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SIMULATION MODEL OF FUNCTIONING PROCESS OF AN ELECTRICAL FACILITY WITH CONSIDERATION OF RELIABILITY OF ITS ELEMENTS

This article offers a variant of a simulating model to estimate reliability of electrical facility early at development stage, using the information about a scope and reliability of its elements.

Keywords: *element, facility, reliability, unit, time to failure, simulation.*

Reliability of modern electrical facilities (EF) is a vital part of their quality and a necessary condition to ensure the functioning efficiency. A scientifically based analysis of EF reliability and efficiency is stipulated by requirements of national and international standards. Such analysis is necessary almost at all life cycle stages of a facility and first of all at a design stage. The main final objective of the analysis is a timely acquisition of reliable information required for the development and realization of well-founded decisions with regard to EF reliability.

A scientific analysis of reliability of EF elements is based on mathematical models. By means of them one could substantiate and estimate the reliability indices, solve the tasks of optimization, synthesis, development and substantiation of decisions. A possibility of an accurate and immediate solution of the indicated tasks has a direct influence upon the efficiency of EF being developed.

One of the most convenient tools of modeling of different processes at the development stage is simulation modeling. Simulation is based on reproduction of the facility functioning in time by means of software tools with consideration of its interaction with an external environment. A basis of any simulating model is as follows:

– development of the model of the facility being studied, based on particular simulating models of subsystems combined into a single whole;

– choice of informational characteristics of the research object, method of their implementation and analysis;

– construction of the model of the object's interaction with an external environment in form of simulating models of influencing factors;

– choice of the method of study of a simulating model in accordance with planning of simulation experiments.

Before we proceed to consideration of reliability matters, it is necessary to define the term "electrical facility". As per [1] within EF we can define the following types of components shown in Fig.1.

Therefore, an electrical product shall correspond to an element, an electrical device shall correspond to an assembly component (AC), and electrical equipment – to an electrical facility, which shall mean a set of electrical and technical devices within a technical system intended for production or transformation, transfer, distribution or consumption of electrical power. An element is the smallest component of the system which cannot be further divided and performing a certain function.

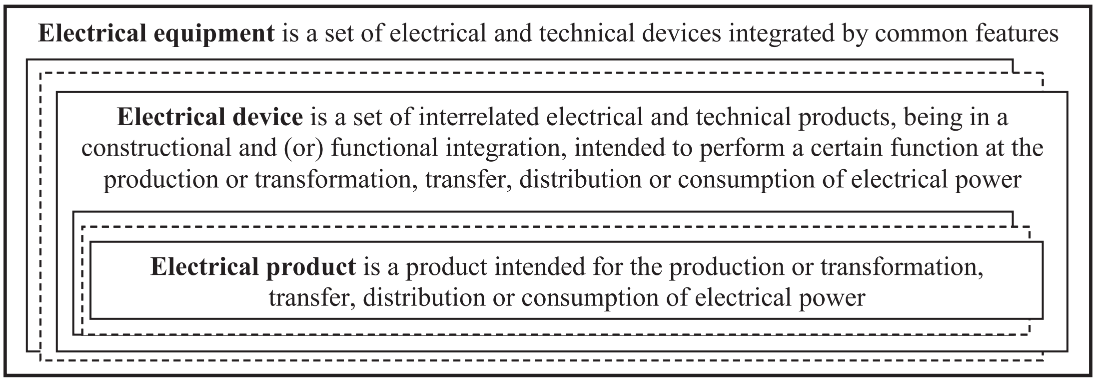

Fig.1. Element base of electrical facility

Fig.2 shows one of the variants of a unit flow diagram representing a simulation modeling of EF functioning with consideration of its elements reliability.

In unit 1 the input data is entered for further modeling of EF functioning. These data could be nominally divided into three groups:

A. System of input data of EF scope:

1. Amount of AC types and elements is p (it was assumed that p=1 corresponds to electrical ACs; p=2 corresponds to mechanical ACs; p=3 corresponds to hydraulic ACs and elements). It is also possible to change the types depending on the availability of elements of other physical nature (electronic, electromechanical, dynamoelectric, etc.). It would be more convenient not to divide elements into types, but it is necessary for further analysis of the modeling results, as it will help to conclude about the measures to improve EF reliability;

2. Amount of ACs of the p-th type within EF is $N^{(p)}$; consecutive number of AC of the p-th type is $i = \overline{1, N^{(p)}}$;

3. Amount of the p-th type within the scope of the i-th AC – $M_i^{(p)}, i = \overline{1, N^{(p)}}$; consecutive number of the element of the p-th type within the scope of the i-th AC $j = \overline{1, M_i^{(p)}}$.

