MODELING OF A SHIP ELECTRIC POWER PLANT OPERATION MODES WITH A DISCRETE-TIME MARKOV CHAINS

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Introduction. The ship's power system (SEPS) at any given time may be in one of several states, determined by the number of generators operating in parallel. The change in the operation mode of the ship power system is due to the switching of electricity consumers. In the presence of power shortage the additional generator is connected to the general network, and at excess of the generated power, there is a disconnection of the generator from parallel work on the general bus [1, 2]. A fundamental aspect of the operation of SEPS is the random nature of the incoming flow of switching applications. Therefore, the task of developing an algorithm for generating random values with different distribution laws for modeling the processes of load switching and changing the state of the power system is important. To solve modeling problems in systems where the change of states is a random process, the theory of discrete-time Markov chains can be used [3, 4].

The aim of the research is the analysis of a ship electrical power system operation and simulation with a few generators using the theory of discrete-time Markov chains for making electrical power systems change of the state diagram and algorithm design of the random values generation for simulation of the load commutation processes.

Materials and methods. Basic property of the Markov chains theory is that the state, in which the system will be in the next moment, depends only on the current state and not depends on the previous states [5]. Vector of states $[S(t)]$ is corresponded to each point of time. The elements of the vector are probabilities of system being in each of the possible state.

$$[S(t_k)] = [S_1(t_k), S_2(t_k), \ldots, S_n(t_n)],$$

$$\sum_{i=1}^{n} S_i(t_k) = 1,$$

where n – the number of generators in the autonomous electrical power system.

Duration of system being in the determinate state is exceeded by a factor of ten the time during that the system goes from one state to another. That's why we'll take the system conversions from one state to another such as they are happened instantly.

Let's consider a ship power system that consists of two generators and the certain number of consumers. If there is enough power reserve (not all the consumers are operated in this mode) only one generator operates into the load and another one is idle. In the lack of generated power, second generator begins to operate with the firs one and takes the part of a load [2]. In Fig. 1. there is a simplified state chart of the such power generating unit.

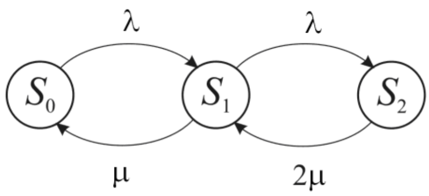

Fig. 1. Simplified state chart of the power generating unit

Such a circuit of operating can be used if the duration of the additional generator start-up is small, and it can be kept off. For stationary requests flow for load switching it can be written as follows:

$$\begin{cases} -\lambda P_0 + \mu P_1 = 0, \\ -(\lambda + \mu)P_1 + \lambda P_0 + 2\mu P_0 = 0, \\ P_0 + P_1 + P_2 = 1. \end{cases}$$

Solution of this system of equations is following:

$$P_0 = \frac{2}{\left(1 + \frac{\lambda}{\mu}\right)^2 + 1}; \; P_1 = \frac{\lambda P_0}{\mu}; \; P_2 = P_0 + P_1.$$

State probabilities are determined by the following expressions for the mode of the both generators operating.

$$P_0 = \frac{1}{1+\left(\frac{\lambda}{\mu}\right)^2}; \; P_1 = \frac{2\lambda P_0}{\mu}.$$

State probabilities for power generating unit that consists of three generators, two of which are operating and one is idle (no-load) can be determined like that:

$$P_0 = \frac{3}{2\left(1+\frac{\lambda}{\mu}\right)^3 + 1}; \; P_1 = \frac{2\lambda P_0}{\mu}; \; P_2 = \frac{\lambda P_1}{\mu}.$$

For model construction of the power generating unit that consists of three synchronous generators it can be used Markov processes. Power generating unit in any moment can be in one of the 5 states: S_0 – all generators are shut down, S_1 – only the first generator is operating, the second one is in the hot standby; S_2 – the first and the second generators are operating, the third one is idle; S_3 – all three generators are operating. Generator as an element of the system can be described by the Boolean function that has two meaning – 0 (off) and 1 (on). Power of the each generator is 300 kW. The value of power consumption is determined by the number of loads that connected to the main switchboard bus bar and is the random variable y – a function $y=f(\alpha, \beta, \ldots, \omega)$ of random variable $\alpha, \beta, \ldots, \omega$, with known distribution laws, that are determined by the analysis of load diagram in the previous time.

