Information Technology Reengineering of the Electricity Generation System in Post-disaster Recovery

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Abstract. The paper considers situations of the impact of various natural disasters on the electricity generating system as part of the energy system of a city or region. The impact of natural disasters in large part change the electricity consumption patterns, which makes it necessary not only to restore the power supply system, but also to conduct a complete review of its operation (reengineering). The paper discusses information technologies that provide a procedure for the reengineering of the electric power system when it is restored after an aggressive external influence, for example, a natural disaster.

Keywords: Information technologies · Natural disasters · Reengineering · Assessing risks · Electricity generation system

1 The Role of Electric Power System

Despite the fact that the humanity has developed various technologies and ability to influence significantly the natural processes, it remains rather vulnerable to aggressive impact of the environment. Natural disaster has become the synonym of inevitable destruction connected with threats to human life, damages to infrastructure and capital goods. Currently, apart from natural, man-made disasters pose a significant threat too, they may affect large regions as well as our planet as a whole, causing the destruction of the biosphere.

A worldwide movement 'Earth Hour' may be used as an example of the population's total dependence on power supply. In 2019 more than 2 billion people in 188 countries of the world took part in this movement [1]. During this hour, the economic activity stops and the social activity drops considerably. Here we talk about an arranged and planned action lasting just one hour once a year. When something like this happens unexpectedly as a result of a natural disaster or accident, the sole fact of electric power lack may become a disaster.

The electric power supply is one of the first life support systems to be repaired. Power supply assures the functioning of various devices, household appliances, technological processes and production. There are various natural disaster consequences for

Published by Springer Nature Switzerland AG 2020
Y. Murayama et al. (Eds.): ITDRR 2019, IFIP AICT 575, pp. 9–20, 2020.
https://doi.org/10.1007/978-3-030-48939-7_2

the electric power systems, including power line breaks and considerable damage to power generating elements.

2 Specifics of Natural Disaster Consequences

Let us define an electric power system as a network of power generating stations of varied capacity, electric substations (transformers of varying types, capacity and voltage), transmission lines of varying voltage and customers with varying consumption levels. Figure 1 presents a layout of an electric power system with power generating stations depicted as circles with a lightning inside, their size corresponds to the amount of electric power that can be produced. A black circle represents a substation (step-down substation), which lowers the transmission line voltage of hundreds of thousands volt to tens of thousands volt and distributes it to potential consumers. A white circle represents a substation (step-down substation), which lowers the voltage of tens of thousands volt to a level suitable for consumption and distributes it to specific consumers. Grey zones represent consumers: production and residential areas, etc. Black lines are transmission lines (Fig. 2).

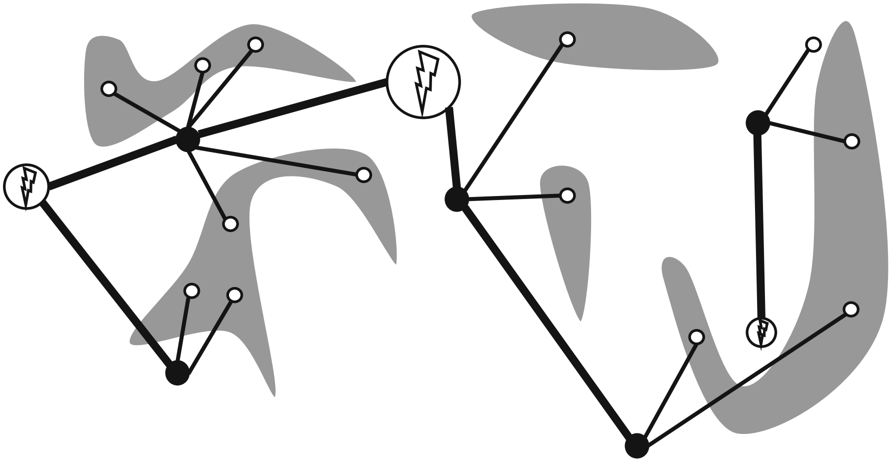

Fig. 1. Layout of an electric power system of a region

Figure 3 shows the objects that are out of order or destroyed, they are marked with a cross. Dashed lines represent power line breaks. Moreover, Fig. 3 shows the consumption areas, which were completely destroyed in comparison to the system's initial state (Fig. 1), they are also marked with dashed lines (Fig. 4).

