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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

DEVELOPMENT OF MULTI-OBJECTIVE OPTIMIZATION METHODS AND ALGORITHMS FOR SELECTION AND ALLOCATION OF DR AND FACTS IN POWER SYSTEMS FROM TECHNICAL AND ECONOMICAL POINT OF VIEW

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GENERAL CHARACTERISTICS OF THE WORK

The actuality of the subject. In modern age, development of countries and electrification of work in all areas, has led to a sharp and steady increase in electricity demand. Given the need to meet this demand, on the other hand, the various problems in the way of energy production have led scientists and experts to think of ways to use the maximum capacity of existing systems. Hence, increase of productivity in electric systems has become one of the topical issues of the day. DR programs and FACTS devices, due to their ability to react quickly to problems in electric systems, allow to solve the main problems of them at the same time. Including, increase system efficiency, improve economic productivity. improve environmental conditions, optimally meet the growing demand for electricity, reduce load peaks, reduce losses, delay capital investment in the construction of new systems, improve dynamic behavior, increase load capacity, voltage profile improvements, increase the security margin of the system and reduce backup costs can be mentioned.

On the other hand, in recent years, numerous studies have been devoted to the problems associated with the application of DR programs and FACTS technologies, the solution of which improves environmental requirements, increases the reliability of power supply and reduces network losses. As a result of the integration of DR programs and FACTS software into distribution networks, the principles of their structure, operation and management have changed significantly. However, during the integration of DR programs and FACTS devices, there are still problems in assessing their technically and economically optimal locations and capacities, as well as in selecting and deploying devices to regulate voltage and reactive power flows. Undoubtedly, to implement the best planning and management strategy in order to increase the capacity of existing networks and reduce losses, appropriate methods and tools are needed to help assess the capabilities and requirements of the network. In planning of DR programs and FACTS devices, multi-objective functions and constraints on the system mode parameters are considered as a matter of conditional optimization.

Among the many methods and tools, the multi-objective evolution algorithm is the most convenient approach to obtaining the optimal set of solutions. From a mathematical point of view, the optimization of DR programs and FACTS devices are the object of multi-objective optimization. Objectives are consisted of the cost of optimal energy supply, minimum cost of electricity received by the consumer, minimum power loss, maintaining the security of the energy system, as well as the optimal capacity and location of DR programs and FACTS devices. Among the scientific studies devoted to the development of optimization methods, the multi-purpose planning model of DR programs and FACTS devices is combined with various methods, such as imitation of engraving, tabulation search and its combination with genetic algorithm (GA) and finally the fuzzy optimization method can be noted. Although the previous work was aimed at reducing losses and the cost of upgrading the power grid, little attention was paid to the issues of voltage compensation, improving voltage stability and increasing the capacity of the power grid. Also the problem of multi-objective optimization was studied with the above-mentioned characteristic purposes. In the current dissertation, to achieve the goal of increasing the efficiency of power systems, from economic -technical point of view, the results of the study of multi-objective optimization with DR programs and FACTS devices are given. Optimization of DR programs and FACTS devices are dealt with several global purposes, which provide the most optimal operation of the system and are expressed as minimum loss, maximum power transmission, minimum deviation of the voltage at the nodes of the system. Furthermore, given the uncertain conditions of the electric charges, FACTS devices connected in series and in parallel, as well as DR programs are planned to maintain optimal and stable operation

Purpose of the work and issues. The main goal of the dissertation is to solve the problems of optimal placement of FACTS devices and DR programs together in order to solve the complex problems of reducing losses in the power grid, increasing static stability and increasing the loadability of the network. Optimization methods have been developed in the error conditions of the network and in the uncertain conditions of the loads, from the technical and economic aspects, in accordance with the following.

1. Optimization of the choice of type, capacity and location of compensating devices, as well as the development of methods for determining the optimal value of the change in power at the load nodes for the situations arising from the failure of the main elements of the system (lines and generating units) are carried out.
2. Development of calculation algorithms for multi-purpose optimization based on modeling the criteria of minimum loss, maximum power supply in the network, maximum load reduction during peak hours
3. Determination of priority means of optimization (maximum loadability or minimum loss in the network) depending on the state of the network.
4. Under optimal operating conditions of the system, development of a method of economic justification of the selected optimal devices are carried out
5. Carrying out computational experiments on the basis of standard IEEE schemes for industrial use of developed methods and algorithms are performed. According to the results of modeling, development of recommendations for operators performing planning and operational management of the power system is dedicated.
6. Influences of different FACTS devices on the system operation efficiency have been compared. Here, instead of just one optimal answer, a number of optimal solutions were obtained in the form of a Pareto front set. The results allowed the system operator to choose between the answers, taking into account available devices and the conditions and needs of power system.
7. The optimal location and capacity of DR programs using multi objective functions are modeled. Following the final targets, FACTS devices and DR program have been implemented together to achieve the highest system efficiency.

8. Setting economic goals, at this stage, the investments required for each optimal solution of the FACTS devices were calculated and the solution corresponding to the minimum costs was determined. In the next stage, according to the cost of the optimal solutions, determining the economic value of the DR program is considered as a target. Following this goal, the system operator chooses the most appropriate and profitable answer.
9. As a final goal, the above-mentioned stages were repeated under uncertain charge conditions.
10. Multi objective functions have been solved using the powerful evolutionary algorithms in order to achieve the goal of finding the most appropriate solutions to the optimization problems. In this dissertation, genetic and TLBO evolutionary algorithms have been designed and used to solve problems.
11. By analyzing and comparing the results of optimization processes and Provide valuable suggestions, operators are now given a choice to use the system more effectively.

Principles of research: Scientific provisions of multi-objective optimization process presented in this dissertation are based on artificial intelligence, genetic algorithm (GA) methodology, teaching learning base optimization method (TLBO), random displacement method, as well as implementation of methods based on expert assessment. During research in Computational experiences, with the help of Matlab and PSAT programs modeling methods of static and transient mods of realized power systems were used. Following the main goal, various methods and techniques have been used in this dissertation. In the first step, the effects of different types of FACTS devices on the power system were studied and the solution of optimization problems using evolutionary algorithms was considered.