Б. Statistics of reliability of different types of elements within EF:

1. Interval estimate of a failure rate for the j-th element within the i-th AC of the p-th type: the upper limit is $\lambda_{i,j}^{(p)в}$; the lower limit is $\lambda_{i,j}^{(p)н}$. Data could be obtained upon the results of operation, if within the EF being developed there are the elements already used in other systems;

2. Minimum and maximum failure rate of the elements of the p-th type is $\lambda_{\min}^{(p)}$ and $\lambda_{\max}^{(p)}$. These estimates shall be used to form the reliability indices of those elements which are absolutely new with no analogues (prototypes).

3. A recovery time of the j-th element within the i-th AC of the p-th type is $Tв_{i,j}^{(p)}$. All elements are assumed to be restorable, as even non-restorable and failed elements could undergo a unit repair, when a defective element (unit) is substituted by a new one or by a unit certainly operable.

B. Model data

1. Time of modeling is T_{mod}. Time of modeling allows setting an EF run time a developer is interested in, taking into account the delays due to failures and upcoming recovery of a defective element, AC.

2. Modeling step is Δt. The length of a modeling step will influence on the details and frequency of the model calculating. If the step length is an hour, we can get complicated dynamics, clearly demonstrating how random processes (failures) may affect the results of the model operation. Traditionally a modeling step is chosen to be a constant, though there are models in relation to which this rule is deliberately infringed. Depending on the time and a modeling step, an interval of modeling is formed which is the simulation time scale interval in which a model will be calculated with a frequency equal to a modeling step. In this case the interval of modeling is defined by the following limits [0, T_{mod}].

Unit 2 is to form the reliability indices of elements and ACs which are random values. Such indices are:

1. Parameter of flow of failures of the j-th element of the p-th type within the i-th AC – $\lambda_{i,j}^{(p)}$. It is defined as a regularly distributed in the interval [$\lambda_{i,j}^{(p)н}$, $\lambda_{i,j}^{(p)в}$] random value

$$\lambda_{i,j}^{(p)} = \left(\lambda_{i,j}^{(p)в} - \lambda_{i,j}^{(p)н}\right)\xi + \lambda_{i,j}^{(p)н};\ i = \overline{1, N^{(p)}},\ j = \overline{1, M_i^{(p)}},$$

where ξ is a regularly distributed in the interval [0, 1] random value formed with a random number generator [2].

For the elements with no information about their reliability due to the fact that they are new and have no analogues, a parameter of flow of failures is formed by the following formula depending on the element type

$$\lambda_{i,j}^{(p)} = \left(\lambda_{\max}^{(p)} - \lambda_{\min}^{(p)}\right)\xi + \lambda_{\min}^{(p)};\ i = \overline{1, N^{(p)}},\ j = \overline{1, M_i^{(p)}}. \quad (1)$$

2. A parameter of flow of failures of the i-th AC of the p-th type is $\Lambda_i^{(p)}$. Index is formed by means of addition of the parameters failure flow of the elements forming the scope of the respective AC

$$\Lambda_i^{(p)} = \sum_{j \subset A_i^{(p)}} \lambda_{i,j}^{(p)};\quad i = \overline{1, N^{(p)}},\ j = \overline{1, M_i^{(p)}}, \quad (2)$$

where $A_i^{(p)}$ is a set of elements forming the scope of the i-th AC of the p-th type.

