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A GLANCE OF OPTIMAL CONTROL EFFECTS ON TECHNICAL AND ECONOMIC OPERATION IN GRID

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Abstract- At present, optimization of multi-objective functions as an important solution to reach the maximum capacity of existing equipment to meet the growing demand for electric energy is at the forefront of research. In this regard, one of the most important areas of research is the optimization of multi-objective functions using the type selection and optimal allocation of FACTS and DR programs. On the other hand, the severe impact of the set of conditions including the occurrence of error, the uncertainty of the nature of the electric charges, the low load and peak load conditions, on the optimization results are still persistent problems of power systems. In this paper the impact of the set of lateral conditions on the flexible optimization process is solved in a complex manner considering technical and economical indices for various multi-objective functions according to the current needs of the system. The research is conducted on a wide range of different compensating equipment and demand response program as well as different single and group installation modes. Implementation of the Pareto Front Selection Method with Evolutionary Algorithm in Optimization Processes cause, the obtained optimal answers meet the expectations of the system operator. Likewise, by analyzing the solutions obtained from optimization processes, valuable suggestions for solving system problems in case of error and load uncertainty are presented. Simulation processes are carried out using the standard IEEE 30-bus system as well as MATLAB and PSAT programs.

Keywords: Operational Condition, Technical Optimization, Economic Optimization, Multi-Objective Function, Demand Response Program, FACTS Devices.

1. INTRODUCTION

Given the inevitability of error occurrence, the nature of load uncertainty in power systems, low and peak load conditions at different hours of the day, ensuring the reliability of the electrical energy delivered to the subscribers, minimizing costs and losses, to achieve the maximum system loadability and finally the optimal utilization of existing power grids and equipment are impossible regardless of the impact of the set of conditions on the optimization process. In power systems, a transmission line outage due to natural disasters, significant change in loads as a result of changing subscriber behavior, changing the hour of peak load and off-peak load in different seasons of the year form a Peripheral set of conditions. The impact of the set of conditions on the optimization process in turn appears in the formation of the multi-objective function and the optimization operation approach. Finally choose the type of compensator equipment, installation of single or combined compensators, compensation for technical indicators of power system, compensation of technical - economic indexes and the selected multi-objective function plays a decisive role in shaping the optimization process approach.

In reference [1], use of FACTS devices in compensation of transmission lines and loads as efficient equipment to improve power system stability is provided. Optimization multi-objective function using demand response program (DR) to improve technical indicators under normal conditions and during cut off one of the transmission lines has been done [2]. In reference [3], optimal location and capacity of DR have been calculated and compared under normal and emergency conditions. Reference [4], provides a power generation planning model incorporating demand response program. Reference [5] discusses the use of TCSC for power grid optimization. Reference [6] also addresses the simultaneous reduction of network losses and increase of system loadability using TCSC under normal and emergency conditions. The results represent the suitable performance of TCSC in power grid compensation under fault conditions. Performance evaluation of parallel FACTS devices for power system optimization has been done under in case of interruption of one of the transmission lines. The optimal solutions confirm the simultaneous improvement of the technical indicators to an acceptable level [7]. In reference [8], overcoming power system problems under fault conditions with the simultaneous installation of parallel and series FACTS devices and demand response program is studied. In this case, more optimal solutions are provided that can be selected by the network operator. It is also possible to make more use of the capacity of existing systems .

In references [9], improvement of technical parameters of power systems under various operating conditions has been carried out with regard to the uncertainty of electric charges. Reference [10] emphasizes the importance of the simultaneous implementation of FACTS devices and demand response program in power network congestion management. In reference [11], efficiency of the proposed optimization method in complex problem solving the technical and economic problems under various operational conditions and considering load uncertainty has been proven. This paper is organized as follows. In the second section, the types of operation scenarios and the impact of peripheral conditions on the results of technical and economic optimization processes are classified. As well as, in this section, multi-objective functions are developed in accordance with each operation condition. The third section deals with the compensation approaches used in this study, the compensating equipment, and the implementation of the DR program. In the fourth section, the methods of evaluating the impact of operating conditions are expanded by providing a flexible optimization process along with evolutionary algorithms and the Pareto Front selection method. The results of the data analysis and the best decision-making method are presented in the fifth section. Finally, Section 6 presents our conclusions.