In the next step, the effect of applying DR programs on improving the system parameters was tested. In multi-objective function of the optimization process, improvement of static voltage stability, increase of system load capacity and reduction of losses are taken into account at the same time. The CPF evaluation criterion was used to assess the static stability improvement of voltage and the loadability of power grid. Also, DR programs and FACTS devices were implemented together. In this dissertation, TLBO and genetic evolution algorithms were designed and used to solve the problems of optimization of power systems.

With incorporating Pareto front methods into TLBO (Teaching Learning Based Optimization) and genetic evolutionary algorithms a set of optimal solutions have been obtained. As well as, in order to evaluate the performance of the TLBO algorithm, this issue has been resolved using the genetic algorithm in different conditions of the power system. Comparing the results of these two algorithms, the effectiveness of the TLBO algorithm has been proven in solving problems of electrical networks. The results show that in some cases, the solutions from the TLBO algorithm may be more suitable. Finally, the system operator can decide on a wider range of responses.

Scientific innovation. Current dissertation work is dedicated to maximum power supply in the power grid, with the help of FACTS devices and DR programs that allow achieving maximum stability and minimum loss and development of methods and algorithms to increase the efficiency of the power system. Scientific innovations are defined as follow:

1. Algorithmic-software tools have been developed to optimize the management of a set of compensating devices that incorporated in the network scheme in series and parallel, as well as the application of load demand regulation to ensure minimum loss and maximum power transmission in the network.
2. A model for evaluating the impact of fault of the main elements of the system - lines and generating units on the efficiency of the power system is proposed.
3. The method and algorithm of their optimal placement in the power system have been developed, taking into account the choice of the type of FACTS devices on the condition of minimum capital expenditures.

4. Assessment of the impact of random fault of network elements on minimum power loss and state of stability according to the voltages of the system has done.
5. Modeling and calculation experiments of optimal modes of power system In the standard IEEE sample power system due to Confirming the effectiveness of complex use of FACTS and DR

Results confirmations. The accuracy of the results obtained from the dissertation, are based on comparative analysis of methods of optimization theory, modern artificial intelligence methods, application of modern methods of forecasting of electricity demand, as well as using FACTS and DR by traditional methods and the results obtained by the proposed multi-objective optimization method. The optimal solutions obtained using the proposed methods, comparisons with the before compensating conditions of the system, clearly show a sharp increase in the system loadability and a decrease in losses.

Practical significance of the work. The results of the study, as well as the developed methods, algorithmic software applications, created a wide range of opportunities for planning and operational management of the power system. Taking into account the management of electricity demands, the optimization process of reactive power compensation devices helps to solve the main problems of power grids. The proposed algorithms and programs also play an important role in scientific and practical research. At present, increasing the efficiency in electricity use in all developed countries and the possibility of using the maximum capacity of existing power grids have been located at the peak of research by scientists and experts. On the other hand, the creation of energy markets in developing countries, supplying electric loads at minimum prices and increasing the stability and reliability of the power system, directly related to socio-economic developments have become one of the current topics of the day. In this dissertation, following the above-mentioned goals, new ways to achieve the goal of meeting the basic needs of the power system are presented.

Approbation of the case. The main provisions and results of the work were reported and discussed at the following conferences:

- In scientific-technical seminars of the Institute of Physics of ANAS, Azerbaijan Scientific-Research and Design-Research Energy Institute;
- Scientific and technical conferences of IRI;
- In international conferences:

1. A. Kazemi A., Shadmesgaran M.R. Damping inter-area oscillations by UPFC considering effect of inertia coefficient / 8th WSEAS International Conference on power systems (PS) 2008, Santander, Cantabria, Spain, September 23-25, 2008 ISSN: 1790-5117
2. Shadmesgaran M.R., Hashimov A.M., Yusifbeyli N.A. Optimal location and capacity of demand response program do to simultaneously power loss reduction and static voltage stability improvement using genetic algorithm / ICTPE, University of South-East Europe Bucharest, Romania, September 2015 Number 16 Code 01PES10 Pages 75-79.
3. Shadmesgaran M.R., Hashimov A.M., Rahmanov N.R. Optimal location and capacity of parallel facts devices in order to improve voltage static stability and power losses reduction using genetic algorithm / ICTPE Conference 12th International Conference on "Technical and Physical Problems of Electrical Engineering" 7-9 September 2016 University of the Basque Country Bilbao, Spain ICTPE-2016 Number1 Code 01POW07 Pages 1-6.
4. Shadmesgaran, M.R., Hashimov, A.M., Rahmanov, N.R. Productivity Comparison of Different FACTS And DR To Enhance Technical Indicators And Economical Operation Of Grid // Proc. of the 2nd IEEE International Conference on Electrical, Communication and Computer Engineering (ICECCE), –Istanbul, Turkey: –14-15 April, – 2020, – p. 362-367.
5. Hashimov, A.M., Rahmanov, N.R., Shadmesgaran, M.R. Multi-Strategy Optimal Control for Compensating Devices in Power System with Wide Range Load Conditions // Proc. of

the 3nd IEEE International Conference on Electrical, Communication and Computer Engineering (ICECCE), – Kuala Lumpur, Malaysia: –12-13 June, – 2021, Accepted.

Publications. 11 scientific works on the topic of the dissertation were published, including 4 articles in international journals (two Scopus - one without co-author), 4 published reports at international scientific conferences (one Scopus) and 3 scientific articles in the journal recommended by the Supreme Attestation Commission under the President of the Republic of Azerbaijan (one without co-author).

The structure and volume of the work. The dissertation consists of introduction 22 pages (45663) and four chapters, chapter I - 51 pages. (60461), Chapter II - 51 pages. (70439), Chapter III - 5 pages. (4253), Chapter IV - 79 pages. (52868), result - 2 pages (2554), compiled on 234 pages, including the total volume of the mark (237402), 132 figures, 47 tables, 123 references, including author's works.

