ISSN 1330-3651
UDC/UDK 621.311.1.001.26:004.421.2

THE OPTIMAL PLACEMENT OF DISTRIBUTED GENERATION

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Original scientific paper
The distributed generation within the distribution and low voltage network is a result of decentralizing electrical power production by introducing the electricity market as well as trying to reduce the greenhouse effect. A new optimum solution has to be found while planning the electro energetic system which includes building new production capacity, a new network and expansion of reactive capacity. The benefits that can be obtained from this optimum solution are of economical, technical and ecological nature. Analytical methods have proven less successful in dealing with nonlinear optimization problems. Evolution algorithms have proven most applicable onto real systems. The aim of this project is to determine the location and the capacity of distributed generation by using genetic algorithms at feeder 10 kV Strizivojna Hrast. The given results have determined the optimum locations and capacity in the 10 kV Strizivojna Hrast feeder.

Keywords: *distributed generation, electrical energy losses, genetic algorithms, optimum location / distributed production capacity*

Optimalan razmještaj distribuirane proizvodnje

Izvorni znanstveni članak
Pojava distribuirane proizvodnje u distribucijskoj i niskonaponskoj mreži rezultat je decentralizacije proizvodnje električne energije uvođenjem tržišta električne energije i napora radi smanjenja efekta staklenika. Kod planiranja elektroenergetskog sustava, a u što spada izgradnja novih proizvodnih kapaciteta, izgradnja mreže i ekspanzija reaktivnih kapaciteta, mora se pronaći optimalno rješenje. Koristi koje se mogu dobiti iz optimalnog rješenja su ekonomske, tehničke i ekološke naravi. Analitičke metode imaju vrlo malo uspjeha u rješavanju nelinearnih optimizacijskih problema. Evolucijski algoritmi pokazali su najveću stopu primjenjivosti na realne sustave. Cilj ovog rada je odrediti lokaciju i snagu distribuirane proizvodnje primjenom genetskog algoritma na vodnom polju 10 kV Strizivojna Hrast. Dobiveni rezultati odredili su dvije najoptimalnije lokacije i snage u napojnom vodu 10 kV Strizivojna Hrast.

Ključne riječi: *distribuirana proizvodnja, genetski algoritmi, gubici električne energije, optimalna lokacija/snaga distribuirane proizvodnje*

1 Introduction

A substantial increase of distributed production in low voltage and medium voltage networks is a result of decentralizing power systems and introducing electricity market as well as favoring renewable energy sources (green energy) to decrease greenhouse effect. It represents a change in the paradigm of electrical energy generation [6]. The implementation in question varies among the countries due to their different national rules and regulations. The development of the distribution system network has to be done as optimally as possible, in order to more efficiently incorporate the distributed production within the distribution network. Inappropriate production placement can lead to increased losses, expenses and can jeopardize the functioning of the system [1]. The distributed generation is used by the consumer at the connection point for one's personal consumption, as well as for supporting the network in terms of capacity. Influencing the network can be both positive and negative. The benefits can be economical, technical and ecological. The distributed production influences the power flows, therefore the network's voltage [11]. It transfers the passive distribution network into an active one and thus influences conduct and management of the network. It is therefore extremely important to optimize and to a certain extent determine the right location and capacity of the distributed power generation. Size and location of distributed generation are crucial factors in the application of distributed generation for its maximum benefits [9]. Furthermore, this is particularly important to achieve the maximum potential benefits: maximum profit, minimum loss, improving voltage conditions, avoiding the construction of unnecessary power lines, increasing the distribution network's reliability and efficiency. The usual aims are reduced to minimizing the losses and maximizing the profits, which indicates that a multiple goal and multiple limitations optimization are being dealt with. Determining an optimal location and capacity with minimum losses is a complex combinatorial-optimization problem [8]. A multi goal optimization can be solved by using standard analytical methods, modern heuristic methods, evolutionary algorithms, hybrid techniques and other various groups. One of the most suitable and widely used methods for solving these types of problems is a genetic algorithm (GA) method, which belongs to the group of evolutionary algorithms. Other heuristic methods [5] have also been used for these types of problems such as optimizing: Taboo search (TS), Ant colony optimization (ACO), swarm optimization (SWO) and other various hybrid techniques. A GA was used to calculate the optimal location and capacity on the radial 10 kV Strizivojna Hrast line which is located in the TS 35/10 kV Đakovo 1, to minimize the losses and limitations in terms of voltage and load on all nods and lines. We have here a multi-dimensional optimization problem with one goal. The aim of this project is determining the optimal location and capacity at a specific example of 10 kV radial line Strizivojna Hrast.