An important characteristic is also changes to the topology of electric power consumption in the aftermath of a natural disaster. Some changes emerge directly, some after a certain period of time. This may be due to a number of factors such as:

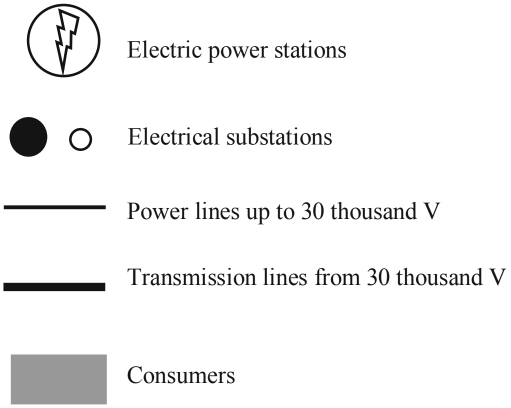

Fig. 2. Figure 1 legend

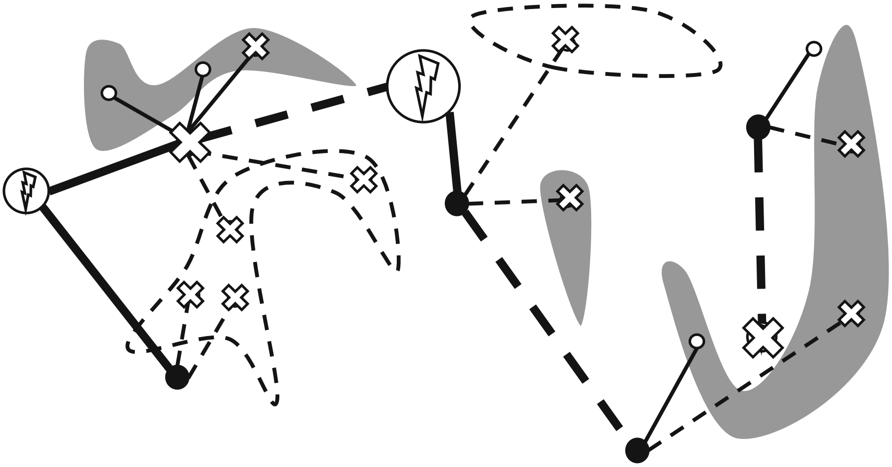

Fig. 3. Example of natural disaster consequences for a region's electric power system

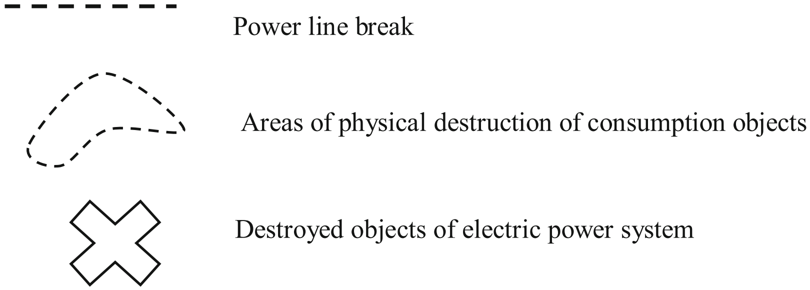

Fig. 4. Figure 3 legend

- physical destruction of objects consuming electricity (production lines, residential areas), reconstruction of which is time-consuming and challenging;
- changes to infrastructure resulting in hindered raw materials and product delivery logistics;
- short- and long-term relocation of population and production facilities, etc.