Summary of the work in the Introduction. The importance of the dissertation topic, is explained in solving the main problems of power systems in modern age. The main purpose of the research, issues, research methods, scientific innovation, main scientific results, practical value of the results and their areas of application are stated. Finally, a summary of the dissertation chapters is given.

In the first chapter. Definitions of the often used terms in the dissertation due to introduce their proper sense, accurate understanding of the issues, to reduce the researchers waste of time when searching for terminology, eliminating doubts and to get rid of long searches terms are presented in this chapter. This chapter also examines the importance of reactive power planning and management, and explains the significant problems in transmission lines in order to prove the effectiveness of the methods, approaches, devices, programs and algorithms proposed in the dissertation. AS well as, in this chapter the definition of compensators in ideal conditions and their different types and how they are connected to the system are described. The purpose of FACTS devices, the structure of their different types and V-I characteristics are presented. Then the principles of their operation, features and forms and methods of application were fully tested. Continuing this issue, the effects of different types of these devices on the parameters of the system and its stability were considered and compared. The results explain the advantages and disadvantages of each type. Continuing with the first chapter, the purpose, types, modeling, working principles, method of use, advantages and disadvantages of the DR program (Demand Response Program) are explained. The significant impact of DR programs on solving network problems has also been investigated. Continuing the issue, the projects of DR programs implemented in practice and their benefits and advantages over other methods were commented.

In the chapter tow. The objective functions considered in the optimization issues are explained. Multi Objective Functions and their advantages for finding optimal solutions are considered. A report on power losses and their formation was also presented. Continuing the issue, various methods of static voltage stability analysis and their use as an indicator in solving optimization problems were given.

The most important parameters in power systems are in conflict. In other words, as one of the parameters improves, the other worsens. The use of multi-objective functions in optimization processes allows you to hold several important parameters of the system in their desired areas. The important parameters to be followed as a goal at the throughout of the dissertation are defined below:

The loadability of the network is explained in terms of F1. In simulations, this parameter is obtained using the CPF continuous power flow method. Achieving the F1 goal guarantees an increase in the network's loadability. Naturally, the increase in loadability allows voltages at all nodes to be located in an acceptable range, improves the stability of the system and, most importantly, allows the network to use its maximum transmission capability.

$$\begin{cases} (F_1 = \lambda)_{Maximum} \\ \\ (F_1 = -\lambda)_{Minimum} \end{cases} \tag{1}$$

- The minimization of losses, one of the most important parameters in the network is explained by the object of F2. Meeting the F2 target ensures a reduction in network losses. Actually, minimizing losses allows the system to be used more efficiently by preventing the waste of investment in the manufacturing sector.

$$(F_2 = \sum_i R_i \times |I_i|^2)_{Minimum} \tag{2}$$

- To reach the target set by the operator the issue of minimizing the capacity of the applied series FACTS devices is given by the objective F3. Meeting the F3 target ensures minimization of capital investment required to implement series FACTS devices to the network.

$$(F_3 = S_{FACTS\_s})_{\min} \tag{3}$$

- To reach the target set by the operator the issue of minimizing the capacity of the applied parallel FACTS devices is given by the objective F4. Meeting the F4 target ensures minimization of capital investment required to implement parallel FACTS devices to the network.

$$(F_4 = S_{FACTS\_p})_{\min} \tag{4}$$

- To reach the target set by the operator the issue of minimizing the capacity of the applied DR programs is given by the objective F5. Meeting the F5 target ensures minimization of costs of DR programs in the network.

$$(F_5 = S_{DR})_{\min} \tag{5}$$

- When system works under light loads improvement of economic criterion by losses reduction gains necessity. In this case achieving the amount set by the system operator for losses is explained in terms of F6. Meeting the F6 target guarantees falling power losses to the price set by the system operator.

$$(F_6 = (PL - PL_{set}))_{\min} \tag{6}$$

- When system works at pick hours, maximization of the loadability criterion gains necessity. In this case achieving the amount set by the system operator for losses is explained in terms of

F6. Meeting the F7 target guarantees rising system loadability to the price set by the system operator.

$$(F_7 = (\lambda - \lambda_{set}))_{\min} \qquad (7)$$

- Finally, the multi-objective function is defined as shown in the following equation in order to satisfy the operator's desires, depending on the conditions of the system.

$$Multi - Objectiv\, Function = Min(F_i)\ \&\, Min(F_j) \qquad (8)$$

Since optimization problems in power systems are multidimensional, nonlinear and discrete, it is necessary to use numerical methods to solve them. On the other hand, due to the complexity of the power system, the solution of optimization problems using numerical methods requires a lot of repetition and calculations and it takes a long time and not convenient. In the presented dissertation, to solve this problem among the most powerful evolutionary algorithms, TLBO (Teaching Learning Base Optimization) and Genetic Algorithm were used. In this way, new methods have been created to solve the problems of the power system at an acceptable time. This chapter also explains the role of evolutionary algorithms in solving optimization problems and the necessity to use them. This chapter also explains the role of evolutionary algorithms in solving optimization problems and the necessity of their application. The working principles of evolutionary algorithms, their planning in solving problems of power systems, their advantages and their importance in solving practical issues are expressed. Continuing this issue, planned and applied methods of the above-mentioned evolutionary algorithms in the grid and the results obtained from optimization process to give wide range of options for making decision by system operator are dedicated.

The genetic algorithm is used as a search technique to solve optimization problems. This algorithm is a unique type of evolutionary algorithm that uses Darwin's evolution theory and the principles of natural selection, as well as biological techniques such as inheritance and mutation, to find optimal solutions. The idea of a genetic algorithm is based on the two principles of nature, selection and the emergence of new generations. In the future generations, the genetic structures of powerful members are repeated and weak members are disappeared. In some cases, mutations occur, meaning that some members of the new generation are much better or worse than their parents.

Finally, nature guarantees more adapting of the creatures that formed by these methods. To apply the genetic algorithm, as shown in Figure 1, the location and capacity of the compensating devices are placed on each chromosome. In this way, the initial population is formed. After processing the crossover operator on the original population, a mutation operator is processed on 5 percent of the bits of the new chromosomes.

