, tends to zero.

Characteristic feature of tree-like PL-network is that in the nodes of its branching input currents of the elementary tree-terminal devices are added in such a manner, that the obtained total current equals the output current of the previous three terminal devices (see Fig. 2).
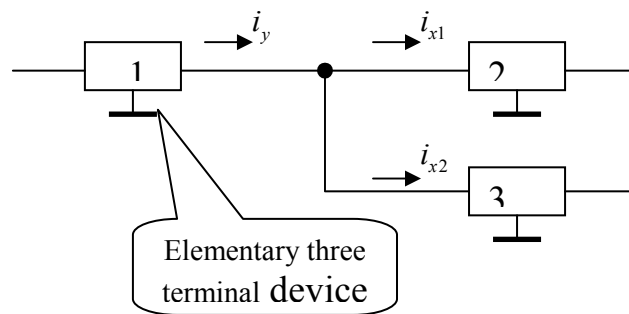

Fig. 2. Example of tree-like network fragment with branching node

In the fragment of the circuit, shown in the Figure, output current i_y of three-terminal device №1, located on the left of the network branching node, equals the sum of $i_y = i_{x1} + i_{x2}$ of input currents of tree-terminal devices №2 and №3, located on the right of the node. In this case the voltage at the inputs of three-terminal devices №2, №3, located on the right of the node, equals the voltage at the output of three-terminal device №1, located on the left of the network node $u_{x2} = u_{x3} = u_{y1}$. Hence, taking into account the character of causal relations in tree-like network, it is necessary while construction the model of elementary three-terminal device, to consider the input current as output variable and output current – as input variable. In this case, the voltage, supplied to elementary three-terminal device on the side of input current, is input, and the voltage on the side of output current – output voltage (Fig. 3).
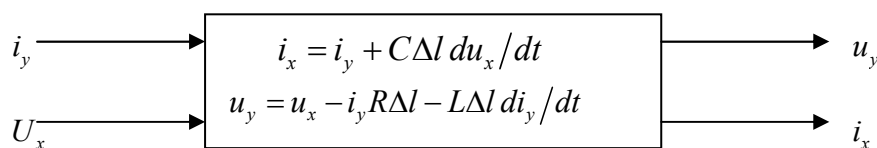

Fig. 3. Model of elementary three- terminal device (MET)

To obtain the close system of differential equations in the process of modeling of tree-like PL-network it is necessary to take into consideration the load at finite branches of electric network tree. In general case, as the model of the load passive one-port, comprising the inductance, capacitor and resister can be considered (Fig. 4).
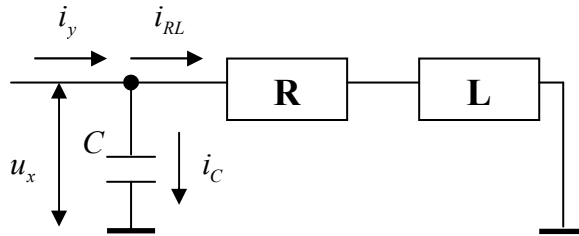

Fig. 4. Passive extreme one-port(load)

The model of extreme one-port (MEO) is described by the system of the equations

$$i_{RL} = \frac{1}{R}u_x - \frac{L}{R}\frac{di_{RL}}{dt},$$

$$i_C = C\frac{du_x}{dt}, \tag{3}$$

$$i_y = i_{RL} + i_C.$$

Here, unlike (1) and (2) symbols R, L, C denote not linear but concentrated values.

