УДК 519.873

MATHEMATICAL MODELS OF RELIABILITY PARAMETERS FOR COMPLICATED POWER SYSTEMS

A.R.Sydor, V.M.Teslyuk,
Lviv Polytechnic National University,
12 S.Bandery Str., Lviv, 79013, Ukraine.

A method of investigation of reliability parameters for complicated power systems by means of generating functions is developed taking account of aging of the system's output elements. Main time parameters for reliability evaluation are examined in this paper. Mathematical models in the form of analytical expressions are worked out for the average duration of the system's stay in each of its states and for the average duration of the system's stay in the prescribed availability condition provided that the lifetime of ageing output elements is circumscribed by the Rayleigh distribution. References 5.

Key words*:* reliability parameters, power systems, Rayleigh distributed ageing elements.

Introduction. Reliability prediction methods are widely used throughout the power engineering, and are often used as a yardstick for comparing various equipment. But these models can be wildly inaccurate when compared with rates of modern devices, and their use can lead to increased costs and complexity while deluding engineers into following a flawed set of perceptions and leaving truly effective reliability improvement measures unrecognized.

In recent years there has been significant progress in the field of power electronic circuit topologies, typical for power systems and, for this reason, one may expect innovations in high inverter systems [2].

There exist different methods of investigation for reliability parameters of complicated power systems [1,3,4]. But existing traditional methods of reliability evaluation are not able to satisfy requirements of investigations of complicated systems such as complicated power systems which provide control, management and monitoring that cover a broad range of tasks.

Models of reliability parameters. In power electronics most beneficial technological innovations have been introduced into process and energy distribution; it being known that in numerous industrial and vehicular applications, the assemblies of mechanically and electrically coupled devices are joined in electronic units of high complexity [5].

Let us consider a symmetric electropower system ramified to level 2 with ageing output elements, where a_1 elements of level 1 are subordinate to an element of level 0, a_2 elements of level 2 are subordinate to every element of level 1. a_1 is a coefficient of ramification to level 1, a_2 is a coefficient of ramification to level 2.

We use $T_{2R}(x_2)$ to denote the average duration of the system's stay in a state of x_2 operating output elements on condition that lifetime of ageing output elements is circumscribed by the Rayleigh distribution.

Under condition $0<x_2\le N_2$ we obtain the following expression:

$$T_{2R}(x_2)=\sum_{x_1=ceil\left(\frac{x_2}{a_2}\right)}^{a_1} C_{a_1}^{x_1} C_{a_2 x_1}^{x_2} \sum_{j_1=0}^{a_1-x_1} C_{a_1-x_1}^{j_1}(-1)^{j_1}\times\sum_{j_2=0}^{a_2x_1-x_2} C_{a_2x_1-x_2}^{j_2}(-1)^{j_2}\int_0^\infty e^{-(\lambda_0+\lambda_1(x_1+j_1))t} e^{-\frac{x_2+j_2}{2\sigma_2^2}t^2}\,dt.$$

Notice that $T_{2R}(0)=\propto$.

The system availability condition is that there are not less than k operating output elements of the system $(0<k\le N_2)$. The sum of average durations of the system's stay in states over count of output elements from k до N_2 is equal to the average duration of the system's stay in the prescribed availability condition k.

Let $T_{\Gamma 2R}(k)$ be the average duration of the system's stay in the availability condition k provided that lifetime of ageing output elements is circumscribed by the Rayleigh distribution. We obtain:

$$T_{\Gamma 2R}(k)=\sum_{x_2=k}^{N_2}\sum_{x_1=ceil\left(\frac{x_2}{a_2}\right)}^{a_1} C_{a_1}^{x_1} C_{a_2 x_1}^{x_2} \sum_{j_1=0}^{a_1-x_1} C_{a_1-x_1}^{j_1}(-1)^{j_1}\times\sum_{j_2=0}^{a_2x_1-x_2} C_{a_2x_1-x_2}^{j_2}(-1)^{j_2}\int_0^\infty e^{-(\lambda_0+\lambda_1(x_1+j_1))t} e^{-\frac{x_2+j_2}{2\sigma_2^2}t^2}\,dt.$$

Let us consider an unsymmetrical electropower system with two nonequivalent branches on level 1, ramified to level 2, with Rayleigh distributed output elements, where 2 elements of level 1 are subordinate to the element of level 0, the first element of level 1 subordinates $a_2^{(1)}$ elements of level 2, the second element of level 1 subordinates $a_2^{(2)}$ elements of level 2. Without loss of generality assume that $a_2^{(1)}<a_2^{(2)}$.

