SELECTION OF OPTIMAL RESTORATION PLAN IN DISTRIBUTION SYSTEMS USING THE HYBRID FUZZY-GREY METHOD

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Abstract. This paper observes an algorithm for distribution systems restoration after the location of a fault has been isolated in a middle-voltage network. An approach to evaluate optimal restoration plan for power distribution systems using a hybrid fuzzy-grey method, is proposed in this paper. The proposed method consists of two stages: the fuzzy multi-criteria evaluation and the grey relational analysis. Fuzzy multi-criteria evaluation was adopted for dealing with imprecise linguistic descriptions in operators' heuristic rules, while the grey relational analysis was used to judge the ranking of preference for each possible restoration plan. The proposed method is applied on a typical distribution system in Nis. Based on calculation results, a variety of possible restoration plans are obtained and ranked according to optimal criteria.

Keywords: distribution system, restoration plan, fuzzy-gray method, criteria, constraints.

INTRODUCTION

The main restoration objective, after the faulted area has been isolated, is to quickly restore the electricity service as much as possible to the interrupted customers outside the faulted zone. Optimal restoration plan selection is a multi-criteria problem since one should, without violation of operative constraints, satisfy a number of criteria in order to reach an optimal restoration plan. Under conditions that will arise in an open and transparent energy market, even more attention will be dedicated to the optimal distribution system restoration. With constant growth of distribution network, system operators find it more and more difficult to select proper solution according to their operative experience. Thus, developing a method that will help operators obtain a satisfactory restoration plan is an imperative. For adequate restoration plan selection, based on various criteria, a number of methods can be used:

- Optimization methods,
- Heuristic methods,
- Expert systems and artificial intelligence,
- Probabilistic methods and methods based on the fuzzy approach.

Criteria function of the optimization method usually requires fulfilling of following demands: minimal loads in out-of-service area, minimal manipulation costs, balanced feeder loads, etc. Then, the following are usually used: mixed integer programming, network programming, or Branch and Bound method. A possibility to precisely define an objective and constraints is a good side of this method. On the other hand, not all aspects can be regarded because of a complex nature of the problem, which is the bad side of this method [1].

Heuristic methods select optimal restoration plan according to algorithms based on the knowledge of characteristics of the distribution network (radial system structure, protection concept, operative experience, etc.) [2]. These methods consider a combination of different methods: state estimation with load flow calculation in radial and weakly meshed networks, optimization methods and methods based on the fuzzy approach [3], [4] and [5]. These methods are more and more used because of their great efficiency, but still, have a lack that their application does not result in an exact optimal solution.
Expert system method uses a knowledge base, while artificial intelligence methods are based on genetic algorithms. These methods are usually used for breakdown estimation, and rarely for distribution system restoration. Another helpful usage of this method is for simulation and operator training.
Probabilistic methods and methods based on the fuzzy approach are based on a fact that a right load value is not known. For unknown value modelling (load reinstate after system service load recovery), the probability theory and random variable or the fuzzy approach are used. In the first case, unknown value is represented by a random variable and its distribution, while in the other, it is presented by a set of possible values [3] - [7].
In this paper, an optimal restoration plan is estimated using the fuzzy-grey relational analysis according to criteria and restraints that must be respected. It is assumed that the faulted zone has been identified and isolated. As criteria for optimal restoration plan selection the following are used: minimal number of switching operations, balanced feeder loads, minimization of maximal feeder load and feeder length optimization.

MATHEMATICAL MODEL

In this paper, the following are adopted as optimal criteria: minimization of switching operations number, minimization of maximal relative feeder loads, minimization of relative feeder loads unbalancing index and feeder length minimization. Besides these criteria, following operative constraints must be considered: no components can be overloaded and radial system structure must be maintained.
To form the mathematical model, a part of a distribution network with N branches and M nodes will be observed (distribution substation 10/0.4 kV/kV). The observed network part is fed by N_{FD} feeders. Feeders can spring from the same or different substations X/10 kV/kV. Maximal allowed current load for each feeder is known: $I_{Fk\max}$, $k=1,..,N_{FD}$. We will assume that feeder currents before fault are known I_{Fk} $k=1,..,N_{FD}$ and that there is enough power reserve in substations X/10 kV/kV. Network operative state is described with a switch state vector $\vec{X}$ ($X(i)=1$ if both switching devices at the start and at the end of the *i*-th feeder are on, $X(i)=0$ if only one of these switching devices is off.).

