Ryszard SZCZEBIOT[1], Sławomir CIEŚLIK[2]

State College of Computer Science and Business Administration in Łomża (1)
University of Technology and Life Sciences, Bydgoszcz (2)

Application of genetic algorithm for optimal placement of wind generators in the MV power grid

Abstract*. The paper presents a modelling method of optimal connection of wind generators to a medium voltage (MV) power grid taking into account minimum active power losses. A genetic algorithm was applied to optimize active power losses in the power grid.*

Streszczenie. *W Pracy przedstawiono metodę modelowania optymalnego podłączenia elektrowni wiatrowych do sieci elektroenergetycznych średniego napięcia. Minimalizowano straty mocy czynnej w sieci stosując w tym celu algorytm genetyczny. (**Zastosowanie algorytmu genetycznego do optymalnego rozmieszczenia turbozespołów wiatrowych w elektroenergetycznej sieci średniego napięcia**)*

Keywords: genetic algorithm, wind generators, power grid.
Słowa kluczowe: algorytmy genetyczne, elektrownie wiatrowe, sieci elektroenergetyczne.

Introduction

Due to a great interest in connecting wind generators into medium voltage power grids, a current problem arises of using the existing power grid infrastructure in an optimal way. In this case it is reasonable to consider two optimization aspects:

− operating optimization of the existing power generating units (or their possible reconstruction),
− or, optimal placement of power generating units to be installed at specific places.

The former problem was presented in paper [1], the latter is considered below.

The paper presents an example of an optimal solution of placing wind generators over a specific area using a method based on a genetic algorithm. The area analyzed encompasses a surface of 81 square kilometers including the existing medium voltage infrastructure. Figure 1 presents a topological segment of a medium voltage power grid where a connection of wind generators is planned.

The aim of the optimization procedure is to determine the connection nodes for wind generators characterized by specific rate powers in such a way as to obtain minimum power losses in the analyzed segment. The planned objective should be reached considering the following limitations: admissible voltage levels in the connection nodes, long-term and short circuit loads in the analyzed power grid, transformer loads in 110/15kV stations, short circuit power in the nodes and specific levels parameters of the quality of electric energy. We should also take into account the limitations arising due to environmental and location conditions.

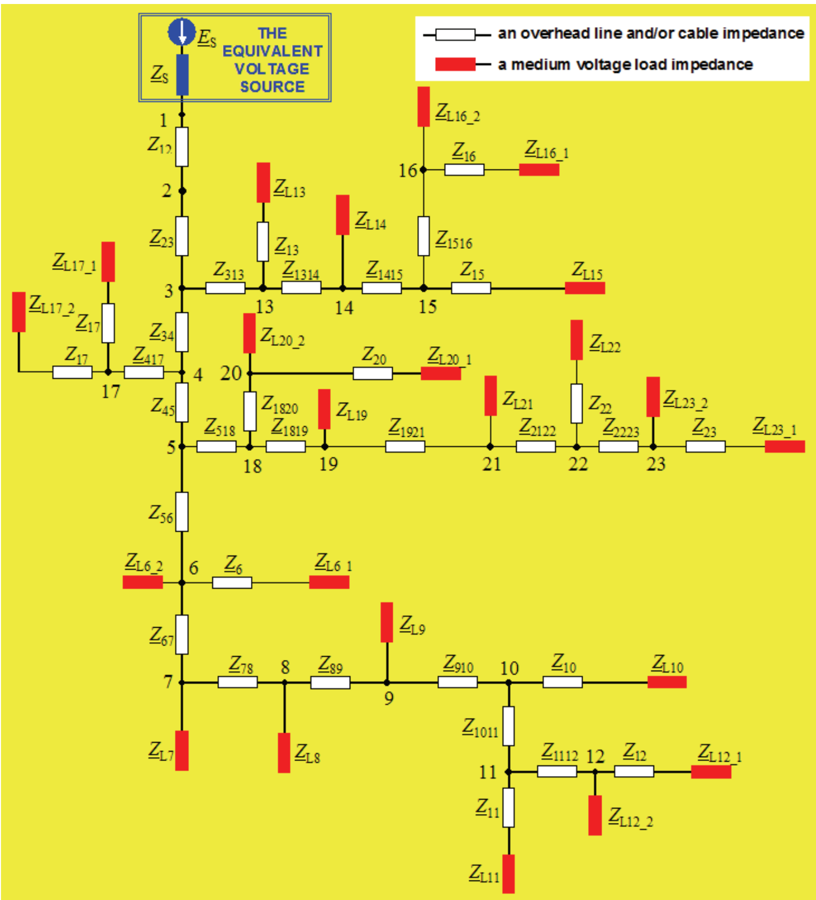

Fig. 1. Topological segment of the analyzed medium voltage(MV) power grid

Mathematical model of a power grid

The analyzed medium 15 kV power grid (see Fig. 1) is described using a linear set of algebraic equations:

$$\mathbf{YV} = \mathbf{I}, \quad (1)$$

where: $\mathbf{Y}_{[23\times23]}$ – complex matrix of specific and mutual admittances of all nodes, $\mathbf{V}_{[23]}$ – vector of complex node potentials, $\mathbf{I}_{[23]}$ – vector of complex currents (including wind generator currents).

The mathematical model assumes the fact that the wind generators are modeled as an ideal current source and can be connected solely to the nodes presented in Fig. 1.

The solution to equation (1) constitutes the vector of potentials in all nodes. Having computed all the node potentials and knowing the impedances of individual segments presented in Fig 1, it is possible to find the current values and active power in the segments and also the value of power losses in the analyzed power grid.

Application of genetic algorithm in power grid optimization

The genetic algorithm [2, 3, 4, 9] is applied to solve the optimization problem where the objective function is defined by the value of active power losses in the presented part of the power grid. It is obvious that the objective function is subjected to minimization.

For the investigation purposes the genetic algorithm was limited to an area of 9x9 kilometers with a possibility switching on wind generators in 23 power grids (M = 23). The following genetic operators were used:

− mutation operated on genes (bits) appearing in the chromosome that determines any grid location with the probability factor P=0.03,
− chromosome inversion (P=0.056),
− gene inversion (P=0.043).

The algorithm starts after producing start population PO_0 using a random number generator. The size of the vector population depends on the number of attached wind generators. The Individuals from each population producing the best solutions create a parental table. Pairs of the best solutions are subsequently crossed over and additionally the parental table is supplemented by some individuals chosen randomly from the worse solutions. The parental table in each population is also supplemented by newly selected individuals in a random way. Such an algorithm of parental selection for crossovers considerably increases the convergence to achieve an optimal solution.

The following logical alternatives were adopted for the final process of the optimization criterion (stop criterion):

− absence of the improvement of objective function value, or
− number of analyzed populations NP is greater than 50 (NP>50).

The results obtained using the genetic algorithm were verified by a standard iterative method. The verification was carried out on the same part of the grid where power losses for all possible placements were computed choosing the best solution. The same result was arrived at by applying the genetic algorithm. Additional tests showed the efficiency of the method.

The proposed algorithm proved to be very effective in spite of the fact that genetic algorithms usually require long lasting computations [5, 6]. Thus the method makes it possible to optimize the connection process of a great number of wind generators into extensive power grid systems.

Increasing the size of the investigated mode, it is possible to apply more refined genetic operators to achieve the best convergence of the solution.

An alternative way of approaching the problem is to use parallel computers with a dedicated parallel genetic algorithm [7, 8].

Investigation results of genetic algorithm

The method was tested on a real power grid limited to an area of 91 km^2 with the possibility of switching on wind generators in 23 connection nodes.

In the first stage of the investigations the iteration method was applied to verify the results obtained using the genetic algorithm.

To do this a connection of two wind generators into the grid was considered. Table 1 shows some solutions of the best connection of two wind generators: a 2 MW one and an 0.8 MW one.

The best solution is achieved by connecting a 2 MW wind generator to node number 10 and an 0.8 MW one to node number 22. For this combination minimum power losses equalled 13.5 kW (Table 1, solution number 1).

Approximately another optimal combination is achieved by connecting a 2 MW wind generator to node number 10 and an 0.8 MW one to node number 23 with almost the same value of power losses (Table 1, solution number 2).

The best solutions are the same and show insignificant power and practical connections can be chosen using technical premises.

Table 1. The best connections for two wind generators

Solution number	Generator Power		Power losses [kW]
	2 MW	0.8 MW	
	Node connection number	Node connection number	
1	10	22	**13.58 (min)**
2	10	23	13.62
3	10	21	14.08
4	9	22	15.12
5	9	23	15.16
6	9	21	15.61
7	10	19	15.91
8	9	19	17.45
9	10	18	18.17
10	8	22	18.55
11	8	23	18.59
12	8	21	19.04
13	9	18	19.71
14	11	22	20.17
15	11	23	20.21

It should be noted that the worst combinations of a 2 MW and an 0.8 MW generators show much greater power losses.