2. POWER SYSTEM OPERATION SCENARIOS

In this study, to assess the impact of operating conditions on the efficiency of the flexible optimization process, eight different scenarios are defined as Table 1. Changing the optimization approach according to different operating scenarios, considering loss reduction, increasing system loadability and stability during searching for optimal solutions, ensure technical and economic indices improvement.

Table 1. Scenario definition of operation conditions

State	Network condition	Load type	Consumption level
Scenario 1	Normal	Fix	Low
Scenario 2	Normal	Fix	Peak
Scenario 3	Normal	Uncertainty	Low
Scenario 4	Normal	Uncertainty	Peak
Scenario 5	Emergency	Fix	Low
Scenario 6	Emergency	Fix	Peak
Scenario 7	Emergency	Uncertainty	Low
Scenario 8	Emergency	Uncertainty	Peak

2.1. Definition of Multi-Objective Functions

The definition of multi-objective functions is done taking into account the operating conditions, the needs of the power system and the interests of the system operator.

2.1.1. Technical Multi-Objective Function

In load peak conditions, the most significant goals for the system operator are to increase the system loadability and provide electricity to consumers in order to prevent blackouts. In this case, the aspects of reducing losses and economic goals become less important. Developing of appropriate multi-objective functions, along with achieving the required loadability of the network, satisfies power loss reduction and minimizing the compensation costs. The multi-objective function for technical optimizations is defined as Equation (1):

$$F(\lambda, PL) = (\lambda_{New} - \lambda_0)_{\max} \ \& \ (PL)_{\min} \tag{1}$$

2.1.2. Economic-Technical by Loss Reduction Approach

In low loads mode, due to no need to increase system loadability, the optimization process aims to reduce system losses, energy costs and environmental pollution. The multi-objective function of economic-technical optimization process by the loss reduction approach is defined using Equation (2).

$$F(PL, C_{compensator}) = (|PL_{New} - PL_{Set}|)_{\min} \ \& \ (C_{compensator})_{\min} \tag{2}$$

Here, in the multi-objective function, approaching to the amount of power losses determined by the system operator with the minimum capacity of the candidate compensating device is desirable. It is clear that the minimum compensatory capacity meets the minimum investment cost required to supply it. Moreover, reducing losses more than the limit set by the operator is considered as waste of investment in compensation sector and is not desirable.

2.1.3. Economic-Technical by System Loadability Increasing Approach

In the economic-technical optimization process, despite the fact that most economic exploitation is desired, however, technical optimization is taking place in the heart of economic optimization. The multi-objective function of economic-technical optimization process by system loadability increasing approach is defined using Equation (3).

$$F(\lambda, C_{compensator}) = (|\lambda_{New} - \lambda_{Set}|)_{\min} \ \& \ (C_{compensator})_{\min} \tag{3}$$

Fault occurring in the power system is inevitable due to natural disasters and other causes. Hence, the optimization process is completed by entering the error conditions in it. As well as, the output of risk management programs or the output of statistical analysis are considered as the best option in calculating the emergency conditions in the optimization process. Owing to the modularity of the simulation process structure, in case of emergency condition without the need to change the multi-objective function and other parts of the process, it is enough to change the information of the test system according to the fault.

2.2. Load Uncertainty Condition

In all operation modes, the scenario method is used to implement load uncertainty conditions. In this method, we select coefficients for applying loads according to the behavior of real loads. Then the optimization operation is performed for each of the coefficients. Using equations 4 and 5, the average of the optimal answers obtained for the indicators of loss reduction and system loadability are presented as the final solutions.

$$PL_m = \frac{\sum_{i=1}^{n} PL_{OPT}(Loads \times KS_i)}{n} \quad (4)$$

$$\lambda_m = \frac{\sum_{i=1}^{n} \lambda_{OPT}(Loads \times KS_i)}{n} \quad (5)$$

Evaluating the efficiency of the optimization process in load peak conditions considering the load uncertainty when an error occurred in the system, helps to make the best decision in the most complex situations and is one of the most remarkable exploitation scenarios. consequently, approaching to the real conditions of power systems, more practical optimal answers are obtained.

