MODIFIED GENETIC ALGORITHM FOR UNIT COMMITMENT OF GRID-CONNECTED MICROGRIDS UNDER REAL-TIME PRICING CONDITIONS

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Abstract: This paper introduces a modification of the genetic algorithm aimed at enhancing the selection process for reproducing the next generation. This modification accelerates the optimization process and improves the outcome. The case study analyzes a grid-connected microgrid comprising renewable energy sources, a battery storage system, prosumers with installed photovoltaic generators, and consumers. The effectiveness of the proposed modification is validated through comparison with two selection algorithms commonly used in the standard genetic algorithms.

Key words: Renewable energy sources, microgrids, genetic algorithm, unit commitment, real-time pricing.

1. INTRODUCTION

The energy and financial crisis that many parts of the world face bring microgrids to the centre of researchers' and engineers' attention. Their ability to provide sustainable and clean energy with decreased distribution costs at any place makes them a better solution than the standard centralized grid prone to outages. One of the main reasons for the increased interest in microgrids is their decentralized control and optimization system. This means they can run and supply energy to the local consumers even if one of the generators is out. Microgrids can be placed anywhere according to the conditions. They are present even in the cities, which makes clean power generation more approachable to commercial consumers. The consumers who consume and produce power at the same time are called prosumers. However, today's microgrids are more complex than the primary microgrids. This is due to the many different dispersed generators connected, the inclusion of storage systems, backup generators, and connection to the local grid or other microgrids. The use of the storage system in the microgrids is recognized as a reliable source of energy that compensates for the stochastic nature of renewable energy sources. In that way, the storage system provides the stability that microgrids lack. However, adding the power exchange to the local power grid creates a complex system that requires proper optimization.

The microgrid optimization research inspects many ways to generate clean power and conserve that power, to lower the power generation costs and make the whole process even more applicable for commercial use [1]. For that purpose, many evolutionary algorithms were inspected, analyzing the costs, power losses, and gas emissions if there is a diesel generator included, as a backup system.

This paper presents a modification in the selection process of a genetic algorithm for the unit commitment of a grid-connected microgrid that consists of prosumers and consumers, photovoltaic and wind generators, and a battery system. The microgrid trades with the local grid under real-time pricing conditions. Based on recent statistical power consumption data, the prices are defined a day ahead and they change hourly. The simulation analyses a 24-hour time period when the microgrid trades with the local power grid.

The proposed algorithm has a prior of using the power generated from the renewable energy sources connected to the microgrid, and deciding whether to use the battery or the local grid for distribution of the excess or needed power. Additionally, the voltage in the nodes has to be maintained within the defined limits.

2. LITERATURE GAP

The literature abounds with many different optimization methods for solving the unit commitment problem of grid-connected microgrids. There are research that considers the voltage variations as an important point during optimization in such a microgrid. The analysis of voltage and frequency, using a genetic algorithm is presented in [2]. Mainly, the optimization targets the operational costs and power losses. The importance of the battery storage system and the benefit of trading with the local grid for grid-connected microgrid is presented in reference [3]. The paper presents a simulated optimization of dispersed generation and system for storing excess power in grid-connected and islanded microgrids. The paper analyses two alternative optimization functions. The first one minimizes the annual power losses, and the second one minimizes the costs of power production. The best results are maintained when the microgrid trades with the local grid and it has a storage system installed.

Today's energy market enables consumers to plan their power consumption to shift and reduce the load peaks so that the power system would not be burdened at a specific part of the day. Therefore, there are power systems that charge different electricity prices for each hour or part of the day. The research regarding that direction investigates the best optimization technique so that the profit of microgrids' operation would be the highest.

A smart grid with two-way communication meters under a real-time pricing mechanism is analyzed in [4]. The results show that the real-time pricing mechanism is effective in load shifting if the response of the consumers is active enough, if the profits on the supplier and consumer side are balanced, and if the costs of the power supplier fluctuate dramatically.

In [5] a genetic algorithm is used for scheduling the battery's charge/discharge in a microgrid with prosumers, by minimizing the power in the point of interconnection of the microgrid with the main grid, and not the economic evaluation. The analysis is made on two prosumers in a microgrid case.

Besides the genetic algorithm, other optimization techniques are used. However, all of them compare their results with the gnetic algorithm as one of the most familiar and trusted heuristics optimization methods. The reference [6] proposes a Particle Swarm Optimization algorithm for solving the unit commitment problem of a microgrid with multiple distributed generators in uncertain electricity market price conditions.

A modified particle swarm optimization is proposed in [7], for scheduling and minimising the operational costs of a grid-connected microgrid with photovoltaic and wind generators, under uncertain real-time prices.

