The implementation of the evolutionary algorithm for optimization of power flow in the high-voltage transmission lines

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Abstract: The paper discusses the possibility of using a computational technique based on evolutionary algorithms in the domain of electro-energetic systems. The purpose of the evolutionary algorithm is to calculate the optimal power flow in high-voltage transmission lines, so as to keep the power of transmission losses as low as possible. The effectiveness of the computational technique based on the evolutionary algorithm is tested by using the example of a hypothetical electro-energetic system, which is composed of several high-voltage lines that operate at different voltage levels. The aim of the evolutionary algorithm is to chose the values of active power that should be transmitted by each high-voltage line in order to minimize the power of transmission losses. The evolutionary algorithm implements the coding system of feasible solutions, which is based directly on real numbers. The only genetic operation that was used during the realization of the evolutionary algorithm was the operation of mutation. Moreover, for the purpose of evaluation of obtained solutions a special form of the fitness function based on penalty factors was constructed, which allowed the evolutionary algorithm to find solutions with the minimal values of transmission losses.

Keywords: electro-energetic systems, optimization of the power flow in high-voltage transmission lines, minimizing the power of transmission losses, evolutionary algorithms

1. Introduction

The aim of the article is to demonstrate that a computational technique based on evolutionary algorithms can be effectively used for the optimization of the active power flow in high-voltage transmission lines. Nowadays evolutionary algorithms are commonly known as an effective and efficient optimization method that can be used in solving optimization problems that arise in many kinds of technical systems [1, 5, 7, 8]. Moreover, evolutionary algorithms can be used to model different phenomena that can be encountered both in natural and artificial systems [2, 4, 6, 10]. In the literature there are numerous examples of successful implementation of evolutionary algorithms in the domain of electrical engineering and electro-energetic systems [9]. For example, evolutionary algorithms can be used for generating the optimal plans of production of electrical energy by distributing the load among different energetic blocks of power plants. In the case of thermal power units evolutionary algorithms can be applied in order to achieve the reduction of the amount of burnt fuel, and thus to lower the emission of pollution and carbon dioxide. A computational technique based on evolutionary algorithms can also be used for scheduling the work of water power plants by indicating the suitable time periods for generating electrical energy using the amounts of water that were stored earlier in huge water reservoirs. Evolutionary algorithms can also be used for the purpose of optimization of the mode of work of pumped-storage power plants that can store electrical energy during the periods of low energy demand by pumping the water into an upper water reservoir. In the case of such systems electrical energy is recovered during the periods of high energy demand. Evolutionary algorithms are able to calculate the amount of water that should be pumped into the upper water reservoir and also to indicate the scheme of pumping and generating mode of work of a hydropower plant, so that the cost of storing electrical energy would be as low as possible [3].

In the article we propose to use the computational technique based on evolutionary algorithms for the purpose of optimizing the power flow in high-voltage transmission lines in such a manner that the transmission energy losses should be minimized. For this aim an experimental electro-energetic system is proposed, in which several transmission lines operate at different voltage levels. The purpose of implementing evolutionary algorithms is to calculate such a scheme of the power flow in high-voltage transmission lines that could guarantee the minimal power of losses in the above-mentioned transmission lines.

2. Specification of the experimental system

Let there be given an electro-energetic system with the topology such as depicted in fig. 1. As can be seen, the entire electro-energetic system is fed with one high-voltage transmission line operating at the voltage level of 750 kV. This transmission line is denoted in fig. 1 by the symbol (9). Further the voltage level is lowered in the transformer station 750/400 kV, which in fig. 1 is denoted by the symbol F, and energy is transmitted by two high-voltage lines denoted by the symbols (7) and (8) that operate at the voltage level of 400 kV. These lines are connected to the 400/220 kV transformer stations that are denoted in fig. 1 by the symbols D and E. Consequently, electrical energy is transmitted by six 220 kV high-voltage lines that are denoted in fig. 1 by the symbols (1), (2), (3), (4), (5) and (6). Moreover, there are three 220/110 kV transformer stations that are denoted in fig. 1 by the symbols A, B and C. These 220/110 kV transformer stations