We use $T_{2R}(x_2)$ to denote the average duration of the system's stay in a state of x_2 operating output elements on condition that lifetime of ageing output elements is circumscribed by the Rayleigh distribution. Under condition $0<x_2\le a_2^{(1)}+a_2^{(2)}$ we obtain the following expression:

$$T_{2R}(x_2)=\sum_{x_2^{(1)}=\max\{0,x_2-a_2^{(2)}\}}^{\min\{x_2,a_2^{(1)}\}}\ \sum_{x_1^{(1)}=ceil\left(\frac{x_2^{(1)}}{a_2^{(1)}}\right)}^{1} C_{a_2^{(1)}x_1^{(1)}}^{x_2^{(1)}} \sum_{x_1^{(2)}=ceil\left(\frac{x_2-x_2^{(1)}}{a_2^{(2)}}\right)}^{1} C_{a_2^{(2)}x_1^{(2)}}^{x_2-x_2^{(2)}} \sum_{j_1=0}^{2-(x_1^{(1)}+x_1^{(2)})} C_{2-(x_1^{(1)}+x_1^{(2)})}^{j_1}\times$$

$$\times(-1)^{j_1}\sum_{j_2=0}^{a_2^{(1)}x_1^{(1)}+a_2^{(2)}x_1^{(2)}-x_2} C_{a_2^{(1)}x_1^{(1)}+a_2^{(2)}x_1^{(2)}-x_2}^{j_2}(-1)^{j_2}\int_0^\infty e^{-\left(\lambda_0+\lambda_1(x_1^{(1)}+x_1^{(2)}+j_1)\right)t} e^{-\frac{x_2+j_2}{\sigma_2^2}t^2}\,dt.$$

Let $T_{T2R}(k)$ be the average duration of the system's stay in the availability condition k provided that lifetime of ageing output elements is circumscribed by the Rayleigh distribution. We obtain:

$$T_{2R}(k)=\sum_{x_2=k}^{N_2}\;\sum_{x_2^{(1)}=\max\{0,x_2-a_2^{(2)}\}}^{\min\{x_2,a_2^{(1)}\}}\;\sum_{x_1^{(1)}=ceil\left(\frac{x_2^{(1)}}{a_2^{(1)}}\right)}^{1} C_{a_2^{(1)}x_1^{(1)}}^{x_2^{(1)}}\sum_{x_1^{(2)}=ceil\left(\frac{x_2-x_2^{(1)}}{a_2^{(2)}}\right)}^{1} C_{a_2^{(2)}x_1^{(2)}}^{x_2-x_2^{(2)}}\sum_{j_1=0}^{2-(x_1^{(1)}+x_1^{(2)})} C_{2-(x_1^{(1)}+x_1^{(2)})}^{j_1}\times$$

$$\times(-1)^{j_1}\sum_{j_2=0}^{a_2^{(1)}x_1^{(1)}+a_2^{(2)}x_1^{(2)}-x_2} C_{a_2^{(1)}x_1^{(1)}+a_2^{(2)}x_1^{(2)}-x_2}^{j_2}(-1)^{j_2}\int_0^{\infty} e^{-\left(\lambda_0+\lambda_1(x_1^{(1)}+x_1^{(2)}+j_1)\right)t}e^{-\frac{x_2+j_2}{\sigma_2^2}t^2}\,dt.$$

In case of failure of an element of level 0 the system will fail completely, therefore probability of failure-free operation Iof this element is maximal. Operation of all elements on other system's levels depends on operation of this element. The system's operation depends on elements of the lowest level the least, therefore probability of failure-free operation of them may be the least.