Table 2. The worst connections of two wind generators

Solution number	Generator power		Power losses [kW]
	2 MW	0.8 MW	
	Node connection number	Node connection number	
515	13	13	144.51
516	14	15	144.84
517	14	14	145.28
518	15	15	145.91
519	14	16	146.44
520	16	16	147.56
521	16	1	148.98
522	15	14	149.81
523	1	2	150.70
524	16	13	153.03
525	2	2	154.32
526	15	16	157.44
527	16	14	162.43
528	16	15	168.46
529	1	1	**172.78 (max)**

Table 2 presents some of the worst solutions of a 2 MW and an 0.8 MW generators.

The worst solution appears when two wind generators (2 MW and 0.8 MW) are connecting to the same node number 1 (172.774 kW power losses, Table 2, solution number 529).

In this modelling method we can connect power generators to the same node.

In the second stage the genetic algorithm was applied with the same generators (2 MW and 0.8 MW) to look for minimum power losses in the grid. The computation time was 14.59 s. on a standard PC computer. Table 3 presents the computation results. As can be seen the both Tables show identical results. However, in some cases the genetic algorithm yields second best solutions.

Using the genetic algorithm it is possible to analyze a greater number of power generators operating in the grid. Table 4 presents an optimal placement of three up to seven wind generators in the grid (see Table 4).

Table 3. Minimum power losses for genetic algorithm

Node connection number	Generator power [MW]	Power losses [kW]
10	2.0	13.58
22	0.8	

Table 4. Computational results for three, four, five, six and seven generators

Node connection number	Generator power [MW]	Power losses [kW]
10	2	12.11
1	0.8	
21	1	
10	2	17.79
1	0.8	
19	1	
1	3	
8	2	23.06
12	0.8	
22	1	
1	3	
1	2.5	
10	2	13.37
22	0.8	
17	1	
10	3	
10	2.5	
10	1.5	
1	2	44.61
9	0.8	
9	1	
6	3	
6	2.5	
13	1.5	
13	0.5	

Table 5. Computational results for fifteen, twenty generators

Generators numbers	Node connection number	Generator power [MW]	Power losses [kW]
15	13	2	116.51
	2	0.8	
	8	1	
	3	3	
	3	2.5	
	2	2.4	
	13	2.3	
	2	2.2	
	1	2.1	
	13	1.9	
	8	1.8	
	3	1.7	
	8	1.5	
	13	1.6	
	13	1.4	
20	1	2	358.59
	20	0.8	
	22	1	
	17	3	
	4	2.5	
	3	2.4	
	3	2.3	
	4	2.2	
	1	2.1	
	6	1.9	
	18	1.8	
	4	1.7	
	3	1.5	
	18	1.6	
	17	1.4	
	4	1.3	
	22	1.2	
	17	1.1	
	17	0.9	
	20	0.7	

The computation time was respectively: 8.34 s. for three, 8.32 s. for four, 11.78 s. for five, 14.21 s. for six and 17.81 s. for seven wind generators using a typical PC computer. Table 5 shows the results obtained for 15 and 20 wind generators.

Conclusion

The use of genetic algorithms for solutions of technical problems embraces a wide spectrum of aspects. Paper [7] deals with an optimal placement of electronic elements on a radiator where the objective function is the temperature minimum in silicon joints. A similar algorithm was used in mobile telephony to obtain an optimal placement of base stations.

The present paper discusses an optimal placement of wind generator in an MV power grid. In this case the objective function is the minimum active power loss in the analyzed section of the power grid. The analysis of the solution for the area of 91 km2 with 23 wind generators allows us to formulate the following conclusions:

− a good convergence of the created algorithm was achieved (the number of the produced populations is less than 50 (NP>50),

− the computation time for a standard PC computer is between about nine and fifty s. (for twenty wind generators),

− the computations of optimal placement of wind generators (two generators in the grid) were verified using the iterative method obtaining identical solutions.

Further research is aimed at elaborating a parallel genetic algorithm to find an optimal placement of wind generators over large areas, including, for example such administrative areas as local regions and provinces.

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dr inż. Ryszard Szczebiot, Państwowa Wyższa Szkoła Informatyki i Przedsiębiorczości w Łomży, Instytut Informatyki i Automatyki, ul. Akademicka 14, 18-400 Łomża, Poland, E-mail: rysbiot@pwsip.edu.pl;
dr inż. Sławomir Cieślik, University of Technology and Life Sciences, ul. Kaliskiego 7, 85-796 Bydgoszcz, Poland, E-mail: slavcies@utp.edu.pl.