Project co-financed by the European Social Investment through the Sectoral Operational Program for Human Resources Development 2007 – 2013
Project title: Promoting science and quality in research through doctoral scholarships
Contract Code: 155420

UNIVERSITY **POLITEHNICA** OF BUCHAREST
Faculty of Power Engineering
Decision No. 657 / 29.03.2021

SUMMARY OF DOCTORAL THESIS

CONTRIBUTIONS TO THE STUDY OF ELECTRIC DISTRIBUTION NETWORKS IN THE PRESENCE OF RENEWABLE ENERGY SOURCES USING PROBABILISTIC CALCULATION TECHNIQUES AND METAHEURISTIC ALGORITHMS

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ACKNOWLEDGEMENTS

On the occasion of completing this stage of my life, I would like to convey some thoughts of thanks to those who guided me and provided my support throughout the development of the doctoral study work.

The doctoral thesis is the result of the effort and the work sustained over a period of several years under the permanent guidance of the doctoral supervisor Professor Emeritus Mircea Eremia, to whom I owe gratitude for the rigour, scientific advice and constructive critical observations received at every stage of my doctoral training stage.

Next, I express my gratitude to the members of the guidance committee for the advice and the suggestions offered. I would particularly like to thank Professor Ion Triștiu and Associate

Professor Lucian Toma for support, and especially for the motivation and trust they gave me throughout my studies period. I also address words of gratitude to Professor Emeritus Nicolae Gonovanov, Professor Constantin Bulac, as well as Associate Professor Mihai Sănduleac for the relevant and constructive advice provided during the support of scientific reports presetend in the department. A thought of thanks goes to Lecturer Dorian - Octavian Sidea for all the support received during the research activity.

Thank you to all my colleagues in the Department of Power Systems of the Univesity Politehnica of Bucharest for their moral support. I also send a message of thanks to my former colleagues at SC&DC SRL, as well as to my current colleagues at E-Distribution Muntenia SA for their generosity and knowledge sharing.

I am grateful for the financial support I have received through the Sectoral Operational Programme for Human Resources Development 2007 – 2013, Contract No. POSDRU/187/1.5/S/155420.

In particular, I would like to express my gratitude and respect for my family for the love, understanding and encouragement they offered.

KEYWORDS

Renewable energy sources; electric distribution network; wind and photovoltaic power plant; probabilistic load flow computation; Genetic algorithms; Grey Wolf Optimizer algorithm; Marine Predators algorithm.

ABSTRACT

The energy section is one of the most important physical concepts for understanding and analysing processes within power systems.

The Earth receives solar energy as radiation from the sun in an amount that far exceeds human use. By warming the planet, the sun generates wind. The wind creates waves, and the sun favours turning water into vapours. Hydraulic energy is also one of the most important renewable energy sources currently in use. Plants photosynthesize, which is essentially a chemical storage of solar energy. Thus, a wide range of so-called biomass products is created, which can be used for the production of electricity, heat and liquid fuels. Interactions between the Sun, Moon and Earth also produce tidal flows that can be intercepted and used to produce electricity. Renewable energy sources (RES) are based on the natural flows and interconnected energy flows of our planet.

Although people have had access for their needs for hundreds of years to most types of renewable sources (sun, wind, water, etc.) only a small part of the technical and economic potential of energy from these non-fossil sources has been acquired and exploited. Using new modern technologies, renewable energy sources offer increasingly cost effective alternatives for all human energy needs. The renewable energy sector has become the most important force for a sustainable economy in the 21st century.

Dealing not only with an economic crisis, caused either by local political disputes or caused by various health crises (Ebola, coronavirus etc.), but also the challenge of climate change, increasing dependence on imports and rising fossil fuel prices, are an urgent issue for which viable alternatives must be found. These solutions will have to help us, in the medium and long term, on how to conserve economic and social livelihoods, but also to maintain a balanced ecological system. By promoting renewable energy technologies, we will be able to address both security of

energy supply and the effects of climate change, while creating a sustainable, forward looking economy.

The field of electricity in Europe and the world is going through transitional stages including decarbonisation and liberalisation of the energy market. The first measures at European level to promote renewable energy sources (RES) were imposed in 1997, with the publication of the European Union White Paper on increasing the contribution of RES to the energy used. The European Union (EU) has set among the main objectives that, by 2010, 12% of electricity consumption should come from non-fossil sources of energy, and in Directive 2001/77/EC guidelines have been established for each EU member state.

The development and use of renewable energy technologies in the European Union began with the adoption of the directive on promoting the use of renewable energy, which included the famous 20% thresholds for all Member States in 2009. It required each Member State to cover 20% of its renewable energy consumption by 2020, to achieve a 20% improvement in energy efficiency and to reach a minimum of 10% in the share of biofuels in the consumption of fossil fuels used in transport.

In order to achieve the objectives set out in the Paris Agreement, the European Union has set new directions on energy and climate for 2030 [1]. Thus, the elaboration of Directive 2009/28/EC on "promoting the use of energy from renewable sources" is followed by the publication of new legislative packages, one of which the most important is the coverage of 32% of RES in the electricity consumption. Therefore, the integration and increase in the number of renewable energy sources will lead to new challenges in the design, development and operation of electric networks.