The example of construction the model of long line with the load at the end of the line is shown in Fig. 5.
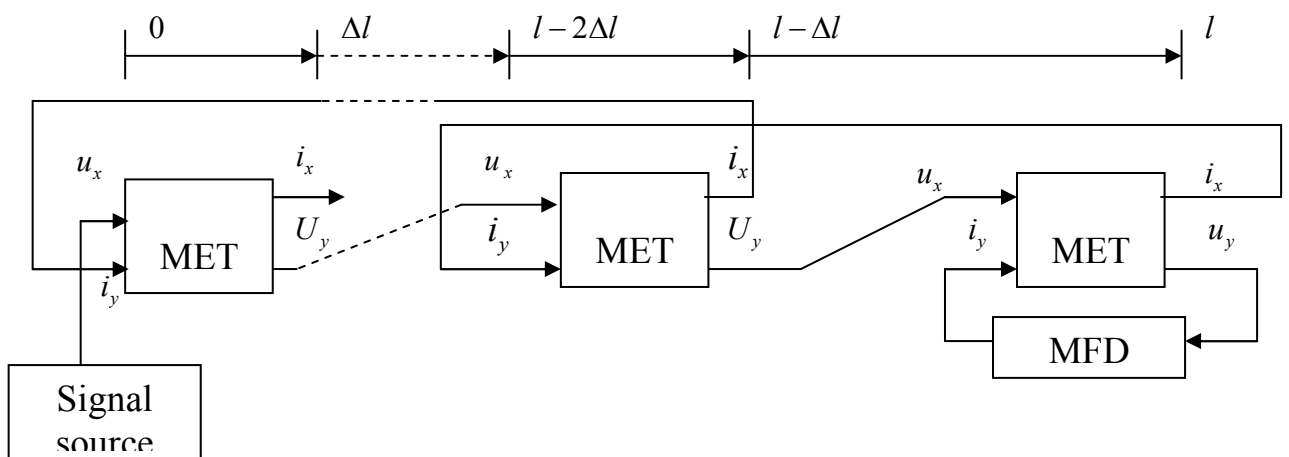

Fig. 5. Model of long line

The example of construction of tree-like network in the point of branching is shown in Fig. 6.
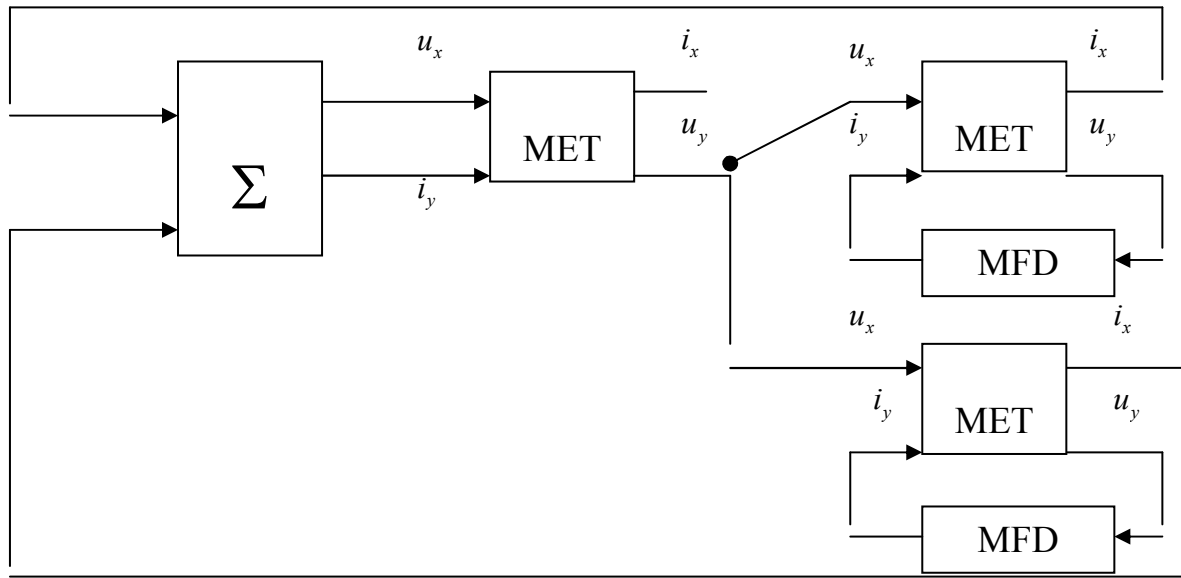

Fig. 6. Model of tree-like network in the point of branching

Variation of network tree while changing the place of signal source location

Digital model of branching PL-networks suggests the directions to the solution of the problem, dealing with the determination of high frequency signal parameters in different points of the given energy supply network at different locations of signal source. Let, for instance, the task of creation of information PL-channel between two preset LSU of multifunctional construction be set. The result of modeling of signal propagation process in electric energy supply network, connecting these LSU, may certify that signal parameters in the points of its reception provide the required level of reliability of the designed information channel. In other case, signal relaying, is needed. To investigate parameters of the signals, propagating from various sources it is necessary to know how to reconstruct the structure of the model.