Genetic algorithm is used to reduce the operational costs of a grid-connected microgrid under real-time pricing conditions, in [8]. The case study analyses a microgrid with photovoltaic and wind generators, a fuel cell, a battery system, and two consumers.

This paper proposes a modified genetic algorithm to solve the unit commitment problem in a grid-connected microgrid with photovoltaic and wind generators, with connected consumers and prosumers, equipped with photovoltaic generators and a battery storage system that serves both the consumers and the prosumers. The microgrid trades with the local power grid under real-time pricing conditions, while maintaining a stable voltage.

3. PROBLEM DEFINITION AND PROPOSED ALGORITHM

The optimization involves integrating two functions: one to determine the utilization of stored power from the battery or purchasing from the grid, and the management of excess power by deciding whether to store it or sell it. Additionally, a function is employed to minimize voltage drop. These functions are represented by equations (1) and (2), respectively. The unit commitment problem is executed within specified technical constraints as defined in this paper.

$$F_1(P_i) = \max\left\{\sum_{i=1}^{T}(B_{DER,i} - C_{grid,i})\Delta t\right\} \tag{1}$$

where, B_{DER} represents the total profit and C_{DER} represents the total costs from microgrid operation. T represents the analyzed period and Δt represents the time interval for data sampling (1 hour).

$$F_2(P_i) = \max\left\{\left(\frac{P_\Sigma}{V_n}\cdot r + \frac{Q_\Sigma}{V_n}\cdot x\right)\cdot l - \Delta V\right\} \tag{2}$$

where, V_r is the rated voltage, and r and x are the resistance and the reactance in Ohms/meter, respectively. l denotes the distance between the nodes, and the permitted voltage drop is denoted with ΔV.

The calculation of total active and reactive power are presented with (3) and (4).

$$P_\Sigma = P_{\mathrm{pv}} + P_{\mathrm{wind}} + \sum_{m=1}^{N_{prosumers}}(P_{\mathrm{pv\_res,m}}) + P_{\mathrm{bat\_dis}} - P_{\mathrm{bat\_ch}} + P_{\mathrm{buy}} - P_{\mathrm{sell}} - \sum_{i=1}^{N_{consumers}}(P_{\mathrm{load,i}}) \tag{3}$$

$$Q_{\Sigma} = Q_{\text{wind}} + Q_{\text{buy}} - Q_{\text{grid}} \tag{4}$$

where, P_{pv} is the power generated from the photovoltaic generator, P_{wind} is the power generated from the wind generator, $P_{\text{pv\_res}}$ is the power generated from the photovoltaic generators installed on the residential objects, $P_{\text{bat\_dis}}$ denotes the power discharged from the battery and $P_{\text{bat\_ch}}$ denotes the power charged, P_{buy} denotes the power bought from the grid, P_{sell} is the power sold to the grid, and P_{load} denotes the load of the consumers. $N_{\text{prosumers}}$ denotes the total number of prosumers, and $N_{\text{consumers}}$ denotes the total number of consumers Variables Q_{grid}, Q_{wind} and Q_{buy} represent the reactive power taken from the grid to the load, the reactive power that the wind generator generates, and the reactive power bought from the grid to maintain stable voltage levels, respectively.

The total profit and costs are outlined in equations (5) and (6). These equations do not include the costs associated with power exchange among the prosumers and consumers. It is assumed that these costs are attributed to individual profits rather than to the community as a whole.

$$B_{DER} = P_{pv} \cdot p_{pv} + P_{wind} \cdot p_{wind} + P_{sell} \cdot p_{sell} + P_{bat\_dis} \cdot p_{bat} \tag{5}$$

$$C_{grid} = P_{buy} \cdot p_{buy} + P_{bat\_ch} \cdot p_{bat} \tag{6}$$

The variables p_{pv}, p_{wind}, p_{sell}, p_{bat} and p_{buy} denote the prices for power generation from the photovoltaic generator, the wind generator, the price for selling the excess power to the grid, the price for charging/discharging the battery, and the price for buying power from the grid, respectively.

