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Evolutionary approach to restoration service of electric power distribution networks

Jan Stępień[1], Sylwester Filipiak[2]
[1](Electrical Engineering Automatics and Computer Science Faculty, University of Technology Kielce, Poland)
[2](Electrical Engineering Automatics and Computer Science Faculty, University of Technology Kielce, Poland)

Abstract:- *In the literature on the distribution systems operation the problem of power delivery recovery in case of the network failure is one of the very important aspects of a proper operation of the distribution systems. An idea of using a classifying system and co-evolutionary algorithm for operation support of electric power distribution systems operators has been presented in the paper. The elaborated method uses the theoretical background of genetic-based machine learning systems. The method shows the ability to collect experience on the base of information on faults, occurred or simulated in the power distribution systems. In the elaborated method the decisive variables, essential from the network operation reliability point of view, described with the use of fuzzy sets theory. A method enabling to formulate scenarios of network configuration changes (at changes in network operation conditions) has been characterised in the paper.*

Keywords: - *Evolutionary Algorithms, classifier system, Distribution Power Networks*

I. INTRODUCTION

The Planning a restoration service for distribution systems is a critical task for dispatchers in a control center. Restoration attempts to supply an ample amount of power to nonfaulty out-of-service areas for as many customers as possible while safely operating the distribution system. Reconfiguration is the process of changing the open/closed status of switches and is done for volt/var support, loss reduction, load balancing and restoration. Reconfiguration for restoration is a combinatorial problem involving searching an enormous space of solutions. The problems with integer variables are NP hard, meaning no known algorithm exists to solve these problems in polynomial time. However, reconfiguration for restoration problem is both NP hard and NP and hence belongs to the class of NP complete problems. For such kind of problems, the solution time increases with an increase in the number of integer variables. However, the solution time generally depends on the formulation.

Many approaches have been proposed to solve the restoration problem from different perspectives. For instance, researchers [1, 2] incorporated dispatcher's experience and operating rules into an expert system to assist the dispatcher. Related investigations formulated the restoration problem as an optimization problem to minimize the number of unserviced customers [3, 4]. This problem has been approached using heuristics [5, 6, 7] mathematical programming [8], meta-heuristics (genetic algorithms, tabu search, simulated annealing) [9, 10] and expert systems [11].

In works [12, 13, 14] are presented methods concerning the use revolution algorithms drawn up to resolve multi-criteria problems in optimising electric power networks. These methods concern the development of specialised means of coding, reproduction methods based on domination and also use of co-evolutionary approaches. Several evolutionary algorithms have been developed to deal with distribution system reconfiguration problems [15, 16, 17, 18]. Although the obtained results have been encouraging, the majority of evolutionary algorithms still demand high running time when applied to large-scale distribution systems. In [14], it was shown that the tree encoding (data structure) used is a critical factor for the performance of evolutionary algorithms applied to such large distribution systems. Other critical aspects of distribution systems are the genetic operators that are implemented. Generally these operators do not generate radial configurations [19]. In order to improve the performance obtained by evolutionary algorithms in distribution system reconfiguration problems, a tree encoding based on graph chains, called graph chains representation, and its corresponding genetic operators were developed in [14]. These operators produce only radial configurations. Although the requirement of a radial configurations is common for distribution system reconfiguration problems, it makes the network modeling more difficult to efficiently reconfigure distribution systems.

The analysed problem of choosing the substitute configuration of the distribution system can be described as a multiobjective programming problem. In the article the author presented the results of his works concerning the method drawn up using the system classifying cooperation with the co-evolutionary algorithm, in order to assist the work of electrical energy distribution systems operators. The elaborated method uses the classifying system to determine, for the assumed conditions, the most profitable distribution network configuration. The important feature of the method is the possibility to form the substitute network configuration with the use of information coming from the simulated network operation states, where the information on reliability parameters of the network or exploitation periods of the network elements can be also exploited.

The article presents, as the application for solution of the analysed problem, the co-evolutionary algorithm cooperating with classifying system as a method typified by the short duration of the calculation process. Reduction of the calculation time (on average by 40 %) results from the fact of use of information written into the population of classifiers, which is the population subject to the evolutionary process. The population of classifiers containing information of various replacement network configurations is formulated with regard to reliability characteristics and operation times of network elements. The principal result presented in this article is an effective method of designating the placement network configurations for cases of breakdown situations for very complex network structures.