3. IMPLEMENTED COMPENSATORS

In the optimization process, in order to reduce losses and increase the loadability of the power system, line compensation and load compensation are carried out. Power electronic based equipment is candidate because of their high reaction speed in the face of power system problems. As well as, the demand response program is implemented due to its ability to quickly run without need for initial investment.

3.1. Line Compensation

Series FACTS devices are used to compensate transmission lines. By compensating line reactance, energy loss is reduced and network loadability and its stability are increased. In this study, TCSC is used to compensate transmission lines with a nominal voltage of 132 kV and DR is applied to compensate distribution network lines. Relationships (6) and (7) show the limitations of TCSC:

$$L_{TCSC} = \{L_i \;\; | 1 \le L_i \le 41 \;\; V_{Li} = 132 \;\; L_i \notin \{UP\}\} \quad (6)$$

$$-0.8X_{Line} \le X_{TCSC} \le 0.2X_{Line} \quad (7)$$

Suitable lines for TCSC installation are specified using Equation (6). Relation (6) Displays possible locations for TCSC installation. In considered test system TCSC is used to compensate transmission network lines with 132 kV. This relationship shows that among the 41 lines in the test system, TCSC is intended for installation on transmission lines with a voltage of 132 kV. The $\{UP\}$ Collection shows the transmission lines where TCSC installation is prohibited due to technical, economic, security, geographical location or other. Implementing risk management programs can also play a role in defining Collection $\{UP\}$. As shown in Equation (7), the allowable range of TCSC capacity changes is defined from 80% of line reactance in capacitive mode to 20% of line capacity in inductive mode.

With regards to the DVR's ability to protect consumers against instantaneous voltage changes, this study suggests installation it on distribution network lines. Furthermore, the efficiency of this equipment is surveyed in different operating conditions. The installation location of the DVR on the distribution network lines with voltage of 1, 11 and 33 kV is shown using Equation (8). In addition, the locations where installation is not possible are determined with set $\{UP\}$. Relationship (9) shows the range of changes in DVR reactance from 80% of the distribution line reactance in the capacitive mode to 20% of the line reactance in the inductive mode.

$$L_{DVR} = \{L_j \;\; | 1 \le L_j \le 41 \;\; V_{Lj} < 132 \;\; L_j \notin \{UP\}\} \quad (8)$$

$$-0.8X_{Line} \le X_{DVR} \le 0.2X_{Line} \quad (9)$$

3.2. Compensation of Electric Loads

Parallel FACTS devices are used for loads compensation. In this case, energy losses in lines are significantly reduced by providing the reactive power required by the loads on sites and preventing reactive power transmission by lines. Moreover, these devices increase the network loadability by improving the dynamic stability of the system. The study uses SVC for 132 kV's buses and DSTATCOM for distribution network buses. Equations (10) and (11) express the limitations of SVC:

$$L_{SVC} = \{L_m \mid 1 \le L_m \le 30 \;\; V_{Lm} = 132 \;\; L_m \notin \{UP\}\} \quad (10)$$

$$-2^{pu} \le Q_{SVC} \le 2^{pu} \quad (11)$$

Relationship (10) shows the permissible buses for SVC installation. This set includes 132 kV buses. This relationship also shows that buses with installation restrictions can be left out of the selection set. The output of the risk management program can be considered in determining the set of impossible buses. The range of SVC capacity changes is defined using Equation (11) from -2 pu in capacitive mode to 2 pu in inductive mode.

In this study, Distribution Static Synchronous Compensator (DSTATCOM) is suggested as a dynamic controller and power quality improver in different operating conditions of distribution network. Relationships (12)-(13) show limitations of STATCOM:

$$L_{DSTATCOM} = \{L_n \,| 1 \le L_n \le 30 \;\; V_{L_n} = 132 \;\; L_n \notin \{UP\}\} \quad (12)$$

$$-0.1^{pu} \le Q_{DSTATCOM} \le 0.1^{pu} \quad (13)$$

Permitted buses for installing DSTATCOM in the distribution network with voltages of 1, 11 and 33 kV is displayed using Equation (12). Distribution buses with impossibility of installation are eliminated by this equation. Relationship (13) shows the changes in DSTATCOM capacity from -0.1 pu in capacitive mode to 0.1 pu in inductive mode.