Objective functions

Objective functions that are considered in this approach are:
- Minimization of switching operations number $f_1(\vec{X})$

$$f_1(\vec{X})=\sum_{i=1}^{N} x_i \ , \tag{1}$$

where $f_1(\vec{X})$ presents a number of switching operations for network operative state described by vector $\vec{X}$, in regard to the initial state $\vec{X}_0$, while x_i is defined as follows:

$$x_i=\begin{cases}1, & \text{if operative state of the } i\text{-th branch is changed,}\\ 0, & \text{if operative state of the } i\text{-th branch is not changed.}\end{cases}$$

Minimal number of switching operations is wanted, so the impact on switches and operative cost could be reduced.

- Minimization of maximal relative feeder loads $f_2(\vec{X})$

$$f_2(\vec{X})=\max\{I_{Fk}/I_{Fk\max}\}\ , k=1, 2, ..., N_{FD}, \tag{2}$$

where $f_2(\vec{X})$ presents maximal relative feeder loads, while I_{Fk} presents a current of the *k*-th feeder after manipulation.

- Minimization of relative feeder loads unbalancing index $f_3(\vec{X})$

When all feeders are operative under the same level of relative load, distribution system is considered as an ideal state of balanced feeding. Percentage of ideal feeder load level $i_{F\,id}(\%)$ is defined as follows:

$$i_{F\,id}(\%) = \frac{\sum_{i=1}^{N_{FD}} I_{Fi}}{\sum_{i=1}^{N_{FD}} I_{Fi\max}} \cdot 100\,,$$

where $I_{Fi\max}$ presents maximal alowed feeder current, while I_{Fi} presents the *i*-th feeder load. Unbalanced feeder load index is, after manipulation, defined by the least-square formula:

$$f_3(X) = \sqrt{\sum_{i=1}^{N_{FD}} (i_{Fi}(\%) - i_{F\,id}(\%))^2}\,, \tag{3}$$

where $i_{Fi}(\%)$ presents percentage of the feeder load current Fi: $i_{Fi}(\%) = \frac{I_{Fi}}{I_{Fi\max}} \cdot 100$. Obviously, the less unbalanced feeder load index, the better system performance.

- Minimization of radial feeder length after manipulation $f_4(\vec{X})$

It can be easily concluded that some of these criteria conflict with each other. For example, criteria „fewer switching operations“ and „more balanced load“, respectively, may be in conflict with each other. Therefore, the work of restoration problem can be regarded as a multiple criteria decision-making problem with existence of operative constraints. Among the various restoration plans, we will try to use the proposed fuzzy-grey approach to develop a quantitative model for evaluating these plans.

THE FUZZY REASONING APPROACH

The fuzzy theory offers a mathematically formulated method for handling the imprecise information. A fuzzy set is a mapping of a set of real numbers onto membership values that lie in the range [0, 1]. An element of a fuzzy set is an ordered pair containing a set element and the degree of membership in the fuzzy set. Higher membership value implies greater satisfaction. Heuristic rules and past experience are important to system operators when selecting a proper restoration plan. Since the heuristic rule expressions usually involve linguistic terms, it is useful to apply the fuzzy set theory in order to effectively capture such linguistic and heuristic knowledge.

In the restoration guidelines, the restoration plan is considered more preferable if it involves “fewer” switching operations and “better” load balances. Obviously, the vague terms “fewer” and “better” are very imprecise in nature and can be conveniently handled by the fuzzy set theory.

The proposed fuzzy multi-criteria evaluation consists of a basic rule, membership functions, and an conclusion procedure. The basic rule is formed with fuzzy rules based on the operators’ knowledge. These rules, which describe relationships in a linguistic sense, are written as pairs of “IF-THEN” statements. The fuzzy rules are expressed in following forms:

IF $f_i(\vec{X})$ is Low, THEN the plan is Good.

