energies

MDPI

Article

Optimization of Active Power Losses in Smart Grids Using Photovoltaic Power Plants

Daniel Pál [1], Ľubomír Beňa [1,2,*], Michal Kolcun [1] and Zsolt Čonka [1]

[1] Department of Electric Power Engineering, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Letná 9, 04200 Kosice, Slovakia; daniel.pal@tuke.sk (D.P.); michal.kolcun@tuke.sk (M.K.); zsolt.conka@tuke.sk (Z.Č.)
[2] Department of Power Electronics and Power Engineering, Rzeszow University of Technology, 35-959 Rzeszow, Poland
* Correspondence: lubomir.bena@tuke.sk

Abstract: This article addresses the reduction of power losses in smart grids. Two optimization algorithms are used in this article. The first method is the enumerative method. The second method of the optimization calculation is based on the self-organizing migrating algorithm. In the first step, the network parameters are calculated based on the input data, and then the target function is determined. In this article, the target function is used to reduce the active power losses that occur during the operation of an electric network. More specifically, we attempt to determine the reactive power with the enumerative and SOMA algorithms to reduce the value of the active power losses. This article intends to illustrate the differences between the selected optimization algorithms. As observed, the optimization algorithm determines the computation time.

Keywords: active power losses; enumerative method; renewable energy sources; self-organizing migrating algorithm; smart grids

check for updates

Citation: Pál, D.; Beňa, Ľ.; Kolcun, M.; Čonka, Z. Optimization of Active Power Losses in Smart Grids Using Photovoltaic Power Plants. *Energies* **2022**, *15*, 739. https://doi.org/10.3390/en15030739

Academic Editors: Teuvo Suntio and Abu-Siada Ahmed

Received: 2 November 2021
Accepted: 16 January 2022
Published: 20 January 2022

1. Introduction

Nowadays, centralized electricity generation is used. Centralized generation is a form of electricity generation in which electricity is produced centrally, in large conventional power plants. Such power plants include nuclear power plants, thermal power plants, and hydroelectric power plants. Power plants are located at great distances, sometimes 100, 200, and 300 km from end users. To minimize losses in the transmission of electricity through the line, following the production of electricity, the voltage of the source is transformed to a higher voltage level. Near the consumer, the voltage is transformed back to a lower voltage level. This is primarily for safety reasons [1]. Transformation between these voltage levels generates losses that need to be minimized to achieve energy efficiency. The centralized topology has both advantages and disadvantages in terms of network operation. The advantage of this system is that electricity flows from the power plants to the consumers and this direction is still known to the system operator. The disadvantage of a centralization topology is that if a failure occurs in the topology the consumers after the failure only receive power from this direction, and this part will be left without power [2,3].

The extension of the centralized system is a decentralized system, where electricity is produced not only centrally but also close to consumers, which ensures production and consumption are as close as possible. Even in this case, a larger amount of electricity is produced in conventional central power plants. The disadvantage of this format is that once a failure occurs in the main lines, many consumers are left without electricity. For this reason, in decentralized generation, conventional power plants are extended by small power plants, which ensure that the failure of the main lines only affects the relevant part in which the failure occurred rather than the whole system [4–6]. In this case, small power plants can partially replace the missing amount of electricity because the electricity is delivered to customers from several directions. These small power plants are usually renewable energy sources, such as photovoltaics, wind turbines, or biomass.

2. Smart Grid

In the 21st century, intelligent technologies are integrated in all aspects of life and in all areas as they have become part of our daily lives, e.g., smartphones, smart clocks, smart lamps, smart cameras, smart fridges, and more [7]. Technology is constantly evolving, and new technological devices are being developed, the aim of which is to improve and facilitate life and tasks in all areas of everyday life.

The current electrical grid has evolved over many years. The current grid can no longer function properly because it was not developed for today's technologies. Recently, renewable energy sources and electric vehicles are playing an increasing role, creating obstacles for the current grid. The smart grid offers a solution that can respond to network problems and fix them automatically [8–10].

In general, considering that the definition of an intelligent network is quite problematic, as each state, each continent has a different approach to this issue. From the point of view of the European Commission's assessment, the smart grid can be described based on the following aspects:

- Flexibility—responds to consumer requirements.
- Availability—all new sources, including renewables, can be connected to the network; however, renewable energy sources cannot always generate electricity.
- Reliability—always ensures the safety and quality of the electricity supply.
- Econobility—efficient network management [11].

According to The Office of Electricity, smart grids are characterized by the following points:

- Higher efficiency in electricity transmission.
- Lower losses.
- Faster network recovery in the event of a failure.
- Reduction of operating and management costs—reduction of energy prices for consumers.
- Security—network resilience to physical or cyber interference.
- Integration of renewable energy sources [10].

3. Renewable Energy Sources

Renewable energy sources are becoming increasingly important in the production of electricity. The reserves of non-renewable resources, especially fossil fuels, are limited, so it is necessary to address the issue of new energy sources. The European Union has set a target of providing 20% of energy from renewable sources by 2020, with this production set to increase to 32% by 2030 [12,13].

Figures 1 and 2 show the trends of global changes in the installed capacity and electricity generation since 2000. These graphs are based on data from the IRENA website. The installed capacity has tripled in 20 years. This is mainly due to solar energy and wind energy, while the amount of other energy sources has increased only slightly or not at all. A similar phenomenon can be observed in electricity generation. In this case, 3000 TWh, which was in 2000, doubled in 16 years. Growth continued after this year, as shown in the graph. Most electricity is produced by hydropower plants, which account for more than half of the total electricity production from renewable sources.

