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Differential Mathematical Models of Intellectualization of Fast Flow Processes on Railway Electricity Supply Networks

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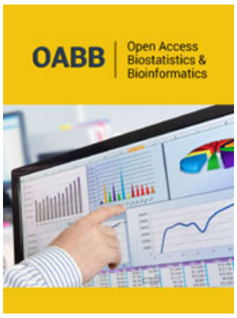

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Abstract

The problem of innovative transformation of railway power supply networks Is Investigated and the direction of researchrelates to the organization of differential mathematical models of optimization of procedures by control of high-speed technological processes of power supply of railways. A graphis proposed, whose logical structure adequately reflects the architecture of the computerized network for managing the power supply system and developed its differential mathematical model. On the basis of the principle of minimax, the optimal strategy of intellectualization of the power supply processes in each of the nodes of the computer network was developed for the cases of the worst combination of the intensity of the requests and the intensity of their service. Hereis a way to ensure that the specified performance of the individual no desands egments of theintelligent computer control network by exploring the extremum off unctionality, implemented in the field of T-images using differential spectra.

Keywords: Differential mathematical models; Methods; Count; Optimal strategy; Intellectualization; Power supply; Network; Architecture; Hauling substation; Optimization; Principle to the minimax

Introduction

The complex problem of innovative transformation of traction electrical networks through the organization of energy-saving technologies and optimization of the processes of power supply to rail transport in the scientific and technical literature is receiving a great deal of attention [1,2]. Obtained a scientific perspectivedirection of research aimed at the development of mathematical models and methods of connection of human intelligence and computing environment [3-5]. A new class of computer-based intelligent systems has emerged focused on integrated intellectualization of a set of procedures for operational and strategic management of high-speed technological processes of energy supply and power consumption. This fact stimulated the emergence of new analytical and intellectual technologies that, on the basis of certain models, algorithms, mathematical theorems, allow to estimate the values of unknown characteristics and parameters of a complex object of study according to known data [6-9].It has become apparent that a qualitatively new set of intelligent traction power systems is possible through the formation of deep mutual integration of the topology of the power grid infrastructure of the power system and the architecture of the distributed computer network. Studies of the evolution of the development of computer networks and complex object management systems have made it possible to conclude that the maximum efficiency of their functioning can be achieved by mutual integration of intellectual resources of managers and modern capabilities of virtually unlimited productivity of distributed computing [7]. At the same time, very little attention was paid to the unsolved part of the problem of innovative transformation of traction electrical networksto the creation of mathematical models and methods of analysis and evaluation of the conditions of optimal functioning of individual nodes and segments of intelligent computer networks for managing high-speed technological processes of power supply.

Goal formulation

The purpose of the work is to organize differential mathematical models of increased intellectual complexity and dimension for analyzing and evaluating the conditions of optimal functioning of nodes and segments of the computer network for managing high-speed technological processes of power supply to railways.

The main research material

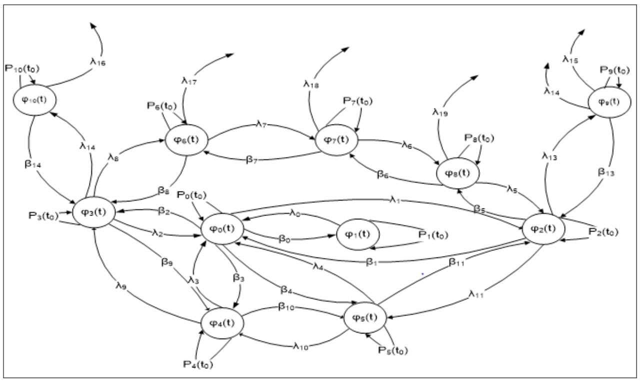

Figure 1: The graph of a computer network for power management at the traction substation level.