IF $f_i(\vec{X})$ is Moderate, THEN the plan is Moderate.

IF $f_i(\vec{X})$ is High, THEN the plan is Bad.

In the previous section, all values of objective functions $f_i(\vec{X})$ are described using three fuzzy sets: Low, Moderate and High. The related membership functions are shown in Fig. 1.

Consequently, the fuzzy sets Good, Moderate and Bad are clearly defined as 1, 0.5 and 0, respectively. This can simplify the computation process and completely satisfy study’s needs.

In the inference procedure, the real value of each objective function is firstly calculated to get the boundary values in fuzzy IF-THEN rules. Consequently, the weighted average described in (4) is applied in order to obtain real values:

$$f_i^* = \frac{\sum_{j=1}^{N_F} \mu_j y_j}{\sum_{j=1}^{N_F} \mu_j}, \tag{4}$$

where μ_j and y_j are boundary value and fuzzy result in the j-th fuzzy rule, respectively. N_F presents a number of fuzzy rules. The values of f_i^* represent the fitness degree of objective functions f_i for each restoration plan.

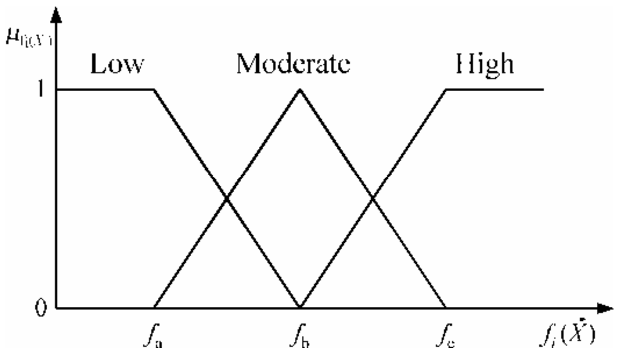

Fig. 1. Fuzzy numbers which represent linguistic variables

As an example, number of manipulations will be reviewed, i.e. that $f_i(\vec{X}) = f_1(\vec{X})$. Assuming that the number of manipulations is 4 and $f_{1a}(\vec{X}) = 1$, $f_{1b}(\vec{X}) = 5$ and $f_{1c}(\vec{X}) = 9$, it is shown that fuzzy values are: Low = 0.25, Moderate = 0.75 and High = 0. These values can be easily reached, considering Fig.2. In order to more clearly illustrate the process of rule evaluation, we will rewrite the related rules as below:

F1: IF $f_1(\vec{X})$ is Low, THEN the plan is Good.

F2: IF $f_1(\vec{X})$ is Moderate, THEN the plan is Moderate.

F3: IF $f_1(\vec{X})$ is High, THEN the plan is Bad.

The rule values F1, F2 and F3 will be 0.25, 0.75 and 0, respectively. After computing the fuzzy rules, we will need to use (4) to translate these results into real values. The weighted average method is used to accomplish the task. Since the singleton values for Good, Moderate and Bad are 1, 0.5 and 0, the corresponding defuzzified value will be $\frac{0.25 \cdot 1 + 0.75 \cdot 0.5 + 0 \cdot 0}{0.25 + 0.75 + 0}$ or 0.625.

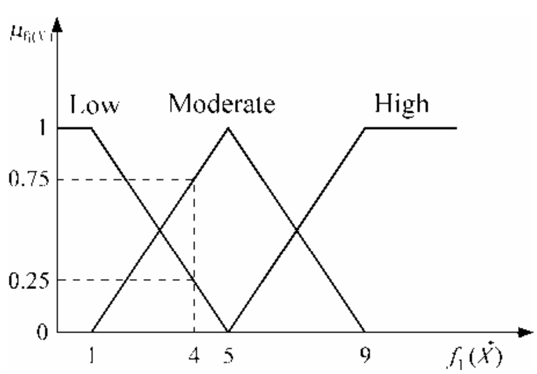

Fig. 2. Linguistic description of manipulation number

GREY RELATIONAL ANALYSIS

The grey system theory was first initiated by Prof. Deng in 1982. The grey relational analysis (GRA) is an important approach of grey system theory in the application of evaluating a set of alternatives in terms of decision criteria. In GRA, the data that contain same features are regarded as sequence. As a tool of quantitative analysis, the GRA can be used to measure the relationship between two sequences by calculating their correlative degrees, which is called grey relational grade (GRG). The GRG is expressed by a scalar between 0 and 1. Up to now, the method has been successfully applied in many fields and has attracted many researchers who will continue exploring this study. The principal formulas of the GRA are briefly described in further text.