II. A METHOD USING THE CLASSIFIER SYSTEM

The classifier system is a system that learns the syntactic simple rules in order to co-ordinate its actions in any environment and includes the three basic components [20, 21]: rule and message system, evaluating system, evolutionary algorithm. In the classifier system the information from the outer environment is processed into the messages of a given format. The messages are further placed on the message list, where they can activate the classifiers. In the elaborated method (based on the classifier system idea) known procedures, performing message processing or classifier evaluation have been used. Certain modifications resulting from the specificity of the considered problem, have been introduced:

- the message about the fault is described in the form: a list with numbers of not supplied nodes, and a list with numbers of fault elements :
  <message>:: =(numbers of not supplied nodes)+ (numbers of fault elements)
- in the classifier notation following syntax has been taken into account in the notation actually used:
  <classifier>::= <condition>:<message>
  <classifier>::=< numbers of not supplied nodes + numbers of fault elements>:<post-fault configuration>

The work [20] contains a detailed description of the procedure implemented by the classifying system connected with the classifiers evaluation and processing. This article below contains a description of the application of the modified co-evolutionary algorithm. In differentiation from the algorithm described in the work [20], for reception of results presented in this work is applied: co-evolutionary article using other genetic operators and modified function sets evaluating solutions contained in particular subpopulations substituted by co-evolutionary algorithm.

With regard for these specific nature of the analysed task the author suggested a two-part description of the announcement (describing the breakdown situation of the network). The first part of the announcement is recorded as a length of zero-ones relating to the number of elements equal to the number of network line sections of the analysed network. Value 1 on the defined position corresponding to the number of the network length, indicates length with power supply, and 0 indicates network node without power supply as a result of breakdown. The second part of the announcement contains information about the damaged elements and also information about the configuration of network elements. For the description of this part of the announcement the author introduced the following marking notation: 0 - means damaged element, 1 - means actually used element, # - means element remaining in reserve. Below is showing an example of the process of creating announcements for the breakdown status of the electric power network system (composed of a small number of elements), the structure of which is reflected in graphic form on drawing 1. For the network graph from drawing 1, the case is examined of a breakdown on line l4.

The announcement describing the considered breakdown status was described as follows:

message 1

111101000110111 | 11#0#####1#11####11##1

The sought for classifiers in the first stage (fig.2):

classifier 1

111101100110111 | 11110###11#1111##11##1

classifier 2

111101111111111 | 11111#01#1#11#1##11##1

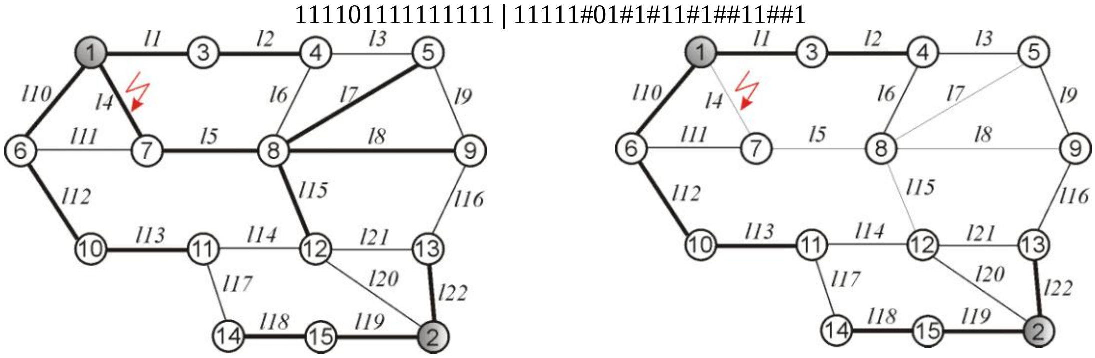

Fig. 1. Graph of the analysed distribution network

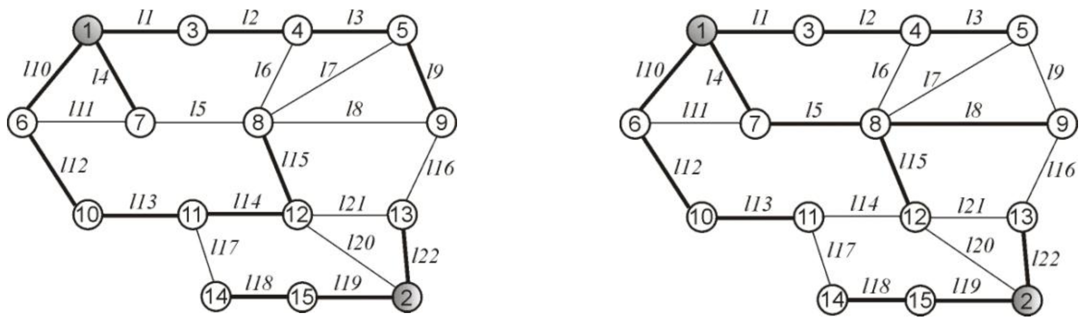

Fig. 2. Graph of the analysed distribution network for classifier 1 and classifier 2

The performance of the process of creation of announcements enables search in the collection of classifiers for information, the use of which assists the process implemented by the co-evolutionary algorithm.