Computer systems and networks are a major component of power supply systems, the basic level of which is the level of traction substations as a basis for carrying out procedures to minimize system costs, optimize power consumption, reliable transportation and competitiveness. The emergence of promising areas of innovation and investment transformation of railroad power systems has helped to develop a new class of smart computer networks for optimal control of power systems. The organization of intellectual systems requires complex research, in the subject area, to create a new model of an optimal strategy for the intellectualization of a wide range of technological processes in the electricity supply network. For the formation of models and criteria for computer optimization of technological processes of power systems management, let us present, in the form of a graph (Figure 1), the architecture of the local power supply control network at the level of traction substations. The graph consists of two types of topologiesstar and circle. The topology of the star type includes node φ0(t), which is the central server of the computer network of the traction substation, node φ1(t) the organization of a single information environment of primary information and database maintenance, node φ2(t)information exchange within the corporate computer network for railway power management, node φ3(t)exchange of information on the Internet system, node φ4(t),which is a server for operational management and maintenance of a complex of automated jobs for power management, monitor ed traction transformers, high voltage switches and power equipment, and node φ5(t)for the organization, in the process, microprocessor and relay protection. The topology of a circle-type graph includes a number of the above common nodes $\varphi_0(t)$ $\varphi_1(t)$ $\varphi_2(t)$ $\varphi_3(t)$ $\varphi_4(t)$ $\varphi_5(t)$, as well as the node φ_6(t-the organization of commercial accounting of electricity at commercial tariffs differentiated by zones of day, $\varphi_7(t)$-the node for monitoring the parameters of the modes of traction networks of electricity supply, node $\varphi_8(t)$-the intellectual processing of commercial and technological information. The considered topology includes nodes $\varphi_9(t)$, $\varphi_{10}(t)$ distributed local network of higher-level power management. In the process of exchange of information between the components of the local area network, the intensity of the request flow is represented by the value and, accordingly, the intensity of the request service flow is determined by the following value βi(t).To analyze the computer architecture of the LAN and determine the probability values, we present a graph in the form of a Kolmogorov differential equation system with appropriate initial conditions [1-6].

$$\frac{dP_0(t)}{dt} = \lambda_0 P_1(t) + \beta_1 P_2(t) + \lambda_2 P_3(t) + \lambda_3 P_4(t) + \lambda_4 P_5(t) - (\beta_0 + \beta_2 + \beta_3 + \beta_4 + \lambda_1) P_0(t)$$

$$\frac{dP_1(t)}{dt} = \beta_0 P_0(t) + \lambda_0 P_1(t)$$

$$\frac{dP_3(t)}{dt} = \lambda_9 P_4(t) - (\lambda_2 + \lambda_8 + \lambda_{14} + \beta_9) P_3(t) + \beta_2 P_0(t) + \beta_8 P_6(t) + \beta_{14} P_{10}(t)$$

$$\frac{dP_2(t)}{dt} = \lambda_1 P_0(t) + \lambda_5 P_8(t) - (\beta_1 + \beta_5 + \lambda_{11} + \lambda_{13}) P_2(t) + \beta_{11} P_5(t) + \beta_{13} P_9(t) \quad (1)$$

$$\frac{dP_{10}(t)}{dt} = \lambda_{14} P_3(t) - \beta_{14} P_{10}(t)$$

with appropriate initial conditions at

$P_0(t) + P_1(t) + P_2(t) + \ldots + P_9(t) + P_{10}(t) = 1$ at, $t = 0$, $P_0(t) = 1$, $P_1(t) + P_2(t) + \ldots + P_9(t) + P_{10}(t) = 0$ ·

Differential mathematical models Based on Puhova differential transformations Puhova[10]

$$P_i(k) = \frac{H^k}{k!}\left[\frac{d^k P_i(t)}{dt^k}\right]_{t=0} \doteq P_i(t) = \sum_{k=0}^{k=\infty} \left(\frac{t}{H}\right)^k P_i(k) \quad (2)$$

Where $P_i(t)$ is an initial function of an argument t that can be n-times differentiated and which has a number of corresponding limitations, including its derivatives;differential T-image of the original function scale factor, the dimension of which coincides with the dimension of the argument t, as a rule, is selected on conditionsthroughout the range of function the original symbol of correspondence between the function the original and its differential T-image, we synthesize the differential mathematical model for calculating, first of all, the values of probabilities $P_0(t)$, $P_1(t)$, $P_2(t)$, $P_3(t)$, $P_4(t)$, $P_5(t)$, $P_6(t)$, $P_7(t)$, $P_8(t)$, $P_9(t)$, $P_{10}(t)$.On the basis of direct differential transformation $P_i(k) = \frac{H^k}{K!}\left[\frac{d^k P_i(t)}{dt^k}\right]_{t=0}$, we synthesize a differential mathematical model oriented for the study of network computing architecture, which can be written as [10]

$$P_0(k+1) = \frac{H}{k+1}\left[\lambda_0 P_1(k) + \beta_1 P_2(k) + \lambda_2 P_3(k) + \lambda_3 P_4(k) + \lambda_4 P_5(k) - \gamma_1 P_0(k)\right]$$