3.3. Demand Response Programs

Solving the problems of power systems and preventing blackouts, providing demand of reliable electrical energy for consumers and achieving defined standards in the field of economic and technical indicators is impossible without the serious participation of consumers. Utilize of the demand response program is recommended in this article Due to its efficiency in various operating conditions and ensuring the benefits of network operators and consumers. Relationships (14) and (15) describe the limitations of demand response program:

$$L_{DR} = \{L_d \mid 1 \le L_d \le 30\ L_d \in \{PQ\}\ L_d \notin \{UP\}\} \quad (14)$$

$$0 \le S_{DR} \le 0.1 S_{BUS} \quad (15)$$

The range of options to implement of the DR program among the network load buses for the subscribers who have tendency for DR contract is expressed by relation (14). Consumer centers and loads that for technical reasons, the need for them to be active or unwillingness of the consumer to enter into a contract, are not possible to implement DR in them are Considered using set {UP}. According to the standards, the average reduction in electricity consumption by subscribers is 10% of their total energy consumption that is expressed by (15).

4. FLEXIBLE OPTIMIZATION PROCESS

The optimization approach adopted in this study makes it possible to compare the efficiency of the flexible optimization process under different operating conditions.

4.1. Approach of Investigating the Effect of Different Operating Conditions on Optimal Solutions

The block diagram of the proposed flexible optimization process is shown in Figure 1. As shown in Figure 1, the operating conditions of the system are considered as an input to the system.

The second option is to choose the type of optimization process that can be considered technical optimization or economic-technical optimization according to the operator tend or system operating conditions. For example, in load peak condition, regardless of economic indicators, providing of the required electrical energy is targeted to prevent blackout.

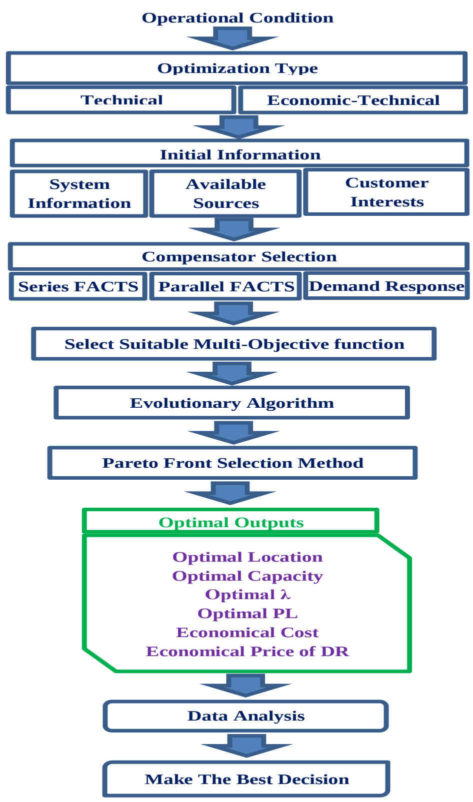

Figure 1. Block diagram of the proposed flexible optimization process

In the next step, the power network information, available compensation equipment resources, and consumers' feedback to participate in the demand response program are introduced into the process. The multi-objective function for each calculation is developed taking into account the selected equipment, the type of optimization and the adopted targets. During the next stage, the optimization of the assigned multi-objective function is performed using the evolutionary algorithm and the Pareto Front selection method. Finally, the best decisions are made based on data analysis.

4.2. Proposed Technical Optimization Process

In the technical optimization process, regardless of economic indicators, optimizing the multi-objective function in order to simultaneous improve the important technical indices of the power system is aimed. Figure 2 shows block diagram of the technical optimization process. This process begins with choosing the type of compensator. The second and third options make it possible to compare the efficiency of the optimization process under different operating conditions.