In the initial part of calculations a message on the fault occurring in the network is being read. Procedures verifying the matching between the classifiers and the generated message are performed subsequently and then the classifiers are assessed. The strength S of the classifier, which has shown the best bid in the so-called auction process, is increased by the reward given by the system. Simultaneously its strength is decreased by the value of the bid given by the classifier. The bid of the best classifier increases the strength of other active classifiers proportionally to their bids. Moreover, the strength of all the active classifiers is decreased by a certain, determined value. The effective bid value has been calculated in a following way [20, 21]:

$$S_i(t+1) = S_i(t) - c_{bid} \cdot S_i(t) - c_{tax} \cdot S_i(t) + r(t) \quad (1)$$

$$B_i = c_{bid} \cdot (e_{bid1} + e_{bid2} \cdot Sp_i) \cdot S_i \quad (2)$$

$$EB_i = c_{bid} \cdot (e_{bid1} + e_{bid2} \cdot Sp_i) \cdot S_i + e_{br} \quad (3)$$

where: B_i - bid value of the i-th classifier, EB_i - effective bid value of the i-th classifier, Sp_i - specificity of the i-th classifier, S_i – strength of the i-th classifier, c_{bid} – investment coefficient (c_{bid}=0,1), e_{bid1}, e_{bid2} – coefficients of the classifier linear specificity function (e_{bid1}=0,65, e_{bid2}=0,35), e_{br} – random value generated with the use of a normal distribution generator, c_{tax} - turnover tax coefficient c_{tax}=001, r - coefficient of reward paid for the best classifier r=2.

The rule and message procedures perform the process of classifiers checking and evaluation, in aspect of using the information contained in them for solving the problematic situations. This allows for appointing of the group of classifiers containing the useful information on the searched post-fault network configuration.

To modifications of the evolutionary algorithm enabling solutions of multi-criteria tasks are counted among others the application of the co-evolutionary approach. Application of the co-evolutionary algorithm to the analysed task creates m population; in each of them the adaptation function is defined on the basis of another component quality indicator vector. After successive performance (population supplementation with new elements), and through renewed reproduction, these populations are connected, and then were again divided so that each population elements may attain an unlimited population. The sought-after solution is the Pareto-optimal collection of solutions.

To encode the individuals representing various network configuration variants in a form of a sparse graph, the bequest of chromosomes in the form of a vector of inversion has been assumed. Each component of the vector of inversion, corresponding to the number of the graph node, is equal to the number of the supplying node. A well-known roulette selection method on the remaining fractional part has been used as a selection method. Two specialised reconfiguration operators have been used in the algorithm to create new solutions (crossover probability pk=0,95, mutation probability pm=0,15). In the presented calculation method creating of new variants of the analysed problem solutions has been realised according to the following procedure:

1) selection of two network configuration variants from the current population (recorded in the vectors of inversion),
2) node selection from the list of nodes with no supply,
3) rewriting of the supply routes of the formerly selected node from the vector selected in step 1 to the auxiliary table,
4) roulette selection of the node from the created table,
5) rewriting of the further part of the supply route from the second vector, starting from the node selected in step 4, to the second of the selected vectors.

The aim of using of this kind of operator, creating new variants of distribution network configuration, was to examine the change variants effectiveness in the part of the networks close to the supply points, as well as in parts of the analysed network system affected by failures. The mutation operator enables to introduce the random changes into the network configuration, according to the following procedure:

1) selection of one variant of network configuration from the current population,
2) node selection from the list of nodes with no supply,
3) rewriting of the supply route for the node selected in step 2 from the network configuration selected in step 1 to the auxiliary table,
4) roulette selection of the node from the table created in the last step,
5) the neighbouring nodes, which are supplied, are considered (in relation to the node selected in step 4) and from among them one is roulette selected and its number is recorded in the vector (from step 1) as a number of the supplying node selected in step 4.

In order to obtain proper solutions following limiting constraints resulting from technical requirements for proper operation of the distribution network have been taken into account:

- not exceeding of the maximum transmission currents of the line sections,
- not exceeding of the allowable voltage drops in the network nodes supply routes,

On the base of the source data [18, 19] and own research following values of significant parameters of the calculation system have been assumed in the calculation procedures: number of classifiers n=200, crowding factor for classifier population cs=3.

