Practical Aspects of Genetic Algorithms' Implementation in Life Cycle Management of Electrotechnical Equipment

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***Abstract*—Some practical aspects of Genetic algorithms' implementation regarding to life cycle management of electrotechnical equipment are considered.**

***Keywords*: life cycle, electrotechnical equipment, genetic algorithms.**

I. Introduction

The task of supporting an optimal conditions of electrotechnical equipment within the specified time is a key task. One of the main stages of the life cycle is the stage of maintenance, which acts as a stage of storage of statistical data, and as a stage of testing and inspection equipment to meet specified performance reliability.

One of the solution techniques, allowing creating effective algorithms for a wide range of tasks, is the usage of a subclass of the directed random search methods – methods of genetic modeling.

Numerous approbation of use and application of genetic methods in scientific and industrial spheres allow saying with confidence that when using the evolutionary methods, realization of the comprehensible well-founded decision search problems is always reached. In overwhelming majority of cases the use of natural analogues gives positive results. This is explained by the fact that the analogue taken from the nature was improved for many years of evolutions and at the present time has the optimum structure [1][2].

The idea is to consider these genetic algorithms regarding to life cycle management of electrotechnical equipment.

Like biological development each technological product develops continuously from a stage of origination (setting up) to a stage of collapse (recycling), going through any environment effects and adapting for them.

Algorithms work with a group of "individuals" – population, each of which represents possible solution of the given problem. Each individual is estimated by a measure of its "suitability" according to how rationally solution of the problem suits to it.

In each generation of the chromosome genetic algorithms (coded solutions) are the result of application of some genetic operations [1]-[3].

II. The Key Genetic Relations Regarding Life Cycle Management of Electrotechnical Equipment

Operations must precede the process of algorithms construction [1]-[3]:

- Selection of the initial conditions;
- Criteria selection (criteria functions);
- Analysis and selection of the boundary conditions.

Selection operations of the initial level depend on the type of the current task and goals, which must be reached as a result of algorithm realization.

If it concerns maintenance of the parameters on the certain level and reliability index of the equipment in the course of its operation then as initial conditions, it is reasonable to use data values of parameters and the indexes defined on a development stage in the form, installed by manufacturer and presented in the maintenance documentation (in particular, in maintenance documentation for the specific type of the equipment).

In this case, the main task is conformity «real reliability of the equipment – reliability set as zero conditions» that is support of higher level of reliability [4].

Iinitial conditions – datum values of the equipment parameters (values of reliability including the level of the serviceability, revitalization, mean time between failures, probability of non-failure operation etc.).

Population of candidate solutions P^t [3] :

$$P^t = \{P_1, P_2, \dots, P_{Np}\},$$

where
$t = 0, 1, 2, \dots$ is the number of generation;
N_p is the population size.

Chromosome consists of genes:

$$P_i = \{g_1, \dots, g_L\},$$

where L is the chromosome's length.

Gene is identified by locus (position) and allele a_j:

$$g_j = \{j; a_j\}.$$

It is necessary to introduce criterion of an optimality estimation which will characterize level of considered solutions under the control of the technical state of the equipment [3]-[6].

Realization of the genetic algorithm assumes the fitness function. This function returns the number, showing how good this chromosome is. The given function will be the criteria for the algorithm forming. In the embodied genetic algorithm it is reasonable at first to define the worse chromosome (having maximum deviations from the target level of parameter) and to measure the index value [3].

The got number is called the bad one with respect to which the quality of the other chromosomes is valued: fitness of the chromosome is calculated as difference between index value, set by the given chromosome and bad index value.

For chromosome P_1 fitness function will be:

$$\omega(P_1) = |n-m|, \qquad (1)$$

where

n is the current index (feature),

m is the specified index.

Let, for example, have a look some time resolution, limited by the first equipment failure. So as a criteria it is reasonable to use the index value of the mean time between failure of the given type of the electrotechnical equipment. The highest the value of the criterion function, the more optimal is the method of the equipment maintenance, the more optimal is the set of methods, providing this maintenance and their content (the set of the actions, the level and the quality of their realization).