2 Using evolutionary algorithms while planning

Optimization problems which may arise while planning a power system can be categorized as big, complex or nonlinear combinatorial problems. The planning done within a power system is usually reduced to expanding production capacities, expanding a transmission and distribution networks as well as expanding the sources of reactive energy. Applying analytical methods onto these problems had limited success and wasn't successfully applied to real problems. Using modern heuristic methods has led to a more realistic representation of system characteristics, conditions and goals. With the emergence of heuristics, new robust, rational methods have been created. Evolutionary algorithms belong to these types of methods and have a high level of stochastic convergence to reach the optimum. This is supported by a mathematical theory which proves not only the convergence but an increase of its level. Planning the electricity production is a high responsibility field which aims to guarantee a carefree supply in the future. In the classically oriented power systems power companies had this task, but by developing an electricity market the new, foreign investment facilities have to be taken into consideration at all voltage levels. Methods like linear programming, mathematical programming and other mathematical methods have a disadvantage of treating the variables in continuous space and they also do not guarantee reaching the global optimum. The most widespread method for expanding production facilities is a linear programming method, but due to its dimension, it has not been successfully applied to realistic problems. To date, artificial intelligence, evolutionary computation and optimization techniques are among the popular techniques that are normally used to solve these matters [13]. Applying a genetic algorithm onto production capacities has shown promising results [10]. They are a subset of a larger set of evolutionary algorithms which find solutions for optimization problems inspired by the natural evolution [3]. The first genetic algorithm was developed by John Holland in 1975 [7]. A genetic algorithm is a heuristic-stochastic method which finds solutions by using genetic heritage and Darwin's theory of the survival of the fittest.

A genetic algorithm allows a randomly chosen population to evolve by maximizing its fitness function and certain selecting conditions (limits). An initial population of a given size must be created to begin the GA search process [12]. After a certain number of generations, the final population should have an individual close to the ideal solution [14]. It does not give an explicit solution like other iterative methods, but it gives a set of possible solutions which are called research space. A genetic algorithm has three phases: in phase 1 a population is created, phase 2 is an estimate based on a fitness function closely related to the aim function and in phase 3 a new population (offspring) is created [2]. Future generations are created based on genetic operators, which are usually elitism, crossover and mutation. Chromosomes are used to present possible solutions of the optimization problem. A fitness function is used to determine the validity of every solution. A chromosome consists of a certain number of parameters $p_1, p_2,...., p_n$ (n – dimensional optimization problem). A chromosome is written in the form of a vector (1).

$$\text{Chromosome} = [p_1, p_2, ..., p_n]. \tag{1}$$

Encoding and decoding of chromosomes is done by a binary, Gray or some other code, but a binary one holds a certain preference. A chromosome is presented by a 0 or 1 and each digit is called a genome. We have to take into consideration that all chromosomes have the same number of genomes. After subjecting the remaining set of solutions to the conditions and fitness function, we apply genetic operators. An elitist operator is rarely used which allows us to use crossbreeding and mutation. There are several types of crossovers and the most famous ones are: crossover in one point, crossover in two points, uniform and semiuniform crossover. The most commonly used are crossovers in one or two points as shown in Fig. 1.

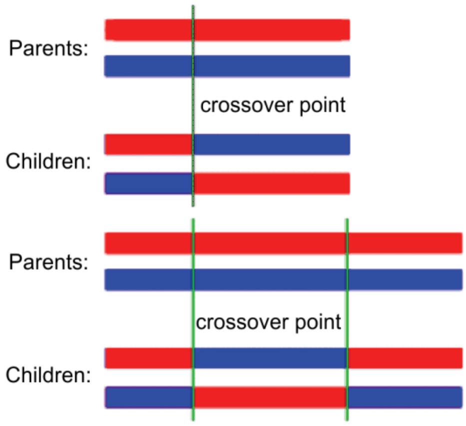

Figure 1 Crossovers in one and two points

Fitness function is an ability of each solution. When creating a new population, their ability has to be taken into consideration. When addressing an optimization problem, a fitness function consists of the sum of weight goals and penalization function which presents limitations. This approach allows the terms to be violated, but the penalties vary depending on the size of the offense as it degrades the fitness function and thus the solution itself. A genetic algorithm has a goal of maximizing the fitness function. Genetic algorithms are suitable for solving limitless (condition free) problems.