A central point in the "European Green Deal" is the actions that are being considered for improving and protecting the environment. The main objective, starting with 2020, was to reduce greenhouse gas emissions, and a plan of measures to reduce them by at least 55% by 2030. Further, the challenge for Europe is the aim of becoming the first climate - neutral continent in 2050 [1]. Therefore, the energy transition that will take place will contain:

- "decarbonisation" by increasing the number of renewable energy sources within energy power systems;
- "development of electrification" together with the challenges arising from the urbanization of the sectors where various users are connected (captive and industrial consumers etc.);
- "decentralisation" correlated with distributed generation and new trends in flexibility due to intelligent electric vehicle charging;
- "digitalisation" which is an integral part of smart grids, as well as the importance of Cyber - Security applications;
- "democratisation" by supporting all segments of society in the development and monitoring of power systems;
- "dynamics" reflecting the exchange of information using easy-to-use IT platforms.

The renewable energy sources with the highest global and national share are wind and photovoltaic power plants. The support schemes chosen have led to the integration of a large number of these types of sources. Smart Grids have also begun to take shape and fulfil different roles in achieving the objectives of energy and environment policies: ensuring security in electricity supply, increasing the quality of the electricity supply service, economic efficiency in a more complex market environment, and increasing the share of energy from renewable sources. An important strategy for the development of energy systems is the progressive introduction of the concept of Smart Grids.

The Lisbon Strategy outlines the general principles on smart grids for the horizon of 2020 and beyond [2,3]: flexibility, reliability, accessibility and economy. The first two requirements, namely flexibility and reliability, respond to the imperative need to adapt electricity grids to the requirements of customers (both consumers and producers) in the short term, and to address the challenges that may arise from the rapid evolution of modern technologies within developed companies. These requirements must also ensure high performance standards for the supply of electricity to consumers. The economy of smart grids requires ensuring an optimal energy mix that is also needed to include renewable energy sources. They will have an influence on the costs of generating and transporting electricity. The third general requirement, accessibility, must ensure that all users can connect to the electric network, in particular for distributed energy sources. Thus, it is a priority to maintain and improve measures on the integration of RES, to improve the controllability of electricity distribution and transmission networks, to encourage active consumers etc. From this concept derives two perspectives: one oriented to the consumer and the other to the electric network.

Climate change due to pollution, reducing the availability of fossil fuels, combined with the prospect of increasing energy demand, have created the framework for the development, integration and operation of renewable energy sources within the electric networks. European policies have succeeded, through the objectives proposed in recent decades, to increase the share of these non-fossil energy sources. Among the most recent proposals of the 'European Green Pact' are those relating to the „European Climate Law" and the „Clean Energy Package for all Europeans".

The transition of distribution networks to active electric networks centres on an approach that focuses mainly on the consumer who is actively involved and has the freedom to make decisions about the possibilities and options he has regarding: the installation of equipment for the production of electricity from renewable sources or from high-efficiency cogeneration, of low power; storage devices; conclusion of a competitive supply contract. The first step was taken with the liberalisation of the energy market starting with 1 January 2021, at which point domestic customers were able to identify a competitive supply offer that meets their needs best.

The most important priorities for modernising electric networks, according to the second approach, are: developing the infrastructure of electric networks, increasing the share of renewable energy sources and optimising the functioning of electric networks [4].

Optimizing the operation of electric networks is the ability to use existing infrastructure as efficiently as possible. It can be addressed in two ways: from a technical and economic point of view.

The connection of wind and photovoltaic power plants to the distribution networks and not only, is mainly determined by the essential conditions of the primary energy sources (wind and sun), but also by the availability of the land, the distance from the injection point into the power system, the possible reinforcements of the electric networks etc. It is possible to consider a proposal on certain support schemes offered to renewable energy producers. To this end, it is possible to grant a percentage, through a bonus, to those who, by implementing these types of projects in the distribution networks, manage to technically optimize the electric network (optimal location and sizing with different objective functions in terms of minimizing energy losses, reactive power control etc.). In general, renewable energy sources are located in areas that are characterized by favourable weather conditions for the production of electricity.

Through these support schemes, the transmission operator and the distribution operators will be able to accomplish several objectives. These may include:

- improving of the distribution or transport service (reducing the duration and average frequency of interruption);
- reducing own technological consumption;

- reducing the load of several network elements and programming investments for the development and optimization of the electrical networks structure.

Improving the infrastructure of the electric networks is a necessary measure in the situation of increasing energy demand.

Issues such as congestion caused from the increase in the number of new consumers in major consumption centres or in generation energy zone lead to the need for investments to increase the transmission capacity of electric networks. In order to achieve this goal, it is proposed: extensions of electrical substations by amplification or installation of new higher power transformers and retrofitting of existing overhead or underground power cables. If the measures listed are not sufficient, solutions may be required to establish new transformer substations or to build new power lines. Therefore, distribution networks will need to be prepared for the integration of distributed sources, active consumers and electric vehicles.