The criteria choice is the main preliminary step when building the algorithm, because only it will define the further algorithm filling, its logical direction and convergence.

One of the important moments is the analysis and the limitation selection of the given system and for the algorithm is its functioning. Limitation can absolutely different indeed:

Economic ones – in the network of the limited founding;

Technological ones – limitation in the instrument base and documentation base, skilled personnel, etc.

Temporal constraints – conducting the actions, etc.

Limitations are the necessary addition, which lets to take into account the particularities of the real technological objects and systems, factors, influencing on its activity. The majority of the real tasks have deterministic character.

Limitations can be also made as some rules and conditions and can be used when selecting and making the possible variants of solutions (heuristics).

In this case, equipment is characterized by particular set of maintenances, with the help of which life cycle following is put into effect [7]. Each application for different methods can be done in different ways. This is the difference in chromosome genes.

This difference will be: in application of various instrument base (for example, in one case optical resources are used at a visual estimation of a state of pendant basic insulators, and in other – there is nothing), taking into account some external factors, in application to various approaches concerning state estimation (up to distance and points control), and also in application to various methods of results processing.

It is necessary to add that all complex of actions should correspond to the circuit of support of the set technical state of the equipment (and to include not only actions for an estimation of the technical state in the form of monitoring and diagnostics, but also reducing and preventive operations etc.).

Changing of the purposes and the problems solved by system, can lead to revision as maintenances of preliminary operations, and a way of "filling" of chromosomes (for example, concerning economic aspect of a problem, the concepts connected with a given problematic and components can be used).

For the interpretation of genetic concepts, the following definitions are introduced [4].

Reproduction. It includes some elements of standardization, as the developed techniques of service and decision-making. As a result of a reproduction we will receive the element of electrotechnical equipment and a set of the regulated actions by means of which its support and the control of its technical state will be carried out.

Crossover. Refinement of existing techniques of the control and equipment service, on the basis of expert estimations and other sorts of the analysis of existing systems. Framing of concrete solutions on upgrading, support of any solutions of documentation base is necessary. The completion phase is development of the standard of the enterprise regulating and considering all features of a set of actions under the control and support of the set technical state of the equipment.

There are a lot of crossover techniques [3]. Indeed the structure of crossover affects the efficiency of genetic algorithm.

Let's introduce three main crossover techniques, which will later be used in the construction of algorithms for optimal life cycle management system of electrotechnical equipment.

1) *One-point crossover*.

Let's have 2 chromosomes P_1 and P_2 in population P: $P_1 \in P$, $P_2 \in P$, which will be choose as parents:

$$P_1 = \{g_1, g_2, \ldots, g_L\},$$
$$P_2 = \{g^1, g^2, \ldots, g^L\}.$$

It is necessary to determine the cut-point of crossover k – this point determines the place of two chromosomes, where they should be "cut", i.e. k is the number (or value) of the code of a gene which is performed after incision chromosome:

$$k \in \{1, 2, \ldots, L\text{-}1\}.$$

In this case there will be two new chromosomes P_1' and P_2' formed by permutations of the elements in chromosomes P_1 and P_2 according to the rule:

$$P_1' = \left\{g_1, g_2, g_k, | \, g^{k+1}, \ldots, g^L\right\},$$
$$P_2' = \left\{g^1, g^2, g^k, | \, g_{k+1}, \ldots, g_L\right\}.$$

Schematically one-point crossover provides convertion two chromosomes and partial exchange of information between them.

2) *N-point crossover*.