Following criteria have been assumed substantial for the optimisation problem of post-fault network configuration:

- minimisation of the number of switching activities leading to obtaining a substitute network configuration:

$$\underset{j}{Min}\ u_1(X_j) = n_j - n_0 \quad \text{where } j = 1, 2, \ldots, m \tag{6}$$

where: Xj – vector containing information on the j-th variant of the distribution network configuration, m – number of solution variants, nj – number of switching activities, n0 - number of switching activities in the basic configuration.

- minimisation of the undelivered power value:

$$\underset{j}{Min}\,u_2(X_j) = \sum_{i=1}^{lw} P_{sr,i} \cdot q_i \cdot T_{p,i} \tag{7}$$

where: $P_{sr,i}$ - average active load of the i-th user node of the network, lw – number of nodes, qi - unreliability factor of the supply circuit of the i-th user node, Tp,i – operation time.

- minimisation of the voltage deviation in the network nodes:

$$\underset{j}{Min}\, u_3(X_j) = \max_i \left(\frac{U_i}{U_N} \cdot 100 \right) \tag{8}$$

where: U_N – distribution network nominal voltage, U_i – voltage value in the i-th user node of the network,

- minimisation of the power load degree coefficient of the found group of the most loaded network elements.

$$\underset{j}{Min}\ u_4(X_j) = \max_k \frac{\sum_{i=1}^{n} P_{\max,i}}{n} \tag{9}$$

where: k - the number of power supply route network nodes of the reception network, n - the number of the most heavily loaded network elements.

- minimisation of the technical losses in the distribution systems:
-

$$\underset{j}{Min}\, u_5(X_j) = \min\{\sum_{i=1}^{g} (\Delta P_i + k_e \cdot \Delta Q_i)\} \tag{5}$$

where: g – number of line section, Pi – loss of active power in i - this line section, Qi – loss of passive power in i- this line section, ke – passive power equivalent,

The assumed membership functions used for the main variables description have been defined as follows:

$$u_{fi}(X) = \begin{cases} 1, & if \quad f_i(X) \leq f_i^{min} \\ \left(\dfrac{f_i^{max} - f_i(X)}{f_i^{max} - f_i^{min}} \right), & if \quad f_i^{min} < f_i(X) \leq f_i^{max} \\ 0, & if \quad f_i^{max} < f_i(X) \end{cases} \tag{11}$$

III. CASE STUDIES

The pre-analysed calculation problem concerns the designation of the supply network configuration for the breakdown operations statuses of the network, arising from damaged network elements, their loading and also the exceeding of permissible voltage deviations in network line sections. The considered breakdown situation of the Medium Voltage electric power distribution network arising from damage to line number 6_8 coming from main station number 6 supplying distributors station number 8. In the presented graph (fig. 3) the filled nodes symbolise the main supplying points, whereas the bold branches symbolise the elements taking part in the load transfer.

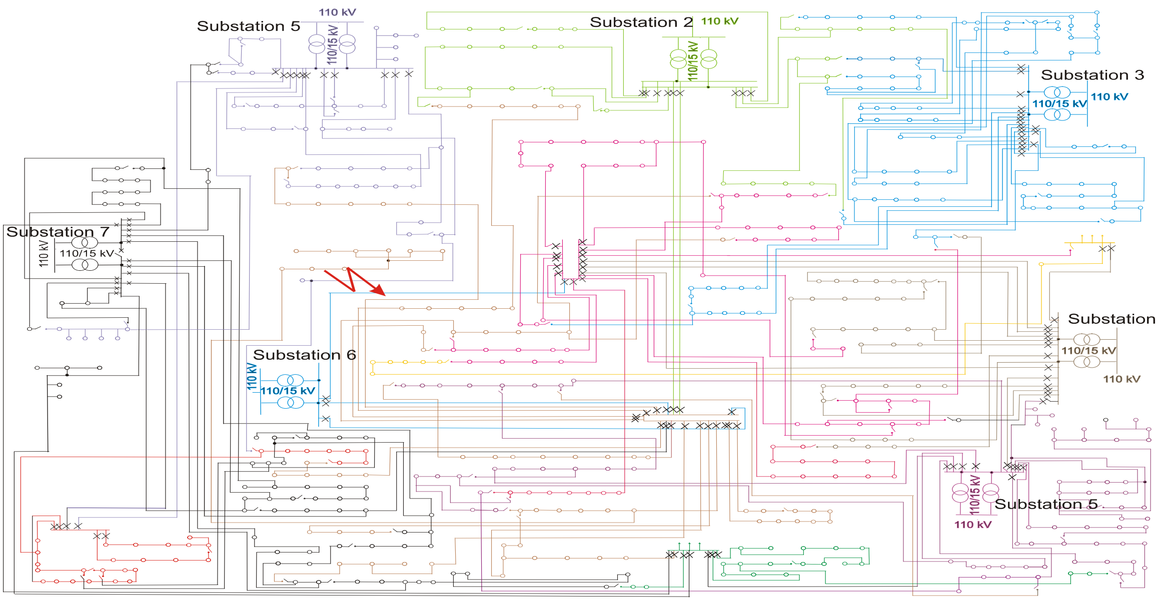

Fig. 3. Diagram of the analysed system of the medium voltage distribution network