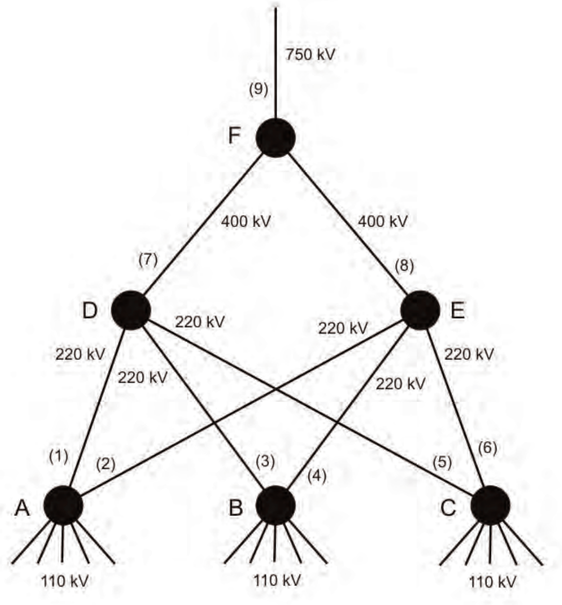

Fig. 1. The topology of high-voltage transmission lines of the experimental electro-energetic system

Ry. 1. Topologia linii przesyłowych wysokiego napięcia przyjęta w przypadku eksperymentalnego systemu elektroenergetycznego

are the main distribution nodes through which electrical energy is delivered to the 110 kV distribution network.

Let us assume that the demand for electrical active power is known for any of the three main distribution nodes, denoted by P_A, P_B, and P_C respectively. The question arises how electrical power should be transmitted by the 220 kV and 400 kV high-voltage lines so as to keep the transmission losses as low as possible. To answer this question, first let us calculate the power of losses in a high-voltage transition line, which is given by the following formula

$$P_L = 3i^2R \tag{1}$$

where i is a current in a phase-wire and R is the resistance of that phase-wire.

The resistance of a phase-wire can be calculated by the following formula

$$R = \rho\frac{l}{S} \tag{2}$$

where ρ is the electrical resistivity of a phase-wire, l is the length of a phase-wire, and S is the area of cross-section of a phase-wire.

Moreover, the apparent power transmitted through the high-voltage line is given by the following formula

$$S = \sqrt{3}ui \tag{3}$$

where u is the voltage level under which the transmission line operates, and i is a current of a phase-wire. The active power transmitted by that high-voltage line is given by the following formula

$$P = S\cos\varphi \tag{4}$$

where φ is the angle of the phase shift between the voltage and current harmonic functions.

Considering the above, the power of losses in a high-voltage transmission line can be calculated by the following formula

$$P_L = \left(\frac{P}{u\cos\varphi}\right)^2 \rho\frac{l}{S} \tag{5}$$

In order to minimize the power of losses in high-voltage transmission lines we implemented an evolutionary algorithm to find the optimal values of active power transmitted in each high-voltage line, which are denoted as P_1, P_2, P_3, P_4, P_5, P_6, P_7 and P_8.

3. Implementation of the evolutionary algorithm

In order to implement the computational technique based on evolutionary algorithms two things must be determined at the beginning. The first is the mode of coding the solutions on the genotypes of the individuals. The second is the proper form of the fitness function.

For the sake of effective realization of numerical experiments the real number coding was implemented. The values of active powers that were transmitted by each high-voltage line were coded on the genotype of each individual. The genotype of each individual was composed of eight genes, which were used for coding the active powers P_1, P_2, P_3, P_4, P_5, P_6, P_7 and P_8 that are transmitted by high-voltage lines (1), (2), (3), (4), (5), (6), (7) and (8).