Unlike one-point crossover, it is necessary to determine the N cut-points in each of P_1 and P_2 chromosomes. Cut-points divide the chromosome into several blocks, and chromosomes exchange sites located within blocks. E.g., the offspring P_1' is formed from the odd blocks of parent P_1 and even blocks of parent P_2. The offspring P_2' is formed from the odd blocks of parent P_2 and even blocks of parent P_1 respectively:

$$P_1 = \{g_1, \ldots, g_a, | g_{a+1}, \ldots, g_i, | g_{i+1}, \ldots, g_k, | g_{k+1}, \ldots, g_L\},$$

$$\underline{P_2 = \{g^1, \ldots, g^a, | g^{a+1}, \ldots, g^i, | g^{i+1}, \ldots, g^k, | g^{k+1}, \ldots, g^L\}},$$

$$P_1' = \{g_1, \ldots, g_a, | g^{a+1}, \ldots, g^i, | g_{i+1}, \ldots, g_k, | g^{k+1}, \ldots, g^L\},$$

$$P_2' = \{g^1, \ldots, g^a, | g_{a+1}, \ldots, g_i, | g^{i+1}, \ldots, g^k, | g_{k+1}, \ldots, g_L\}.$$

However, it is necessary to take into account that a large number of cut points may result in loss of "good" parents properties.

3) *"Cut and splice"*.

"Cut and splice" crossover is used by forming the second and further generation.

In this approach, the blocks are analyzed in both chromosomes and partial correspondence between the elements of the first and second parents with forming offsprings is set. In the portable block the duplicate genes (alleles) are replaced by genes (alleles) presented in the locus of original chromosome:

$$P_1 = \{g_1, g_2, \ldots, | g_i^i |, | g_k, \ g_{k+1}, \ldots, g_L\},$$
$$\underline{P_2 = \{g^1, g^2, \ldots, \ldots, \ | g^k, | g_i^i \ |, \ldots, g^L\}},$$
$$P_1' = \{g_1, g_2, \ldots, | g_i^i |, | g^k, | g_{k+1} |, \ldots, g^L\},$$

where

g_i^i is duplicate gene in chromosomes P_1 and P_2:

$$g_i^i := \{i, a_{k+1}\}.$$

Mutation. In whole, a mutation is the ambiguous phenomenon in most cases calling negative consequences. In this case under mutation we will understand effect of some factors on equipment maintenance. To mutation factors we refer:

- Environment conditions (the external factor, in view of object distribution is important);
- Skills degree of operating staff.

Let's introduce two main mutation techniques, which will later be used in the construction of algorithms for optimal life cycle management system of electrotechnical equipment.

1) *One-point mutation*.

In the chromosome P_1, $P_1 \in P$, it's need to determine (randomly or specifically) the two positions (two loci) (i) and (L-i):

$$P_1 = \{g_1, g_2, \ldots, g_i, \ldots, g_{L-i}, \ldots, g_L\}.$$

Genes corresponding to selected positions, g_i and g_{L-i}, are rearranged. It caused to form a new chromosome:

$$P_1' = \{g_1, g_2, \ldots, g_{L-i}, \ldots, g_i, \ldots, g_L\}.$$

2) *N-point mutation*.

It's necessary to determine the N cut-points in the chromosome P_1, $P_1 \in P$.

After that step by step the genes located to the right of the cut-points are exchange of each other in order of their location. The gene located to the right of the last cut-point goes into position in front of the gene corresponding to the first cut-point:

$$\underline{P_1 = \{g_1, \ldots, g_a, | g_{a+1}, \ldots, g_i, | g_{i+1}, \ldots, g_k, | g_{k+1}, \ldots, g_L\}},$$

$$P_1' = \{g_1, \ldots, g_a, | g_{k+1}, \ldots, g_i, | g_{a+1}, \ldots, g_k, | g_{i+1}, \ldots, g_L\}.$$

Inversion. Inversion is a mathematical construction that allows the inversion based on parent chromosome (or part thereof) to create a offspring chromosome.

Let's introduce two main inversion techniques, which will later be used in the construction of algorithms for optimal life cycle management system of electrotechnical equipment.

1) *One-point inversion*.