For the below considered breakdown situation in the analysed network, which is composed of 556 network nodes the author accepted the abbreviated description of announcements and also classifiers. The abbreviated description however contains instead of the zero-one tract (part of the first announcement) the numbers of line sections deprived of power, whereas as part of the second announcement the numbers of damaged elements are given. In the elaborated calculation model a so-called vector of inversion has been used for the network configuration description. As a result of the accomplishment of the first stage of the process the announcement creation for the searched for classifiers is shown in table 1.

In the column relating to network configurations noted in the inversion vector only the initial and final elements of this vector are noted. According to the idea of classifying systems through the process of announcement creation, then follows the evaluation of the revealed classifiers, which consists of the calculation of the so-called offer of the classifiers being the measure of their suitability to resolve the analysed task. The offer for classifier number 1 (table 1) calculated according to dependencies 2 and 3 amounted appropriately to $B_1 = 0{,}919$ and $EB_1 = 0{,}904$. Whereas the offer for classifier number *2* amounted correspondingly to $B_2 = 0{,}939$ and $E_2 = 0{,}937$ and the offer for classifier number 3: $B_3 = 0{,}827$ and $E_3 = 0{,}840$.

As a result of the performance of the process of the creation and evaluation of announcements executed in the first stage, as the classifier with the best offer is defined as classifier number 1. This classifier served to create the announcement of the following stage of classifiers search. In the analysed case in the process performed in the second stage further classifiers were not sought for.

Table 1. Active classifiers

No	condition: (numbers of non-supplied nodes) and (numbers of fault elements)	answer of system (recorded in the vectors of inversion)	S_i – strength of the *i-th* classifier	Bid
1.	*(178, 179, 180, 181, 182, 177, 178) and (8_22)*	x,x,x,x,x,x,x,6,2,5,7,13,14,15,16,9,29 3,17,18,19,9,,57,9,59,60,450,5, ...	$S_1 = 10$	$B_1 = 0{,}919$ $EB_1 = 0{,}940$
2.	*(29, 73, 72, 71, 70, 69, 68) and (8_29)*	x,x,x,x,x,x,x,6,6,5,1,13,14,15,16,9,18 ,19,20,9,9,8,2,9,59,60,450,5,61,...	$S_2 = 10$	$B_2 = 0{,}939$ $EB_2 = 0{,}937$
3.	*(22, 23, 24, 25, 26) and (8_178)*	x,x,x,x,x,x,x,6,6,5,1,13,14,15,16,9,18 ,19,20,9,9,8,2,9,59,60,450,5,61,...	$S_3 = 10$	$B_2 = 0{,}827$ $EB_2 = 0{,}840$

As a result of the performance of the announcement creation process and the evaluation of active classifiers (table 2), information was obtained, which might be used to create a population (size 100÷120) of solution variants subsequently created by the co-evolutionary algorithm. This algorithm is based simultaneously on 5 subpopulations, from which each evaluation was the basis for another adaptation function (dependencies 6 to 10). The sought-after solution in this case is a collection of solutions in the form of alternative configurations of the analysed network. The choice of the final solution variant depends upon the decision maker decider, who in this instance may be the operator managing the operation of the electric power Medium Voltage distribution network.

The course of the process designating the best solutions in subpopulation no. 3 is shown in drawing 6. Cooperation of the co-evolutionary algorithm with the classification system enables significant reduction of time of obtainment of solutions (reduces the iterative calculation process on average by 40 %), which is significant from the practical point of view in the application of this method in current systems of distribution network operation management.

Figures 4b and 5b show the realisation of the calculation process, which used information for active classifiers. Information on the best solutions in subpopulations no. 3 and no. 4 is shown in graphic form on drawings 6 and 7. As a solution to the task of designating a substitute network configuration in the event of a breakdown of the analysed distribution network, obtained with the use of co-evolution algorithm the best solution variants is accepted from 5 subpopulations.