Fitness function is equal to the objective function $F(x) = f(x)$ for a limitless maximization problem. Minimization problem can easily be reformulated into a maximization problem, even before applying a GA. The conversion is done using the Eq. (2).

$$F(x) = \frac{1}{1 + f(x)} \tag{2}$$

A general minimization problem with limits is reformulated into a general minimization problem without any limits by using the penalty function concept $\phi(x)$. If we want to use a genetic algorithm and finalize the maximization we use Eq. (3):

$$F(x) = \frac{1}{1 + \phi(x)}. \tag{3}$$

3 A genetic algorithm in determining location and capacity of distributed generation

Proper location of the distributed production is crucial in order to achieve minimum losses in the technical and environmental terms or the maximum profit. The goal is to find an optimal location and size of distributed production within the network which will meet the condition of the voltage at each bus in the range of

1+0,05 or 1–0,05 p.u. and that the lines are loaded below the nominal value of MW. We used constant loads and different constraints in our method which arises from [9].
The genetic algorithm for minimizing losses in a network does the following things:

Step 1: Randomly choose a set of pairs (location, capacity) of distributed production. Set $k = 1$. Enter the maximum number of iterations m.

Step 2: Calculate the losses in the system based on the power flow of each pair (location, capacity) by modeling the distributed production by using negative load. Record the losses related to each pair. (location, capacity).

Step 3: Check if all the conditions are met for each pair (location, capacity) in terms of voltage and line load for each bus and each line.

Step 4: If all the voltages and loads in MW are within limits for the matching pair (location, capacity) accept the pair for the population of the future generation. Otherwise, reject the pair that does not meet the criteria (location, capacity) and do not use it for the future population.

Find a pair (location, capacity) which has minimum losses. If $k = m$ is presented as a pair (location, capacity) to minimum losses. The end.