Figure 5 shows an example of changes to electricity consumption topology. Marked with the dashed line are the initial consumption areas (Fig. 1), grey areas are the supposed emerging consumption areas.

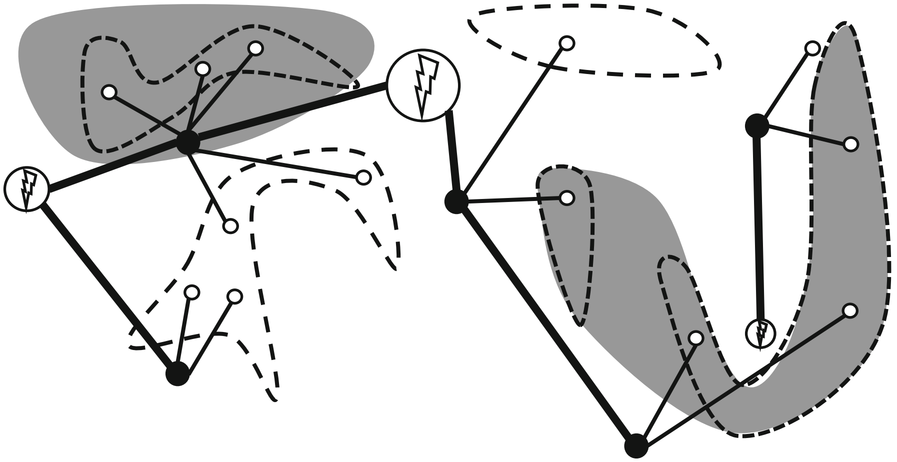

Fig. 5. Layout of changes to electricity consumption topology after a natural disaster

In case of minor damages, the main task is to assure reconstruction measures, which may be taken by public utilities, private maintenance companies or consumers themselves.

In case of complete destructions, the main task is to develop the system from scratch.

Most often, natural disasters cause partial damage to the system, putting some of its elements out of function.

3 Problem Statement

In any country of the world electric power systems wear out and require constant modernisation. Modern societies regularly develop new requirements for the sustainability of electric power systems (“green” energy) [2]. Such systems are, as a rule, large-scale and of high importance for both consumers and the state as a whole. Thus, power system modernisation strategy is to be based on the modelling results of the expected capacity of power generation and its consumption levels. An example of a poorly-planned modernisation process is Australia in 2019, where nearly 200 000 people suffered from rolling blackouts. Australian Minister for Energy Liliana D'Ambrosio stated that the loss of power capacity happened primarily due to the complete close-down of three coal power stations and reduced production on the remaining ones [3]. The power stations were closed within the context of improving sustainability of power production (reduction of CO_2 and sulphur oxide emissions in the process of coal burning). In other words, the abovementioned blackouts in Australia were not caused by an emergency or a man-made disaster, nevertheless, poorly-managed modelling of energy consumption process caused considerable damage.

Under such conditions, the problem of reengineering (redesign of an electric power system considering the damage, emerging technologies and estimations of consumption levels) reads as follows:

Let us suppose, there is an electric power system (Fig. 1). As a result of a natural or a man-made disaster the station was partially damaged (Fig. 3), it has to be restored or modernised.

An electric power system includes:

- sources of electric power production of varying capacity – these may be large and small, fixed and mobile, nuclear, thermal, solar, wind and other power stations;
- electric power transmission system – transmission lines, step-up and step-down substations;
- end consumers;

It is necessary to design a new power station based on the elements of the old power station that will correspond to the estimated changes in the power consumption topology.

- As a rule, the following issues require solutions:
- Which power stations require what kind of modernisation?
- Where should extra power units be located?
- Where should new power stations be located?
- What part of infrastructure should be elaborated and in which area?
- There may also be the task of electric power exchange with other regions (trade, seasonal and daily transmissions).