$$P_1(k+1) = \frac{H}{k+1}\left[\beta_0 P_0(k) - \lambda_0 P_1(k)\right]$$

$$P_2(k+1) = \frac{H}{k+1}\left[\lambda_1 P_0(k) + \lambda_5 P_8(k) - \gamma_2 P_2(k) + \beta_{11} P_5(k) + \beta_{13} P_9(k)\right] \quad (3)$$

$$P_3(k+1)=\frac{H}{k+1}\left[\lambda_9 P_4(k)-\gamma_3 P_3(k)+\beta_2 P_0(k)+\beta_8 P_6(k)+\beta_4 P_0(k)\right],$$

$$P_0(k+1)=\frac{H}{k+1}\left[\lambda_4 P_3(k)-\beta_4 P_0(k)\right]$$

Wherethe initial conditions for $t=0$ and $k=0$ are represented as $P_0(t=0)=P_0(0)=1$, $P_i(t=0)=P_i(0)=0$; $-\gamma_1=(\beta_0+\beta_2+\beta_3+\beta_4+\lambda_1)$; $\gamma_2=(\beta_1+\beta_5+\lambda_1+\lambda_3)$; $\gamma_8=(\lambda_5+\beta_6)$ $\gamma_3=(\lambda_2+\lambda_8+\lambda_4+\beta_9)$; $\gamma_4=(\lambda_3+\lambda_9+\beta_0)$; $\gamma_5=(\lambda_4+\lambda_0+\beta_1)$; $\gamma_6=(\lambda_7+\beta_8)$; $\gamma_7=(\lambda_6+\beta_7)$.

Having implemented the substitution of initial conditions $P_0(t=0)=P_0(0)=1$ $P_i(t=0)=P_i(0)=0$, $t=0$, $k=0$, $i=1,2,..0$ in the differential mathematical model (3), at k=0, we obtain the discrete spectrum in the form $P_0(1)=-\gamma_1 H$; $P_1(1)=\beta_0 H$; $P_2(1)=\lambda_1 H$; $P_3(1)=\beta_2 H$; $P_4(1)=\beta_3 H$; $P_5(1)=\beta_4 H$; $P_6(1)=0$; $P_7(1)=0$; $P_8(1)=0$; $P_9(1)=0$; $P_0(1)=0$.

The following values are obtained T-discrete $P_0(1)=-\gamma_1 H$, $P_1(1)=\beta_0 H$, ... $P_0(1)=0$ substitute in the differential model (3) and at k=1 we compute the following set of discrete in the form

$P_0(2)=\frac{H^2}{2}(\lambda_0\beta_0+\lambda_1\beta_1+\lambda_2\beta_2+\lambda_3\beta_3+\lambda_4\beta_4+\gamma_1^2)$; $P_1(2)=-\frac{H^2\beta_0}{2}(\gamma_1+\lambda_0)$;

$P_2(2)=\frac{H^2}{2}[\beta_4\beta_1-\lambda_1(\gamma_1+\gamma_2)]$; $P_3(2)=\frac{H^2}{2}[\lambda_9\beta_3-\beta_2(\gamma_1+\gamma_3)]$;

$P_4(2)=\frac{H^2}{2}[\lambda_4\beta_4-\beta_3(\gamma_1+\gamma_4)+\beta_2\beta_9]$; $P_5(2)=\frac{H^2}{2}[\lambda_1\lambda_1-\beta_4(\gamma_1+\gamma_5)+\beta_3\beta_0]$; (3)

$P_6(2)=\frac{H^2}{2}\lambda_6\beta_2$; $P_7(2)=0$; $P_8(2)=\frac{H^2}{2}\lambda_8\beta_5$; $P_9(2)=\frac{H^2}{2}\lambda_1\lambda_3$; $P_0(2)=\frac{H^2}{2}\lambda_4\beta_2$.

Acting on an analogy for $k=2$, $k=3,\dots k=n$ we obtain, respectively, a set of discretes $P_i(0)$; $P_i(1)$; $P_i(2)$,.. $P_i(k)$ $(i=1,2,..0)$ the number of which is determined by the precision required.