Table 2. Active classifiers after process evaluating

No	condition: (numbers of non-supplied nodes) and (numbers of fault elements)	answer of system (recorded in the vectors of inversion)	S_i – strength of the *i-th* classifier
1.	*(178, 179, 180, 181, 182, 177, 178) and (8_22)*	x,x,x,x,x,x,x,6,2,5,7,13,14,15,16,9,293,17,18, 19, ,55,56,57,9,59,60,450,5,...	$S_1=10+2$
2.	*(29, 73, 72, 71, 70, 69, 68) and (8_29)*	x,x,x,x,x,x,x,6,6,5,1,13,14,15,16,9,18,19,20,9, 9,856,57,9,59,60,450,5,61,...	$S_2=10+0,47$
3.	*(22, 23, 24, 25, 26) and (8_178)*	x,x,x,x,x,x,x,6,6,5,1,13,14,15,16,9,18,19,20,9, 9,856,57,9,59,60,450,5,61,...	$S_3=10+0,47$
...	...	...	...
4.	*(8,22,28,29,31,73,178,195,291,292,338,339,23,167,32,72,179,196,287,293,337,,,...) and (6_8)*	x,x,x,x,x,x,x,4,6,5,1,13,14,15,16,9,18,19,20,9, 9,856,57,9,59,60,450,5,61, ...	$S_4=10$

a) random generated initial population b) used information for active classifiers

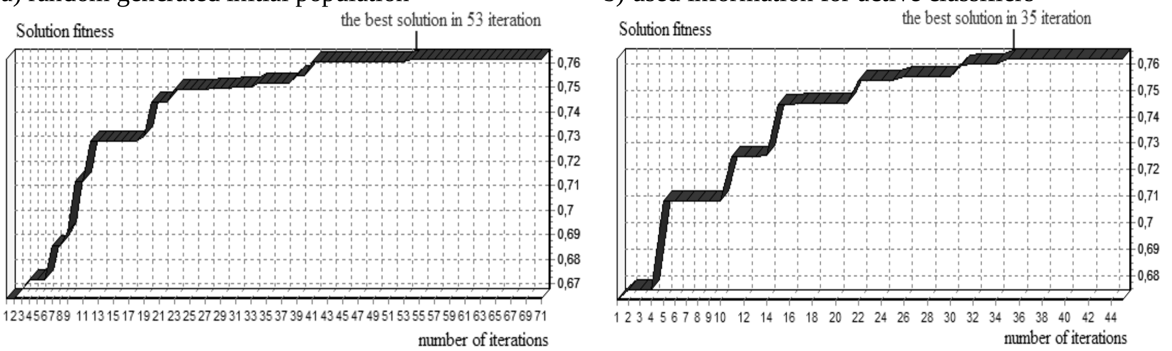

Fig. 4. Example of best solutions fitness waveform in subpopulation number 3

Information concerning the best obtained solutions is shown in table 3. In cooperation of the co-evolution algorithm with the classifying system after performance of the calculation process the best solutions obtained from particular subpopulations the solutions are written into the classifier collection.

a) random generated initial population b) used information for active classifiers