It's necessary to determine the cut-point of inversion k in the chromosome P_1, $P_1 \in P$:

$$k \in \{0, 1, 2, \ldots, L+1\}.$$

Offspring P_1' is formed by inversion of the segment located to the right of cut-point k in the chromosome P_1:

$$\underline{P_1 = \{g_1, g_2, g_k, | g_{k+1}, \ldots, g_L\}},$$
$$P_1' = \{g_1, g_2, g_k, | g_L, \ldots, g_{k+1}\}.$$

2) *N-point inversion*.

It's necessary to determine the N cut-points in the chromosome P_1, $P_1 \in P$. Then elements formed inside the blocks are inverted:

$$\underline{P_1 = \{g_1, \ldots, g_a, | g_{a+1}, \ldots, g_i, | g_{i+1}, \ldots, g_k, | g_{k+1}, \ldots, g_L\}}$$

$$P_1' = \{g_1, \ldots, g_a, | g_i, \ldots, \ g_{a+1}, | g_{i+1}, \ldots, g_k, | g_L, \ldots, g_{k+1}\}$$

Reduction. Reduction is a mathematical construction (based on the analysis of the population) that allows to reduce the size of the population to a predetermined value after one or more generations of genetic algorithm.

The primary purpose of the reduction is eliminating unsuccessful decisions and maintaining population at an optimal level (depending on computer memory).

Reduction carried out the following procedures:

1) the forming a reproduction group from all the solutions generated in the population P^t,

2) the selection of solutions in the following population.

Size of new population N^{t+1} is defined as:

$$N^{t+1} = N^{t} + N_{OC} + N_{OM} + N_{OI},$$

where
N^{t} is the size of population on step before (t), N_{OC} is the number of offsprings produced by crossover, N_{OM} is the number of offsprings produced by mutation, N_{OI} is the number of offsprings produced by inversion.