Initial tree of the network corresponds anisotropic non-cyclic tree-like graph [7]. This graph reflects the topology of energy supply network. The model of signal propagation, built on initial tree, corresponds to location of signal source in root node, where energy distribution in energy system starts.

To investigate signal propagation from the source, located in random node of the network, it is necessary to reconstruct the tree, so that its root be the node, where signal source is placed. In case of such tree variation the direction of its ribs may change, and incidence (connectivity of any two vertices) remain without changes. Let us consider formal algorithm of tree variation on the example.

Fig. 7 shows the graph G_0 of initial tree. Vertices of the graph correspond to the points of energy supply network branching. As branchings are realized in distributive devices, then the places of possible installation of the sources and receivers of the signals also coincide with the points of branching.
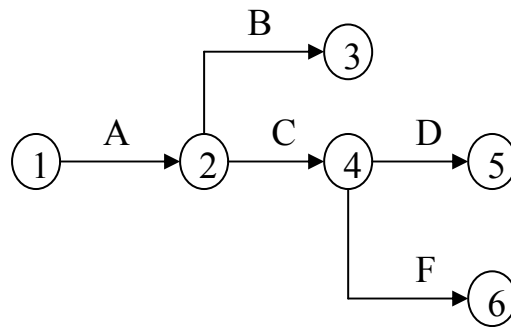

Fig. 7. Structure of energy supply

Ribs of this graph correspond the sections of electric energy supply network, realized, as a rule, by cables of different types, lengths and cross-section. In digital model of PL-network each rib of graph G_0 corresponds the vector of parameters, comprising a number of elementary three-terminal devices on the modeled section, length of the elementary section of the network and linear values of the resistance, inductance and capacitance. These vectors remain unchanged at all variations of the network tree. In Fig. 7 the ribs of the graph G_0 are denoted by the letters of Latin alphabet.

The structure of the graph will be presented by incidence array. Taking into account anisotropy of the graph, reflecting the direction of signal transmission we will denote its ribs by the numbers of connected vertices, so that, in the first place the vertex- source of the signal is indicated, and in the second place – signal discharge. For instance, in Fig. 7, these are ribs 1-2; 2-3; 2-4; 4-5; 4-6. Let rows correspond to sources and columns – to rows in the array. Incidence array for initial tree has the form, shown in Table 1.

Table 1

	1	2	3	4	5	6
1 >		A	0	0	0	0
2	a		B	C	0	0
3	0	b		0	0	0
4	0	c	0		D	F
5	0	0	0	d		0
6	0	0	0	f	0	

Ribs of the graph are elements g_{ij} of this array. If the rib is activated in the model, the corresponding element of the array will be denoted by capital letter. If the element of the array corresponds to two connected vertices but the corresponding rib is not activated in the considered model, we will denote the array element by lower case letter.

Let, for instance, the source of signal be located in node 3. To synthesize the model it is necessary to reconstruct the tree of the network, so that, its root be the vertex 3.

1. We look through row 3. Each element of row 3 is compared with symmetrical relatively main diagonal, element. If the element of the analyzed row – low case letter, and the symmetrical element – capital letter, then we change notations of both elements into the opposite ones. In all other cases we keep previous values. In the given case element $g_{32} = b$ should be activated ($g_{32} \rightarrow B$) and symmetrical to it element $g_{23} = B$ should be disactivated ($g_{23} \rightarrow b$).

Table 2

	1	2	3	4	5	6
1		A	0	0	0	0
2	a		b	C	0	0
3 >	0	B		0	0	0
4	0	c	0		D	F
5	0	0	0	d		0
6	0	0	0	f	0	

2. We look through rows, numbers of which equal the second indices (numbers of stocks) in the notations of row 3 elements, denoted by capital letters. In the given case it is row 2. In this row all the elements, denoted by capital letters we remain without changes (element C remains unchanged) and status of the elements, denoted by low case letters, we change on the opposite one (element $g_{21} = a$, we activate $g_{21} \rightarrow A$, element $g_{12} = A$, symmetrical to it, we disactivate $g_{12} \rightarrow a$). Elements, in which the second indices indicate the rows, changed at the previous step, remain unchanged (in the given case it is element $g_{23} = b$).