Considering a reference sequence $x_0=(x_0(1), x_0(2), ..., x_0(n))$ and m comparative sequences $x_i=(x_i(1), x_i(2), ..., x_i(n))$, $i= 1, 2, ..., m$, where $x_i(k)$ represents the k-th entry in x_i, $k=1, 2,..., n$. The grey relational coefficient (GRC) of x_i with respect to x_0 in k-th entry, is as follows:

$$\gamma(x_0(k), x_i(k)) \equiv \frac{\Delta_{\max} - \Delta_{0i}(k)}{\Delta_{\max} - \Delta_{\min}}, \tag{5}$$

where

$$\Delta_{\max} \equiv \max_{\forall i} \max_{\forall k} \left| x_0(k) - x_i(k) \right|, \tag{6}$$

$$\Delta_{\min} \equiv \min_{\forall i} \min_{\forall k} \left| x_0(k) - x_i(k) \right|, \tag{7}$$

$$\Delta_{0i}(k) \equiv \left| x_0(k) - x_i(k) \right|. \tag{8}$$

The GRGs between each comparative sequence x_i and the reference sequence x_0 can be derived from the average of the GRC, which is denoted as:

$$\Gamma_{0i} = \sum_{k=1}^{n} \frac{1}{n} \gamma(x_0(k), x_i(k)), \tag{9}$$

where Γ_{0i} represents the degree of relation between each comparative sequence and the reference sequence. The higher degree of relation means that the comparative sequence is more similar to the reference sequence then comparative sequences.

We can use the grey relational measure to find out the similarity between each comparative sequence and the reference sequence formed by the selected ideal objective function if each restoration plan is described with its objective function and if it is regarded as the comparative sequence. Therefore, the GRG represents the preference degree for each restoration plan.

In the second stage of the proposed approach, the GRA is used to measure the preference degree for all possible restoration plans.

PROGRAM ALGORITHM FOR RESTORATION PLAN SELECTION

The steps of the proposed fuzzy-grey approach used to rank each restoration plan and choose a satisfactory plan are:

Step 1. Select a network part to be restored from data base elements and operative grid state.

Step 2. Generate a set of all switch state vectors (altogether 2^n restoration plans).

Step 3. Generate all possible restoration plans by dealing with the on/off status of switches according to operation constraints. If none of the restoration plans does not satisfy the criteria, go to Step 1 and select bigger network part or decide which consumers will remain powerless.

Step 4. Use (1) – (4) to compute the values of objective functions of all possible restoration plans derived from Step 1.

Step 5. Use the fuzzy multi-criteria computation to evaluate the fitness degree of the objective functions for each restoration plan.

Step 6. Use the proposed GRA model to calculate the preference index of each feasible plan.

Step 7. Rank the restoration plans in preference order according to their GRGs.

In Step 3., selection of possible restoration plans is done as follows:

- Eliminate all restoration plans which have number of engaged branches N_u different then the number of nodes M (if N_u<M, then all nodes are not fed; if N_u>M, then configuration is not radial).
- For remaining plans check the radial condition, and if it's fulfilled, feeder currents are evaluated.
- Eliminate configurations in which some feeder load is bigger then maximal allowed for that feeder.

TEST EXAMPLE

The proposed method is applied on real distribution system part shown in Fig. 3. The network consists of 21 branches and 17 nodes (distribution substations) which are fed from two substations 35/10 kV/kV by 5 feeders. In Fig. 3. branch numbers are shown, feeder lengths in kilometres and rated power values of the transformers in kVA, while "x" signifies tripped switching devices in 10kV cells in distribution substations because of the maintenance of radial system structure. In Table 1 maximal allowed feeder loads and feeder loads before appearance of the fault are shown. The most unfavourable case from restoration point of view is a fault on some of the feeders in the period of great loads when the remaining feeders must take all of the load from the faulted feeder. Thus, it is assumed that the fault appears on a branch 13 and, therefore, 5 distribution substations remain powerless after isolating the faulted branch.