Obtained, thus, at $n=2$ set of discrete $P_i(0)\ P_i(1)\ P_i(2)$ substitutefo rtheinversedifferentialtransformation $P_i(t)=\sum_{k=0}^{k=\infty}\left(\frac{t}{H}\right)^k P_i(k)$, mathematical dependence (2) we obtain in analytical form, the value of probabilities $P_0(t)$, $P_1(t)$, $P_2(t)$, $P_3(t)$, $P_4(t)$, $P_5(t)$, $P_6(t)$, $P_7(t)$, $P_8(t)$, $P_9(t)$, $P_0(t)$ the status of the nodes in the local computer network for power management

$P_0(t)=1-\gamma_1 t+(\lambda_0\beta_0+\lambda_1\beta_1+\lambda_2\beta_2+\lambda_3\beta_3+\lambda_4\beta_4+\gamma_1^2)\frac{t^2}{2}$; $P_1(t)=\beta_0 t-\beta_0(\gamma_1+\lambda_0)\frac{t^2}{2}$;

$P_2(t)=\lambda_1 t+[\beta_4\beta_1-\lambda_1(\gamma_1+\gamma_2)]\frac{t^2}{2}$; $P_3(t)=\beta_2 t+[\lambda_9\beta_3-\beta_2(\gamma_1+\gamma_3)]\frac{t^2}{2}$; (4)

$P_4(t)=\beta_3 t+[\lambda_4\beta_4-\beta_3(\gamma_1+\gamma_4)+\beta_2\beta_9]\frac{t^2}{2}$; $P_5(t)=\beta_4 t+[\lambda_1\lambda_1-\beta_4(\gamma_1+\gamma_5)+\beta_3\beta_0]\frac{t^2}{2}$;

$P_6(t)=\lambda_6\beta_2\frac{t^2}{2}$; $P_7(t)=(\lambda_7\lambda_8\beta_2+\beta_6\lambda_1\beta_5)\frac{t^3}{3!}$; $P_8(t)=\lambda_1\beta_5\frac{t^2}{2}$; $P_9(t)=\lambda_1\lambda_3\frac{t^2}{2}$; $P_0(t)=\lambda_4\beta_2\frac{t^2}{2}$.

Differential models for optimization of power management procedures

The values of probabilities $P_0(t)$, $P_1(t)$, $P_2(t)$, $P_3(t)$, $P_4(t)$, $P_5(t)$, $P_6(t)$, $P_7(t)$, $P_8(t)$, $P_9(t)$, $P_0(t)$ of the state of each node of the graph can be used to formulate the criterion of the optimal strategy of computer intellectualization of power management procedures [10].

$$\theta_i(t)=\frac{1}{T}\int_{t=t_0}^{T}P_i(t)d\,,\ i=0,1,2\dots \quad (5)$$

Each node on a local area network operates in a conflict between the intensity of the request flow λi(t)and the intensity of the service flow of the applicationsβi(t), which is the dominant in such conditions is the adherence of the subjects of the conflict to the minimum principle. Achieving optimum performance at each node of the computer network can be rationally followed by the strategy of forming the service flow intensities βi(t), that minimize the chargeat the maximum service flowintensitiesλi(t), which can be writtenas $\Theta_i{}^*(\lambda_i,\beta_i)=\min_{\beta_i\in E_\beta}\max_{\lambda_i\in E_\lambda}\Theta_i(\lambda_i,\beta_i)$ $i=0,1,2\dots$(6). In formulating the optimal strategy, it is likely to proceed from the condition that the maximizing charge λi(t),is formed, provided that it is minimized by the application service system βi(t),ie

$$\Theta_i{}^*(\lambda_i,\beta_i)=\min_{\lambda_i\in E_\lambda}\max_{\beta_i\in E_\beta}\Theta_i(\lambda_i,\beta_i)\ \ i=0,1,2\dots \quad (7)$$

Subject to the fulfillment of mathematical dependences (6), (7),

$$\min_{\beta_j\in E_\beta}\max_{\lambda_i\in E_\lambda}\theta_i(\lambda_i,\beta_i)=\max_{\lambda_i\in E_\lambda}\min_{\beta_j\in E_\beta}\theta_i(\lambda_i,\beta_i)=\theta_i^{*opt}(\lambda_i^{opt},\beta_i^{opt}) \quad (8)$$

Search strategiesλi(t) opt, opt,are called optimal [3-8].The overall strategy is to find the law of changing the flow of service intensity βi(t), which realizes the minimization of the functional (5) at stochastic intensity of the flow of service requests λi(t), within the appropriate limits. Therefore, due to the antagonism of the goals of the subjects of information conflict, the dominant strategy of optimal intellectualization procedures for rapid technological processes will be a strategy based on the principle of minimax, ie.

$$\min_{\beta_i\in E_\beta}\max_{\lambda_i\in E_\lambda}\Theta_i(t,P_i\lambda_i,\beta_i)\quad (9)$$