3. Mean time to failure of the i-th AC of the p-th type is $T1_i^{(p)}$. It is defined by the formula

$$T1_i^{(p)} = \frac{1}{\Lambda_i^{(p)}};\quad i = \overline{1, N^{(p)}}.$$

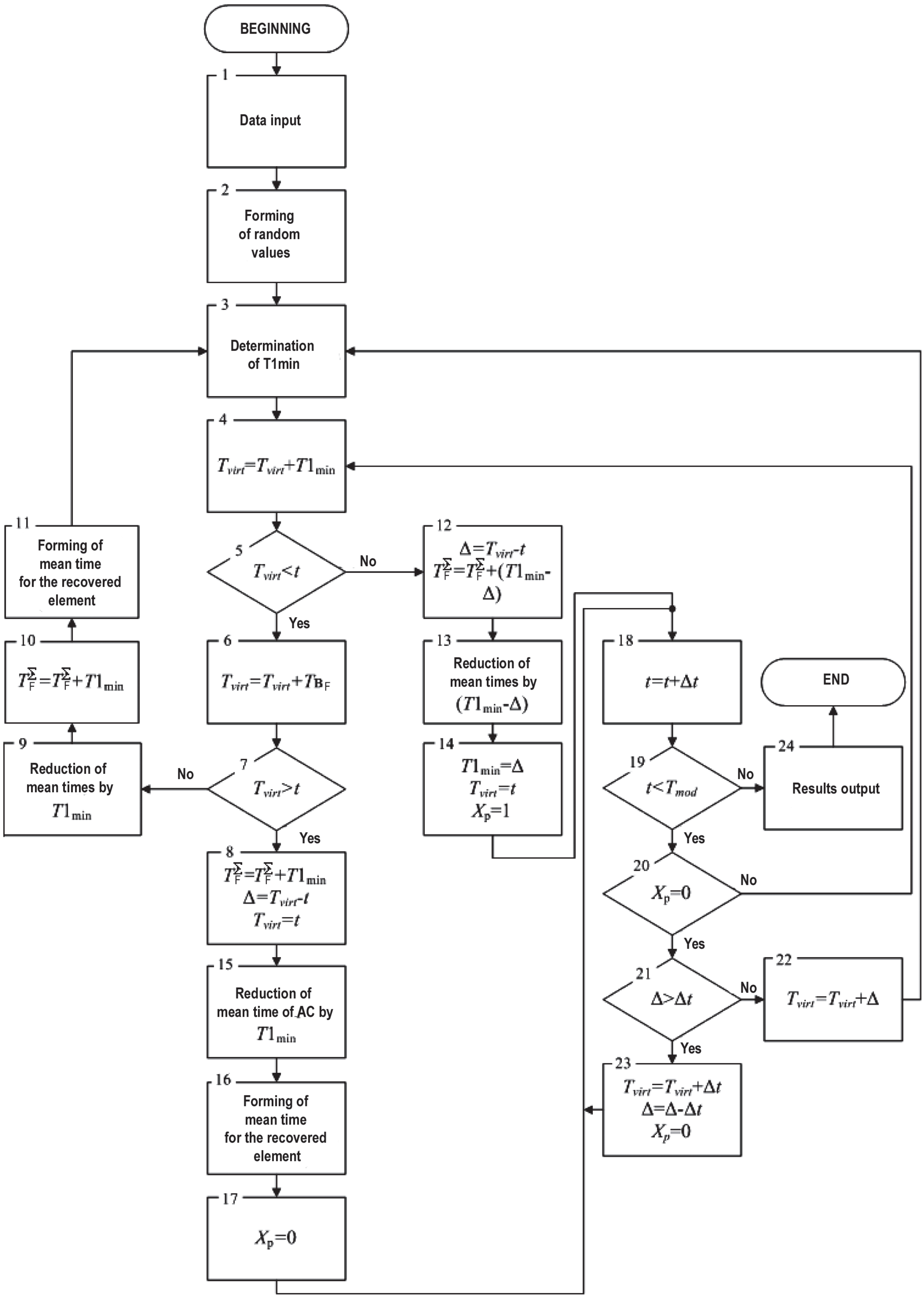

Fig.2. Unit flow diagram of EF functioning with consideration of reliability of its elements

4. Mean time to failure of the j-th element of the p-th type within the i-th AC is

$$T1_{i,j}^{(p)} = \frac{1}{\lambda_{i,j}^{(p)}}; \quad i = \overline{1, N^{(p)}},\ j = \overline{1, M_i^{(p)}}. \qquad (3)$$

Unit 3 makes comparison and choice of the element with a shortest mean time to failure among electrical, mechanical and hydraulic units first, and then it defines the element with a shortest mean time to failure among ACs, i.e. the element which turns out to be the first one. As a failure of the element, and therefore, the AC the element refers to, will result in the failure of the whole facility, the received mean time to failure is the mean time to failure for the EF being developed.

Unit 4 provides a forming of virtual time with consideration of the shortest mean time between failures using the formula

$$T_{virt} = T_{virt}^{*} + T1_{\min},$$

where T_{virt}^{*} is a virtual time value, corresponding to a previous step of the model.