Currently, dispatch centres monitor the state of electrical networks including power lines, power transmission and distribution stations, power plants. Intelligent dispatch centres will be able to incorporate the telecontrol system of the entire distribution networks with the monitoring systems of renewable sources (dispatchable and non-dispatchable) and with the classic manufacturers. Thus, one can define and develop the concept of microgrid. Distribution networks will be transformed from passive networks into active networks in the sense that decision - making and control are distributed, and power flow can be bidirectional. Also, the function of an active distribution network is to efficiently interconnect production sources with electricity users, thus allowing them to function optimally, in real time. This will take place under the conditions of the existence of a high-performance telecommunications infrastructure. Among the main challenges can be: allocation of communication channels, computer security, redundant equipment etc.

Distribution networks have a large number of consumers and, with the connection of renewable energy sources in the context of the development of smart electrical networks, the tracking and accuracy of permanent operating regimes reach new challenges.

The study of possible operating regimes is the main purpose in the planning and programming stages that are carried out to determine the optimal operating regimes, from a technical and economic point of view, respecting all restrictions, regulations and safety conditions.

The load flow computation from a determinist perspective will choose certain initial conditions considered representative (usually the maximum, average and minimum active powers) for which the operating regimes are calculated. These may lead to an incomplete image of the results obtained.

Given the wide variability of the power generated, as well as the random participation in the coverage of the production curve, studies on the functioning of the electric networks are based on the probabilistic load flow computation. This approach can use: Monte Carlo simulations, analytical and approximation methods [5, 6, 7].

The analysis of the distribution network in the presence of one or more renewable energy sources can be carried out using modern research means including indicators, functions and statistical methods [8]. They help to obtain a clearer overview of the main state quantities (voltage magnitude, currents, power losses). A load flow calculation for a distribution electric network, based on known recordings of the energy meters such us the average hourly active and reactive powers of consumers and the active powers injections from renewable energy sources for one year is studied in [45].

The implementation of probabilistic computation techniques is also applied in medium - and long - term appropriateness studies for the functioning of the electric power system. The Monte -

Carlo method can be used for random generation of consumption, balance and injected / power injection of generetaros. Sensitivity analyses can also be obtained for different analysis scenarios containing system reserves by adjustment type and sources [9,60].

In [66] a modelling solution of load curves using algebraically polynomials linear, parabolic and third order was studied. Also, there are studies in literature which are based on the analysis of the influence and determination of different functions for modeling the wind, respectively the solar irradiation [68, 71].

Planning the development and operation of electric networks in the medium and long term requires knowledge, not only of the evolution of electricity consumption, but also of the operation of renewable energy sources in view of the increase of their connection in low and medium voltage distribution networks.

The research carried out in this thesis aimed at assessing the impact of the integration of RES on the load flow computation and the study of the optimal location and sizing of photovoltaic power plants. The first objective is to study wind and photovoltaic power plants in distribution networks, with the aim of probabilistic load flow based on the fact that the input data are defined by means of probability density functions. The second objective is to solve the optimization problem which uses three metaheuristic algorithms for the optimal location and sizing of photovoltaic power plants.

The doctoral thesis is structured in six chapters, which are thus structured and articulated, to ensure coherence, consistency and clarity. A relevant bibliographic list and annexes are added to them.

In the first chapter "Introduction" are presented the main challenges that led to the appearance of renewable sources. Solutions to overcome the current context, including finding an alternative from the perspective of the consumption of fossil fuels on the one hand and halting the evolution of climate change on the other, as well as the implementation of the concept of smart grids, lead to a gradual process of integration of renewable energy sources.

Chapter two "Renewable energy sources" aims to describe on fossil energy sources, especially those with the highest integration share at global and national level, wind and photovoltaic power plants. The main types of wind generators as well as photovoltaic panels are presented. Aspects concerning the connection of renewable energy sources to the distribution networks, as well as the impact of these non-fossil energy sources, are analysed. Also the technical part of the regulations and the way of operation, respectively the operation of wind and photovoltaic power plants for different adjustment strategies is presented.

The directive, which is based on the Clean Energy for All Europeans programme, proposes a new main objective to be implemented by 2030. The aim is for RES to reach 32% of final electricity consumption.

Chapter three entitled "Analysis of the impact of wind and photovoltaic power plants on the load flow computation" describes the calculation of the load flow using the Newton - Raphson method. The first part addresses the deterministic computation of the operating regime which is based on the fact that the input parameters necessary to solve the problem are considered to have a fixed value for each working regime. A research is carried out on the operation of the distribution network and on the influence that the connection of two renewable sources has on lines loading, voltage magnitude and active power losses. A flow chart explaining the load flow computation algorithm used to perform the study is presented in figure 1.

In the second part, the probabilistic load flow by which loads, respectively renewable energy sources, will be modelled using probability density functions is presented. Finally, the changes that occur by integrating probabilistic models into the load flow programme developed in Matlab for the analysis of the operating regime are described.