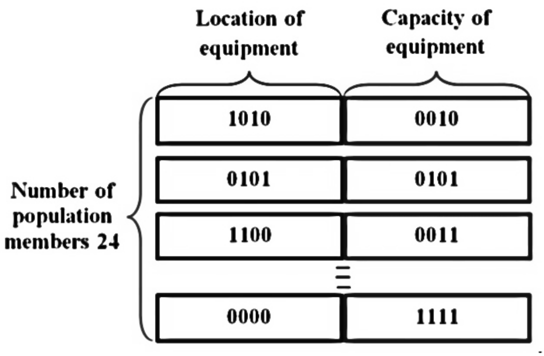


Fig.1. A population sample in a genetic algorithm.

The TLBO algorithm is one of the modern evolutionary algorithms which was first proposed to solve optimization problems by R.V. Rao, V.J. Savsani and D.P. Vakharia in the journal Elsevier Computer Aided Design in 2011. This algorithm is based on the principles of intelligent work, teaching a teacher in a class, and learning styles of students. The teacher plays a role in students' learning by explaining course topics in the classroom and students' better learning depends on the teacher's knowledge and style of expression. In addition to the teacher's influence, students' ability to research and share information with each other helps them learn better. The TLBO algorithm has been adopted as a search method using these principles to solve optimization problems.

The block diagram of the modeling of the TLBO algorithm is shown in Figure 2:

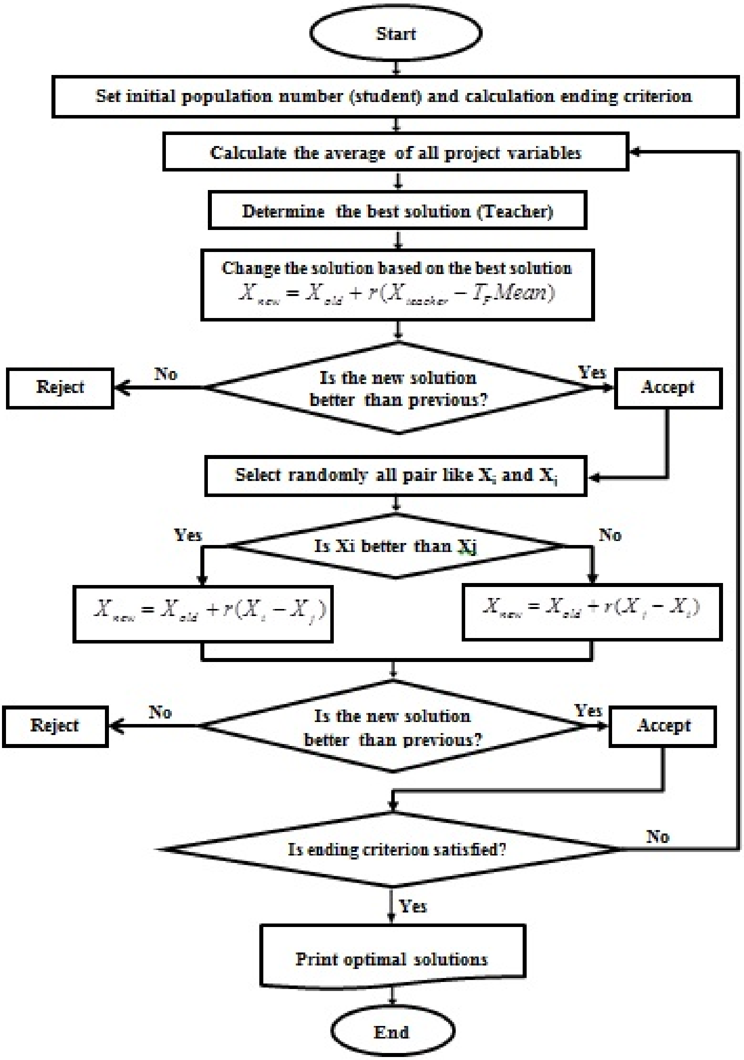


Fig.2. Flow chart of TLBO evolutionary algorithm.

Based on this block diagram, the TLBO evolution algorithm is programmed and designed to solve the problem in the optimization process in the following sequence:

- The number of members of the population is determined.
- The completion criterion is set.
- The initial population is determined randomly.
- The target parameters of the multi-objective function are calculated.
- Using the Pareto Front selection method, members are ranked according to their winning numbers.
- The best member is accepted as a teacher.
- The influence of the chosen teacher is processed to improve the students.
- Students' interactions with each other are processed to improve them.
- By meeting the end condition, optimal solutions are presented in the process output.

A multi-objective function has been used in the optimization process to ensure that various problems of the power system are solved at the same time. It is clear that each member of the population is evaluated from several points of view in the current situation, and therefore their comparison and classification is not easily possible. To solve this problem, Pareto front law was programmed and incorporated to the optimization process. In this way, using this criterion, the superior members are selected on behalf of the Pareto front and the optimal answers are presented at the end of the optimization process. Figure 3 shows a block diagram of the programming of the Pareto front selection method. Also in this chapter, the optimization processes mentioned above are explained taking into account the fault conditions of the system. The fault conditions in this section when a problem occurs, the opening of one of the lines is considered. As well as, the mentioned optimization processes have been developed and presented taking into account the load uncertainty conditions.