The technical constraints regarding the installed equipment are presented in (7-12). With (7) and (8) the power generation range of the photovoltaic and wind generator are defined. Equation (9) defines the power generation range of the photovoltaic generators installed on the prosumers.

$$P_{PV,\min} \le P_{pv,i} \le P_{PV,\max}, \forall i \in [0,T] \tag{7}$$

$$P_{wind,\min} \le P_{wind,i} \le P_{wind,\max}, \forall i \in [0,T] \tag{8}$$

$$P_{pv\_load,\min} \le P_{pv\_load,i} \le P_{pv\_load,\max}, \forall i \in [0,T] \tag{9}$$

Battery's minimal and maximal power exchange are presented with (10), and their state of charge is presented with (11).

$$0 \le P_{bat,i} \le P_{bat,\max}, \forall i \in [0,T] \tag{10}$$

$$0 \le SoC_{bat,i} \le 1, \forall i \in [0,T] \tag{11}$$

Equation (12) defines the limits of power trading with the local power grid.

$$P_{grid,\min} \le P_{grd,i} \le P_{grid,\max}, \forall i \in [0,T] \tag{12}$$

The voltage variation limits to the consumers are defined with (13) and to the installed generators (photovoltaic and wind) with (14).

$$0,9 \cdot V_{\text{n}} \le V_{\text{load}} \le 1,1 \cdot V_{\text{n}} \tag{13}$$

$$0,95 \cdot V_{\text{n}} \le V_{DERs} \le 1,05 \cdot V_{\text{n}} \tag{14}$$

The voltage drop calculation is presented with (15).

$$V(t,i+1) = V(t,i) + \frac{\left(\sum P_i(t)\right) rl + \left(\sum Q_i(t)\right) xl}{V_n}, \forall i \in [0, n_{nodes}] \quad (15)$$

Fig. 1 shows a flowchart of the proposed modification of the genetic algorithm for unit commitment optimization.