Table 3

	1	**2**	**3**	**4**	**5**	**6**
1		a	0	0	0	0
2	A		b	C	0	0
3 >	0	B		0	0	0
4	0	c	0		D	F
5	0	0	0	d		0
6	0	0	0	f	0	

3. We look through rows, numbers of which equal to the second indices (numbers of rows) of the elements of row 2, denoted by capital letters. In the given case these are rows 1, 4. In row 1 element $g_{12} = a$ does not change, as row 2 was changes at the previous step. In row 4 element $g_{42} = c$ does not change, as row 2 was changed at the previous step. Hence, the process of graph transformation is over. Its form at arrangement of signal source in node 3 is shown in Fig. 8a.
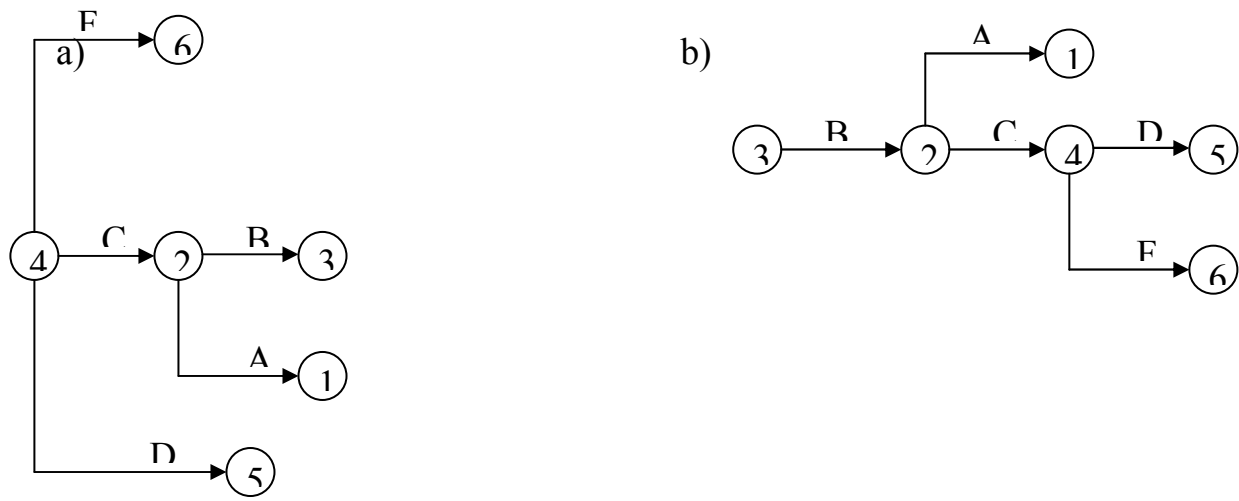

Fig. 8. Variations of PL-network graph at the change of signal source location a) the source is placed in node 3 ; b) the source is placed in node 4

Let, for instance, signal source be located in node 4. To synthesize the model, it is necessary to reconstruct the network tree so that, vertex 4 be its root. Using the analogous algorithm we obtain the desired graph (Fig. 8b).

The example of model usage for analysis of the conditions of information signals passage in energy supply system of multistory building