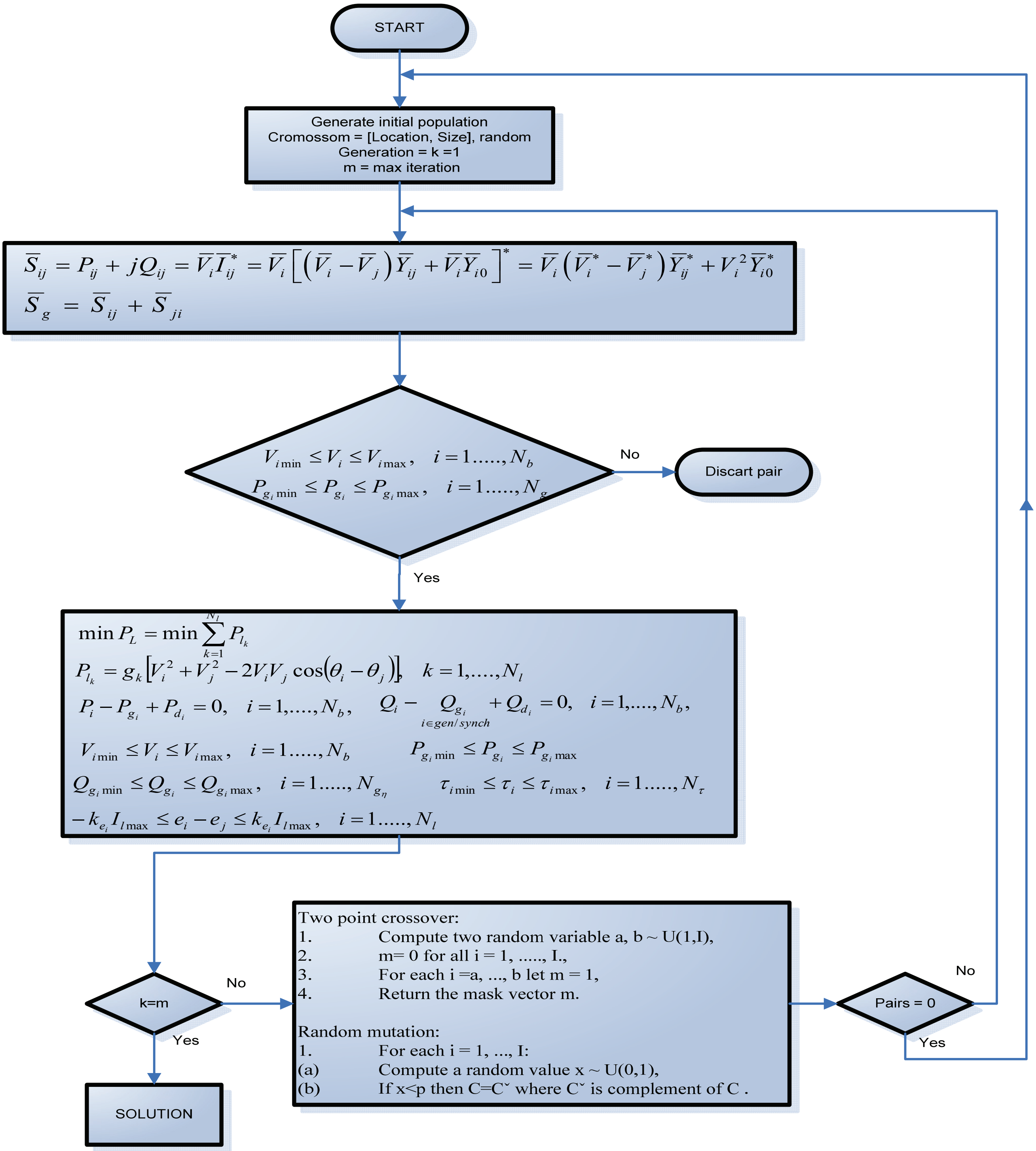

Figure 2 Genetic algorithm for determining location and capacity of the distributed production

Step 5: Use a surviving population of pairs (location, capacity) and submit them to a crossover and mutation to get a new generation.

If the population, after Step 4, equals zero return to Step 1.

Step 6: Use a new, randomly chosen population as offspring. Move to Step 2.

Detailed display of the genetic algorithm is given in the diagram shown in Fig. 2.

The GA begins by defining a chromosome or an array of variable values to be optimized. If the chromosome has M_{var} variables (M_{var} - dimensional optimization problem) given by $a_1, a_2, ..., a_{M_{\mathrm{var}}}$, then the chromosome is written as an M_{var} element row vector.

$$\mathrm{Chromosome} = [a_1, a_2, ..., a_{M_{\mathrm{var}}}].$$

For coding and decoding we used binary code which is the most common. Also we used two point crossover (4) and mutation (5).

$$\begin{aligned} &\mathrm{Parent\ 1} = [00|1011|11] \\ &\mathrm{Parent\ 2} = [01|0000|10] \\ &\mathrm{Offspring\ 1} = [00000011] \\ &\mathrm{Offspring\ 2} = [01101110] \end{aligned} \tag{4}$$

$$\begin{aligned} &\mathrm{Offspring\ 1} = [00000001] \\ &\mathrm{Offspring\ 2} = [01101100] \end{aligned} \tag{5}$$

4 Results

TS 35/10 kV Đakovo 1 consists of two transformation fields with total power of 16 MW. It is powered from 110/35/10 kV Đakovo 2 by dual 35 kV long transmission lines. TS 35/10 kV Đakovo 1 has a possibility of additional power supply from feeder 35 kV Mikanovci. TS 35/10 kV Đakovo 1 has 11 feeders at 10 kV bus. Feeder 10 kV Strizivojna has 33 TS 10/0,4 kV in a line, and at the end has an interpolated switchyard (RS) 10 kV Strizivojna Hrast. Feeder 10 kV Strizivojna Hrast with its adjoining production locations is given by Fig. 3. The locations and capacity are shown in Tab. 1. All calculations are made for average loads. Power flows [4] are calculated in Easy Power.

Table 1 Arbitrary distribution of power and location of the distributed production

Feeder name (node)	Budrovci 7	Budrovci 6	Budrovci 5	Budrovci 2	Piškorevci	Piškorevci 3	Strizivojna 7	Strizivijna Hrast	Strizivojna 5	Soljak
Location	1	2	3	4	5	6	7	8	9	10
Power / MW	2	2	3	1	2	3	2	3	2	1

The solution is presented in the form of chromosomes (6).