When it comes to electric power system reengineering, the following aspects should be taken into consideration [4]:

- technologies constantly develop and progress, the issue of their obsolescence emerges almost directly after the completion of construction or modernisation, therefore an important question to answer is whether modernisation is generally appropriate. New technologies have to bring positive effects, corresponding to their costs and outperforming the use of previous technologies. Thus, the decision on replacement or modernisation of obsolete equipment should be taken based on the complex analysis of its costs and effect;
- the scale of electric power systems is so large that even for the strongest economies it is hardly possible to finance the modernisation of the whole system at once;
- electric power systems are large, extensive and operating systems that are of high importance for the economic and social processes of the population. Electric power

outages may lead to accidents and disasters, therefore, the reengineering project has to enable constant electric power delivery;

- equipment amortisation and maintenance measures – any kind of equipment wears out and requires maintenance, therefore after a certain period of time it has to be withdrawn. This has to be taken into account when modernising parts of the electric power systems;
- the need for electric power demand estimations – although the level of power consumption increases, the geography of its demand constantly changes, it may both expand and scale down in a particular region. Therefore, decision on the start of the construction or modernisation has to be taken following the comprehensive modelling based on the estimated changes to demand and development of the region.

Due to the abovementioned difficulties, the reengineering of the electric power systems is as a rule limited to the replacement of the outdated, obsolete or defect equipment. A major incident, such as a natural disaster, may create the space required for a proper electric power system reengineering [5, 6].

As a result, elaborating a project that corresponds to the new operating conditions.

4 Algorithm of the Electric Power System Reengineering

1. Gathering data on the initial state of the power system (Fig. 1). This type of data should be gathered in advance. Apart from the actual information, various action plans in case of a natural disaster have to be elaborated.
2. Gathering data on the operability of the power system elements in the aftermath of a natural disaster (Fig. 3). This type of data is gathered in the immediate aftermath of a natural disaster. It may come from witnesses, unmanned aircrafts, satellites and automatic integrity testers.
3. Forecasting the topology of consumption development (Fig. 5). Estimations may be based on the factual transfer of consumers (production relocation, population resettlement) or on similar situations.
4. Clustering the consumption areas in order to determine approximate installation locations of current and prospective substations (Fig. 6). In order to assure efficient clustering and installation of new power substations, it is necessary to set a variety of parameters, some of them may be determined prior to the natural disaster with the help of modelling.
5. Developing a new electric power station with certain restrictions (Fig. 7).

Specifics of electric power system reengineering [7]:

1. In order decide on the better topology for the power system reengineering, it is required to specify the acceptable solution space.
2. Using the multi-criteria decision-making approach.
3. Optimisation criteria used to develop the system may be defined as the length of power lines, general consumer capacity, general power transmission losses and costs.