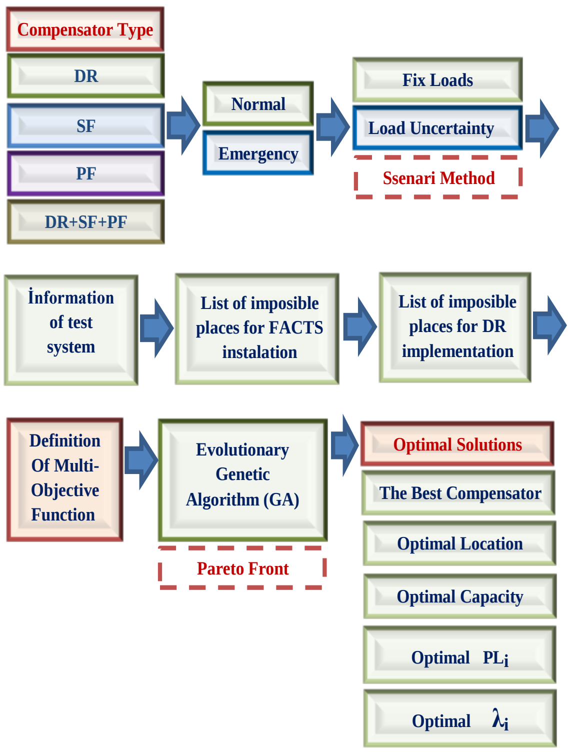

Figure 2. Block diagram of the proposed technical optimization process

During the next stages, after defining the basic information and limitations, it is time to select the most appropriate multi-objective function to achieve the set goals. In the next step, the designated multi-objective function is optimized using the evolutionary algorithm and the Pareto Front selection method. As can be seen in the figure, at the output of the optimization process, the optimal values of the compensating devices along with the optimal values of the determined technical indices are presented for operator use.

4.3. Economic-Technical Optimization Process

The block diagram of process of economic-technical optimization is shown in Figure 3. At the beginning of the process, as the first option, the desired technical index is selected and targeted by the network operator depending on the operating conditions of the system and the adopted policies. In the second and third steps, the definition of operating conditions makes it possible to compare the efficiency of the optimization process under different operating conditions.

In the following, after defining network information and existence constraints, the most appropriate multi-objective function is determined. In the next step, the optimization of the multi-objective function ensures separately the achievement of the technical index "targeted by the operator" with the smallest capacity of each compensating device and demand response program. During the next stages, the cost of investment required for optimal technical values obtained for each device is calculated separately [12, 13]. For the next phase, economic price of the optimal DR, is calculated based on the lowest cost obtained for the equipment [14]. Analysis of the data obtained from the output of the process, provides very valuable information to make the best decision by the operator.

4.4. Evolutionary Algorithm

In this research, optimization problem solving to find global optimal solutions according to the use of numerical methods, the nature of the power grid and the existence of enormous number of options is impossible within acceptable time without the use of an evolutionary algorithm. Here, in the genetic evolutionary algorithm used for various optimization processes, the initial population changes between 24 and 80. The length of each variable is considered 10 bits. Each chromosome contains the information about locations and capacities of the compensating devices, and its length is obtained by multiplying the number of used variables by 10. Implemented genetic algorithms achieve optimal global solutions instead of a few tens of millions of iterations in less than 100 retries.

4.5. Pareto Front Selection Method

When it comes to using a multi-objective function in the optimization process, each chromosome of population has more than one indicator to evaluate. Given that these indicators are in conflict with each other, it is not easy to evaluate and align chromosomes. To solve this problem in the recommended optimization process, along with the genetic evolutionary algorithm, the Pareto Front selection method is used. In this method, after the population chromosomes are installed in the network and calculating their relevant indicators, are sieved at the same time as assessment. The chromosomes that do not fail in at least one of their indices compared to the other members are selected to form the next generation. Hence, evaluating and selection of the best chromosomes that satisfy the conditions of the multi-objective function are become possible.