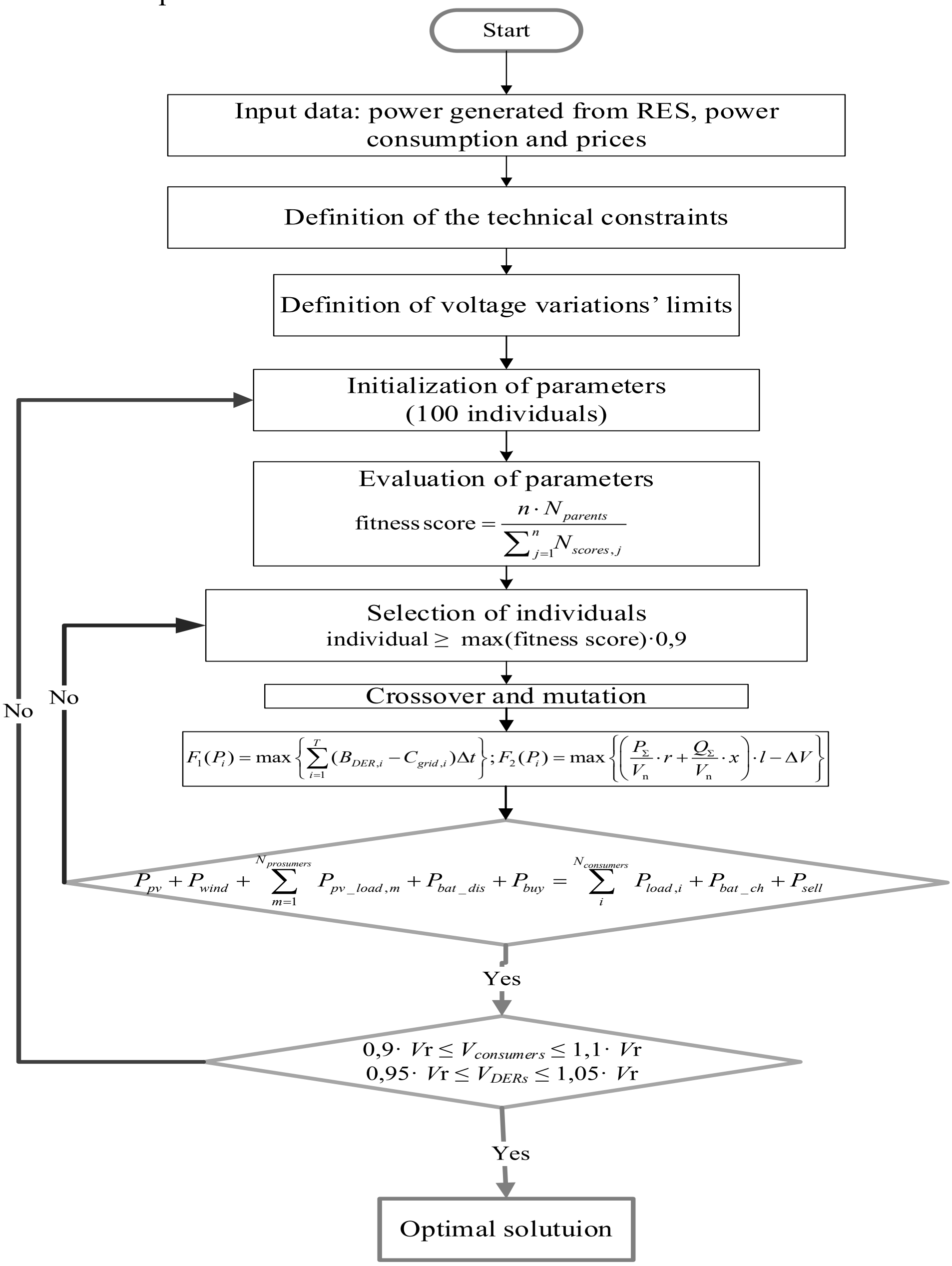

Fig. 1. Flowchart of the proposed modification of the genetic algorithm

In the initialization of the parameters, each parameter is assigned a hundred randomly generated values that are in the defined range. This includes how much of the generated power by each of the distributed generators will be used to supply the consumers, how much power will be stored or taken from the battery, and how much power will be bought or sold to the grid. Then, each of the values of the parameters is checked and scored with a fitness score by the solution it provides. Next, the individuals with the best fitness scores are selected to be parents and to produce the next generation. In this selection process, the individuals with a score higher that the 90% of the best score are selected for further reproduce. This decreases the number of potential parents, but creates more space for the next generation of individuals, whose parents have the best genes. The next generation is produced by mixing the genes of their parents, mutation some of the parents and using the parents themselves. In this way, a set of individuals which have to be tested for the optimization functions is created. The solutions that fit the best are conditionally optimal solutions. If the next generation does not provide a better solution, then the current conditionally optimal solution becomes the optimal one.

4. SIMULATION

The proposed modification of the genetic algorithm is tested on a case study of a grid-connected hybrid system consisting of a photovoltaic and wind generator, battery storage system, and a residential load community. The residential community consists of three prosumers and two consumers. Prosumers can exchange surplus power amongst themselves and provide power to consumers when available.

However, simultaneous power exchange and consumption are not feasible. Additionally, the energy stored in the battery can be utilized to meet consumers' needs during periods of high demand. The analysed microgrid is presented in Fig. 2. The case study network is according to the IEEE low voltage test network, as presented in [9].

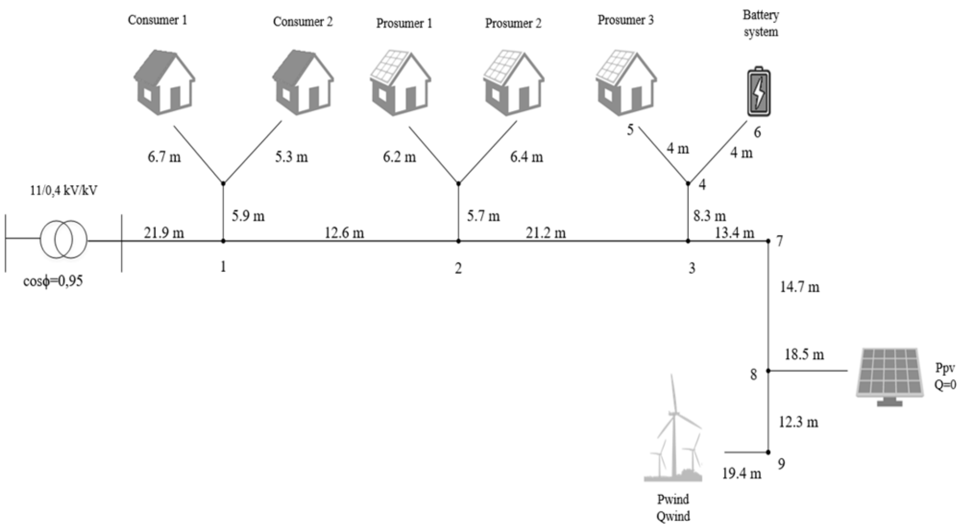

Fig. 2. Diagram of the analysed microgrid according [9]

The inclusion of a diesel generator in the microgrid is noted; however, its usage is limited to instances of local power grid outages, which fall outside the scope of this paper's research.

Table 1 outlines the technical constraints of distributed generators installed in the microgrid, as well as those on residential objects, the battery, and power trade limits with the grid.

Table 1. Technical constraints of the installed equipment.