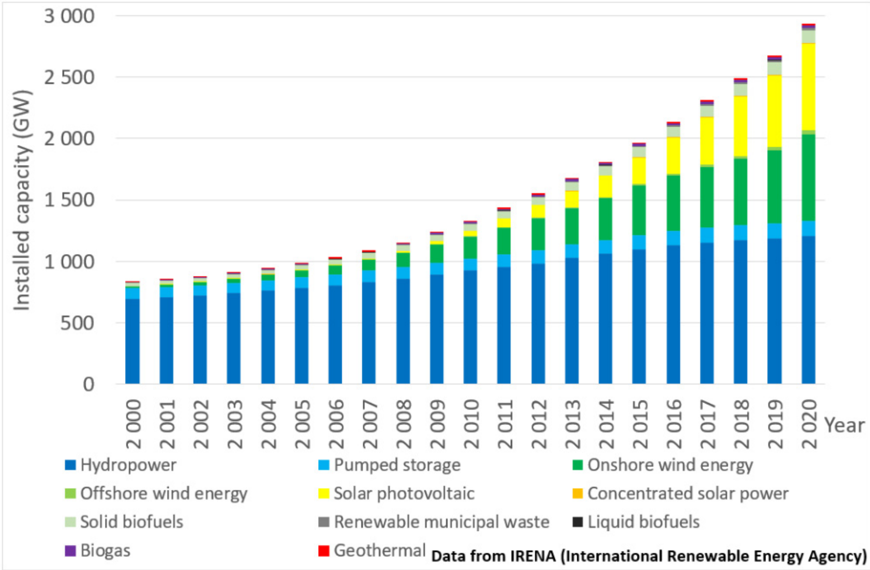

Figure 1. Global installed renewable energy capacity trend [14].

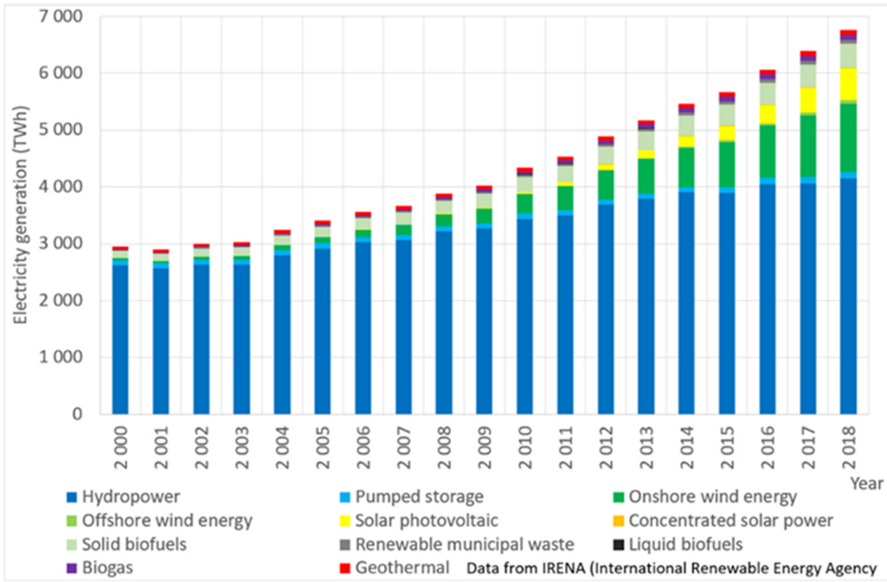

Figure 2. Global renewable electricity generation trend [14].

4. Possibilities of Active Power Loss Reduction

In this article, one of the renewable energy sources is used to reduce the loss, specifically photovoltaic power plants. As has been seen in the previous pictures, the installed capacity of these power plants has greatly increased in recent years, thus having a very large impact on the grid.

At present, photovoltaic panels have an efficiency of around 20%, but in laboratory conditions, where it is possible to set optimal conditions, such as the temperature, humidity, and solar energy gradient, the efficiency can be much higher [15,16].

Renewable energy sources with direct voltage are connected to the network via inverters [17,18], through which it is possible to influence losses in the network. Each inverter has a P-Q (working diagram). The diagram is characterized by rated active and reactive power. The P-Q diagram determines whether reactive power is supplied in parallel when active power is supplied to the network. Some inverters can supply maximum active power with zero reactive power. A reactive power supply to the network requires a limitation of the active power supply [19–22].

Another type of an inverter can supply reactive power to the grid even when the maximum active power is used [19–21], as shown in Figure 3.

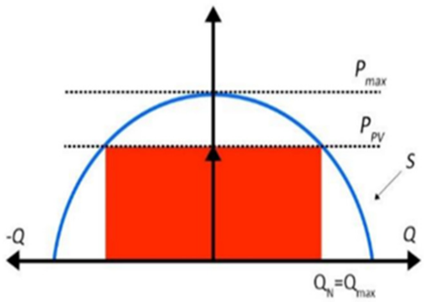

Figure 3. P-Q diagram of inverters [19].

Volt-Var Control methods can be classified into three categories:

1. Decentralized Volt-Var Control—local volt/var controllers receive local information of the power system states.
2. Centralized Volt-Var Control—central volt/var controllers receive all the information of the power system states.
3. Hierarchical Volt-Var Control—controllers are organized in a hierarchical structure. All the controllers can receive partial or all information of the power system states [23].

If voltage regulation at the point of common coupling (PCC) is required, regulation is implemented in accordance with the function shown in Figure 4.