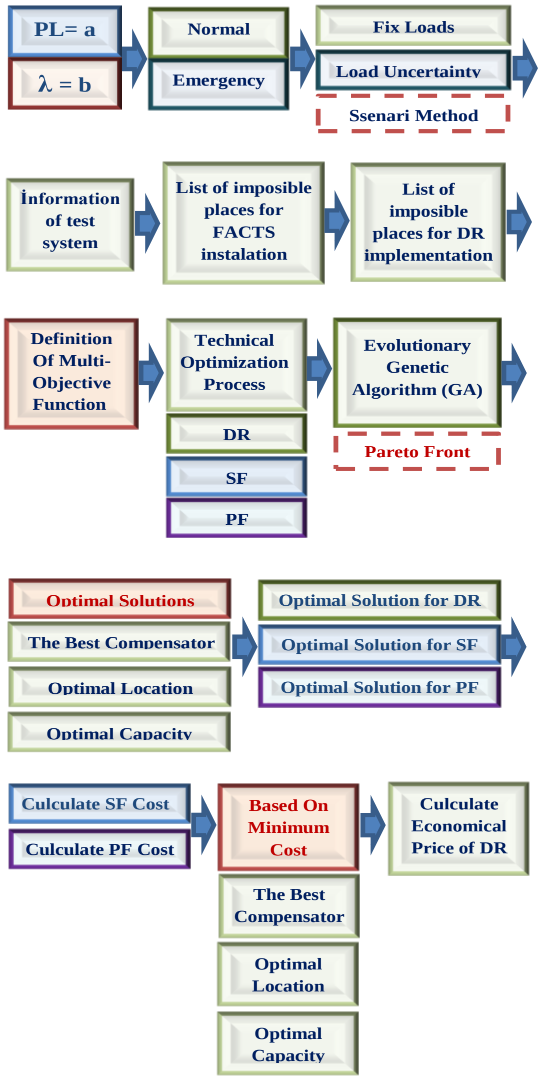

Figure 3. Block diagram of the proposed economic-technical optimization process

5. DATA ANALYZING AND MAKING DECISION

In this section, the results of technical and economic optimization processes of multi-objective functions for different operating conditions are analyzed. First, by comparing the results of technical optimization, the effect of operating conditions on the loss index is surveyed. Here, the comparative analysis of the loss index data along with the type, optimal location and capacity of the compensating devices for different operating conditions, together with the loadability index of the system, provides very valuable information to the system operator.

This information can solve system problems, especially in low-load and middle-load conditions. In the next step, the same thing is repeated for the system loadability index. The information obtained from this section is very useful for solving system problems in peak load conditions. It is worth noting that the system operator uses this information to achieve more options to make the best decision. Finally, the data obtained from economic-technical optimizations are analyzed.

For this purpose, in any operating conditions, obtained optimal solutions in each compensation methods are compared. The information taken from this section are very important to achieve the set goal at the lowest cost.

In Table 2, for each operation mode, the first eleven optimal solutions with the best loss reduction index are presented. The first column shows the operation mods of the system during the optimization process. As well as, corresponding to each of these optimal solutions, the optimal location and capacity of DR and the optimal location and capacity and type of series and parallel FACTS devices are given in columns 2 to 9, respectively. Finally, the tenth and eleventh columns show the optimal values obtained for the indices of multi-objective functions. It is worth to mention that Table 2 allows the system operator to choose the most suitable option according to the operating conditions, the set goals and the available resources.

Table 2. Comparison of the effect of operating conditions on power loss index optimization