$$\text{Chromosome} = [\text{location, capacity}] \tag{6}$$

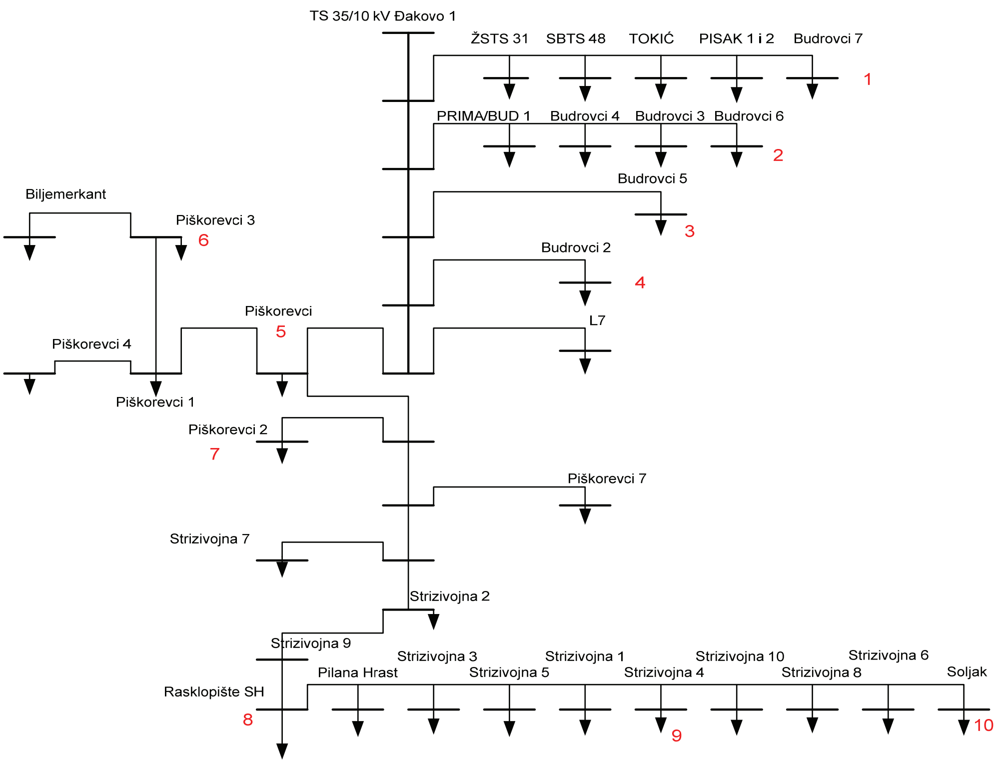

Figure 3 Power field 10 kV Strizivojna Hrast with production locations of the distributed production

After subjecting the initial, randomly chosen set (location, capacity) of distributed production to the given conditions related to the voltage and load only node Budrovci 7 did not qualify. Capacity and losses are standardized to 1000 kW which presents the lowest chosen power of the distributed production, and the other arbitrary values are 2000 kW and 3000 kW. The optimal set of locations-power of the first generation of distributed production with losses is shown in Fig. 4. The optimal location and capacity are presented with minimum losses while satisfying the conditions. The losses increase from left to right, thus presenting optimal locations and capacity for each individual network connection, shown in Fig. 4.

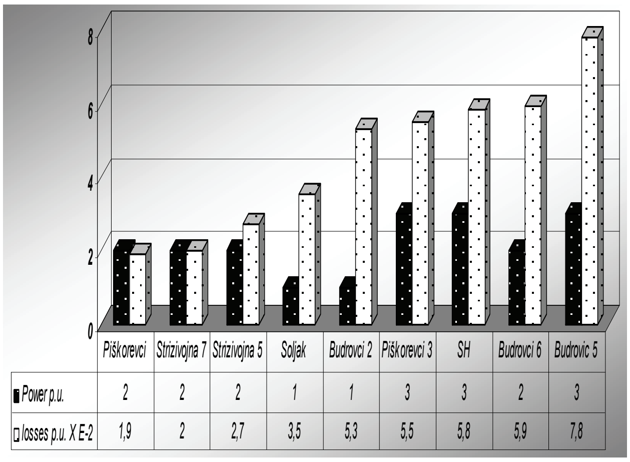

Figure 4 Capacity and location of distributed production's first generation

Optimum location and capacity are provided by a set of solutions at the Piškorevci node with capacity of P = 2000 kW with losses of 19 kW. A genetic algorithm does not give an exact solution but a set of possible solutions by choosing a certain amount of arbitrarily chosen generations.

Simultaneously distributed generation connected with minimum losses is possible in three nodes, as shown in Tab. 2.

Table 2 Multiple connection of distributed production's first generation

Feeder name (node)	Piškorevci	Strizivojna 7
Power / MW	2	2
Total losses p.u. × E-2	7,4	