The use of the minimax strategy (9) minimizes the functional (5) even in the worst-case combination of the flux intensities λi(t) andβi(t). Using the direct differential transform (2), the criterion $\theta_0(t)=\frac{1}{T}\int_{t_0}^{T}P_0(t)d$ looks like [10].

$$\Theta_i^*=\sum_{k=0}^{k=\infty}\frac{p_i(k)}{k+1}$$

Using the resulting set T-discrete, according to (3), we form an optimization procedure based on the differential spectrum. After substitution of the set, the discrete in (10), the state model for the φi (t) th node of the LAN will look like

$$\Theta_{i=0}^*(\lambda_i,\beta_i)=1-(\beta_0+\beta_2+\beta_3+\beta_4+\lambda)t+(\lambda_0\beta_0+\lambda_1\beta_1+\lambda_2\beta_2+\lambda_3\beta_3+\lambda_4\beta_4+\gamma_1^2)\frac{t^2}{2}\ (11).$$

The procedure for finding optimal strategies for the intensity of the application flowsand the flow of service intensity of thefunctionalapplication is inseparably linked to the study of its extrema by substituting (10) the values of the corresponding discrete. It is known that, under the Kuhn-Tucker theorem, the necessary conditions for the existence of a functional extremum are conditions that allow one to determine the optimal strategy in appearance [3,8].

$$\begin{cases}\frac{d}{\lambda_0}(\Theta_0^*(\lambda_i,\beta_i)=0,\\ \dots\dots\\ \frac{d}{\lambda_0}(\Theta_0^*(\lambda_i,\beta_i)=0,\end{cases}\quad \begin{cases}\frac{d}{\beta_0}(\Theta_0^*(\lambda_i,\beta_i)=0\\ \dots\dots\\ \frac{d}{\beta_0}(\Theta_0^*(\lambda_i,\beta_i)=0\end{cases}\qquad (12)$$

Implementing the substitution of expression (11) into the system of equations (12) and taking, respectively, partial derivatives, we obtain a system of linear algebraic equations, solving which and obtain optimal strategies andThe extremum signs in the strategies and are determined based on verification of sufficient conditions by

$$\begin{cases} \frac{d^2}{\lambda_0^2}(\Theta_0^*(\lambda_i,\beta_i)\rangle 0, \\ \ldots\ldots \\ \frac{d^2}{\lambda_0^2}(\Theta_0^*(\lambda_i,\beta_i)\rangle 0, \end{cases} \begin{cases} \frac{d^2}{\beta_0^2}(\Theta_0^*(\lambda_i,\beta_i)\rangle 0 \\ \ldots\ldots \\ \frac{d^2}{\beta_0^2}(\Theta_0^*(\lambda_i,\beta_i)\rangle 0 \end{cases} \quad (13)$$

Conducting research by analogy, that is, substituting the valuesfrom (11) into the system of equations (13) and taking the second partial derivatives, we obtain a system of algebraic equations whose solution indicates the fulfillment or failure of sufficient conditions. By calculating the values of the optimal strategiesandaccording to (12), which meet the conditions (13) and substituting them in (11), we determine the optimal functioning of the graph node nodeφ0(t)^{ro}, which reflects the local computer network of the distance control of the power supply of the traction substation.

Conclusion

A. On the basis of the research of the problem of innovative transformation of power supply networks of railways scientifically substantiated direction of further research is connected with the formation of a qualitatively new set of intelligent power supply systems by conducting deep mutual integration of the topology of the electricity network infrastructure and architecture of the distributed computer network of power management technologies for saving and the formation of new knowledge.

B. Based on the concept of synthesis of intelligent power supply systems, the logical architecture of the distributed computer environment and ways of representing it in the form of a graph that adequately reflects the topology of the electrical system on the basis of which the differential mathematical model of the computer architecture of power supply management and methods for determining the probabilities of state states.

C. On the basis of the minimax principle, an optimal strategy of computerized intellectualization of high-speed traction power supply technological processes is proposed, even in cases of the worst antagonism in each node or segment of the intellectual computer network, the intensity of the request flowλi(t)and the intensity of the service flow βi(t).

In order to guarantee the set parameters of optimal functioning of individual nodes and segments of the intelligent computer control network, an intelligent method of finding the optimal strategy for computer intellectualization of electricity supply processes was developed based on determining the intensity of service requests λ_i^{opt} and the flow of service intensity β_i^{opt} by studying the extremum of realizable functionality $\Theta_i^*(\lambda_j,\gamma_j)$, in the field of T-images using the discrete differential spectrum.

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