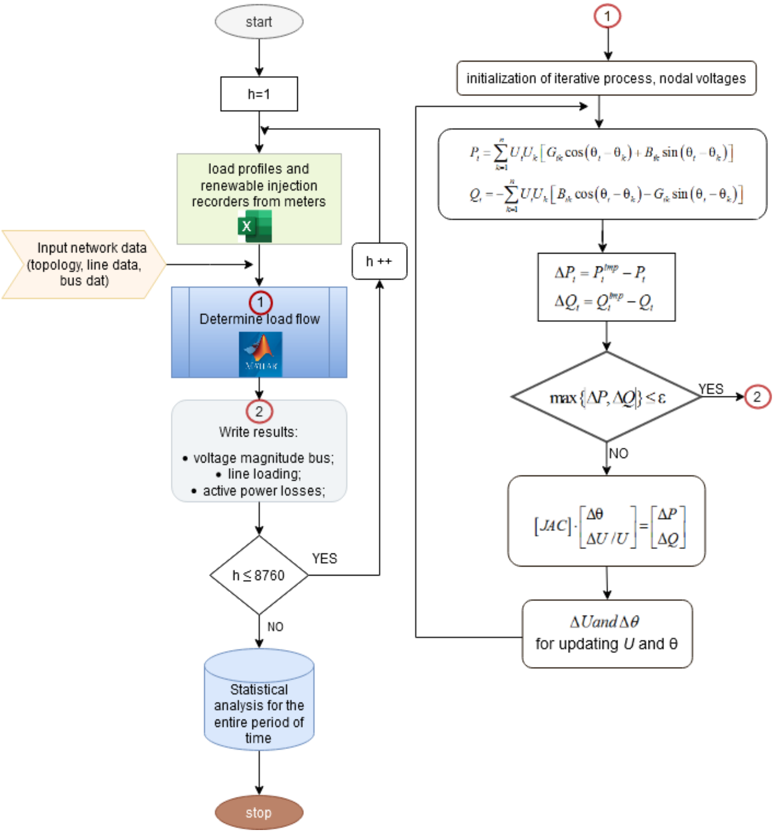


Fig. 1. Flow chart of the algorithm.

The statistical models used for loads, wind and PV system are defined using the probability density functions. Monte Carlo simulations (MCS) artificially generate values of a probability distribution by using in each simulation an independent set of random variables.

The general sequence used to obtain the random variables consists of [77]:

Step 1. Reading and managing measured input variables;

Step 2. Computing probability density function with maximum likelihood estimation;

Step 3. Extracting specific parametres corresponding to the studied function;

Step 4. Generating random variables.

Figure 2 illustrates the flow chart explaining the probabilistic load flow (PLF) algorithm used.

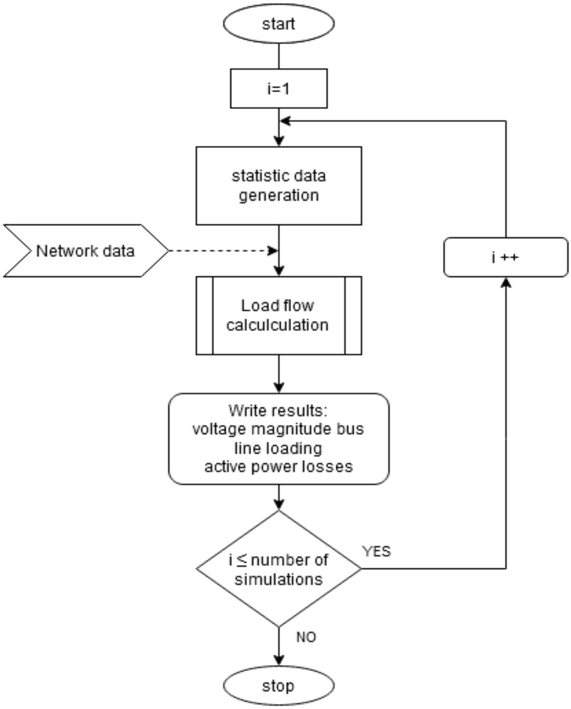


Fig. 2. Flow chart of the PLF algorithm using Monte Carlo method.

The algorithms described are applied to a medium voltage distribution electric network Test 1 - 20 kV which is specific to a suburban area of Bucharest. It ensures supply to 10 consumers through 11 underground cables and it is showed in figure 3.

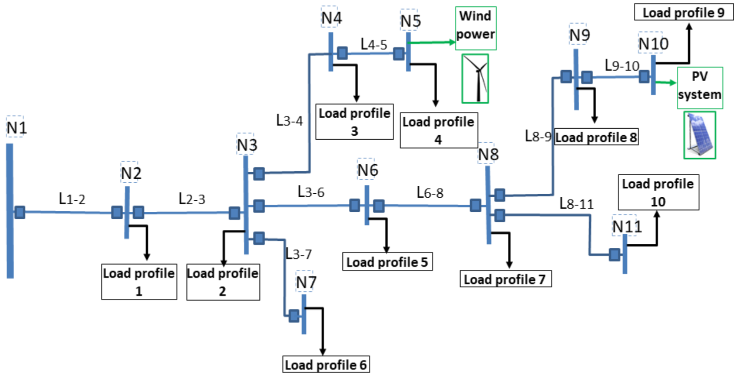


Fig. 3. Direct distribution network Test 1 - 20 kV.