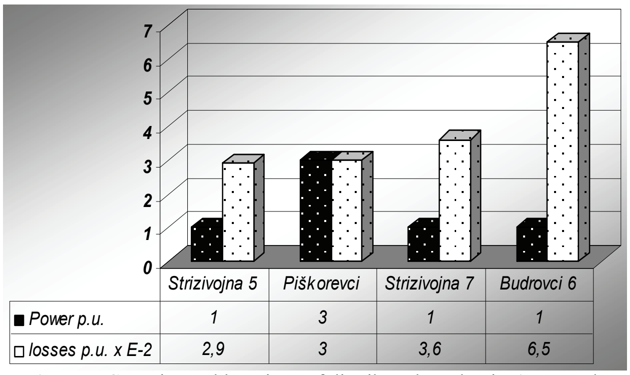

Figure 5 Capacity and locations of distributed production's second generation

Fig. 5 shows the second generation of optimal solutions with minimal losses after crossing the chromosomes in two points between the second and fifth genome, mutating the sixth genome and subjecting them to the required conditions. From the initial 10 locations-power in the second generation only four remained. The optimal location – power is at Strizivojna 5 node with the power of P = 1000 kW and the losses of 29 kW. Fig. 5 also shows from left to right the optimal set locations-power of the distributed generation which are individually connected onto the network. Total losses in network without any distributed generation are 100 kW.

Tab. 3 shows the maximum number of simultaneously connected distributed generation with minimal losses.

Table 3 Multiple connection of the distributed production's second generation

Feeder name (node)	Strizivojna 5	Piškorevci
Power / MW	1	3
Total losses p.u. × E-2	6,3	

Fig. 6 shows the third generation's set of optimal solutions after crossing the chromosomes in two points and mutating the sixth genome after submitting them to required conditions.

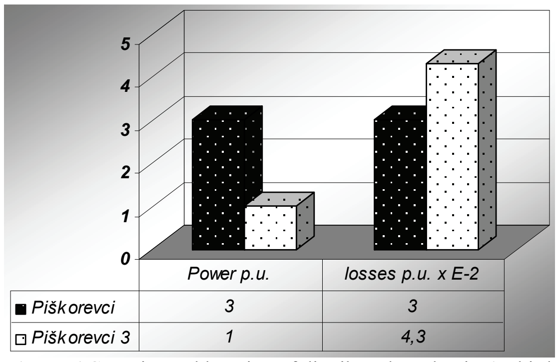

Figure 6 Capacity and location of distributed production's third generation

The third generation solutions present only two possibilities for nodes Piškorevci and Piškorevci 3. The optimum solution for the distributed production's location – power is at the node Piškorevci with the capacity of P = 3000 kW and losses 30 kW.

According to both offered solutions in Tab. 4 a simultaneous connection of the distributed production is possible. If we compare an individual connection of the distributed production (Fig. 6) with multiple connections of the distributed production (tab. 4) we can see an almost double increase in losses.

Table 4 Multiple connection of distributed production's third generation

Feeder name (node)	Piškorevci 3	Piškorevci
Power / MW	1	3
Total losses p.u. × E-2	7,4	

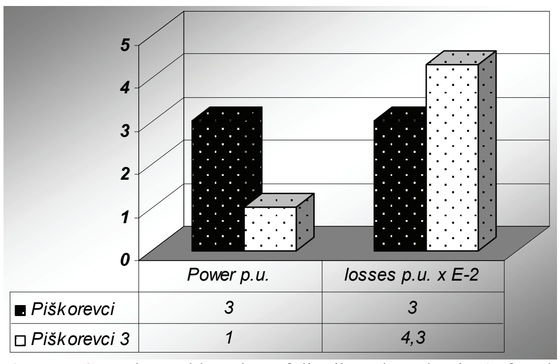

Figure 7 Capacity and location of distributed production's fourth generation

Fig. 7 shows a set of the fourth generation of optimum solutions after crossing the chromosomes in two points and mutation of the sixth genome for submission to the required conditions. The third and fourth generation's solutions are identical and present two possibilities for the nodes Piškorevci and Piškorevci 3. An optimal solution of the distributed production's location-power is at the node Piškorevci with the capacity of P = 3000 kW and losses of 30 kW.

Simultaneous connection is possible of distributed generation of both possible solutions as shown in Tab. 5. If we compare the single connection of the distributed production (Fig. 7) with multiple connection of distributed production (Tab. 5) we see that there has been an almost double increase in losses. The third and fourth generation's solution has remained unchanged.

Tab. 5 illustrates optimum locations and power after the fourth generation shown in the radial line 10 kV Strizivojna Hrast. Location No. 1 belongs to the node Piškorevci with power P = 3 MW and the other optimum location belongs to the node Piškorevci 3 with power of P = 1 MW shown in Fig. 8.