Conclusions. The paper deals with mathematical models of main time reliability characteristics for unrestorable complicated electropower systems.

Without use of reliability characteristics it is impossible to settle a number of problems of systems' design and operation, for example: selection of structure and rational redundancy, organization of inspection monitoring and preventive maintenance. It is necessary to work out methods of reliability prediction with regard for systems' specific features such as possibility of structure rearrangement, preservation of serviceability in case of partial failures at the expense structural redundancy.

Thus, expressions are worked out for evaluation of two main time reliability parameters of complicated electropower systems: – the average duration of the system's stay in a state of x_2 operating output elements; – the average duration of the system's stay in the prescribed availability condition.

1. *Chen G., Yuang X., Tang X.* Reliability analysis of hierarchical systems // Proceedings of Annual Reliability and Maintainability Symposium RAMS-2005, Alexandria, Virginia USA. – 2005. – Pp. 146–151.

2. *Dawidziuk T.* Resonant pole inverters // Tekhnichna elektrodynamika. – 2006. – №1. – Pp. 89–94.

3. *Linquist T., Bertling L., Eriksson R.* A method of age modeling of power system components based on experiences from the design process with the purpose of maintenance optimization // Proceedings of Annual Reliability and Maintainability Symposium RAMS-2005, Alexandria, Virginia USA. – 2005. – Pp. 82–88.

4. *Robinson D.G.* Reliability analysis of bulk power systems using swarm intelligence // Proceedings of Annual Reliability and Maintainability Symposium RAMS-2005, Alexandria, Virginia USA. – 2005. – Pp. 96–102.

5. *Vodolazov V., Vinnikov D., Laugis J., Leita T.* Interinstitutional activity in professional training in power electronics // Tekhnichna elektrodynamika. – 2008. – №7. – Pp. 58–61.

МАТЕМАТИЧНІ МОДЕЛІ ПАРАМЕТРІВ НАДІЙНОСТІ ДЛЯ СКЛАДНИХ ЕЛЕКТРОЕНЕРГЕТИЧНИХ СИСТЕМ

А.Р. Сидор, В.М. Теслюк,
Національний технічний університет «Львівська Політехніка»,
вул. С.Бандери, 12, 79013, Львів, Україна.

Розроблено метод дослідження надійності параметрів складних електроенергетичних систем за допомогою твірних функцій, враховуючи старіння вихідних елементів системи. У даній статті досліджено основні часові параметри для оцінювання надійності. Розроблено математичні моделі у вигляді аналітичних формулювань для середньої тривалості перебування системи в кожному зі станів та для середньої тривалості перебування системи у встановлених умовах придатності, якщо строк експлуатації старіючих вихідних елементів обмежений розподіленням Релея. Бібл. 5.

Ключові слова: параметри надійності, електроенергетичні системи, старіючі елементи розподілення Релея.

МАТЕМАТИЧЕСКИЕ МОДЕЛИ ПАРАМЕТРОВ НАДЕЖНОСТИ ДЛЯ СЛОЖНЫХ ЭЛЕКТРОЭНЕРГЕТИЧЕСКИХ СИСТЕМ

А.Р. Сидор, В.М. Теслюк,
Национальный технический университет «Львовская Политехника»
ул. С.Бандеры, 12, 79013, Львов, Украина.

Разработан метод исследования надежности параметров сложных электроэнергетических систем с помощью производящих функций, учитывая старение выходных элементов системы. В даной стате исследовано основные временные параметры для оценки надежности. Разработаны математические модели в форме аналитических выражений для средней продолжительности пребывания системы в каждом из состояний, а также для средней продолжительности пребывания системы в установленных условиях пригодности, если время эксплуатации стареющих элементов ограничены распределением Рэлея. Библ. 5.

***Ключевые слова*: параметры надежности, электроэнергетические системы, стареющие элементы распределения Рэлея.

Надійшла 20.12.2011
Received 20.12.2011