Parameter	Meaning	Value	Unit
P_{pv}	Installed capacity of the photovoltaic generator	10	kW
P_{wind}	Installed capacity of the wind generator	3	kW
P_{pv_res}	Installed capacity of the photovoltaic generators installed on the residential objects	7	kW
P_{bat_ch} P_{bat_dis}	Maximal charge power Maximal discharge power	2	kW
P_{buy_max}	Maximum power bought from the grid	20	kW
P_{sell_max}	Maximum power sold to the grid	35	kW
C_{bat}	Battery's capacity	20	kWh
SoC_{bat_min}	Minimal battery state of charge	10	%
SoC_{bat_max}	Maximal battery state of charge	100	%
η_{ch} η_{dis}	Efficiency coefficient of charge/discharge	95	%

5. RESULTS AND DISCUSSION

The results form a simulation of 24 hours are presented in this chapter. The change of the electricity prices, along with the total power demand form the consumers and the prosumers are shown in Fig. 3.

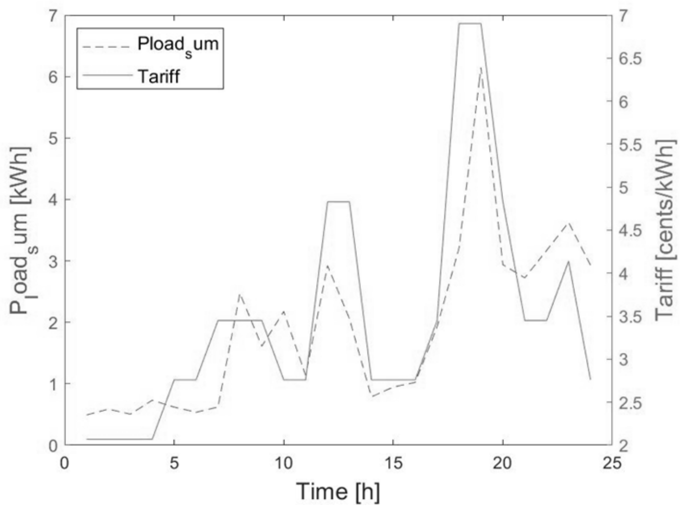

Fig. 3. Power price variations and load curve over one day (24 hours)

The Fig. 4 illustrates the unit commitment using the proposed genetic algorithm modification. Positive power exchange values of the battery denote discharging, while negative values indicate charging. Similarly, positive values with the grid signify power purchase, and negative values indicate power sale.

The graph illustrates that during periods of increased power consumption and correspondingly high electricity prices, the microgrid relies on the power stored in the battery, leading to a minimal percentage of power bought from the grid.

From the obtained results it can be concluded that the proposed algorithm obtains better results than the standard genetic algorithm when using a tournament and uniform selection. That results in increased profitability, and higher battery utilization, as summarised in Table 2. In this way, the microgrid is less dependable on the local power grid and using optimally its resources.

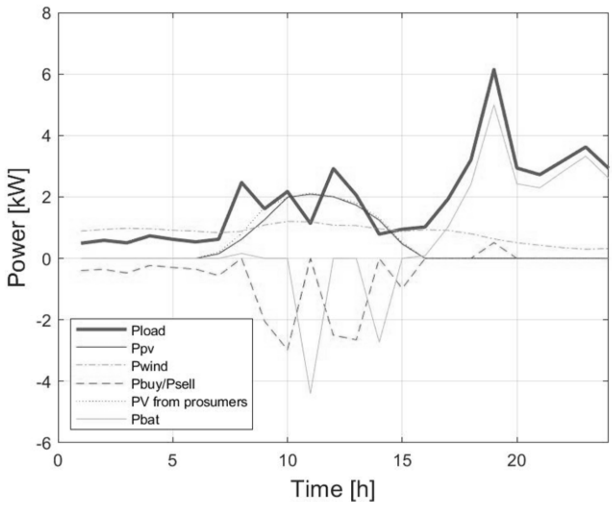

Fig. 4. Optimal unit commitment using modified genetic algorithm for α=0,9

Table 2. Comparison of the obtained results using different selection methods

Method	GA with Tournament selection	Standard GA with uniform selection	Modified GA
Total profit(€ct)	224.0605	224.0685	**224.0877**
P_{buy} (kW)	0.513	0.513	**0.513**
P_{sell} (kW)	13.817	13.816	**13.814**

6. CONCLUSION

In this paper, the optimization of a grid-connected microgrid with connected prosumers and consumers was analysed. The optimization functions include the unit commitment and voltage regulation in the critical nodes.

The paper proposes a modification of the genetic algorithm to obtain better results in the optimization process. The modification is in the selection process, and although some of the potentially good individuals are lost during this type of selection, the results show that the proposed modification provides better results than the standard selection algorithms. This validation of the improvement paves the way for further enhancement.

In future work, the research could include the usage of different types of backup systems and could analyze the demand response in real-time pricing conditions.

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Remark:

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