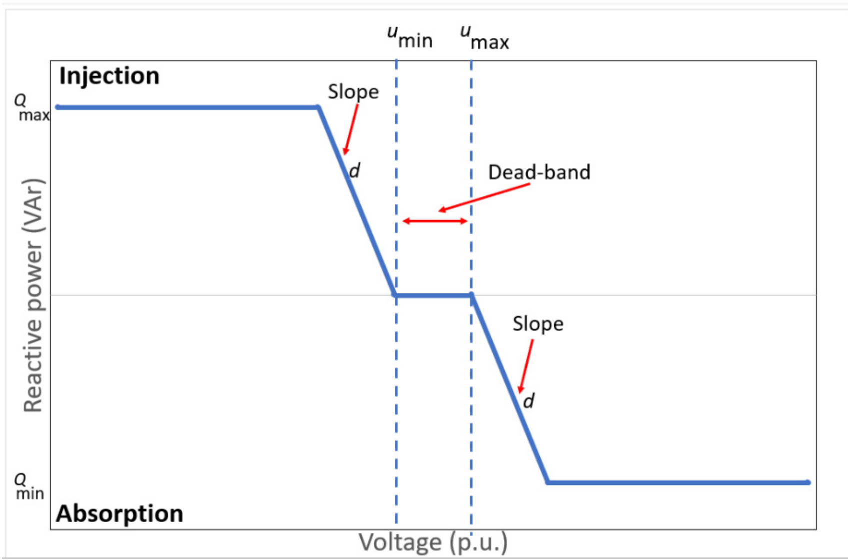

Figure 4. Voltage/Var function requirement for inverters [24].

This characteristic is defined by the following parameters:

- Q_{max} and Q_{min} represent the reactive power range of the inverter;
- u_{min} and u_{max} represent the boundaries in which there is no change in the reactive power; and
- d is a parameter that specifies the linear decrease of the curve.

The resulting injected/absorbed reactive power can be computed as follows:

$$Q_{inj} = 100 \cdot (u_{min} - u_{meas}) \cdot \frac{S_{nom}}{d} \tag{1}$$

$$Q_{max} \leq Q_{inj} \leq Q_{min} \tag{2}$$

$$Q_{abs} = 100 \cdot (u_{max} - u_{meas}) \cdot \frac{S_{nom}}{d} \quad (3)$$

$$Q_{max} \leq Q_{abs} \leq Q_{min} \quad (4)$$

where u_{meas} (p.u.) is the voltage value measured at the point of common coupling and S_{nom} is the total apparent power of the inverter.

5. Optimization of Active Power Losses

Minimization of active losses in the power system represents one of the non-linear optimization problems. These problems can be solved using suitable mathematical methods, which can be grouped as follows:

1. Classical optimization methods: these methods are based on strict mathematical techniques requiring calculation of the function gradient according to the regulated variables (for example, the projective gradient method, reduce gradient method, and sequential quadratic programming method).
2. Alternative optimization methods: these methods are a combination of classical and stochastic methods. These methods use the properties of artificial intelligence (ability to retain knowledge, and to learn and solve problems), e.g., evolution algorithms (e.g., genetic algorithms, SOMA algorithm), expert systems, and methods using artificial neural networks [25].

The goal of optimization algorithms is to identify the extreme value in a certain set of possible solutions, in which the use of suitable combinations of variants defines the desired maximum or minimum.

These algorithms must be used in cases where classical calculation methods do not achieve the required accuracy or their use for a given type of task is not possible due to the complicated definition of the calculation parameters. In the field of power engineering, it is possible to solve a very wide range of tasks using optimization methods. This article addresses the identification of the minimum active power losses in a network using two optimization methods.

5.1. Enumerative Method

This method calculates all possible combinations that may occur in a given optimization problem. For this reason, the computation time is very long, so the method is only recommended for solving simple tasks in cases where not many parameters are used. When solving more complex optimization problems, the calculation process can take several hours or days, and solving more complicated tasks with many parameters may take even longer [25].

5.2. Self-Organizing Migrating Algorithm (SOMA)

The use of numerical methods is not suitable for solving all types of optimization tasks. The use of the enumerative method is often inefficient, mainly due to the long duration of the calculation. In these cases, alternative optimization methods can be used. One such method is the SOMA method. These new optimization methods enable relatively fast (lasting several minutes to hours) solving of even complex optimization problems. When the parameters of optimization problems are exactly determined, the solution can be implemented in real time [25].

5.2.1. Self-Organizing Migrating Algorithm Parameters

Two types of parameters are used in the SOMA algorithm: control and termination. These parameters are shown in Table 1.

Table 1. SOMA parameters.

Parameter	Type	Set Parameter
PathLength	Control	1.20
Step	Control	0.05–0.10
Population size	Control	15
Migration	Termination	15
Error	Termination	10^{-6}

The individual parameters of SOMA can be characterized as follows:

1. PathLength—is the length that the active element travels until it stops at a certain distance from the leader position. The usual setting range is between 1 and 3. The most commonly used value is 3, which means that in this case, the active element can move away until its path is tripled. When set to 1, the active element reaches exactly the same position as the leader [25]; thus, the minimum value should be greater than 1. This ensures the features always move away from the leader, and that the algorithm examined the environment and, after some time, found the best solution.
2. Step—this parameter is used to sample the path of the active element [25].
3. Population size—using this parameter, it is possible to set the size of the population, which is how many elements the population consists of. Within the population, it is recommended that the minimum number is set to a value of 10, and the maximum value is defined by the problem solver [25].
4. Migration—is the first termination parameter. This parameter determines how many times it is possible to change the location of elements in the population It is recommended that its minimum value is set to 10, and the maximum value is not defined [25].
5. Error—this is the second termination parameter. It is used to set when the algorithm should end its task with a certain accuracy. The algorithm detects the difference between the leading element and the worst element [25]. Setting the error parameter is a very important task as it can be used to determine how accurately the program will perform the calculations. The dependence of the calculation time on the error is shown in Figure 9.