First 11 Best Loss Reduction - Technical Optimization - GA								
Operation condition	Optimal Location of DR	Optimal Capacity of DR (%)	Optimal Location of Series FACTS (Line Number)	Optimal Capacity of Series FACTS (%)	Optimal Location of Parallel FACTS (Bus Number)	Optimal Capacity of Parallel FACTS (pu)	Power loss (pu)	Power System Loadability (λ)
N-Fix L	24	7.5	12	56	12	0.045	0.0958	3.394
N-Fix L	24	8.8	16	72	12	0.175	0.202	4.082
N-Fix L	5	8.8	12	65	9	0.0945	0.0411	2.915
N-Fix L	16	7.5	16	72	12	0.2366	0.4649	4.764
N-Fix L	23	7.5	12	56	12	0.0371	0.0754	3.245
N-Fix L	3	9.4	16	53	12	0.0645	0.0791	3.307
N-Fix L	24	5.6	12	68	12	0.0137	0.045	3.089
N-Fix L	28	3.8	12	80	12	0.0371	0.0802	3.378
N-Fix L	29	8.8	16	67	12	0.174	0.2867	4.287
N-Fix L	3	9.4	16	37	12	0.0723	0.1227	3.498
N-Fix L	21	3.8	12	80	12	0.0215	0.051	3.231
E-Fix L	24	8.8	12	79	9	0.0912	0.0434	3.023
E-Fix L	24	9.2	12	80	1	1.2023	0.0434	3.028
E-Fix L	24	6.3	19	5.6	12	0.0802	0.2915	3.918
E-Fix L	30	5.6	12	45	12	0.0723	0.2365	3.837
E-Fix L	21	7.5	13	25	12	0.0723	0.2241	3.735
E-Fix L	23	6.3	16	57	12	0.0802	0.0961	3.407
E-Fix L	26	5	16	47	12	0.0919	0.1534	3.661
E-Fix L	9	5	16	44	12	0.0919	0.167	3.684
E-Fix L	30	8.8	7	59	12	0.0762	0.2541	3.907
E-Fix L	16	8.8	16	58	12	0.088	0.1074	3.478
E-Fix L	24	5	37	70	12	0.0723	0.2256	3.801
N-Un L	1	1.3	16	38	12	0.0723	0.1007	4.136
N-Un L	2	1.9	16	39	12	0.0723	0.099	4.13
N-Un L	1	1.9	16	51	12	0.0723	0.0769	4.036
N-Un L	9	6.3	36	38	12	0.0645	0.1563	4.401
N-Un L	24	8.8	12	79	8	0.7566	0.0315	3.585
N-Un L	20	6.3	16	57	12	0.0271	0.1935	4.774
N-Un L	24	9.4	12	79	5	0.8504	0.0315	3.584
N-Un L	29	6.3	36	46	12	0.0606	0.1372	4.337
N-Un L	1	8.8	16	51	12	0.088	0.107	4.262
N-Un L	1	4.4	16	51	12	0.088	0.1058	4.256
N-Un L	15	5	16	50	12	0.088	0.1108	4.287
E-Un L	30	7.5	12	78	10	0.0137	0.0419	3.753
E-Un L	30	8.8	12	69	12	0.0137	0.0349	3.644
E-Un L	30	2.5	16	75	12	0.0723	0.0452	3.844
E-Un L	24	2.5	16	78	12	0.0723	0.0422	3.784
E-Un L	29	2.5	16	75	12	0.0802	0.0487	3.854
E-Un L	30	7.5	12	78	12	0.0293	0.0516	3.936
E-Un L	30	7.5	12	75	12	0.0293	0.051	3.905
E-Un L	30	9.4	12	80	12	0.0606	0.0326	3.629
E-Un L	26	3.8	16	78	12	0.0919	0.0497	3.902
E-Un L	30	2.5	16	77	12	0.0723	0.0435	3.829
E-Un L	30	7.5	12	78	12	0.0137	0.0349	3.74

In Figure 4, the radar diagram is used to compare the loss reduction index of obtained optimal solutions in different operating conditions. This figure compares the loss reduction index of optimal solutions in four different operating conditions. In this diagram, to better understand the effect of operating conditions on the loss reduction index, the obtained points are connected with colored lines. The asymmetry of the obtained curves proves the severe effect of the operating conditions on the optimal results. Figure 4 shows that in normal conditions, when all subscribers are active near their nominal load, the system suffers the most losses with an average $PL_{average}$= 0.140 pu. The system operator chooses the best option from the optimal solutions obtained from the flexible optimization process according to the operation condition, the required system loadability and the available compensating equipment.

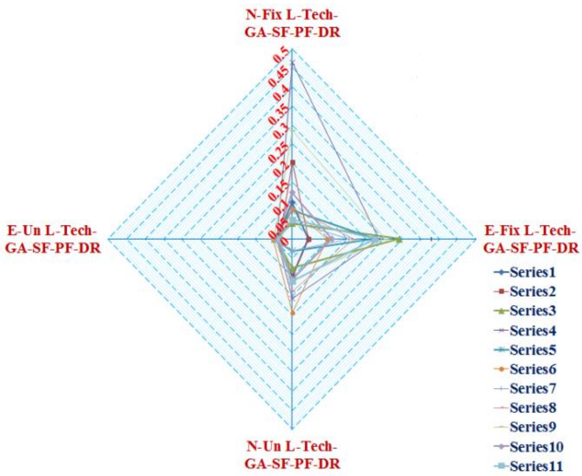

Figure 4. Comparison of power loss index of optimal solutions in different operating conditions

Eleven optimal solutions of the technical optimization process with the best system loadability index are presented in Table 3. Column 1 shows the operation mode of the power system. The second and third columns show the optimal location and capacity of Demand Response program. As well as, in the fourth to ninth columns, the optimal location and capacity and the type of series and parallel FACTS devices corresponding to the mentioned optimal solutions are presented, respectively. Finally, the optimal values obtained for the multi-objective function indices of the power system (losses reduction and system loadability) are offered in the tenth and eleventh columns. In peak consumption, the information of this table is very important in order to make the best decision and prevent blackout.