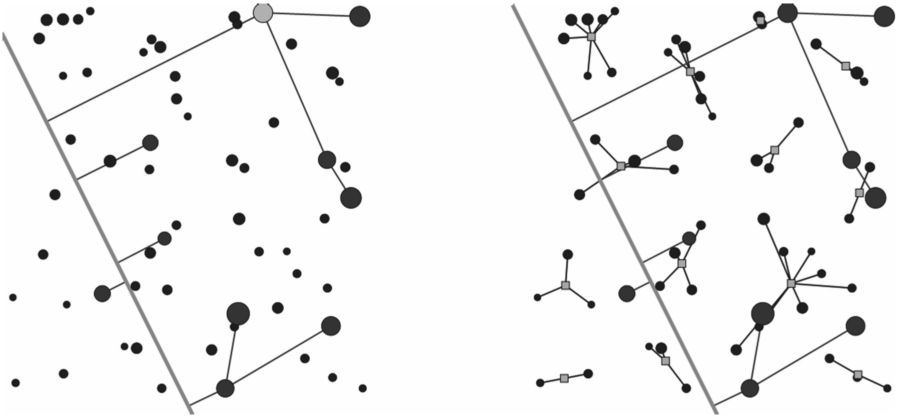

Fig. 6. Example clustering the consumption areas

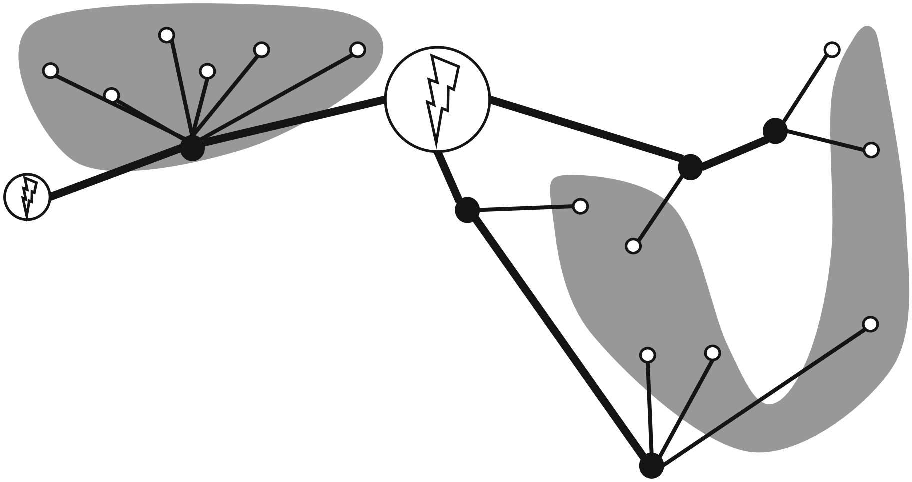

Fig. 7. Example a new electric power station with certain restrictions

4. It will be rational to apply comprehensive criteria compiling all power network efficiency factors.

5 Specifying Feasible Area

Social-economic approach presumes structurisation and detailed description of each of the electric power system element as a set of three constraints. Necessary is to be able to assess the state of the power system in order to compare possible alternative reengineering projects and make a decision on the realisation sequence, which will assure the required values [8]. Thus, the state of the electric power system is determined by the set of characteristics (1).

$$P_C = P_1 \cup P_2 \cup P_3, \tag{1}$$

with P_C as the set of electric power system characteristics; P_1, P_2, P_3 as the tuple of characteristics of the electric power system economic, social and ecological effect.

A variety of the electric power system characteristics may be described as follows:

$$P_i = \langle p_{i,j} \rangle, \tag{2}$$

with $i = \overline{1,3}$ as the number of the limitation block for the electric power systems (economic, social and ecological), and $j = \overline{1,n}$ as the number of the local characteristic of the i-th block.

When applying the limitations to the set of the possible alternatives D, there are three emerging subsets: $S_{P1} \subseteq D$, resulting from the limitations of the economic block P_1; $S_{P2} \subseteq D$, resulting from the limitations of the social block P_2; and $S_{P3} \subseteq D$, resulting from the limitations of the ecological block P_3.

The intersection of the three subsets produces the set of admissible states (feasible area) D^D (3) (Fig. 8).

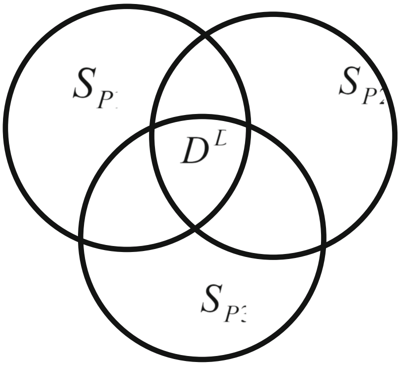

Fig. 8. Schematic representation of determining the admissible value space

$$D^D = S_{P1} \cap S_{P2} \cap S_{P3}. \tag{3}$$

Under the set of possible values (D) we understand any state of the electric power system that can be characterised by the maximum interval of parameter change. This means that these parameters are not limited and define the space of the electric power system's unconditional existence. However, in real-world conditions not all parameter values are admissible due to financial and economic, technical, moral and ethical, social, ecological and other reasons. This results in the necessity to determine the set (space) of admissible parameter values (states) in every single case separately.