Chapter four entitled "Optimal determination of the location and power of photovoltaic power plants using metaheuristic algorithms" presents the mathematical model behind the realization of an optimization calculation program, using an evolutionary algorithm (genetic algorithm) and two algorithms of biological inspiration (the optimization grey wolf algorithm and the marine predators algorithm). The formulation of the optimization problem is based on the optimal determination of the PV systems connection node in the distribution network, as well as the value of the maximum injected active power, in order to minimize active power losses.

The metaheuristic algorithms can be divided, by their inspiration source, into three main classes: evolutionary, physics-based and swarm intelligence. Genetic algorithms (GA) represent the most popular method from the first class [84]. Applications of GA can also be found in optimization problems specific to power systems, from power losses reduction [90, 91], determination of the parameters of photovoltaic cells and panels [92] to optimal FACTS devices placement [95, 96].

Grey Wolf Optimizer (GWO) algorithm was developed by Mirjalili et al. in [101] and represents a novel swarm-based metaheuristic technique. It was inspired by the the grey wolf's hunting behavior and technique. The algorithm is applied in optimization models for load flow computation that includes renewable energy sources [102, 103] and voltage stability [105].

The Marine Predators algorithm (MPA) has been developed by Faramarzi et al. in [109] and represents a novel swarm-based meta-heuristic technique. It was introduced in 2020 and is inspired by the foraging strategies of ocean predators and their interactions with prey. Recent studies are using the Marine Predators algorithm to accurately estimate the parameters or optimal pattern structure of three dimensions of PV arrays [110, 111].

The studies presented in [115, 116] focus on determining the optimal location and sizing of PV systems in a distribution network using metaheuristic algorithms. A performance analysis is also performed by comparing the results obtained by the MPA with those obtained by the GA in paper [115] and GWO with GA in paper [116].

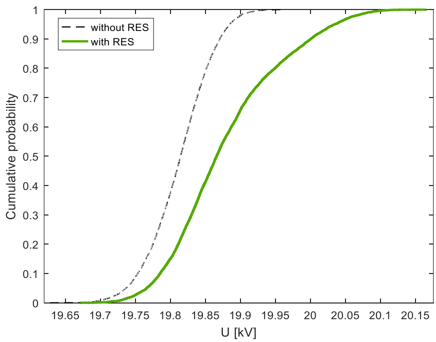
Chapter five presents "Case studies" and is divided into two subchapters, depending on the objectives analysed. In the first subchapter, the load flow computation is analysed from two perspectives (deterministic and probabilistic) and a summary of the results obtained is presented.

Table 1 centralizes the values for maximum loadings [%] of the electrical lines from the Test 1- 20 kV network for both the probabilistic and the deterministic load flow. Deterministic load flow considers as input variables data from meters recorders (loads consummation, wind and PV systems injection) which are fixed values for each load flow computation. For the simulations performed with the Monte Carlo method (8760 random values), the active powers demanded by the consumers, were randomly generated using the Normal probability density function, the wind speed using the Rayleigh probability density function (PDF), and the solar irradiance using the Beta probability density function.

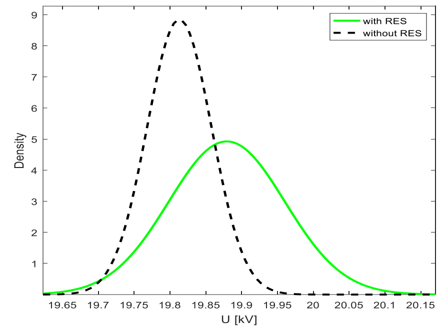
Table 1. Loading lines of the distribution network Test 1 - 20 kV.

Line	Probabilistic load flow calculation - maximum loading [%] -					Deterministic load flow - maximum loading [%] -
	Set 1	Set 2	Set 3	Set 4	Set 5	
L_{1-2}	80,2	81,5	81,0	81,5	82,8	80,0
L_{2-3}	74,5	78,6	77,5	78,2	76,6	76,0
L_{3-4}	25,2	27,9	27,2	25,0	25,8	24,9
L_{4-5}	23,1	25,1	24,0	23,3	23,8	22,7
L_{3-6}	55,1	55,3	58,6	55,5	55,1	55,6
L_{6-8}	54,3	53,5	57,3	54,1	53,9	54,8
L_{8-9}	49,9	49,6	52,7	51,0	50,0	51,4
L_{9-10}	46,0	46,0	46,0	45,9	46,0	46,0
L_{8-11}	5,9	5,8	5,8	5,8	5,8	5,8
L_{3-7}	7,5	7,4	7,4	7,5	7,4	7,2

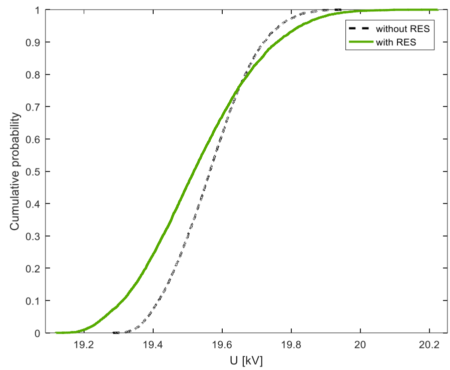
Figure 4 *a-d* illustrates the cumulative probability functions (CDF) and PDF for the voltage magnitude at busses 5 and 10.