The fitness function is formed by several components and is given by the following formula

$$\begin{aligned} f = &\left(P_1 + P_2 - P_A\right)^2 + \left(P_3 + P_4 - P_B\right)^2 + \left(P_5 + P_6 - P_C\right)^2 + \\ &\left(P_1 + P_3 + P_5 - P_7\right)^2 + \left(P_2 + P_4 + P_6 - P_8\right)^2 + \\ &P_{L1} + P_{L2} + P_{L3} + P_{L4} + P_{L5} + P_{L6} + P_{L7} + P_{L8} \end{aligned} \tag{6}$$

The fitness function has a character of a penalty function. The first component is related to the active power balance of the node A. The second is related to the active power balance of the node B. The third is related to the active power balance of the node C. The forth is related to the active power balance of the node D, and the fifth is related to the active power balance of the node E. In the ideal case, all these active power balances should be equal to zero. The other component of the fitness functions is the sum of powers of losses P_{L1}, P_{L2}, P_{L3}, P_{L4}, P_{L5}, P_{L6}, P_{L7} and P_{L8} in high voltage lines. The objective is that the sum of powers of losses should be as low as possible.

For the sake of numerical experiments the following numerical values of system's parameters were assumed.

The demand of active power in the distribution nodes A, B and C:

P_A = 340 MW,
P_B = 420 MW,
P_A = 370 MW.

The length of high-voltage transmission lines:

$l_1 = 280$ km,
$l_2 = 200$ km,
$l_3 = 180$ km,
$l_4 = 160$ km,
$l_5 = 190$ km,
$l_6 = 220$ km,
$l_7 = 380$ km,
$l_8 = 330$ km.

The area of cross-section of wires of high-voltage transmission lines:

$S_1 = 280$ mm^2,
$S_2 = 400$ mm^2,
$S_3 = 320$ mm^2,
$S_4 = 360$ mm^2,
$S_5 = 460$ mm^2,
$S_6 = 420$ mm^2,
$S_7 = 760$ mm^2,
$S_8 = 600$ mm^2.

The electrical resistivity of wires of all high-voltage transmission lines was assumed as:

$$\rho = 2{,}82 \cdot 10^{-8} \Omega \cdot m.$$

Moreover, the coefficient of reactive power was assumed to be of the same value for all high-voltage transmission lines:

$$\cos\varphi = 0{,}95.$$

4. Results of numerical simulations

In order to demonstrate that the computational technique based on evolutionary algorithms can be effectively used to minimize the power of losses in high-voltage transmission lines we created an initial population that in further steps underwent genetic operations of mutation and selection. The population was composed of 100 individuals and that number of individuals did not change during the realization of the evolutionary algorithm, so the size of the population was constant during the whole time of evolutionary computations. The population of the first generation of the evolutionary algorithm was initialized randomly in such a manner that the values of active powers that were coded on the genotypes of the individuals, with random numbers from the interval (100 MW, 300 MW).

The results of evolutionary computations were obtained after the elapse of 10 million of generations of the evolutionary algorithm. The values of active powers transmitted by the high-voltage lines are presented below:

$P_1 = 121{,}1$ MW,
$P_2 = 218{,}8$ MW,
$P_3 = 198{,}7$ MW,
$P_4 = 221{,}2$ MW,
$P_5 = 167{,}5$ MW,
$P_6 = 202{,}4$ MW,
$P_7 = 487{,}4$ MW,
$P_8 = 642{,}5$ MW.

Below there are also given the powers of transmission losses:

$P_{L1} = 9{,}4$ MW,
$P_{L2} = 15{,}4$ MW,
$P_{L3} = 14{,}3$ MW,
$P_{L4} = 14{,}0$ MW,
$P_{L5} = 7{,}4$ MW,
$P_{L6} = 13{,}8$ MW,
$P_{L7} = 23{,}2$ MW,
$P_{L8} = 44{,}3$ MW.

Fig. 2 presents how the results, obtained with the use of the computational technique based on evolutionary algorithms, were changing during the generations of the evolutionary algorithm. Fig. 2 shows eight plots of active powers P1, P2, P3, P4, P5, P6, P7 and P8 that were transmitted via the high-voltage lines (1)–(8), depending on the number of generations of the evolutionary algorithm. The number of generations is given in thousands of generations. As can be seen from the plots in fig. 2, the solutions that were obtained in consecutive generations of the evolutionary algorithm approached asymptotically the optimal values of active power transmitted by the high-voltage lines. The obtained solutions begin to stabilize for the number of generations of the evolutionary algorithm greater than 2 million.