5.2.2. SOMA Strategies

The SOMA algorithm operates according to various strategies based on how individuals move towards others. In this article, the following four options are explained with a more detailed approach:

1. AllToOne—AllToOne is the most commonly used SOMA strategy and has been used in this article. After creating an initial population, individuals choose each other, with the best becoming a leader (LEADER). During migration, other individuals begin to move toward the leader through the steps. The step value is defined in the SOMA parameters. If, when moving towards the leader, he finds a better purpose function value, then the individual stores the value in the memory and the individual returns to its original place. With such a procedure, the individual walks the entire length of his journey, and at the end, the individual goes to the best place that has been stored in his memory. This process is repeated by each individual, again choosing the best one who will be the new leader [25]. The whole process is repeated until at least one termination parameter is met. The number of migration cycles is achieved or the difference between the best and worst individuals is less than the "error" end parameter. The principle of the AllToOne strategy is shown in Figure 5.

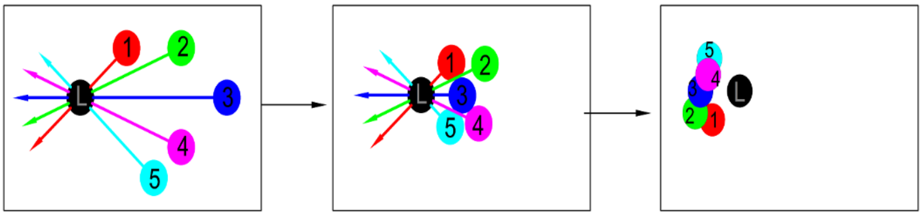

Figure 5. The principle of an all-to-one strategy [25].

2. AllToAll—the difference, compared to the previous strategy, is that after generating the initial population, individuals do not choose a leader for each other, and each individual is equal. All individuals move to all individuals (AllToAll) using a predefined step. When moving during the migration round, individuals observe whether their own actual values of the purpose function are better or worse compared to the starting positions. If they find a better one, they store the position in their memory and return to their initial position. After completing the entire journey, individuals update their positions based on their memory. In this case, the whole process is repeated until at least one termination parameter is met [25]. The advantage of this strategy is a higher likelihood of finding a global extreme due to the migration of individuals. The disadvantage is the computational complexity, as it takes longer to find the best individual in the population. The principle of an all-to-all strategy is shown in Figure 6.

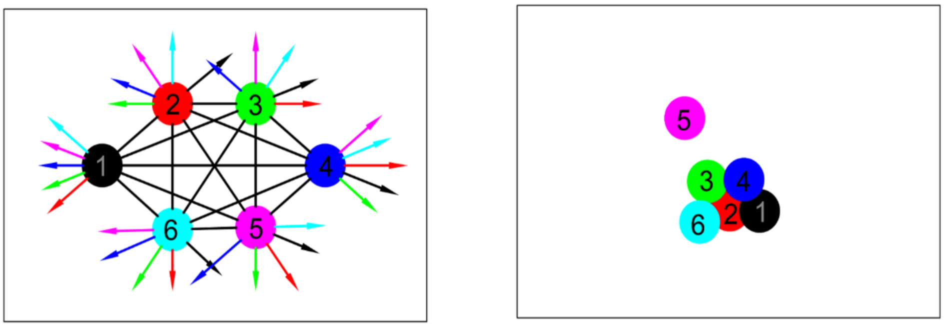

Figure 6. The principle of an all-to-all strategy [25].

3. AllToAllAdaptive—the adaptive all-to-all strategy is almost the same as the previous one. The only difference is that in this case, if the individual finds a better value in his path, he will not only memorize the position, but the position will also become his new starting position. In the next migration round, the individual starts from this position. If he finds a better one while moving, he updates the position. The whole procedure is repeated until the end of the algorithm [25].
4. AllToAllRand—this strategy is similar to the first strategy (AllToAll), except in this case, the individuals move towards the leader. The difference is that leaders are not selected on the basis of the best purpose function but are selected at random from the population [25].

6. Simulated Network

A diagram of the electrical network is shown in Figure 7. The electricity network consists of 18 nodes, which are usually consumption nodes. MV/LV transformers are connected to two nodes (5, 15). At these points, it is possible, e.g., to use inverters to change the reactive power, which will affect the node voltage and consequently the losses in the network. For the program to be able to work with transformers, the scheme is supplemented by two more nodes, namely nodes 19 and 20. The additional nodes are used to enable the use of transformer impedance. The impedances of the individual branches of the network and the impedances of the transformers are shown in Table 2. Table 3 contains the active and reactive powers in all nodes of the network.

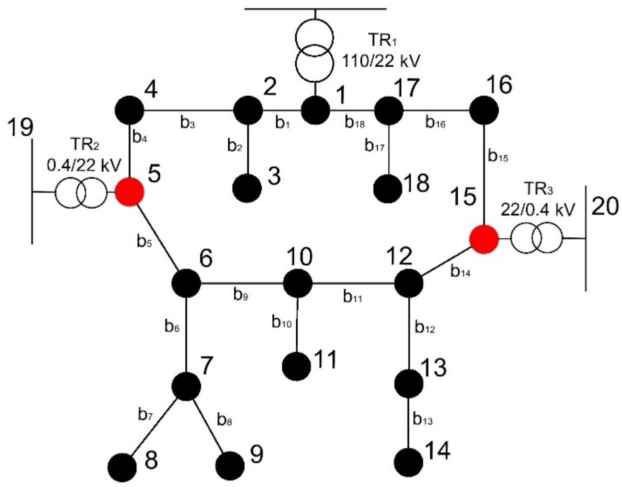

Figure 7. Simulated network diagram.