The admissible state space (D^D) (3) of any specific electric power system is determined by the limitations of all critical characteristics set in the form of systems of equations or inequations defining certain multivariate space. This means that any admissible state of the socio-economic system may be presented in the form of a point in the space of admissible states.

Defining the admissible space of the socio-economic system states means that all critical characteristics of the electric power system $\langle h_{i,j} \rangle$ (2) have the following limitations

$$p_{i,j}^{L} \leq p_{i,j} \leq p_{i,j}^{U};$$
$$p_{i,j} = p_{i,j}^{P}, \tag{4}$$

with L, U, P as the corresponding indices of the lowest, highest and admissible values of local characteristics of the electric power system state.

Each of the inequalities or Eqs. (4) defines a local limit, and taken as a set they define a certain area in the n-dimensional space of characteristics. This does not exclude the possibility of uniting several characteristics into functionally related groups. Such interpretation presents the state of every separate electric power system as a multivariate point in the admissible functioning space. Then, the shortest distance from the point showing the state of the system to the limit of the admissible space may be interpreted as a the quantitative index of the system's sustainability. Every local characteristic defines a certain limit of the admissible space, and their functionally related group defines a certain fragment of the limit of the admissible space. Then, the distance from this fragment of the limit to the point of the actual state of the system characterises social, economic, ecological or any other stability of the system.

Given the abovementioned, the formula to determine the characteristic of the electric power system's stability margin based on any local characteristic is in natural indicators and reads as follows

$$\Delta p_{ij} = p_{ij}^{R} - p_{ij}^{B}, \tag{5}$$

with B, R as correspondingly border and real values of the characteristic. In relative indicators it reads as follows

$$U_{ij} = \frac{|\Delta p_{ij}|}{p_{ij}^{U} - p_{ij}^{L}} \cdot 100\%. \tag{6}$$

Sustainability estimations of a functionally related group of indicators are more difficult to make. In this case, it is suggested to estimate the sustainability according to the following non-dimensional indicator

$$U_i = \sum_{j=1}^{n} a_{ij} p_{ij}^{N}, \tag{7}$$

with a_i as the non-dimensional indicators of relative importance of i-th characteristic provided that $0 \le a_{ij} \le 1$, $\sum_{j=1}^{n} a_{ij} = 1$; and p_{ij}^{N} as the normalised value of i-th local electric power system characteristic.

The following conditions must be met for normalised local characteristics: dimensionlessness; limitedness, same interval of possible values [0,1]; invariance in regard to the direction of dominance (min, max); non-negativity.

All the abovementioned requirements are met in the following normalisation model [9]

$$p_{ij}^{N} = \frac{\left| p_{ij}^{R} - p_{ij}^{B} \right|}{p_{ij}^{U} - p_{ij}^{L}} = \frac{\left| \Delta p_{ij} \right|}{p_{ij}^{U} - p_{ij}^{L}}. \tag{8}$$

a_i value is determined by either expert judgement or comparator identification. Sustainability indicator U ranges between [0, 1] and directly characterises stability margin of the socio-economic system based on any group of parameters or as a whole.

The DTW (dynamic time warping) algorithm, enabling analysis and comparison of number sequences, may be used to determine the correlations, analyse the dynamics of electric power consumption and make prognoses [10].

6 Normalization of Criteria Values

If there is no possibility to evaluate one or several variables in cash equivalent, it is then only possible to compare the alternatives and choose the one with the highest efficiency rate. The task of comparing alternative reengineering projects may be reduced to the task of making summarised assessment in the process of multivariate assessment.