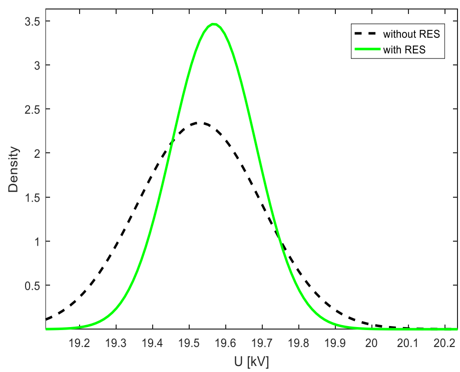
(a) CDFs for bus 5;



(b) PDFs for bus 5;



(c) CDFs for bus 10;



(d) PDFs for bus 10;

Fig. 4. CDFs and PDFs of voltage magnitude for simulations consider with / without RES.

The black dotted line represents the voltage level obtained from simulations using Monte Carlo method for the case without renewable energy sources, while the green-colored line shows the voltage magnitude obtained with the RES connected.

In the second subchapter, the location and maximum injected active power of one or more photovoltaic power plants are analysed in order to minimize active power losses, while maintaining all bus voltages and line currents within the acceptable range. A comparison of the results obtained with the three metaheuristic algorithms was also presented.

The results presented in the case study are performed on a medium voltage distribution network, inspired from a real 20 kV distribution network from Romania, both in terms of topology and parameters. The considered network consists in 25 buses which supply 24 loads and it is shown in figure 5.

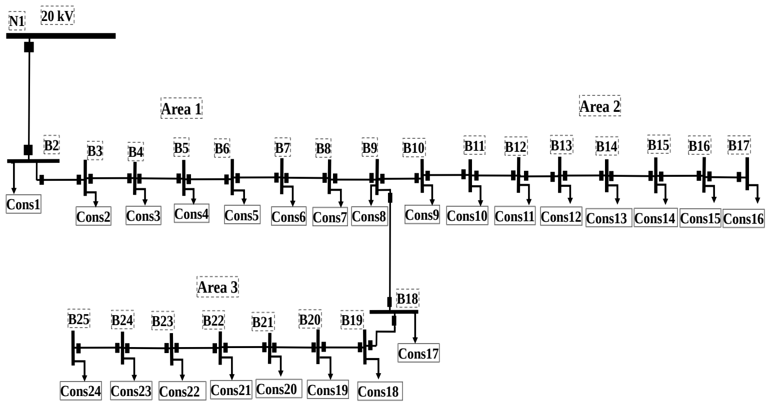


Fig. 5. Distribution network Test 2 - 20 kV.

For the first case analyzed, the maximum power, injected by the PV system, was established at P_{max} = 5 MW. This value was considered based on the size and characteristics of the analyzed network; as a larger PV system is not feasible from an economical point of view.

As PV generation only takes place in the daytime, the 10th to 16th time intervals are selected for solving the optimization problem. In this manner, the optimal location and sizing of the PV system is determined in 84 different scenarios (12 months × 7 hourly intervals). From the resulting 84 preliminary optimal solutions, the most widespread are chosen as candidate solutions for the next step. Then, a load flow computation is performed for a one-year period on the candidate solutions, and the yearly average active power losses are computed. The candidate solution with the lowest active power losses is finally chosen as the optimal solution for placement the PV system.

For the optimization problem, a total number of 50 iterations and a population size of 50 individuals were considered for the three algorithms.

In figure 6 a comparison between the average annual active power losses using Grey Wolf Optimizer and Genetic Algorithm is presented. It is noted that the first algorithm provides higher performance because lower active power losses are obtained in each time interval.

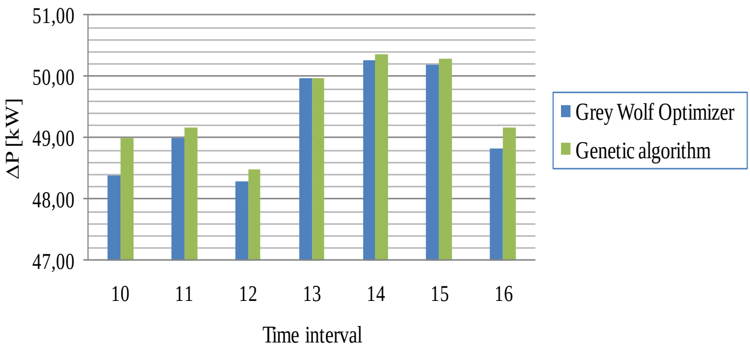


Fig. 6. Average active power losses for the analyzed time interval.