Let's simulate the action of the Markov discrete chain. System initial state is specified. The matrix row of transition probability for this state is setting transition probability from the current state to another. The new state is a discrete random value.

$$\begin{matrix} & S_0 & S_1 & S_2 & S_3 \end{matrix}$$
$$|p| = \begin{vmatrix} 0.1 & 0.9 & 0 & 0 \\ 0.05 & 0.7 & 0.25 & 0 \\ 0 & 0.6 & 0.3 & 0.1 \\ 0 & 0 & 0.8 & 0.2 \end{vmatrix}$$

Let's consider the transition matrix row according to the state of autonomous electrical power system with the one operating generator. The probability that the system will stay in the same state is 0.7. The probability of another generator's connection in parallel operation is 0.25. Probability of generator's halt is 0.05. There is generated random value ξ. Let us suppose that it is 0.473. It means that the system moves from the state S_0 to the state S_1, so only one generator was on. There is generated next random value for example 0.831. It means that the system moves to the state S_2, so the second generator will parallel operate with the first one. The new random value is 0.936 and system stays in the state S_2 (with the two parallel operating generators). This algorithm continues until it will be received the states, in which autonomous electrical power system can be during the day. It is necessary to make 6·24=144 iterations if the step of the discrete time is 10 minutes.

Each consumer is described by its operation diagram which doesn't depend on the operation states of the other consumers. Examined consumers are characterized by the individual operation modes and have the random commutation process. In Fig. 2 there are requests flow for load switching.

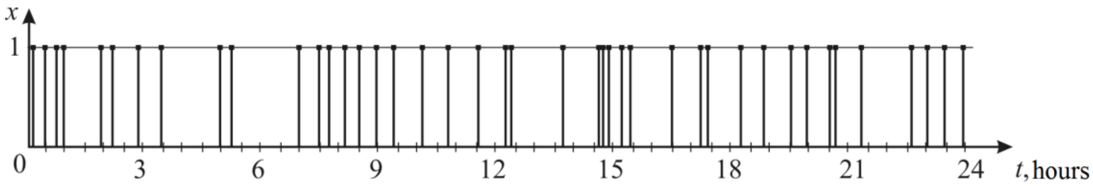

Fig. 2. Requests flow for load switching

The total load of the autonomous electrical power system depends on the simultaneous operation of the great number of the power consumers in operation conditions by different load. The determination of the total changed loads should be done by using the loads graphs of the individual consumers with a glace of their divergence [6]. There are peaks in day load curve of the autonomous electrical power system that caused by loads' turning on and off in power plant's operation conditions. Identification of these peaks is necessary for adverse conditions prevention of the electroreceiver operation.

In this case a change of the system state is specified by only one generator's turning on or off, for example, if there are two operating generators the system can turn to the state with one operating generator or to the state with the three parallel operating generators. But the load's program analysis shows that by one operating generator by consumers activation it is possible that consumers' total power will be more than two generators total power. That is why the system with one operating generator in K-moment can turn to the state with three operating generators in (K+1)-moment and on the contrary similar situation is possible for the state in which there are no operating generators, however for consumers supply by the electric power it is necessary the operation at once of two generators (transition from Q_0 to Q_2).

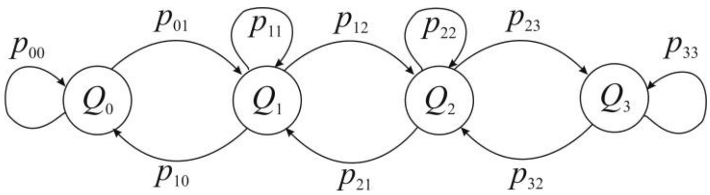

Fig. 3. State graph of one generator's system

There are in Fig. 3: Q_0 – there are no operating generators, consumers' total power – 0; Q_1 –there is one operating generator, consumers total power 250 kW at most; Q_2 – there are two operating generators, consumers total power 500 kW at most; Q_3 – there are three operating generators, consumers total power 750 kW at most. $\{Q_0 , Q_1, Q_2, Q_3\}$ – possible system states.