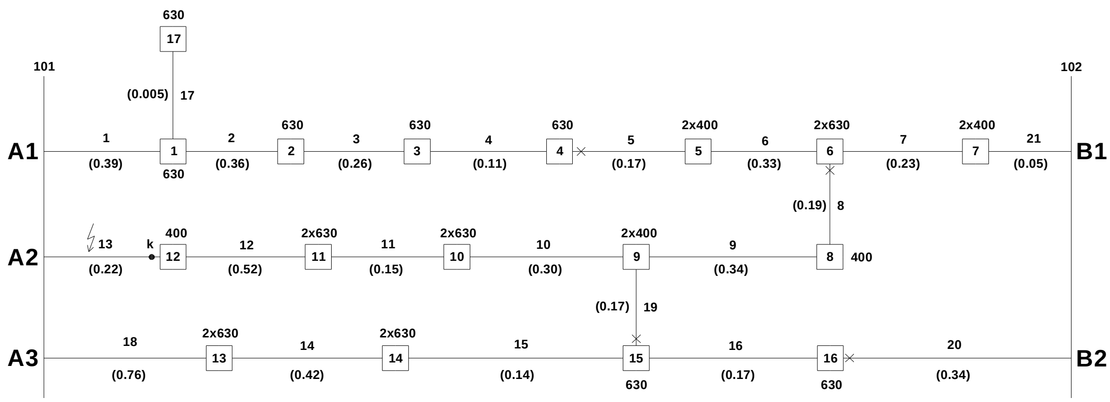

Fig. 3. Distribution system model

TABLE 1 - Maximal allowed 10 kV feeder loads and feeder loads before appearance of the fault

Feeder	A1	A2	A3	B1	B2
$I_{Fi\,max}$ [A]	265	235	274	225	265
I_{Fi} [A]	182	209.59	198	115.56	0

TABLE 2 - Feeder currents and total feeder lengths for different restoration plans

Restoration plan	Switch state vector	Feeder current [A]				Total length [km]			
		A1	A3	B1	B2	A1	A3	B1	B2
1	[011111101111010111111]	0	102.4	223.67	238.05	0	1.18	1.99	1.475
2	[011111110111010111111]	0	102.4	208.88	252.84	0	1.18	1.65	1.665
3	[101111101111010111111]	58.24	102.4	223.67	179.81	0.395	1.18	1.99	1.11
4	[101111110111010111111]	58.24	102.4	208.88	194.6	0.395	1.18	1.65	1.3
5	[110111101111010111111]	87.36	102.4	223.67	150.69	0.755	1.18	1.99	0.85
6	[110111110111010111111]	87.36	102.4	208.88	165.48	0.755	1.18	1.65	1.04
7	[111011101111010111111]	116.48	102.4	223.67	121.57	1.015	1.18	1.99	0.74
8	[111011110111010111111]	116.48	102.4	208.88	136.36	1.015	1.18	1.65	0.93
9	[111101101111010111111]	145.6	102.4	223.67	92.45	1.125	1.18	1.99	0.57
10	[111101110111010111111]	145.6	102.4	208.88	107.24	1.125	1.18	1.65	0.76
11	[111101111111001111011]	145.6	52	106.4	260.12	1.125	0.76	0.65	2.07
12	[111101111111010111011]	145.6	102.4	56	260.12	1.125	1.18	0.51	2.07
13	[111101111111011011011]	145.6	130.4	28	260.12	1.125	1.32	0.34	2.07
14	[111101111111011110011]	145.6	0	158.4	260.12	1.125	0	1.07	2.07
15	[111110101111010111111]	171.44	102.4	223.67	66.61	1.295	1.18	1.99	0.24
16	[111110110111010111111]	171.44	102.4	208.88	81.4	1.295	1.18	1.65	0.43
17	[111110111111001111011]	171.44	52	106.4	234.28	1.295	0.76	0.65	1.74
18	[111110111111010011111]	171.44	102.4	28	262.28	1.295	1.18	0.34	1.91
19	[111110111111010111011]	171.44	102.4	56	234.28	1.295	1.18	0.51	1.74
20	[111110111111011011011]	171.44	130.4	28	234.28	1.295	1.32	0.34	1.74
21	[111110111111011110011]	171.44	0	158.4	234.28	1.295	1.07	1.74	0
22	[111111001111010111111]	212.21	102.4	223.67	25.84	1.625	1.18	1.99	0.01
23	[111111010111010111111]	227	102.4	208.88	25.84	1.815	1.18	1.65	0.01
24	[111111101111010111110]	238.05	102.4	223.67	0	1.855	1.18	1.99	0
25	[111111110111010111110]	252.84	102.4	208.88	0	2.045	1.18	1.65	0