If the 5 MW limit restriction set as the maximum injected power had been removed, the objective function would have been minimal for a value of approximately 6,5 MW.

The second case considered three PV systems with the maximum power injected by each PV system of P_{max} = 3 MW. The case of optimal placement of three RES in the entire network Test 2- 20 kV and the case with area restrictions (each photovoltaic system in one area) were also studied.

The average value of the objective function, determined by each algorithm in all 84 simulations taking into account area restriction, is shown in figure 7. The MPA obtained better results compared with the other two algorithms.

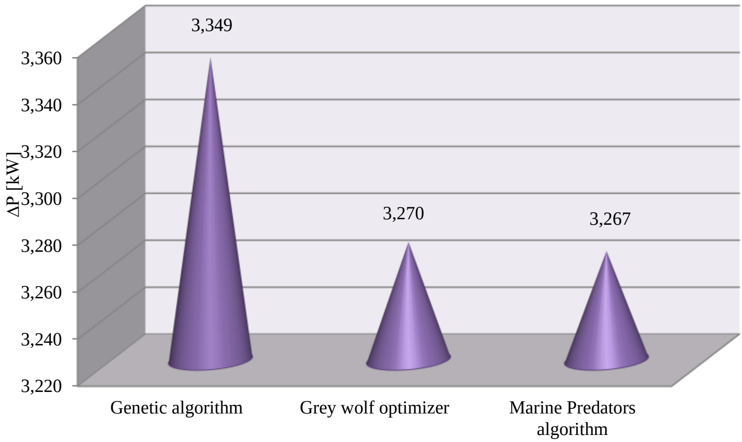


Fig. 7. Average objective function values determined by the metaheuristic algorithms.

The results provided by the three algorithms are similar. However, the ,,marine predators” algorithm proved superior both in terms of results regarding the location and objective function value as it employs an efficient combination between the Lévy and Brownian search strategies. In figure 8 is illustrated the convergence curve for the 16th time interval for each month of the year. The developed program that uses the algorithm presents fine adjustments of the optimal solution during the last iterations.

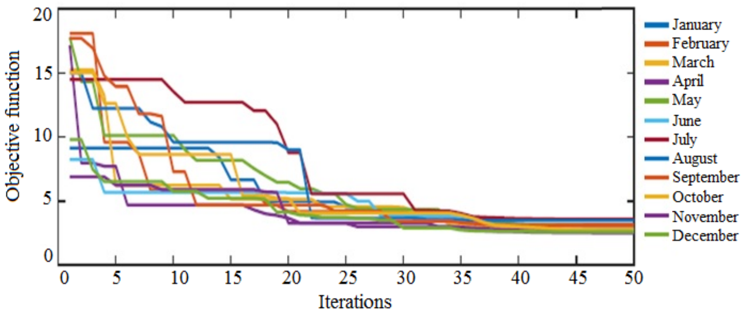


Fig. 8. Convergence curves obtained using ,,marine predators" algorithm

In the first part of Chapter Six entitled "Final Conclusions and Perspectives" the conclusions on the subject and objectives of the doctoral thesis are set out, and finally the personal contributions and proposals for further research are mentioned.

The topic addressed in the doctoral thesis is of scientific interest and is particularly relevant in view of current concerns about the influence of renewable energy sources on the operation of distribution networks. Due to the random nature of the production of these non-fossil energy sources and loads, the computation load flow analyses considerating active power losses, maximum loads lines, as well as maximum bus voltages are actual. Also, the optimal determination of the location and size of non-dispatchable low installed power photovoltaic power plants in a distribution network provides important information to distribution operators from the perspective of operational management and optimization of their operation.

In the context of integration in the distribution network of an increasing number of renewable energy sources, particular attention should be paid to stationary and dynamic load flow analyses. Likewise tools should also be developed and proposed that are more efficient for the accuracy of production notifications of dispatchable wind and photovoltaic power plants.

The most effective tool for evaluating the process of analysis of the behavior of electric networks is the load flow computation. It represents an important objective of analysis, both of the operational planning of its operation, and also in the case of design studies, respectively of the development of distribution and transmission networks. Given the massive trend of integration of renewable energy sources over the past two decades, there are numerous studies that analyze their impact on the probabilistic load flow computation. The studies carried out are based on the analysis of the influence and determination of the most suitable function for wind modelling and solar irradiance. Estimating the variation in wind speed and solar irradiance for the forecasts production is an important factor in determining the accuracy of the methods, which leads to the evaluation of the energy produced by a wind and photovoltaic power plant.

In the doctoral thesis, the probabilistic load flow computation was applied using the Monte Carlo method. This method is suitable for representing all aspects of an electricity system that can have an impact on the electric network such as: voltage buses, load lines, active power losses. In other words, generating random numbers using the Monte Carlo method leads to a variety of possible states. After carrying out an appropriate number of simulations (in the order of thousands and tens of thousands), it becomes possible to estimate the sizes characteristic of nodes and branches.