Table 2. Branch parameters.

Branch	R (Ohm)	X (Ohm)	B (Siemens)	Branch	R (Ohm)	X (Ohm)	B (Siemens)
b.1	1.500	1.650	0.174×10^{-6}	b.11	1.453	1.001	9.640×10^{-6}
b.2	2.001	1.027	9.347×10^{-6}	b.12	1.518	0.779	7.091×10^{-6}
b.3	1.200	1.320	0.139×10^{-6}	b.13	1.449	0.743	6.768×10^{-6}
b.4	1.170	1.287	0.136×10^{-6}	b.14	1.202	0.828	7.978×10^{-6}
b.5	1.904	1.311	0.126×10^{-6}	b.15	0.960	1.056	0.111×10^{-6}
b.6	2.004	1.380	0.133×10^{-6}	b.16	1.260	1.386	0.146×10^{-6}
b.7	2.208	1.133	0.103×10^{-6}	b.17	1.932	0.991	9.024×10^{-6}
b.8	1.656	0.850	7.735×10^{-6}	b.18	1.350	1.485	0.157×10^{-6}
b.9	1.904	1.311	0.126×10^{-6}	b.19—TR2	6.292	28.350	0
b.10	1.403	0.966	9.307×10^{-6}	b.20—TR3	6.292	28.350	0

Table 3. Node parameters.

Node	P (MW)	Q (MVAr)	Node	P (MW)	Q (MVAr)
1	0	0	11	0	0
2	−2	−0.3	12	−1.3	−0.1
3	−1.2	−0.15	13	−0.9	−0.15
4	−1.6	−0.2	14	−1.5	−0.1
5	0	0	15	0	0
6	−1.2	−0.1	16	−2.5	−0.4
7	−0.9	−0.1	17	−2.9	−0.4
8	−1	−0.05	18	−3	−0.5
9	−1.4	−0.25	19	1	0
10	−0.1	−0.05	20	1	0

Calculation of Steady Network Operation

Based on the parameters of the nodes and branches and based on the network topology (Figure 7), the steady state of the network is calculated. The steady state of the network is a state in which the defined parameters of the network remain unchanged until the calculation of the steady-state operation of the network is completed. In real conditions, such a state, due to variable load, climatic conditions, faults, etc., does not exist. However, simplifications can be considered in the calculations when these states and variables remain unchanged until the end of the calculation. The calculation of steady-state operation before the application of optimization algorithms is important due to the possibility of comparing the results before and after optimization. The results of the steady-state solution are shown in Table 4. As can be seen, the voltages at all nodes are within the allowable ranges. The voltage of all nodes is less than 25.3 kV and more than 20.7 kV. The lowest voltage is in the 9th node—21,007 kV. The total active loss in the network is 971 kW and the reactive loss is 993 kVAr.

Table 4. Results of the steady-state solution.

Node	Voltage [kV]	Branch	Active Power Losses [MW]	Reactive Power Losses [MVAr]
1	23.000	b.1	0.196	0.215
2	22.362	b.2	0.006	0.003
3	22.248	b.3	0.056	0.062
4	22.056	b.4	0.024	0.027
5	21.855	b.5	0.067	0.046
6	21.468	b.6	0.050	0.034
7	21.127	b.7	0.005	0.003
8	21.020	b.8	0.008	0.004
9	21.007	b.9	0.001	0.001
10	21.519	b.10	0.003	0.002
11	21.580	b.11	0.000	0.000
12	21.503	b.12	0.020	0.010
13	21.322	b.13	0.007	0.004
14	21.216	b.14	0.031	0.021
15	21.712	b.15	0.013	0.014
16	21.847	b.16	0.067	0.074
17	22.195	b.17	0.037	0.019
18	21.908	b.18	0.340	0.374
19	22.102	b.19	0.013	0.058
20	21.830	b.20	0.013	0.059
		Total losses	0.971	0.993

7. Solving the Optimization Problem

7.1. Target Function

Before solving optimization problems, it is necessary to derive the target function used to describe the goal of solving a given task. This article aims to minimize network losses. The elimination of losses results in a reduction of the financial costs by adhering to adequate values. The losses that occur in a network are expressed as the sum of the active power at all nodes of the network:

$$\Delta\dot{S} = \sum_{i=1}^{n}\left[(U_{ai} - j * U_{ri}) * \sum_{j=1}^{n}\left(U_{aj} + j * U_{rj}\right) * \left(g_{ij} - j * b_{ij}\right)\right], \tag{5}$$

$$\Delta P = \sum_{i=1}^{n} P_i = \sum_{i=1}^{n} U_{ai} * \sum_{j=1}^{n} \left(U_{aj} * g_{i,j} + U_{rj} * b_{i,j} \right), \tag{6}$$

where S is the apparent power, U_a is the active part of the voltage at the i-nodes, U_r is the reactive part of the voltage at the i-nodes, g_{ij} is the real component of the nodal admittance matrix, b_{ij} is the imaginary component of the nodal admittance matrix, and P is the active power.

The following constraints are used in the calculations:

- The voltages in the nodes are $\pm 10\%$ of the voltage at the balance (in the first) node. The voltage at the balance node has a value of 23 kV; therefore, it is necessary to maintain a voltage of 20.7–25.3 kV.
- The value of the reactive power at the control nodes is 0–1 MVAr.

7.2. Research Limitations

In our program, two optimization algorithms are used: the enumerative method and the SOMA algorithm. With both optimization algorithms, any network can be solved, regardless of the mains voltage, the number of nodes, or the number of wires.