A virtual time T_{virt} is the time formed by the addition of interlacing times to failure and recovery times of EF.

Unit 5 provides a comparison of virtual time with the current model time t, changing with a step Δt. A model time is an "artificial" time in which a model "lives in", or in other words it is a time which is a simulation, a prototype (a model) of real EF time. To take the count of model time and provide a correct chronological sequence of the principal events, a so called model time counter is used in a simulating model. This counter is a variable t to fix the current value of a model time. During the system modeling the counter is being continuously adjusted in accordance with the principal events that occur in real EF. In the offered simulating model a model time is adjusted with a constant step Δt.

If a virtual time T_{virt} is less than a model time t, at this stage the operation is passed to an operator 6, in which a virtual time T_{virt} increases by a recovery time value $Tв_{i,j}^{(p)}$ of a defective element, corresponding to the recovery time of the whole EF – $Tв_K$, ($Tв_{i,j}^{(p)} = Tв_K$). Then in unit 7 a virtual time T_{virt} is again compared with a model time t.

Further operation of the EF functioning model should be considered using different scenarios depending on the size of a modeling step. Possible variants of information situations are given in figures 3, 4.

Information situations 1 and 2.

A specified modeling step Δt is quite long and includes several interlacing periods of operation and recovery of the facility elements (AC). Difference between the situations 1 and 2 is that by the time a recurrent modeling step Δt is over, the facility is still in operating condition (information situation 2 – the facility is still being recovered).

Algorithm of operation of a model in case of information situation 1 is as follows. If the comparison in unit 7 shows that a virtual time is less than a model time $T_{virt} < t$, then the operation is passed to unit 9, in which mean times to failure $T1_{i,j}^{(p)}$ of other EF elements are adjusted by the formula

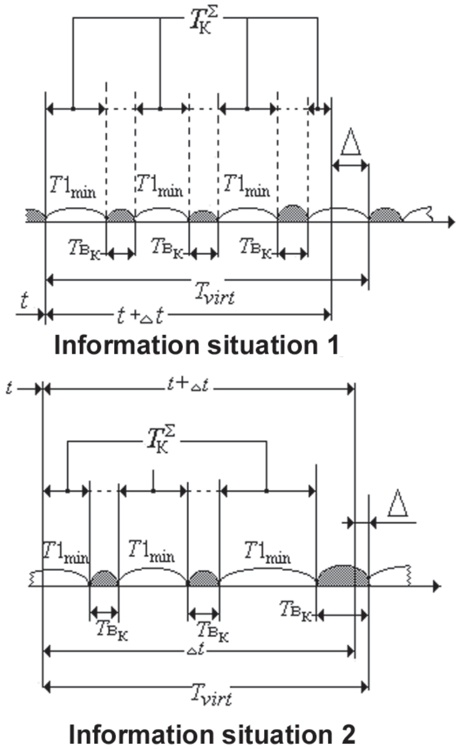

Fig.3. Information situations for $\Delta t >> T1_{\min}(Tв_k)$

$$T1_{i,j}^{(p)} = T1_{i,j}^{(p)*} - T1_{\min}; \quad i = \overline{1, N^{(p)}},\ j = \overline{1, M_i^{(p)}}, \qquad (4)$$

where $T1_{i,j}^{(p)*}$ is a preceding value of mean time to failure.

Further in unit 10 total time of EF operation T_F^{Σ} if formed by addition of times to failure of the elements failed during the facility functioning. Total time of facility operation T_F^{Σ} is required for analysis of EF reliability upon the results of the whole simulation modeling.

Unit 11 forms a new time to failure for the element that substituted the failed one, by formulas (1 – 3). The operation is passed to unit 3 and the cycle is repeated until virtual time T_{virt} exceeds a model time t in a comparison unit 5, and operation is passed to unit 12, in which Δ is defined, a value specifying the difference between a virtual time T_{virt} and a model time t. Besides total time of EF operation T_F^{Σ} is adjusted here by the following formulas

$$\Delta = T_{virt} - t,$$

$$T_F^{\Sigma} = T_F^{\Sigma*} - (T1_{\min} - \Delta),$$

where $T_F^{\Sigma*}$ is a preceding value of total time of facility operation.

Then in unit 13 mean times to failure of other elements is adjusted by the formula

$$T1_{i,j}^{(p)} = T1_{i,j}^{(p)*} - (T1_{\min} - \Delta); \ i = \overline{1, N^{(p)}},\ j = \overline{1, M_i^{(p)}},$$

where $T1_{i,j}^{(p)*}$ is a preceding value of time to failure.