Topological scheme of the investigated system is shown in Fig. 9.
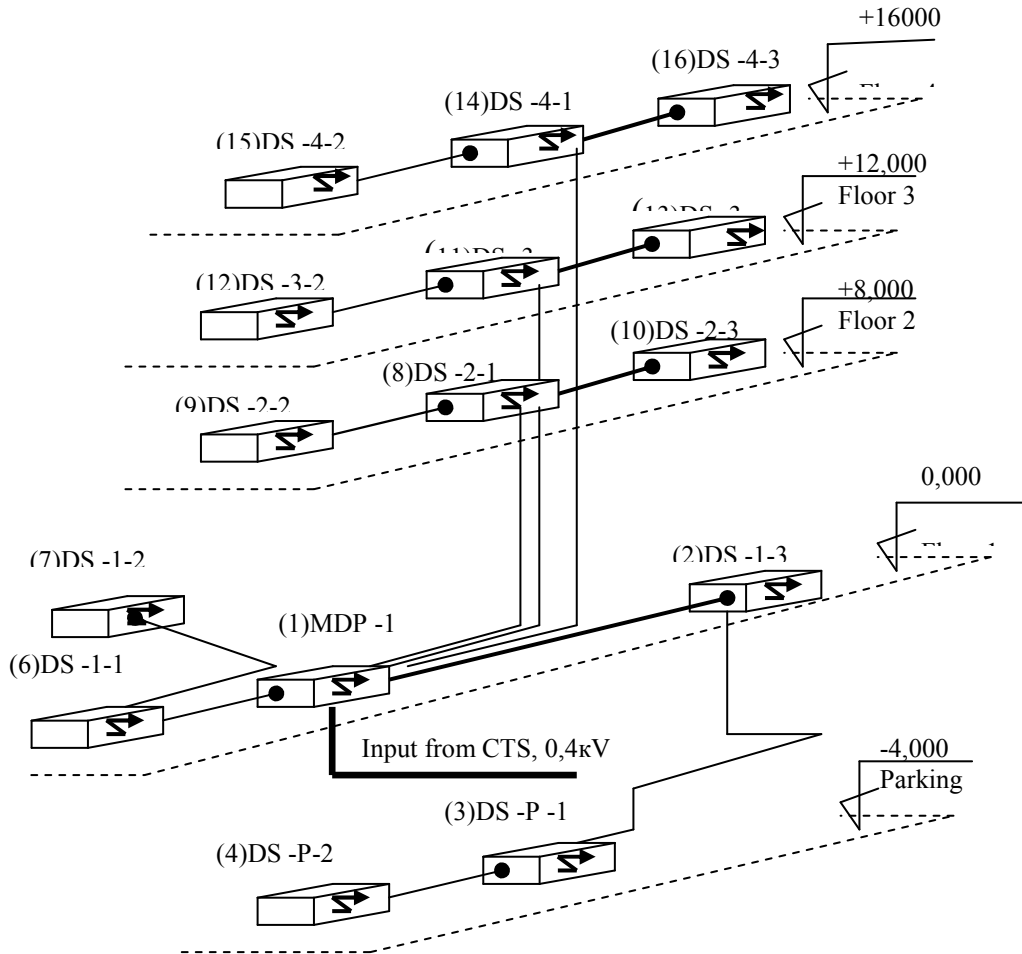

Fig. 9. Topological scheme of energy supply system of multistorybuilding

The example of synthesis of MATLAB – model.
Model №1: source of the signal is in vertex 1 (Fig. 10)

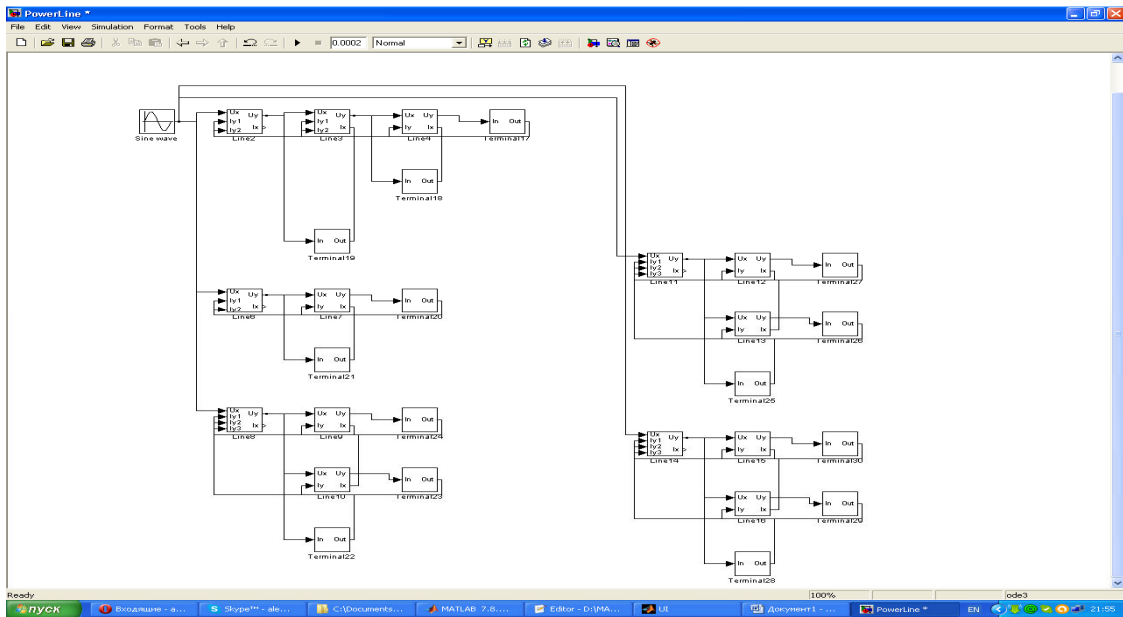Fig.10. Table of the task of system structure