Current constraints include an insufficient computing capacity. The larger the network, the longer the calculations; therefore, the use of more powerful computers would enable a comparison of increasingly larger networks.

The other limitation is that currently, the program cannot calculate tasks in real time. With the development of the program, which we are constantly developing, it will be possible to make real-time calculations.

7.3. Solving the Optimization Problem by the Enumerative Method

In this method, all the combinations that may occur when solving the task are calculated. The enumerative method of solving a problem has several advantages and disadvantages. One advantage is that the algorithm works with simple commands; thus, there is no need to define complex functions, and the principle of the calculation can be relatively easily understood. The biggest disadvantage of this solution is the computational time, which ranges from a few minutes to several hours.

In this case, the value of the reactive power could be influenced simultaneously at two places, namely at the 5th and 15th nodes. The results of the steady-state solution using the enumerative method after the optimization calculation are shown in Table 5. The calculations show that the values of the ideal reactive power at the first control node must be set to 0.52 MVAr and to 0.58 MVAr at the second control node. If these values are set, the active losses are reduced to 0.958 MW and, at the same time, the voltages are higher at the nodes. The calculation time is 628.77 s.

Table 5. Results of the steady-state solution using the enumerative method after optimization calculation.

Node	Voltage [kV]	Branch	Active Power Losses [MW]	Reactive Power Losses [MVAr]
1	23.000	b.1	0.192	0.211
2	22.401	b.2	0.006	0.003
3	22.287	b.3	0.055	0.060
4	22.127	b.4	0.023	0.025
5	21.956	b.5	0.067	0.046
6	21.571	b.6	0.049	0.034
7	21.232	b.7	0.005	0.003
8	21.125	b.8	0.008	0.004

Table 5. *Cont.*

Node	Voltage [kV]	Branch	Active Power Losses [MW]	Reactive Power Losses [MVAr]
9	21.112	b.9	0.001	0.001
10	21.622	b.10	0.003	0.002
11	21.683	b.11	0.000	0.000
12	21.606	b.12	0.019	0.010
13	21.426	b.13	0.007	0.004
14	21.321	b.14	0.030	0.021
15	21.814	b.15	0.012	0.013
16	21.920	b.16	0.065	0.071
17	22.233	b.17	0.037	0.019
18	21.947	b.18	0.334	0.367
19	22.849	b.19	0.016	0.071
20	21.931	b.20	0.013	0.059
		Total losses	0.958	0.998
Calculation time [s]:		628.77		Ideal reactive power according to the calculation [MVAr]
Number of calculated combinations		10,000	Node 5	0.52
			Node 15	0.58

The functional dependence of the active power losses on the regulated variables in three-dimensional space considering the regulation of reactive power at the same time at two different places is shown in Figure 8. In any case, with suitable combinations of reactive power, it is possible to achieve a minimum total active loss in the network. The minimum occurs if 0.52 MVAr power is set at the 5th node and 0.58 MVAr at the 15th node. Then, the total active loss is 0.958 MW.

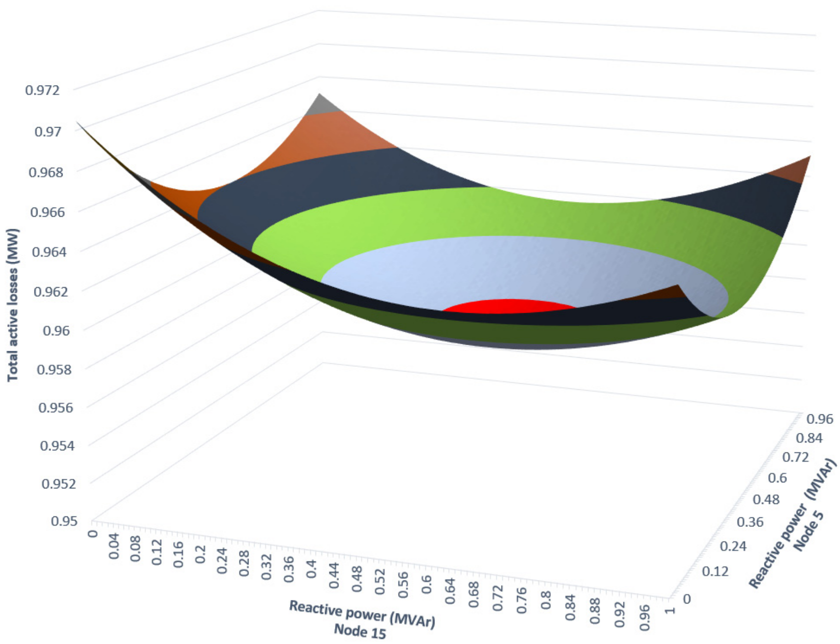

Figure 8. Dependence of the total active losses on the reactive power.

7.4. Solving the Optimization Problem Using the SOMA Algorithm

In this case, the SOMA (self-organizing migration algorithm) algorithm, which is an optimization algorithm, is used in the calculations. Like all other optimization methods, the SOMA algorithm has both positive and negative aspects. The advantage of this algorithm is its high calculation speed, while the appropriate setting of its parameters leads to quality results being obtained. The negative aspect of the SOMA algorithm is the relatively demanding calculation process and also the fact that inappropriate parameter setting can lead to the identification of only the local rather than the global minimum.

In our program, it is possible to use standard settings in the calculations. The disadvantage of using default values is that the calculation time is longer. Therefore, the settings for a specific network should always be updated so that the best computing time for the network is achieved.