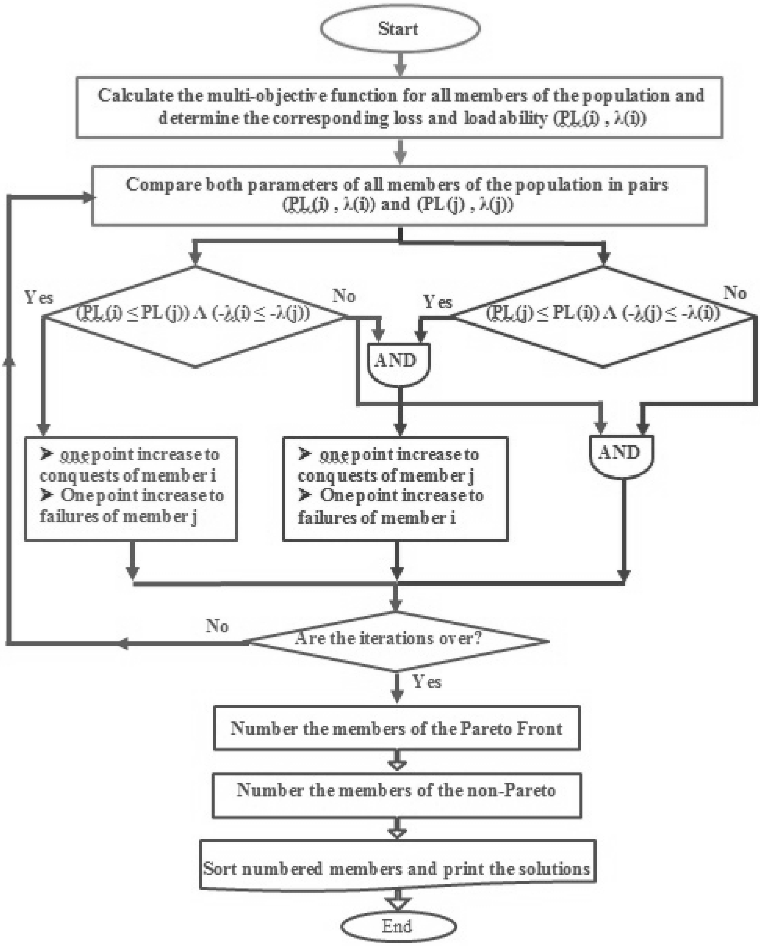


Fig.3. The block diagram of the programming of the. Pareto front selection method.

The third chapter. Explains the technical aspects of optimization processes, methods of economic analysis, and proves the need for economic optimizations. Algorithms and flow charts of economic analysis are presented in this direction. Continuing this issue, the process of selecting the most economical compensating device that meets the conditions of technical requirements are explained and the related methods for determining the economic value of the DR program are presented.

Figure 4 shows a block diagram of the technical optimization process when all the compensation devices are applied incorporated together.

- In this process the choice of series and parallel FACTS devices and DR program, the type of evolutionary algorithm, the normal or fault conditions of the system, the fixed or load uncertainty conditions, and the power grid information are determined as process inputs by system operator.
- At the exit of the process, optimal locations and capacities of compensating devices that meet the conditions of the multi-purpose function, as well as calculated optimal losses and loadability are presented.

Technical optimization in the presented dissertation means that minimizing the power losses in power grid and maximizing system loadability at the same time without taking into account the type, capacity and capital investment required for implementation of compensators.

Although some of the technically optimal solutions are not affordable because they require heavy costs, the importance of these processes has been proven to protect the network from blackouts.

Figure 5 shows a block diagram of the economic-technical optimization process.

- As shown in the block diagram, in the first step optimal locations and capacities for each of the compensating devices using technical optimization process have been found to achieve the desired parameter to the value set by system operator.
- In the second step, the costs of series and parallel FACTS devices were calculated based on the obtained optimal solutions.
- In the third step economic price of DR contract was determined based on the minimum costs.
- The solutions obtained from the developed methods and algorithms allowed the system operator to operate

economically at low loads conditions and increase the network loadability at peak loads.

In the presented dissertation, in the process of economic-technical optimization, the type, location and capacity of the cheapest compensating devices were determined following the purpose of achieving to the set value of the parameter by the operator.

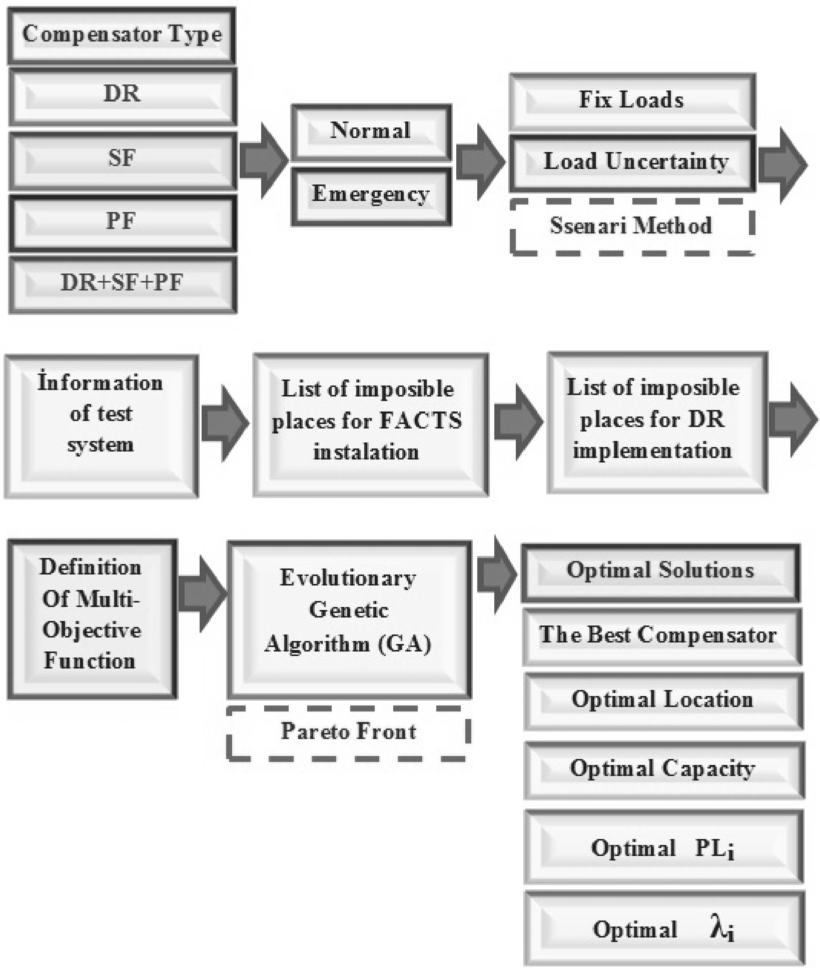


Fig.4. Block diagram of technical optimization processes.