The particular circumstances of multivariate assessment are the values lying in the initial informational measuring basis, which have varying semantics and correspondingly varying physical dimensions, interval of possible values, scales of measurement and directions of dominance. This means that all factors included in the model of scalar multivariate assessment have to appear in the normalised form [11]:

$$P(z) = P(\Lambda, K(z)), \tag{11}$$

with $P(z)$ as the summarised scalar assessment; P as the operator defining the structure of the assessment model; $\Lambda = \langle \lambda_t \rangle$, $t = \overline{1, T}$ as the tuple of the normalisation coefficients; $K = \langle k_t \rangle$, $t = \overline{1, T}$ as the tuple of heterogeneous factors.

A more convenient and universal form of the model (11) is the normalised one

$$P(z) = P(A, K^N(z)),$$

with $A = \langle a_t \rangle$, $t = \overline{1, T}$ as the tuple of non-dimensional weighting coefficients of the relative importance of local factors; and $K^N = \left\langle k_t^N \right\rangle$, $t = \overline{1, T}$ as the tuple of normalised local factors.

A tuple requires the following conditions

$$0 \leq a_i \leq 1, \sum_{i=1}^{n} a_i = 1.$$

7 Conclusions

- In the aftermath of natural disasters it is recommended to organise electric power system reengineering instead of reconstruction measures
- Natural disasters may cause shifting of electricity consumption topology
- Electric power system reengineering is a complex multi-step process, its main objective is to redevelop the system so that it corresponds to the new requirements
- We used social-economic approach to specify the acceptable value space as well as mathematical tools of multi-criteria decision-making
- Social-economic approach has proven to assure a sustainable solution

References

1. Earth hour 60+. Earth hour infographic, https://www.earthhour.org. Accessed 09 Dec 2019
2. Midillia, A., Dincerb, I., Ay, M.: Green energy strategies for sustainable development. Energy Policy **34**, 3623–3633 (2006)
3. IA REGNUM. In Australia, tens of thousands of people were left without electricity due to the heat. https://regnum.ru/news/2560864.html. Accessed 09 Dec 2019
4. Hammer, M., Champy, J.: Reengineering the Corporation: A Manifesto for Business Revolution. Harper Business, Manhattan (1993). 223 p.
5. Grebennik, I., Khriapkin, O., Ovezgeldyyev, A., Pisklakova, V., Urniaieva, I.: The concept of a regional information-analytical system for emergency situations. In: Murayama, Y., Velev, D., Zlateva, P. (eds.) ITDRR 2017. IAICT, vol. 516, pp. 55–66. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-18293-9_6
6. Grebennik, I., Reshetnik, V., Ovezgeldyyev, A., Ivanov, V., Urniaieva, I.: Strategy of effective decision-making in planning and elimination of consequences of emergency situations. In: Murayama, Y., Velev, D., Zlateva, P. (eds.) ITDRR 2018. IAICT, vol. 550, pp. 66–75. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-32169-7_6
7. King, T., El-Hawary, M., El-Hawary, F.: Optimal environmental dispatching of electric power systems via an improved Hopfield neural network model. IEEE Trans. Power Syst. **10** (3), 1559–1565 (1995)

8. Jech, T.: Set Theory. Springer, Heidelberg (2006). https://doi.org/10.1007/3-7643-7692-9
9. Dasgupta, A.: Set Theory: With an Introduction to Real Point Sets. Springer, New York (2014). https://doi.org/10.1007/978-1-4614-8854-5
10. Nechiporenko, A., Gubarenko, E., Gubarenko, M.: Authentication of users of mobile devices by their motor reactions. Telecommun. Radio Eng. **78**, 987–1003 (2019)
11. Tzeng, G.-H., Huang, J.J.: Multiple Attribute Decision Making: Methods and Applications. CRC Press Taylor & Francis Group, Boca Raton (2011)