Even in this case, it is possible to use two nodes at the same time to influence the network losses. The optimal reactive power in these two places must be set to a value of 0.555 MVAr, thus minimizing the total active losses in the network. With 0.555 MVAr values, losses are reduced to 0.958 MW. The calculation time in this case is 8.51 s. The results of the steady-state solution using the SOMA algorithm are shown in Table 6.

Table 6. Results of the steady-state solution using the SOMA algorithm after optimization calculation.

Node	Voltage [kV]	Branch	Active Power Losses [MW]	Reactive Power Losses [MVAr]
1	23.000	b.1	0.192	0.211
2	22.402	b.2	0.006	0.003
3	22.287	b.3	0.055	0.060
4	22.128	b.4	0.023	0.025
5	21.959	b.5	0.067	0.046
6	21.573	b.6	0.049	0.034
7	21.234	b.7	0.005	0.003
8	21.127	b.8	0.008	0.004
9	21.114	b.9	0.001	0.001
10	21.623	b.10	0.003	0.002
11	21.684	b.11	0.000	0.000
12	21.606	b.12	0.019	0.010
13	21.426	b.13	0.007	0.004
14	21.321	b.14	0.030	0.021
15	21.813	b.15	0.012	0.013
16	21.921	b.16	0.065	0.071
17	22.233	b.17	0.037	0.019
18	21.946	b.18	0.333	0.367
19	22.894	b.19	0.016	0.071
20	21.932	b.20	0.013	0.059
		Total losses	0.958	0.998
Ideal reactive power according to the calculation [MVAr]			0.555	
Calculation time [s]:			8.507	

As shown in Figure 9, the error parameter greatly affects the calculation time. When the error value is high (from 10^{-1} to 10^{-6}), the calculation time is relatively fast, with a maximum of 10 s. In this investigated example, the switching point occurs when the error value reaches 10^{-7}. At this point, the calculation time suddenly increases almost 10-fold. If the value of the error has to be increased to achieve a more accurate result, the calculation time may increase several times. It is important to emphasize that this graph only applies to this example. In other examples, the switching point is located elsewhere.

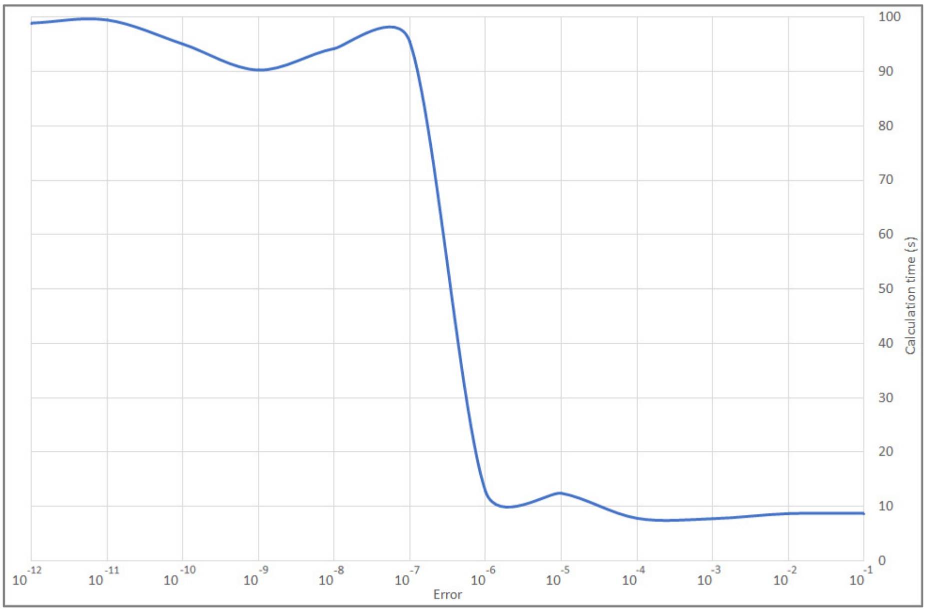

Figure 9. Dependence of the calculation time on error.

8. Conclusions

The main goal of this paper was to present optimization algorithms that can be used to solve problems occurring in the operation of a network. Using optimization algorithms, it is possible to identify the optimal value of reactive power at selected nodes, which it is influences the power losses in a network. It was found that the value of the total effective loss changed with the reactive power. With both optimization algorithms, we found that the loss was reduced by 1.34%. This is essentially negligible for such a small network but may be higher for larger networks. As shown in this article, both methods—enumerative and SOMA algorithm—have advantages and disadvantages. It is always necessary to choose the method that is most ideal for the solved problem. The results showed that in this case, a program based on the SOMA algorithm is more appropriate because the results of the ideal reactive power were almost identical while the computation time of the SOMA algorithm was 70 times lower.

For the program to be used in real life, we assume that the calculations will be performed in a central control room that will communicate with other sources in the network.