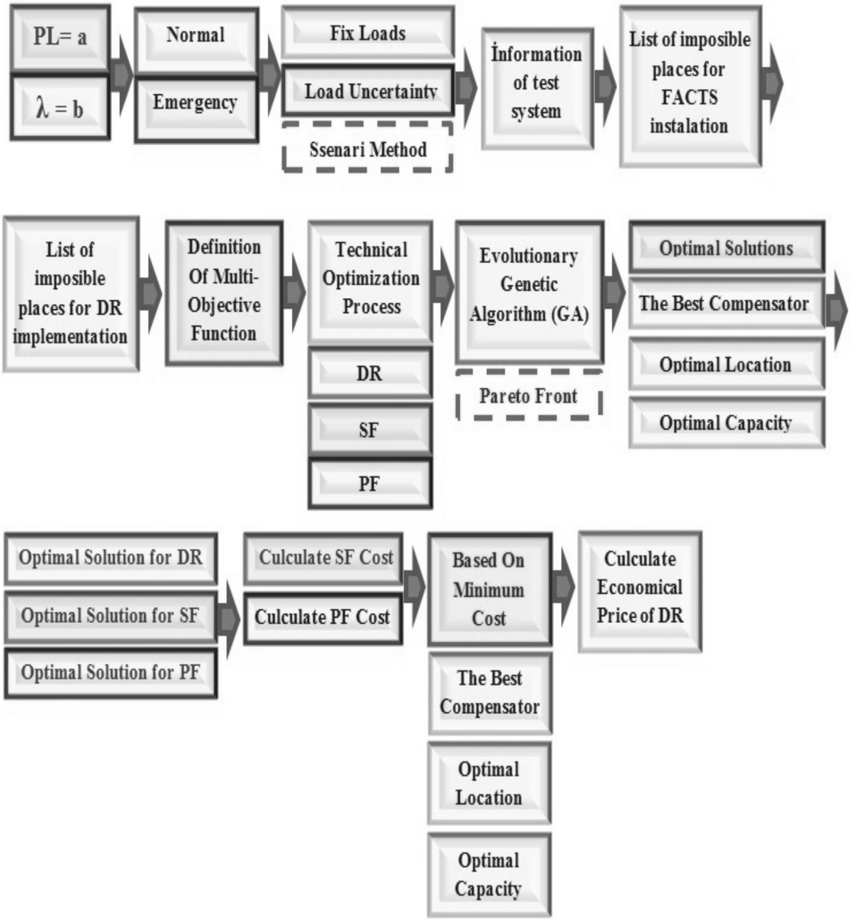


Fig.5. Block diagram of economic-technical optimization processes.

In practice, the amount of load is not fixed, and optimization processes lead to additional costs when performed relative to the maximum load.

- The use of the Scenario method in optimization processes has been applied here to avoid additional costs.
- In the scenario method, the technical optimization process is solved separately for 100, 85 and 70 percent of the loads and the average value of the obtained solutions is calculated.

The fourth chapter. The fourth chapter is devoted to simulations. All of the multi-objective function optimization processes proposed in the dissertation were simulated on a 30-buses IEEE test system using MATLAB and PSAT programs. The optimization process has been designed step by step to increase the efficiency of the system and achieve the main goal. In this regard, 80 programs have been written, taking into account the conditions of the system, the needs of the operator, the compensation devices, technical and economic objectives, normal and fault conditions and the loads uncertainty. The simulations were written and executed in mfile format.

In this chapter, simulations are performed under conditions where different series FACTS devices are used, different parallel FACTS devices are used, different series and parallel FACTS devices are used together, DR programs are used, different series and parallel FACTS devices and DR programs are used that incorporated together. The results were presented in the form of tables and diagrams and comparative analyzes were conducted. It should be noted that all of the above simulations were performed separately using both different evolutionary algorithms (Genetic and TLBO) and their obtained solutions were analyzed and compared using tables and diagrams. In order to select the superior members by screening the answers obtained at the output of evolutionary algorithms in optimization processes, the Pareto front selection method was programed and incorporated to them. Continuing the issue, the results obtained from the simulation were investigated, comparative analyzes were conducted from various aspects, and valuable information and suggestions were provided to the operator for the operational management of the system.

Figure 6 also shows a sample graph obtained from the optimization processes. The red stars in the picture show the solutions on the Pareto front and the blue circles show the non-pareto set. As can be seen in the figure, both criteria of non-pareto responses lose their significance because they are defeated in front of at least one pareto answer. The answers on the Pareto front set satisfy the main purpose, allowing for more efficient use of the power grid in different conditions of the system.

The table shows an example of the results obtained from the optimization processes from the economic-technical point of view. In this table, the costs of the various compensation devices to bring the desired parameter to a certain value set by the system operator are given separately. Also, the price of DR is offered at the lowest cost. As can be seen from the table, due to the required costs of different compensation devices to achieve the goal set by the system operator, are drastically different, the importance of economic optimization issues raised in the dissertation is proved.