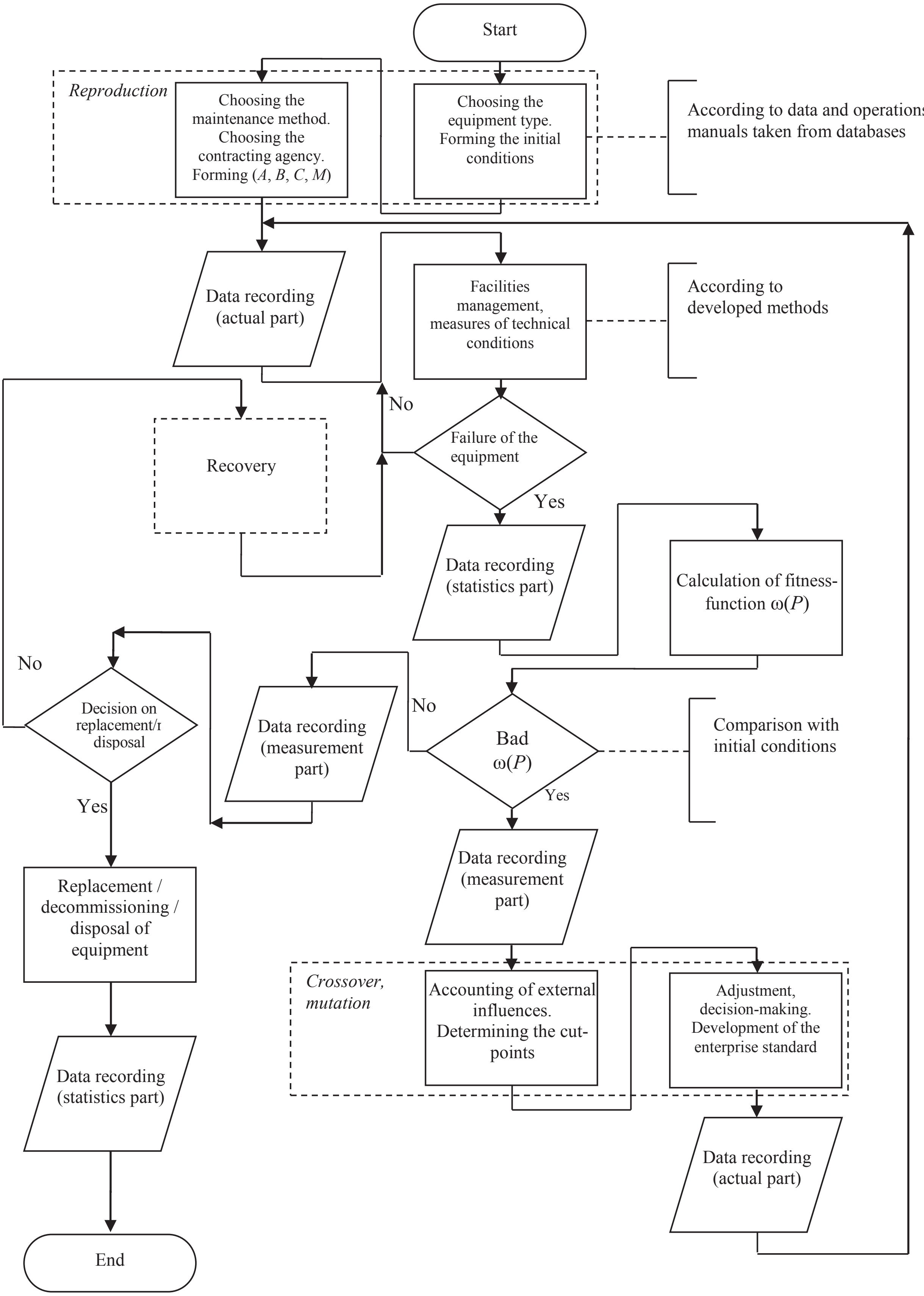

Fig. 1. Generic flowchart of life cycle management system of electrotechnical equipment with the use of genetic algorithms.

III. Implementation Of Genetic Algorithms In The Task Of Supporting An Optimal Conditions Of Electrotechnical Equipment

Generic flowchart of life cycle management system of electrotechnical equipment with the use of genetic algorithms is showed in the Fig. 1. From the figure it can be seen that the performance of each group of measures to support the optimal conditions affects the function of the life cycle equipment as a whole [8]-[11].

The reliability plan also includes a detailed description of reliability tools and criteria for critical items list [7]. As the function of reliability, the function of the life cycle equipment $R'(t)$ should provide maximum effort to specified conditions, i.e., the effective maintenance model should ensure the maintenance of the set of indicators at the appropriate level:

$$R'(t) = R_0 - (A(p) + B(p) + C(p) + M(p) + \ldots) \leq 0,$$

where R_0 is the specified reliability, $A(p)$, $B(p)$, $C(p)$, $M(p)$ are the "parts" of reliability, provides a variety of measures [9][10][12]. $A = \{a_1, a_2, a_3\}$ is a variety of information-obtain-actions,

a_1 – monitoring by «hectic rush», a_2 – monitoring, based on the visual examination of the equipment, a_3 – monitoring with the use of infrared and ultraviolet control,

$B = \{b_1, b_2, b_3\}$ is a variety of rules of estimation of technical conditions, b_1 – analysis based on risk model, b_2 – analysis based on probabilistic assessment of failures, b_3 – analysis based on expert judgment,

$C = \{c_1, c_2, c_3\}$ is a variety of maintenance and repair activities, c_1 – maintenance by «hectic rush», c_2 – preventative maintenance, c_3 – maintenance within a system of service within a given technical condition,

$M = \{m_1, m_2, m_3\}$ is a variety of management methods.

Let's introduce the next basic heuristics:

$$H_1 = \{a_1 c_1\},$$
$$H_2 = \{a_2 c_2\},$$
$$H_3 = \{a_3 c_3\}.$$

Each group of measures provides a certain level of selected indicators, the value of which varies from 1 to 10. The initial conditions are based on the available basic parameters of reliability of different types of electrotechnical equipment.