Table 5 Multiple connection of the distributed production's fourth generation

Feeder name (node)	Piškorevci 3	Piškorevci
Power / MW	1	3
Total losses p.u. × E-2	7,4	

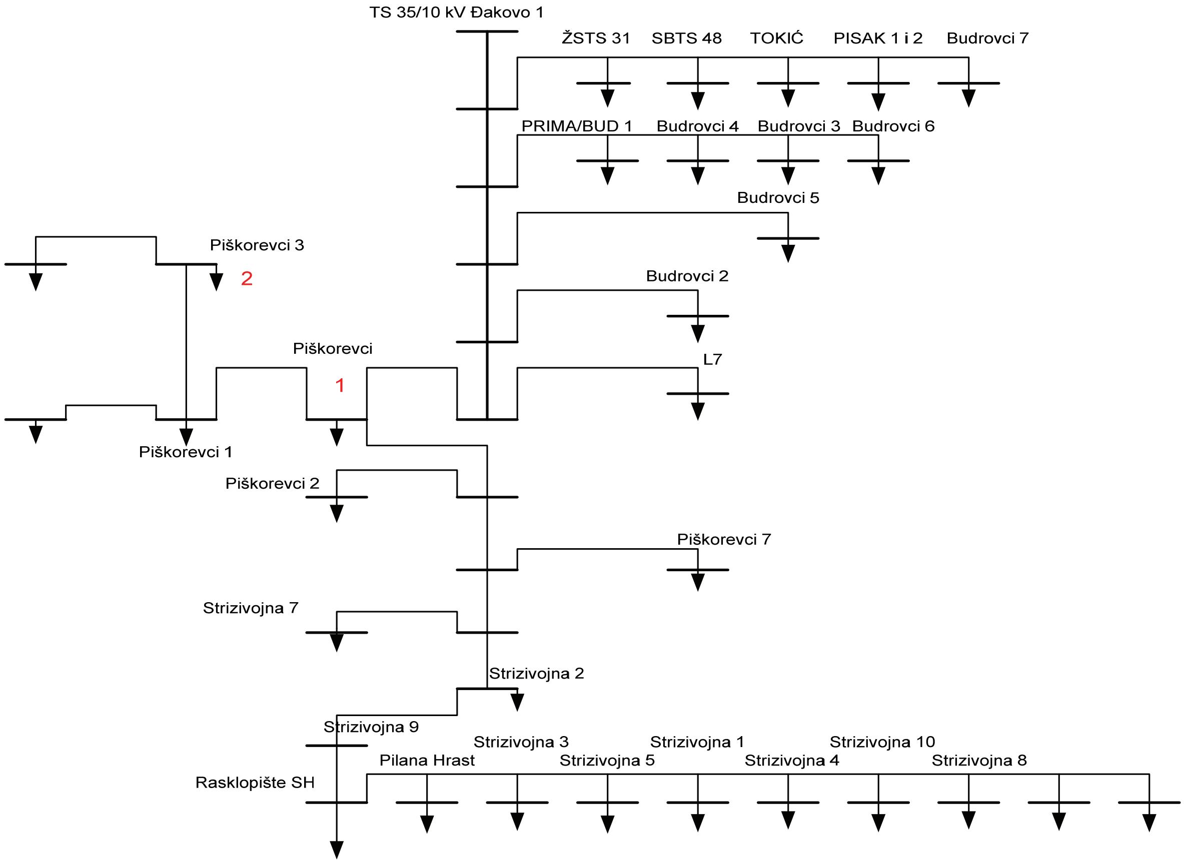

Figure 8 Optimum location at VP 10 kV Strizivojna Hrast

The total losses from the first generation to the fourth generation are shown in Fig. 9. The number of possible optimal solutions decreases from generation to generation. If we compare the single best optimal solution from each generation, we see that the fourth generation does not have the best single optimal solution in relation to minimal losses, but the crucial one was the first generation.

When we are dealing with multiple simultaneous optimal schedules the minimal losses are in the second generation which offers four optimal solutions among which the two best ones can simultaneously be realized as distributed producers. Connecting the third solution (producer) leads to violating the set conditions shown in Fig. 10.

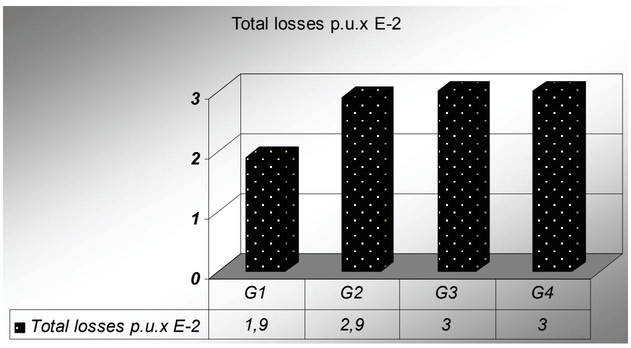

Figure 9 Overall losses in all generations

Different loads will provoke different bus voltages. The result of these new conditions will lead to new location and sizes.