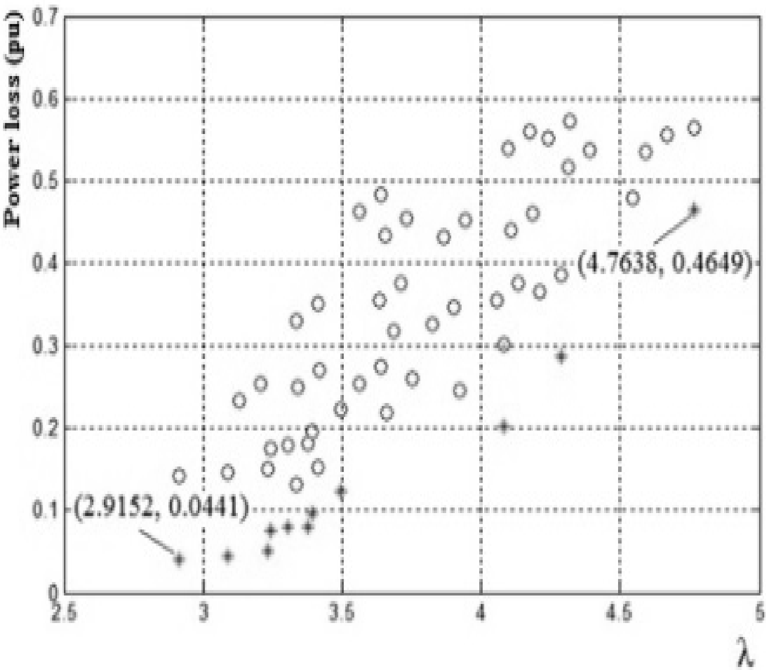


Fig.6. A sample of the results obtained from technical optimization processes.

A sample of the solutions obtained from the process of economic-technical optimization under normal system conditions

Table 1.

Economic analysis – Normal condition - Genetic algorithm												
Equipment type	**PL=0.0450 (Target)**						**λ=2.6 (Target)**					
	Equipment name	**Optimal Location (Bus / Line)**	**Optimal Location (Between Buses)**	**Optimal Capacity**	**Dimension**	**Optimal costs (Dollar)**	**Equipment name**	**Optimal Location (Bus / Line)**	**Optimal Location (Between Buses)**	**Optimal Capacity**	**Dimension**	**Optimal costs (Dollar)**
Series FACTS	TCSC	12	6-10	0.28	kVAr	43.05	TCSC	36	27-28	2.07	Mvar	315220
Parallel FACTS	DSTATCOM	10	-	10	kVAr	1273.8	DSTATCOM	23	-	30	kVAr	3821.1
Consumer side management	DR	5	-	7.18	MVA	-	DR	21	-	2.01	MVA	-
Economic price of DR $/MVA	5.99						1901.05					

Comparison of optimal responses obtained using GA and TLBO evolutionary algorithms under normal system conditions

Table 2.

Power losses	Loadability λ	Type of implemented evolutionary algorithm
0.0411	2.9152	GA
0.0414	3.0331	TLBO
0.0416	3.0336	TLBO
0.0450	3.0891	GA
0.0510	3.2309	GA
0.0612	3.2893	TLBO
0.0754	3.2454	GA
0.0791	3.3069	GA
0.0802	3.3780	GA
0.0958	3.3941	GA
0.1227	3.4979	GA
0.1251	3.6821	TLBO
0.1863	3.9125	TLBO
0.2020	4.0816	GA
0.2733	4.2774	TLBO
0.2867	4.2868	GA
0.3320	4.5025	TLBO
0.4054	4.7342	TLBO
0.4085	4.7752	TLBO
0.4649	4.7638	GA

An example of a comparative analysis of the responses obtained from various optimization processes in the presented dissertation is explained in Table 1. Under normal conditions of the system, using GA and TLBO evolutionary algorithms, 20 optimal responses were obtained at the output of the Pareto front selection method. These responses are ranked relative to the size of the network loss. As can be seen from the table, although the least loss was obtained using the GA evolution algorithm, the second and third answers were found using the TLBO algorithm. It can be concluded that the answers obtained from the two algorithms perfectly gave the system operator the opportunity to choose from the more options. The first line of the table explains the realization of the main goal. This response reduced system losses to 0.0411 pu and at the same time increased the system loadability to 2.9152. The amount of loads in practice depending on the behavior of the participants is not definitive to the network operator. For this reason, if the optimization processes are calculated based on the maximum load, the operator incurs additional costs. Another example of graphs obtained from comparative analysis is given in Figure 7. As can be seen from the figure, the answers obtained from the developed methods and algorithms satisfy the conditions of the multi-objective function in the fixed and uncertainty conditions of loads in accordance with the main purpose and allowed for more efficient operation of the network by reducing losses.

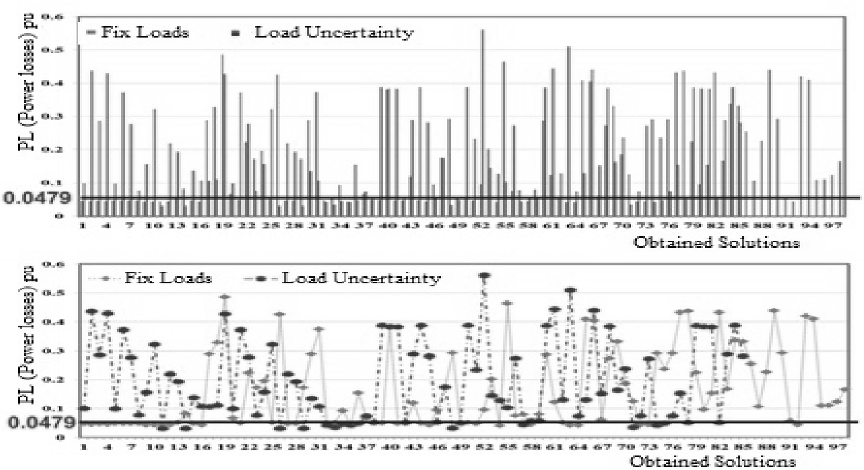
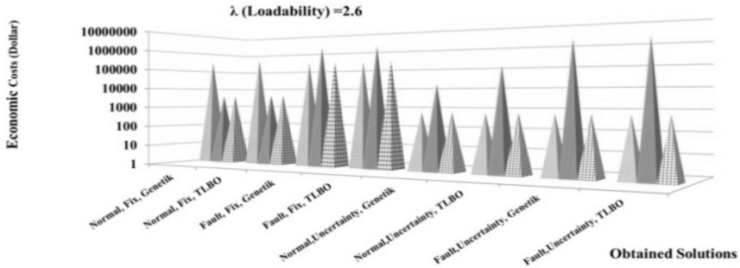


Fig.7. Comparison of solutions from technical optimization processes in fix and uncertainty load conditions.