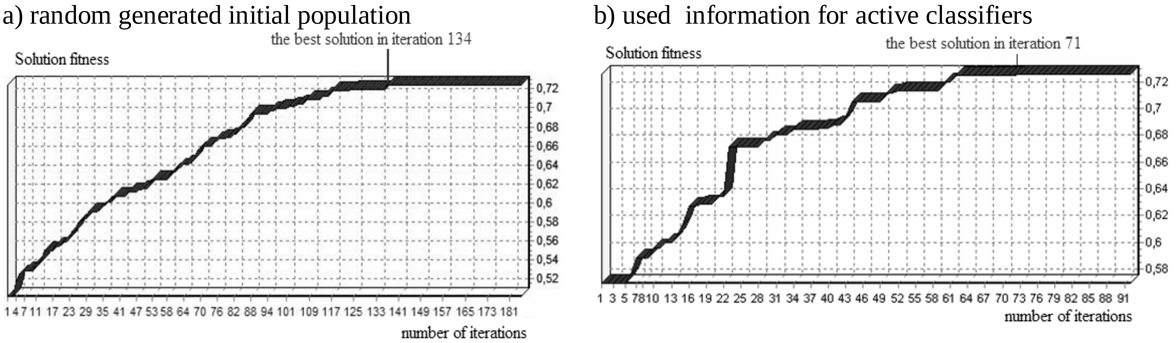

Fig. 5. Example of best solutions fitness waveform in subpopulation number 4

Table 3. Information concerning the best obtained solutions

No.	The value of the affiliation function of the best solution obtained in subpopulation
1	For the best obtained network configurations for criterion 1 the calculated affiliation function value amounted to: $\underline{\boldsymbol{u_1(x)=0,893}}$, additionally: $u_2(x) = 0,896$, $u_3(x) = 0,547$, (maximal voltage deviation 2,23%) $u_4(x) = 0,703$ (loading coefficient of the group of most heavily loaded elements in network: 0,669), $u_5(x) = 0,535$
2	For the best obtained network configurations for criterion 2: $\underline{\boldsymbol{u_2(x) = 0,998}}$ additionally: $u_1(x) = 0,571$, $u_3(x) = 0,752$, $u_4(x) = 0,686$, $u_5(x) = 0,667$
3	For the best obtained network configurations for criterion 3: $\underline{\boldsymbol{u_3(x) = 0,765}}$ additionally: $u_1(x) = 0,607$, $u_2(x) = 0,943$, $u_4(x) = 0,698$, $u_5(x)=0,670$
4	For the best obtained network configurations for criterion 4: $\underline{\boldsymbol{u_4(x) = 0,729}}$ additionally: $u_1(x) = 0,519$, $u_2(x) = 0,985$, $u_3(x) = 0,752$, $u_5(x) = 0,682$
5	For the best obtained network configurations for criterion 5: $\underline{\boldsymbol{u_5(x) = 0,740}}$ additionally: $u_1(x) = 0,521$, $u_2(x) = 0,790$, $u_3(x) = 0,734$, $u_4(x) = 0,569$

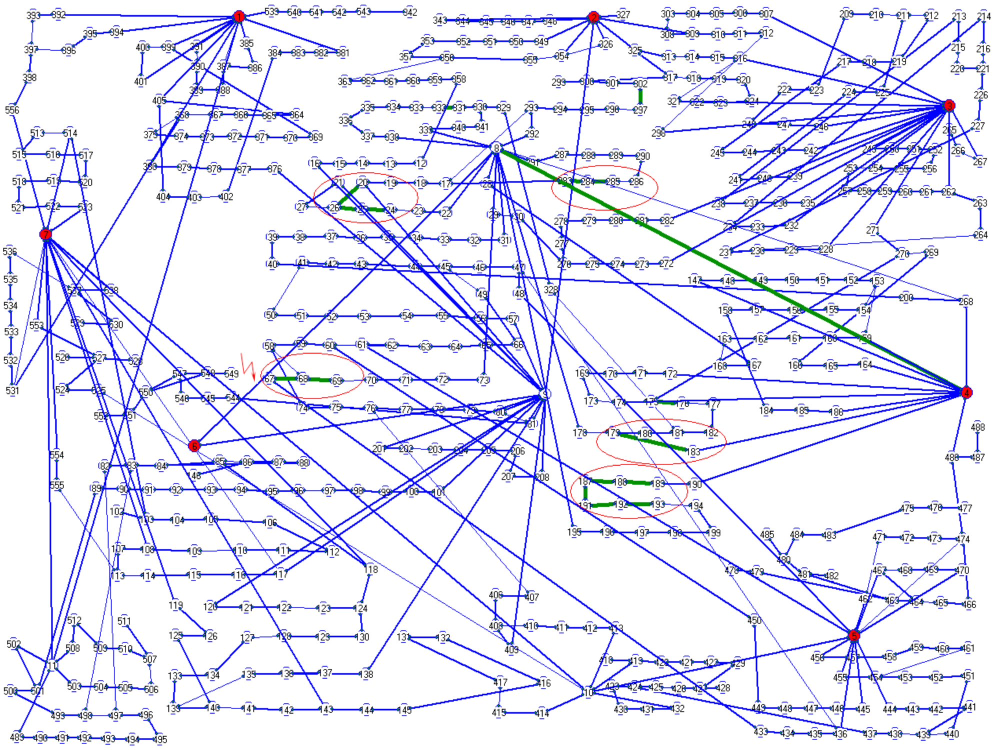

Fig. 6. Graph of the analysed distribution network with network configurations, being the best solution obtained in subpopulation3 (changes highlighted)

IV. CONCLUSION

This article describes the development of this type of calculation methods, simultaneously containing their own innovative solution proposals concerning the application of a classification system working with the co-evolutionary algorithm. The calculations performed for the mapped real system of the medium voltage municipal distribution network of 556 nodes have given satisfactory results, confirming the adequate direction of the research. On the base of the results obtained so far the authors assume that the results can be further used in creation of decisive procedures for complex power electric systems management, taking the fault operation states into special consideration. The method proposed by the author of the work is typified by the short time of designating the most rational post breakdown configurations in complex electric power Medium Voltage distribution network structures. It is the use by the classifying system working with the co-evolution algorithm that enables the effective creation of substitute scenarios for the Medium Voltage electric power distribution network. The method drawn up may be used in current systems managing the work of distribution networks to assist network operators in taking decisions concerning connection actions in supervised electric power systems

REFERENCES

[1] C. C. Liu, S. J. Lee, S. S. Venkata, An expert system operational aid for restoration and loss reduction of distribution system. *IEEE Trans. on Power Delivery*, vol. 3, 1988, pp. 619-629.