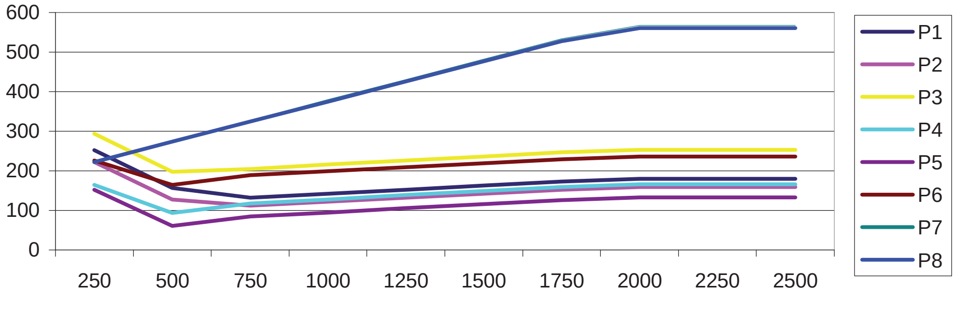

Fig. 2. The plots showing how the results obtained with the use of the evolutionary algorithm were changing during the different numbers of generations of the evolutionary algorithm

Rys. 2. Wykres ilustrujący rezultaty stosowania algorytmu ewolucyjnego w funkcji liczby osobników poszczególnych pokoleń

5. Conclusions

In the paper we demonstrated that the computational technique based on evolutionary algorithms can be effectively used in the domain of electro-energetic systems. The implementation of the evolutionary algorithm allowed to find the optimal values of active powers transmitted by high-voltage lines. The obtained results are optimal in the sense that they can guarantee that the powers of transmission losses are as low as possible.

Further research in this domain will concentrate on the development of a graphic user interface through the medium of which the user will be able to define the arbitrary topology of an electro-energetic system with any number of power stations of different types, any number of high-voltage transmission lines operating at different voltage levels, and any number of power distribution nodes. In the case of such a system, the genetic material of the evolving population would be generated automatically on the basis of the electro-energetic system topology that was defined by the user via the graphic interface.

Further development of the system will also concentrate on the generation of optimal plans of electrical energy production. In this case pumped-storage power stations will be taken into account for the purpose of storing the energy. The aim of the evolutionary algorithm will be to create the work schedule of pumped-storage power stations, so as to minimize the costs of production of electrical energy in the 24-hour time horizon.

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Zastosowanie algorytmu ewolucyjnego w celu minimalizacji mocy strat przesyłowych w liniach wysokich napięć

W artykule rozważono możliwości wykorzystania techniki obliczeniowej opartej na algorytmach ewolucyjnych w obszarze elektroenergetyki. Zadaniem algorytmu ewolucyjnego było wyznaczenie optymalnego rozpływu mocy w elektroenergetycznych liniach przesyłowych pod kątem minimalizacji termicznych strat przesyłowych. Efektywność technik obliczeniowych opartych na algorytmach ewolucyjnych została przetestowana na przykładzie hipotetycznego systemu elektroenergetycznego złożonego z kilku linii przesyłowych pracujących na różnych poziomach napięć. Zadaniem algorytmu ewolucyjnego było dobranie wartości mocy czynnych, które miały być przesyłane przez każdą z linii, pod kątem minimalizacji mocy strat przesyłowych. W przypadku rozważanego algorytmu ewolucyjnego zastosowano system kodowania oparty bezpośrednio na liczbach rzeczywistych. Jedynym operatorem genetycznym, który został wykorzystany, był operator mutacji. Ponadto na potrzeby dokonywania skutecznej oceny jakości poszczególnych rozwiązań opracowana została specjalna postać funkcji dopasowania zawierająca czynnik kary, co pozwoliło algorytmowi ewolucyjnemu na znajdowanie rozwiązań charakteryzujących się minimalnymi wartościami mocy strat przesyłowych.

Słowa kluczowe: systemy elektroenergetyczne, optymalizacja rozpływu mocy w liniach wysokich napięć, minimalizacja mocy strat przesyłowych, algorytmy ewolucyjne

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