In unit 14 the least time between failures is setting equal to the Δ value, a feature of performance capacity of the facility X_p is given the value 1 (functionally operative) and a virtual time becomes more equable to a model time $T_{virt} = t$. Then the operation is passed to unit 18, in which a model time t increases by a value of a modeling step Δt until it exceeds a model time T_{mod} and the experiment is over.

Operation of a simulating model in case of information situation 2 is similar to the situation 1 with the difference that a moment when a virtual time T_{virt} exceeds a model time t comes after it is increased by a value of recovery time $Tr_F = Tr_{i,j}^{(p)}$ of a failed element, and, consequently EF as well (unit 6), after that the operation is passed from comparison unit 7 to unit 8.

Unit 8 specifies total time of facility operation T_F^{Σ} and adjusts the following time parameters of a model: value Δ and a virtual time T_{virt}

$$T_F^{\Sigma} = T_F^{\Sigma *} + T1_{\min},$$

$$\Delta = T_{virt} - t,$$

$$T_{virt} = t.$$

From unit 8 the operation is passed to unit 15, which similarly to unit 9 adjusts times to failures of the elements by the formula (4). Unit 16, similarly to unit 11, forms a new time to failure for the element that substituted the failed one after recovery, by the formulas (1 – 3). In unit 17 a feature of performance capacity of the facility X_p is given the value 0 (the facility is faulty and is now under recovery). Then the operation is passed to a comparison unit 18 to define end of modeling or its further continuation.

Information situations 3 and 4.

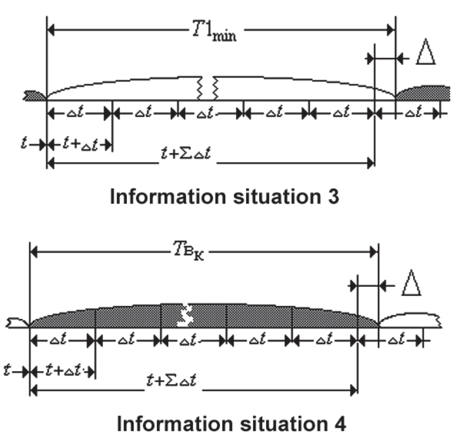

Fig. 4. Information situations for $\Delta t << T1_{\min}(Tr_F)$

A specified modeling step Δt is quite small and for a sequent adjustment of a recovery time value $Tr_{i,j}^{(p)}$ (situation 3) or a time between failures $Tf_{\min}$ (situation 4) several iterations of a model are required with a step-by-step increase of a model time t by Δt value. In these situations a recovery time $Tr_{i,j}^{(p)}$ or a time between failures $Tf_{\min}$ of EF gradually decrease by a value of modeling step Δt. For this purpose in a simulating model there is a cyclic and sequent repetition of operations in the following units: for information situation 3 ($T1_{\min}$>>Δt) – 4 – 5 – 12 – 13 – 14 – 18 – 19 – 20 – 4; for information situation 4 $\left(Tr_F = Tr_{i,j}^{(p)} >> \Delta t\right)$ – 18 – 19 – 20 – 21 – 23 – 18. Decrease of the value $T1_{\min}$ shall be until a model time t exceeds a virtual time T_{virt} in a comparison unit 5, and the operation is passed to unit 6 (situation 3); similarly the adjustment of $Tr_{i,j}^{(p)}$ shall be performed until a Δ value is more than a modeling step Δt in a comparison unit 21, after which the operation is passed to unit 22 (situation 4).

A suggested algorithm being repeated cyclically forms time characteristics of the functioning of EF and its components (total time of operation, total recovery time, time to failure, etc.) until a model time t with a step Δt exceeds a modeling time T_{mod}. When the simulation modeling is completed, the results obtained shall be delivered to unit 24. Using the research results, a developer gets the possibility to estimate the reliability indices of the elements, ACs and the whole EF [3, 4], as well as to evaluate a contribution to the formation of reliability level of the facility elements and different types of ACs.

Based on the primary results of modeling one can take measures to improve reliability level of the elements, then an experiment could be repeated. Thus, using a suggested simulating model of EF functioning with consideration of reliability of its elements it is possible at early stages of development to forecast which reliability level the facility will have and how it can affect the efficiency and quality of its use.

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