Figure 8 shows a sample of graphs obtained at the output of economic-technical optimization processes. As can be seen from the figure, the costs of different compensating devices to achieve the goal set by the operator are drastically different. In this way, the practical significance of the main goal has been proved due to economically operate the power system and deliver electricity to the competitive market at the lowest price.



	Normal, Fix, Genetik	Normal, Fix, TLBO	Fault, Fix, Genetik	Fault, Fix, TLBO	Normal,Uncertainty, Genetik	Normal,Uncertainty, TLBO	Fault,Uncertainty, Genetik	Fault,Uncertainty, TLBO
AF(Xarc)	315220	340839	207790	207790	661	661	661	661
PF(Xarc)	3821.1	4203.2	1215700	1221734.16	14008	95363	1243590	1243590
DR-ın iqtisadi Xərcləri	3821.1	4203.2	207790	207790	661	661	661	661

Fig.8. A sample graphs obtained in the output of economic -technical optimization processes.

Figure 20 also uses the logarithmic axis to show and compare significantly different quantities in a graph. In different conditions of the system, some of the solutions obtained from a technical point of view associated with very high costs are non-practical and set aside. In other words, the answers obtained from the technical optimization process without testing from the economic point of view cannot be offered in practice. Also, some conditions of the system the compensation of which depends on heavy costs, identified in the name of crisis conditions, can be included in the input of risk management processes. Naturally, at the end of the economic optimization process, the cheapest option is selected, and the price of DR contracts is calculated based on it.

In the dissertation, in the process of optimization of economic analysis, a comparison of the costs of different devices is performed in order to increase the load capacity to λ = 2.6. In this regard, it has been proven that there are sharp differences in costs. Here, the price of DR is determined on the basis of its technically optimal capacity and the optimal price of the cheapest FACTS devices. Furthermore, a comparison of the optimal responses obtained from the GA and

TLBO algorithms was performed in order to reduce the losses in the optimization processes of economic analysis to PL = 0.0450. In this regard, the solutions obtained from the GA evolutionary algorithm were obtained at a lower cost than the solutions obtained from the TLBO algorithm under some network conditions. In this section, the various conditions of the network (normal, fault, fix loads and load uncertainty) are considered.

In the comparative economic analysis, the optimal solutions obtained from the GA and TLBO algorithms were compared in order to increase the load capacity in the optimization processes to $\lambda = 2.6$. In this direction, only under certain loads and normal network conditions, the solutions obtained from the two algorithms were different. Also in this analysis, the sharp increase in compensation costs in some cases is described as critical points for the system operator.

In order to reduce losses in the economic optimization processes to PL = 0.0450, comparison of the optimal solutions obtained under normal and fault conditions of the system was performed. In this regard, the impact of problems in the optimization processes is proved. According to the results obtained, uncertain loads and system failures can incur heavy costs for the network operator. Finally, it can be concluded that the data obtained from economic analysis play an important role in the proper management of the network. The detailed information obtained from this study allows electric network operators and all professionals working in this field to use electrical systems more efficiently.

The main results of the work

1. In this dissertation, different approaches to solving the problem of power system optimization and maximum use of the capacity of existing systems in accordance with the operating conditions, including low load, peak load, normal conditions, fault conditions, fixed loads and load uncertainty are classified and for each approach, multi-strategy optimization processes were designed and presented. In this way, a robust and flexible system suitable for research, evaluation, forecasting, decision-making and control was obtained. This work was presented in

the form of 68 simulation programs and 215 optimal answers [96, s.34-42].

2. In the technical optimization approach, in order to increase the efficiency of the power system, regardless of the location and capacity of installing series and parallel FACTS devices and the demand response program and related costs, optimization of the multi-objective function was performed. The optimal solutions obtained in this approach have the advantages of reducing losses, increasing static voltage stability and increasing system loadability. These answers were sorted using the Pareto Front evaluation and selection method [102, s.21-29].
3. At peak load conditions, the results obtained from the technical optimization approach with a large load index were able to solve the system problem and prevent global blackouts [1, s.15-24].
4. In the economic approach to solve the problem under maximum load conditions, optimal solutions to achieve the loadability index λ= k1 set by the system operator were obtained using the strategy with the least cost [99, s.1-6].
5. In the economic approach to solve the problem under low load conditions, optimal solutions to achieve the loss reduction index PL=k2 set by the system operator were obtained using the strategy with the least cost [99, s.1-6].
6. The sharp differences in costs obtained for different strategies in one approach proved the importance of the multi-strategy optimization process [97, s.1-10].
7. The use of multi-strategy optimization process in the optimization approach provided more choices to the system operator according to the operating conditions and available compensation equipment [99, s.1-6].
8. Using the optimization process of multi-strategy, the optimal economic price of the demand response program for concluding the relevant contracts was determined [96, s.34-42].
9. By performing comparative analyzes, important information was provided to the system operator to make decisions.

List of published scientific works on the topic of the dissertation:

1. A. Kazemi A., Shadmesgaran M.R. Damping inter-area oscillations by UPFC considering effect of inertia coefficient / 8th WSEAS International Conference on power systems (PS) 2008, Santander, Cantabria, Spain, September 23-25, 2008 ISSN: 1790-5117.
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3. Hashimov A.M., Yusifbeyli N.A., Shadmesgaran M.R Impact of UPFC on energy efficiency considering effect of shunt capacitors / Institute of Physics of ANAS, Energetikanın problemləri, 2012, Number 1 Проблемы энергетики.
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11. Shadmesgaran, M.R., Hashimov, A.M., Rahmanov, N.R. A Glance at the Effects of System Operating Conditions on both Technical and Economic Multi-Objective Optimization // International Journal on "Technical and Physical Problems of Engineering" (IJTPE), – 2021. Volume 12, – p.1-10.

Candidate contribution to work with co-authors:

[8], [9] - performed independently.

[1], [2], [3], [4], [5], [6], [7], [10], [11] - problem statement, article composition, research, conclusion, information.

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