Characteristic values of fuzzy numbers for selected objective functions are:

1) Minimization of switching operations number f_1 ($f_{1\mathrm{a}} = 1$, $f_{1\mathrm{b}} = 5$ and $f_{1\mathrm{c}} = 9$),

2) Minimization of maximal relative feeder loads f_2 ($f_{2\mathrm{a}} = 90\%$, $f_{2\mathrm{b}} = 95\%$ and $f_{2\mathrm{c}} = 100\%$),

3) Minimization of relative feeder loads balancing index f_3 ($f_{3\mathrm{a}} = 20$, $f_{3\mathrm{b}} = 60$ and $f_{3\mathrm{c}} = 100$),

4) Minimization of radial feeder length f_4 ($f_{4\mathrm{a}} = 1.5\,\mathrm{km}$, $f_{4\mathrm{b}} = 1.9\,\mathrm{km}$ and $f_{4\mathrm{c}} = 2.3\,\mathrm{km}$).

Switch state vectors that fit all practical network configurations after restoration are presented in Table 2. Besides that, expected values of feeder currents and total feeder lengths for each restoration plan are also given in this table. Current values are attained by rated transformer powers and operative network state.

TABLE 3 - Objective function values and corresponding weighted averages

Restoration plan	f_1	f_2 [%]	f_3 [%]	f_4 [km]	f_1^*	f_2^*	f_3^*	f_4^*
1	5	99.41	95.29	1.99	0.50	0.059	0.3875	0.059
2	7	95.41	94.55	1.66	0.25	0.459	0.7937	0.068
3	5	99.41	78.09	1.99	0.50	0.059	0.3875	0.274
4	7	92.83	75.57	1.65	0.25	0.716	0.8125	0.305
5	5	99.41	73.01	1.99	0.50	0.059	0.3875	0.337
6	7	92.83	69.44	1.65	0.25	0.716	0.8125	0.382
7	5	99.41	71.04	1.99	0.50	0.059	0.3875	0.362
8	7	92.83	66.45	1.65	0.25	0.716	0.8125	0.419
9	3	99.41	72.43	1.99	0.75	0.059	0.3875	0.345
10	5	92.83	67.02	1.65	0.50	0.716	0.8125	0.412
11	3	98.16	75.02	2.07	0.75	0.184	0.2875	0.312
12	3	98.16	73.52	2.07	0.75	0.184	0.2875	0.331
13	3	98.16	77.51	2.07	0.75	0.184	0.2875	0.281
14	3	98.16	87.29	2.07	0.75	0.184	0.2875	0.159
15	5	99.41	76.34	1.99	0.50	0.059	0.3875	0.296
16	7	92.83	70.46	1.65	0.25	0.716	0.8125	0.369
17	5	88.41	70.54	1.74	0.50	1.00	0.70	0.368
18	7	98.97	80.23	1.91	0.25	0.103	0.4875	0.247
19	5	88.41	68.94	1.74	0.50	1.00	0.70	0.388
20	5	88.41	73.18	1.74	0.50	1.00	0.70	0.335
21	5	88.41	83.47	1.74	0.50	1.00	0.70	0.207
22	5	99.41	86.71	1.99	0.50	0.059	0.3875	0.166
23	7	92.83	85.25	1.81	0.25	0.716	0.6062	0.184
24	5	99.41	95.29	1.99	0.50	0.059	0.3875	0.059
25	7	95.41	94.55	2.045	0.25	0.459	0.3187	0.068