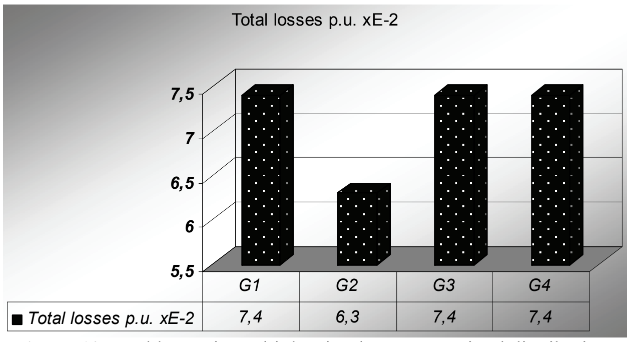

Figure 10 Total losses in multiple, simultaneous, optimal distribution

5 Conclusion

Applying a genetic algorithm to find the optimal power distribution and location based on minimal losses shows a fast convergence towards a set of optimal solutions. After presenting four different generations of optimal solutions we can see that the best one acquired is in the first generation. The total losses in the second, third and fourth generation do not have many differences, the number of optimal solutions is narrowed. The overall losses and the number of solutions in the third and fourth generation are identical. By creating the fifth generation, by doing a different kind of crossover and mutation, the set of solutions would not survive the required conditions and we would, in a way, have again the set with a huge number of solutions. There is another option which is less likely due to the already considerably minimized losses and that gives one or two solutions whose total losses are smaller than those of the fourth generation. The number of solutions declines from generation to generation, but if we have more distributed productions simultaneously connected onto the network, we can see that the second generation is the most optimal, offering two solutions with minimal losses, while the third and fourth generations offer two solutions simultaneously, but with more losses. In the future cases, alongside technical aspects, both economic and environmental aspects can be taken into consideration, while optimizing the distribution production. For some optimization problems modern, heuristic methods like Ant colony optimization, Taboo search and Swarm optimization offer certain improvements in the method of determining optimal location and power, and as such, can be the subject of future research.

6 References

[1] Akorede, M. F.; Hizam, H. A review of strategies of optimal placement of distributed generation in power distribution systems. // Research journal of applied science. 5, (2010), pp. 137-145.

[2] Biswas, S.; Goswami, S. K. Genetic algorithm based optimal placement of distributed generation reducing loss and improving voltage sag performance. // ACEEE, (2010), pp. 49-51.

[3] Hopgood, A. A. Intelligent systems for engineers and scientists. // CRC Press, Florida, 2001.

[4] Jozsa, L. Tokovi snaga u mreži. // ETF Osijek, Osijek, 2001.

[5] Lee, K. Y.; El-Sharkawi, M. A. Modern heuristic optimization techniques: Theory and applications to power systems. // Wiley & Sons, New Jersey, 2008.

[6] Rao, S. S. Engineeiring optimization. // Wiley & Sons, New Jersy, 2009.

[7] Sedighizadeh, M.; Rezazadeh, A. Using Genetic algorithm for distributed generation allocation to reduce losses and improve voltage profile. // Engineering and technology. 37, (2008), pp. 251-256.

[8] Singh, D.; Singh, D.; Verma, K. S. GA based optimal sizing & placement of distributed generation for loss minimization. // Engineering and technology. 35, (2007), pp. 101-107.

[9] Singh, R. K.; Goswami, S. K. A genetic algorithm based approach for optimal allocation of distributed generations in power systems for voltage sensitive loads. // ARPN Journal of engineering and applied sciences. 4, (2009), pp. 78-87.

[10] Song, Y. H. Modern optimization techniques in power systems. // Springer, New York, 1999.

[11] Sulaiman, M. H.; Aliman, O.; Rahim, S. R. A. Optimal embedded generation allocation in distribution system employing real coded genetic algorithm method. // Engineering and technology. 62, (2010), pp. 591-596.

[12] Vrcan, Ž.; Lovrin, N. Genetic algorithm based optimization of conveyor belt material cross section area. // Technical Gazette. 17, 2(2010), pp. 137-147.

[13] Payasi, R. P.; Singh, A. K.; Singh, D. Review of distributed generation planning: objectives, constraints, and algorithms. // International journal of engineering, science and technology. 3, 2(2011), pp. 133-153.

[14] Shukla, T. N.; Singh, S. P.; Naik, K. B. Allocation of optimal distributed generation using GA for minimum system losses in radial distribution networks. // International Journal of Engineering, Science and Technology. 2, 3(2010), pp. 94-106.

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