Author Contributions: Conceptualization, D.P. and L'.B.; methodology, D.P.; software, D.P.; validation, D.P., L'.B. and M.K.; formal analysis, D.P.; investigation, L'.B.; resources, D.P. and Z.Č.; data curation, D.P.; writing—original draft preparation, D.P and L'.B.; writing—review and editing, D.P and L'.B.; visualization, D.P. and Z.Č.; supervision, L'.B.; project administration, M.K.; funding acquisition, M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Slovak Research and Development Agency under the contract No. APVV-19-0576 and the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences under the contract no. VEGA 1/0757/21.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Electricity Explained, How Electricity Is Delivered to Consumers. Electricity Is Delivered to Consumers through a Complex Network. Available online: https://www.eia.gov/energyexplained/electricity/delivery-to-consumers.php (accessed on 30 August 2021).
2. Bouffard, F.; Kirschen, D.S. Centralised and distributed electricity systems. *Energy Policy* **2008**, *36*, 4504–4508. [CrossRef]
3. Lost in Transmission: How Much Electricity Disappears between a Power Plant and Your Plug? Available online: http://insideenergy.org/2015/11/06/lost-in-transmission-how-much-electricity-disappears-between-a-power-plant-and-your-plug/ (accessed on 30 August 2020).
4. Innovations and Decentralized Energy Markets? Available online: https://www.thecgo.org/research/innovations-and-decentralized-energy-markets/ (accessed on 1 September 2021).
5. Zhou, Y.; Cao, S.; Hensen, J.L.; Lund, P.D. Energy integration and interaction between buildings and vehicles: A state-of-the-art review. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109337. [CrossRef]
6. Zhou, Y.; Cao, S. Coordinated multi-criteria framework for cycling aging-based battery storage management strategies for positive building—Vehicle system with renewable depreciation: Life-cycle based techno-economic feasibility study. *Energy Convers. Manag.* **2020**, *226*, 113473. [CrossRef]
7. Internet of Things, Mikko Hyppönen: Smart Devices Are "IT Asbestos". Available online: https://www.verdict.co.uk/mikko-hypponen-smart-devices-it-asbestos/ (accessed on 1 September 2021).
8. The Smart Grid Could Hold the Keys to Electric Vehicles. Available online: https://innovationatwork.ieee.org/the-smart-grid-could-hold-the-keys-to-electric-vehicles/ (accessed on 27 August 2021).
9. Smart Grids: What Is a Smart Electrical Grid—Electricity Networks in Evolution. Available online: https://www.i-scoop.eu/industry-4-0/smart-grids-electrical-grid/ (accessed on 25 August 2021).
10. The Smart Grid. Available online: https://www.smartgrid.gov/the_smart_grid/smart_grid.html (accessed on 25 August 2021).
11. European Smart Grids Technology Platform. *Vision and Strategy for Europe's Electricity Networks of the Future*; European Smart Grids Technology Platform: Brussels, Belgium, 2006; pp. 1–38.
12. 2020 Climate & Energy. Available online: https://ec.europa.eu/clima/policies/strategies/2020_en (accessed on 1 September 2021).
13. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the Promotion of the Use of Energy from Renewable Sources. Available online: https://eur-lex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32018L2001&from=SK (accessed on 1 September 2021).
14. Solar Energy. Available online: https://www.irena.org/solar (accessed on 1 September 2021).
15. Most Efficient Solar Panels: Solar Panel Cell Efficiency Explained. Available online: https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/ (accessed on 25 August 2021).
16. What Are the Best Solar Panels Available? Top Brands and Products Compared. Available online: https://news.energysage.com/best-solar-panels-complete-ranking/ (accessed on 25 August 2021).
17. Dec, G.; Drałus, G.; Mazur, D.; Kwiatkowski, B. Forecasting Models of Daily Energy Generation by PV Panels Using Fuzzy Logic. *Energies* **2021**, *14*, 1676. [CrossRef]
18. Dralus, G.; Mazur, D.; Gołębiowski, M.; Gołębiowski, L. One Day-Ahead Forecasting at Different Time Periods of Energy Production in Photovoltaic Systems Using Neural Networks. In Proceedings of the 2018 International Symposium on Electrical Machines (SME), Andrychow, Poland, 10–13 June 2018; pp. 1–5.
19. Crisp, J.; Sharma, R.; George, T.; Hagaman, S.; Nguyen, H. Solar Inverter Interactions with DC Side. Available online: https://www.digsilent.com.au/publications/2018/papers/Solar%20inverter%20interactions%20with%20the%20DC%20side%20V3.pdf (accessed on 1 September 2021).
20. Ivas, M.; Marušić, A.; Havelka, J.G.; Kuzle, I. P-Q capability chart analysis of multiinverter photovoltaic power plant connected to medium voltage grid. *Int. J. Electr. Power Energy Syst.* **2020**, *116*, 105521. [CrossRef]
21. Ali, A.; Raisz, D.; Mahmoud, K. Sensitivity-based and optimization-based methods for mitigating voltage fluctuation and rise in the presence of PV and PHEVs. *Int. Trans. Electr. Energy Syst.* **2017**, *27*, e2456. [CrossRef]
22. Golebiowski, L.; Gołębiowski, M.; Mazur, D. Inverters operation in rigid and autonomous grid. *COMPEL—Int. J. Comput. Math. Electr. Electron. Eng.* **2013**, *32*, 1345–1357. [CrossRef]
23. Li, Q.; Zhang, Y.; Ji, T.; Lin, X.; Cai, Z. Volt/Var Control for Power Grids with Connections of Large-Scale Wind Farms: A Review. *IEEE Access* **2018**, *6*, 26675–26692. [CrossRef]
24. Gubert, T.C.; Colet, A.; Casals, L.C.; Corchero, C.; Domínguez-García, J.L.; Sotomayor, A.A.d.; Martin, W.; Stauffer, Y.; Alet, P.-J. Adaptive Volt-Var Control Algorithm to Grid Strength and PV Inverter Characteristics. *Sustainability* **2021**, *13*, 4459. [CrossRef]
25. Davendra, D.; Zelinka, I. Self-Organizing Migrating Algorithm, Methodology and Implementation. In *New Optimization Techniques in Engineering*; Springer International Publishing AG: Cham, Switzerland, 2016; ISBN 978-3-319-28159-9. Available online: https://link.springer.com/book/10.1007%2F978-3-319-28161-2 (accessed on 1 September 2021).