Let's assume that each of the groups of measures has the same weight in forming the reliability in current time. Thus the maximum value ($A(p)$ + $B(p)$ + $C(p)$ + $M(p)$ + ...) is equal to 40.

In case of absolute terms (e.g. time between failure $t_{\max}$) it can be used the calibration scale groups of measures of reliability indices of a particular type of equipment:

- $t_{\max}$ corresponds to 40 relative units,
- calculating the calibration factor $k_K = \dfrac{t_{\max}}{40}$,
- the computational procedures returns to the operator the value of the function of the life cycle equipment in absolute terms $(a_n + b_n + c_n + m_n) \cdot k_K$.

E.g., to suspension insulators PS-70 with $t_{\max}$ = 360 months, the calibration factor is $k_K = 9$ and the equation of the function of the life cycle equipment takes the form:

$$a_n + b_n + c_n + m_n \geq 40, \qquad (2)$$

where

$n = 1...3$ is the name of heuristic.

The first generation of chromosomes is formed basing on the evaluation of a particular type of electrotechnical equipment in four different power systems (Table 1).

TABLE I
GENERATION OF NEW POPULATION

Chromosome	**(*a*, *b*, *c*, *m*)**
P_1	(5, 5, 8, 7)
P_2	(2, 5, 4, 3)
P_3	(5, 4, 4, 3)
P_4	(8, 4, 7, 7)

To calculate the coefficients of fitness $\omega(P_i)$, it's necessary to substitute each solution in (2) and find the deviation from the formula (1) (Table 2).

TABLE II
CALCULATION OF THE FITNESS-FUNCTION

Chromosome	$\omega(P)$
P_1	40-25=15
P_2	40-14=26
P_3	40-16=24
P_4	40-26=14

The higher fitness (less the value of $\omega_i(P)$), the greater the chance of being selected as a parent chromosome (Table 3).

TABLE III
SELECTION OF PARENT CHROMOSOMES

1st parent chromosome	**2nd parent chromosome**
P_4	P_1
P_4	P_3
P_4	P_2
P_1	P_3
P_1	P_2
P_3	P_2

Let's use the crossover for generation the offspring chromosome (Table 4). The result is a second generation of chromosomes with their usual fitness (Table 5).

TABLE IV
CROSSOVER

1st parent chromosome	**2nd parent chromosome**	**Offspring chromosome**
(8| 4, 7, 7)	(5| 5, 8, 7)	(8, 5, 8, 7)
(8| 4, 7, 7)	(5| 4, 4, 3)	(8, 4, 4, 3)
(8| 4, 7, 7)	(2| 5, 4, 3)	(8, 5, 4, 3)
(5| 5, 8, 7)	(5| 4, 4, 3)	(5, 4, 4, 3)
(5| 5, 8, 7)	(2| 5, 4, 3)	(5, 5, 4, 3)
(5| 4, 4, 3)	(2| 5, 4, 3)	(5, 5, 4, 3)

TABLE V
OFFSPING'S FITNESS

Offspring chromosome	$\omega(P)$
(8, 5, 8, 7)	40-28=12
(8, 4, 4, 3)	40-19=21
(8, 5, 4, 3)	40-20=20
(5, 4, 4, 3)	40-16=24
(5, 5, 4, 3)	40-17=23
(5, 5, 4, 3)	40-17=23

Continuing in this way, one chromosome eventually reaches fitness, equal to 0 or close to it.

IV. CONCLUSION

It is also necessary to take into account additional "financial" criterion, calculating the additional factors of fitness. Thus, the choice of the optimal solution will be a synthesis of solutions for two functions: the function of "reliability" and function of "costs" [3][13].

The difficulty and the goodness of action realizations in technical state of the equipment increases, the number of the operations required for the algorithm realization increases. But in spite of the apparent bulking, algorithms are simple in their accomplishment because of their coherency.

Electronic educational resources were developed using an educational process for training students with the specializations "Electrical Power Supply," "Automation of Technological Processes and Production," and "Automated Management of Product Life Cycle" of Perm National Research Polytechnic University.

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