Fig. 11. Synthesized program of the model

The result of automatic synthesis of model №1 (Fig.11)
The results of modeling PL – network are given in Table. 4.

Table 4

Relative amplitudes of signals depending on the places of location of the sources and receivers

	1	2	3	4	6	7	8	9	10	11	12	13	14	15
1	-	1	0.98	1.03	1	0.97	1	0.93	0.93	1	0.89	0.89	1	0.85
2	1	-	1	1.05	0.53	0.51	0.53	0.49	0.49	0.53	0.47	0.47	0.53	0.45
3	0.48	1	-	1	0.25	0.25	0.25	0.24	0.24	0.25	0.23	0.23	0.25	0.22
4	0.4	0.82	1	-	0.21	0.2	0.21	0.19	0.19	0.21	0.19	0.19	0.21	0.18
6	1	0.53	0.52	0.55	-	1	0.53	0.5	0.5	0.53	0.47	0.47	0.53	0.45
7	0.76	0.41	0.4	0.42	1	-	0.41	0.38	0.38	0.41	0.36	0.36	0.41	0.35
8	1	0.61	0.6	0.63	0.61	0.59	-	1	1	0.61	0.54	0.54	0.61	0.52
9	0.57	0.35	0.34	0.36	0.35	0.34	1	-	0.57	0.35	0.31	0.31	0.36	0.29
10	0.55	0.33	0.33	0.35	0.33	0.32	1	0.55	-	0.33	0.3	0.3	0.33	0.28
11	1	0.5	0.5	0.52	0.5	0.49	0.5	0.47	0.47	-	1	1	0.5	0.43
12	0.6	0.31	0.3	0.32	0.31	0.3	0.31	0.28	0.28	1	-	0.6	0.31	0.26
13	0.59	0.3	0.29	0.31	0.3	0.29	0.3	0.28	0.28	1	0.59	-	0.3	0.25
14	1	0.43	0.42	0.45	0.43	0.42	0.43	0.4	0.4	0.43	0.39	0.39	-	1
15	0.63	0.27	0.27	0.28	0.27	0.27	0.27	0.25	0.25	0.27	0.24	0.24	1	-

Conclusions

1. Universal adaptive digital model of the processes of high frequency signals propagation in branching tree-like network of multistory multifunctional building energy supply, having the possibility of automatic readjustment, has been developed.

2. The developed model provides the possibility in certain projects of PL-networks, from the point of view of reliability and noise immunity of information network to select location of sources, receivers and relay stations of high frequency signals.

REFERENCES

1. Patrick Harder. A Guide to Wireless Technologies / Patrick Harder // ASHRAE Journal. – 2011. – Volume 38, Issue 6. – P. 532 – 536.

2. Jelena Misic Wireless Personal Area Networks : Performance, Interconnection, and Security with IEEE 802.15.4 / Jelena Misic, Vojislav Misic. – John Wiley & Sons, 2008 . – 336 p.

3. Pereira, Javier Handbook of Research on Personal Autonomy Technologies and Disability Informatics / Pereira, Javier. – Idea Group Inc (IGI), 2010. – 462 p.

4. Carson J. R. Wave propagation in overheard wires with ground return / J. R. Carson // Bell System Techn. Journ. – 1926. – vol. 5, № 4. – P. 539 – 554.

5. Carson J. R. Propagation of periodic currents over a system of parallel wires / J. R. Carson, R. S. Hoyt // Bell System Techn. Journ. – 1927. – vol. 6, № 3. – P. 495 – 545.

6. John D. Kraus Electromagnetics / John D. Kraus. – New York, NY : McGraw-Hill, 1984. – 462 p.

7. Diestel R. Graph Theory / Diestel R. – Springer, 2005. – 410 p.

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