[2] Y. Y. Hsu, M. Huang, Distribution system service restoration using a heuristic search approach. *IEEE Trans. on Power Delivery*, vol. 7, 1992, pp. 734-740.

[3] Y. Fukuyama, H. D. Chiang, Parallel genetic algorithm for service restoration in electric power distribution systems. *Electric Power & Energy Systems*. vol. 18, no. 2, 1996, pp. 111-119.

[4] K. N. Miu, H. D. Chiang, B. Yuan, Fast service restoration for large-scale distribution systems with priority customers and constraints. *IEEE Trans. on Power Systems*, vol. 13. no. 3, Aug. 1998, pp. 789-795.

[5] A. L. Morelato, A. J. Monticelli, Heuristic search approach to distribution system restoration. *IEEE Trans. Power Delivery*, vol. 4, Oct. 1989, pp. 2235-2241.

[6] S. Wu. K. L. Tomsovic, C. S. Chen, A heuristic search approach to feeder switching operations for overload, faults, unbalanced flow and maintenance. *IEEE Trans. Power Delivery*. vol. 6. Oct. 1991, pp. 1579-1586.

[7] D. Shirmohammadi, Service restoration in distribution networks via network reconfiguration. *IEEE Trans. Power Delivery*, vol. 7, Apr. 1992, pp. 952-958.

[8] K. L. Butler, N. D. R. Sarma, R. Prasad, Network reconfiguration for service restoration in shipboard power distribution systems. *IEEE Trans. Power Systems*, vol. 16, Nov. 2001, pp. 653-661.

[9] Y. Hsiao, C. Chien, Enhancement of restoration service in distribution systems using a combination fuzzy-GA

method. IEEE Trans. Power Systems, vol. 15, Nov. 2000, pp. 1394-1400.
[10] S. Toune, H. Fudo, T. Genji, Y. Fukuyama, Comparative study of modern heuristic algorithms to service restoration in distribution systems. *IEEE Trans. Power Delivery*, vol. 17, Jan. 2002, pp. 173-181.
[11] C. Chao-Shun, C-H. Lin, T. Hung-Ying, A rule-based expert system with colored petri net models for distribution system service restoration. *IEEE Trans. Power Systems*, vol. 17, Nov. 2002, pp. 1073-1080.
[12] S. Khushalani, J.M. Solanki, N.N. Schulz, Optimized Restoration of Unbalanced Distribution Systems. *IEEE Transactions on Power Systems*, no. 22, Issue 2. 2007, p. 624-630.
[13] Y. Kumar, B. Das, J. Sharma, Multiobjective, Multiconstraint Service Restoration of Electric Power Distribution System With Priority Customers. *IEEE Transactions on Power Delivery*, no. 23, Issue 1, 2008, p. 261-270.
[14] A. C. B. Delbem, A. C. P. L. F. Carvalho, N. G. Bretas, Main chain representation for evolutionary algorithms applied to distribution system reconfiguration. *IEEE Trans. Power Systems*., vol. 20, no. 1, Feb. 2005, pp. 425-436.
[15] K. Nara, A. Shiose, M. Kitagawa, T. Ishihara, Implementation of genetic algorithm for distribution systems loss minimum reconfiguration. *IEEE Trans. Power Systems*, vol. 7, no. 3, Aug. 1992, pp. 1044-1051.
[16] L. Augugliaro, F. R. Sanseverino, Multiobjective service restoration in distribution networks using an evolutionary approach and fuzzy sets. *Elect. Power Energy Syst.*, vol.22, 2000, pp. 103-110.
[17] J. Stępień Z. Madej, Evaluation of structural redundancy efects in medium voltage cable networks. *Rynek Energii* No 4(83), 2009, pp. 55-62
[18] J. Stępień: Changes in demand structure of energy carriers with the use of waste heat and renewable energy. Rynek Energii Issue: 5, OCT 2008, p. 58-62
[19] J. Stępień, Evaluation of structural redundancy effects in medium voltage cable networks. *Przegląd Elektrotechniczny* Volume: 84 Issue: 4 2008, p. 128-131.
[20] S. Filipiak, Application of classifier system and co-evolutionary algorithm in optimisation of medium-voltage distribution networks post-fault configuration. *Electronics and Electrical Engineering*, 9(115), 2011, 9–15.