In general form the transition probability matrix is following:

$$| P_{ij} | = \begin{vmatrix} P_{00} & P_{01} & P_{02} & P_{03} \\ P_{10} & P_{21} & P_{31} & P_{13} \\ P_{20} & P_{21} & P_{22} & P_{23} \\ P_{30} & P_{31} & P_{32} & P_{33} \end{vmatrix}, \quad \sum_{j=0}^{n} p_{ij} = 1, \quad i = \overline{1,n}.$$

In addition the Markov's chain are characterized by state probability's vector:

$$S(t) = \{S_0(t), S_1(t), S_2(t), S_3(t)\},$$

which shows probability $S_i(t)$ of system being in the state Q_i :

$$\sum_{i=1}^{n} S_i(t) = 1.$$

For the autonomous electrical power system, that consists of the three generators the transition probability matrix is following:

$$| P_{ij} | = \begin{vmatrix} 0.05 & 0.95 & 0 & 0 \\ 0.1 & 0.7 & 0.2 & 0 \\ 0 & 0.6 & 0.3 & 0.1 \\ 0 & 0 & 0.9 & 0.1 \end{vmatrix}.$$

Equation for stationary probability definition is following:

$$\begin{cases} S_0 = p_{00}S_0 + p_{10}S_1 \\ S_1 = p_{01}S_0 + p_{11}S_1 + p_{21}S_2 \\ S_2 = p_{12}S_1 + p_{22}S_2 + p_{32}S_3 \\ S_3 = p_{23}S_2 + p_{33}S_3 \end{cases}.$$

Results and discussion. The solution of this system of equations let us define the probability being of the autonomous electrical power system in each state. In Fig. 4 there is a system's state graph by two simultaneous operating generators (in case of power shortage for consumers' supply).

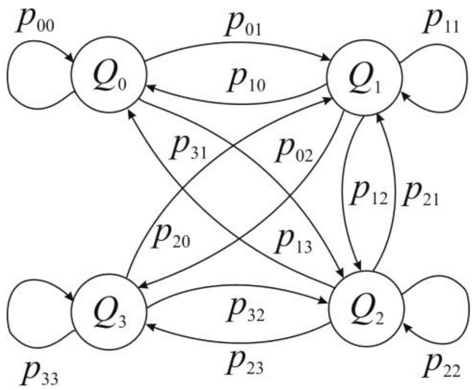

Fig. 4. System's state graph with two generators

For such case the system of equations of stationary probability is following and the transition probability matrix are following:

$$\begin{cases} S_0 = p_{00}S_0 + p_{10}S_1 + p_{20}S_3 \\ S_1 = p_{01}S_0 + p_{11}S_1 + p_{21}S_2 + p_{31}S_3 \\ S_2 = p_{02}S_0 + p_{12}S_1 + p_{22}S_2 + p_{32}S_3 \\ S_3 = p_{13}S_1 + p_{23}S_2 + p_{33}S_3 \end{cases}, \quad |P_{ij}| = \begin{vmatrix} 0.05 & 0.9 & 0.05 & 0 \\ 0.1 & 0.6 & 0.2 & 0 \\ 0.05 & 0.6 & 0.25 & 0.1 \\ 0 & 0.2 & 0.7 & 0.1 \end{vmatrix}$$

The solution of the system of equations is the meanings of steady probabilities' being of power system in each of the states.

Conclusions. As a result of the work, models of Markov processes were developed, which are presented in the form of graphs and describe the processes of change of SEPS operation modes (i.e. states). Using the method of statistical modeling, the operation of SEPS with three generators was simulated. A time diagram is obtained, which shows how the process of changing the state of the power system takes place. The developed algorithm for generating random values for different distribution laws allowed to perform modeling of load switching processes and obtain individual diagrams of consumer work. Using the load switching diagram, it is possible to determine such parameters as the frequency of power bursts, the average number of bursts for a given time interval, the probability of a burst. Knowledge of these parameters will determine the parameters of the correlation function, which can then be used as a characteristic of the perturbing action in voltage stabilization systems, which opens up opportunities for solving the problem of suppression of impulse random interference.

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