TABLE 4 – Restoration plans sequence ranked by optimality

Sequence	Γ_{0i}	Switching operations	Restoration plan
1	0.8954	000011010000001000010	19
2	0.8901	000011010000010000010	17
3	0.8813	000011010000000100010	20
4	0.8563	000000011000001000110	10
5	0.8472	000011010000000001010	21
6	0.7918	000110011000001000110	8
7	0.7819	001010011000001000110	6
8	0.7785	000011011000001000110	16
9	0.7615	010010011000001000110	4
10	0.6746	000010111000001000110	23
11	0.6251	100010011000001000110	2
12	0.6203	000000010000001000010	12
13	0.6172	000000000000001000110	9
14	0.6153	000000010000010000010	11
15	0.6070	000000010000000100010	13
16	0.5745	000000010000000001010	14
17	0.5554	000110000000001000110	7
18	0.5489	001010000000001000110	5
19	0.5378	000011000000001000110	15
20	0.5320	010010000000001000110	3
21	0.5034	000010100000001000110	22
22	0.4989	000010011000001000111	25
23	0.4966	000011010000001100110	18
24	0.4749	100010000000001000110	1
25	0.4749	000010000000001000111	24

Table 3 presents objective function values for each restoration plan, as well as corresponding weighted averages attained by defuzzification. In Table 4 restoration plans are ranked according to the degree of relation Γ_{0i}. Plans with higher value of Γ_{0i} can be regarded as better.

As it can be seen, optimal plan is number 19, and it is necessary to execute following switching operations. Branches 5, 8 and 20 are switched on, and branches 6 and 15 are switched off. Forming of restoration plan list has an advantage because it enables system operator to make the final decision. If system operator estimates based on his operative experience that, for example, manipulation with some switching device is not safe, he can choose the next suitable restoration plan.

CONCLUSIONS

Rapid restoration and fast return to a normal operating condition after a distribution system fault has become increasingly critical. In this paper, the fuzzy-grey analysis approach is proposed to obtain a satisfactory restoration plan for distribution system restoration. With a proposed method, the system operators can easily make a right decision. This method considers numerous criteria and simply calculates quantitative evaluation of restoration plan optimality. Thereby, a sequence of restoration plans is received, starting from the best toward the worse, whereby it is enabled for the system operator to select the most adequate restoration plan according to multiple criteria and his operating experience. Proposed algorithm is a very rapid and effective one.

LIST OF REFERENCES

1. D. Popović, D. Bekut, V. Treskavica, Specialized DMS algorithms, DMS group, Novi Sad, 2004. (in Serbian)
2. Hsu Y and all, 1992, “Distribution system service restoration using a heuristic search approach”, IEEE Trans. Power Del., Vol. 7, No. 2, pp. 734-780, April.
3. Hsu Y Y and Kuo H C, “A heuristic based fuzzy reasoning approach for distribution system service restoration”, IEEE Transactions on Power Delivery, Vol. 9, No. 2 April 1994.
4. Q. Zhou, D. Shirmohammadi and W.H Edwin Liu, “Distribution Feeder Reconfiguration For Service Restoration And Load Balancing, IEEE Transactions on Power Systems, Vol. 12, No. 2, May 1997.
5. J. Rodrigo A. Rodriguez and Alberto Vargas, “Fuzzy Heuristic Methodology to Estimate the Load Restoration Time in MV Networks”, IEEE Transactions on Power Systems, Vol. 20, No. 2, May 2005.
6. W.H. Chen, M.S. Tsai and H.L. Kuo, “Distribution System Restoration Using the Hybrid Fuzzy-Grey Method”, IEEE Transactions on Power Systems, Vol. 20, No. 1, February 2005.
7. D. Popović and Ž. Popović, “A Risk Management Procedure for Supply Restoration in Distribution Networks”, IEEE Transactions on Power Systems, Vol. 19, No. 1, February 2004.