Estimating the loads elements of electric network due to the random nature of the consumers, respectively the injection of power from renewable energy sources, and followed by practical measures to make investments, leads to increased safety in consumers supply and to reduce the cost of active power losses.

The probabilistic approach by which the range of variation of status sizes, corresponding to the variation of input sizes, is simulated, can lead to increased rigour in obtaining results. The application of the Monte Carlo method for the probabilistic load flow computation in which loads were modelled with the Normal and Weibull probability density functions, wind speed using the Rayleigh and Weibull functions, and solar irradiance with Beta probability density function, led to results close to reality compared to the deterministic approach in which the values are fixed for each load flow computation.

The problem of optimal placement and sizing of the PV system has been studied with three metaheuristic algorithms and technically offers effective perspectives for improving the function, operation, as well as the possibility of further development of the distribution network. Both the evolutionary algorithm and the biological inspiration studied provided similar results. The use of the marine predators algorithm has led to obtaining the lowest average value of the objective function implemented with the Matlab program. For the location and sizing scenarios, one or three photovoltaic power plants connected to a distribution network were considered. The two scenarios studied for the optimization computation were: single photovoltaic power plant in the entire electric network and three photovoltaic power plants (with and without area restrictions).

Personal contributions from the doctoral thesis can be grouped into two categories, the applications of probabilistic computation methods of the load flow computation for a distribution network in the presence of the wind power planat and the photovoltaic power plant, respectively the establishment of the optimal location and size of the PV system, as follows:

(i) Conduct a detailed documentary study on the types of wind generators, photovoltaic panels, as well as aspects related to the connection of renewable electricity sources to the distribution network;

(ii) Presentation of a summary of the evolution of RES at Global and European level and the influence of the health crisis

(Covid - 19) on the pace of integration of new capacities over the past year; aspects of the main technical requirements imposed on wind and photovoltaic power plants as well as the way of operation for certain adjustment strategies have been described;

(iii) Elaboration of a bibliographical study on the applications and methods of probabilistic load flow computation, the use of the Monte Carlo method and the probability density functions;

(iv) Determination of the optimal location and sizing of the PV system using metaheuristic algorithms Grey Wolf and Marine Predators, respectively the Genetic algorithm;

(v) Development of calculation programs for:

- carrying out a case study for statistical analysis of the operation of a distribution network for one year, with / without renewable energy sources. It allows the connection of consumers and two RES in any of the nodes of the distribution network studied.

- analysis of the main state sizes of an electric network studied for the load flow computation in a deterministic and probabilistic manner.

- models of probability density functions for active powers consumed (Normal, Log - Normal, Weibull, Rayleigh, Gamma), wind speed (Normal, Log - Normal, Weibull, Rayleigh, Gamma) and solar irradiance (Normal, Log - Normal, Weibull, Beta, Gamma) have been implemented and studied. These are the random part of getting input data. The generation of continuous random variables is the main element for the probabilistic load flow computation;

- an evolutionary algorithm (genetic algorithm) and two biological-inspired algorithms (grey wolf and marine predators) were used for optimization computation. The aim was to obtain minimum average loss of active power provided by all acceptable range for bus voltages and line maximum currents. In order to achieve this objective, the optimal determination of the location and active power injection of photovoltaic power plants in a distribution network has been studied.

(vi) Exploitation and dissemination of research through the participation and publication of works at national and international conferences: International Conference on Modern Power Systems (MPS), Cluj - Napoca, 15 - 17 June 2021; International Conference on Applied and Theoretical Electricity (ICATE), Craiova, 27 - 29 May 2021; International Symposium on Fundamentals of Electrical Engineering (ISFEE), Bucharest, 5-7 November 2020; CIGRE Regional South - Est European Conference (RSEEC), Bucharest, 12 - 14 October 2020; International Conference on Energy and Environment, Energy Saved today is asset for future (CIEM), Bucharest, 19-20 October 2017; International Conference on Energy and Environment, Clean and Safe Power, Iaşi, 22 - 23 October 2015; Scientific Bulletin of the University Politehnica of Bucharest, Seria C, Vol. 83, Nr.1, 2021.

The whole issue addressed is based on relevant theoretical sources in the field, processed, analysed and summarised accordingly.

For further scientific research, the studies presented in the doctoral thesis can be continued taking into account for the following aspects:

- methods of choosing sectioning areas for urban distribution networks with looped configurations that have connected renewable energy sources and global assessment of energy losses;

- carrying out the probabilistic load flow computation for low voltage electrical networks that have known the data for all its elements (load profiles, topology, etc.) in order to estimate its own technological consumption;

- analysis of several probability density functions for load modeling;

- achieving a strategy to find the function that best shapes the load profile and implementing the specific consumer probability density functions in the connection node within the permanent load flow program;

- the possibility of implementing in probabilistic load flow computation that produce consumption forecasts of a database containing the main parameters of a statistical function with their range of variation;

- optimal location of renewable sources using other objective functions.

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