Figure 5 compares the best eleven answers obtained to increase system loadability using technical optimization processes in different operating conditions. The drastic changes in system loadability prove the importance of taking into account operating conditions in optimization processes, which is the main topic of this article. As can be seen in the figure, the proposed flexible optimization process offers optimal solutions with loadability indices within acceptable range for all operating condition. Average loadability index $\lambda_{average}$=3.86 under fix load operation conditions and the mean loadability index $\lambda_{average}$=4.51 under load uncertainty conditions, express the fact that taking in to account the load uncertainty condition in the optimization process, appears as system loadability development.

Table 3. Comparison of the effect of operating conditions on system loadability index optimization

First 11 Best System Loadability - Technical Optimization - GA								
Operation condition	Optimal Location of DR	Optimal Capacity of DR (%)	Optimal Location of Series FACTS (Line Number)	Optimal Capacity of Series FACTS (%)	Optimal Location of Parallel FACTS (Bus Number)	Optimal Capacity of Parallel FACTS (pu)	Power loss (pu)	Power System Loadability (λ)
N-Fix L	24	7.5	12	55.8	12	0.045	0.096	3.394
N-Fix L	24	8.8	16	72.2	12	0.175	0.202	4.082
N-Fix L	5	8.8	12	65	9	0.095	0.041	2.915
N-Fix L	16	7.5	16	72.2	12	0.237	0.465	4.764
N-Fix L	23	7.5	12	55.8	12	0.037	0.075	3.245
N-Fix L	3	9.4	16	52.7	12	0.065	0.079	3.307
N-Fix L	24	5.6	12	68.3	12	0.014	0.045	3.089
N-Fix L	28	3.8	12	79.7	12	0.037	0.08	3.378
N-Fix L	29	8.8	16	67	12	0.174	0.287	4.287
N-Fix L	3	9.4	16	37.1	12	0.072	0.123	3.498
N-Fix L	21	3.8	12	79.7	12	0.022	0.051	3.231
E-Fix L	24	6.3	19	5.63	12	0.08	0.292	3.918
E-Fix L	30	5.6	12	44.9	12	0.072	0.237	3.837
E-Fix L	30	7.5	38	3.66	12	0.08	0.292	3.997
E-Fix L	30	6.3	34	57.2	12	0.092	0.433	4.346
E-Fix L	30	8.8	3	33.2	12	0.092	0.438	4.354
E-Fix L	30	6.3	34	73.3	12	0.092	0.433	4.349
E-Fix L	24	5	16	44.1	12	0.023	0.337	4.264
E-Fix L	30	8.8	34	73.1	12	0.084	0.333	4.112
E-Fix L	30	8.8	7	58.6	12	0.076	0.254	3.907
E-Fix L	2	5	16	69.9	12	0.017	0.44	4.631
E-Fix L	29	7.5	38	53.7	12	0.08	0.293	4.021
N-Un L	1	1.3	16	38.3	12	0.072	0.101	4.136
N-Un L	29	6.3	16	46	12	0.043	0.437	5.57
N-Un L	20	6.3	16	47.6	12	0.027	0.286	5.078
N-Un L	29	6.3	16	46.4	12	0.043	0.43	5.551
N-Un L	2	1.9	16	39	12	0.072	0.099	4.13
N-Un L	20	6.3	16	47.6	12	0.039	0.373	5.371
N-Un L	26	8.1	36	52.2	12	0.08	0.277	5.048
N-Un L	1	1.9	16	50.8	12	0.072	0.077	4.036
N-Un L	9	6.3	36	38.3	12	0.065	0.156	4.401
N-Un L	17	6.3	16	44.4	12	0.027	0.322	5.197
N-Un L	24	8.8	12	79	8	0.757	0.032	3.585
E-Un L	30	7.5	12	78	10	0.014	0.042	3.753
E-Un L	30	8.8	12	68.7	12	0.014	0.035	3.644
E-Un L	30	2.5	16	74.9	12	0.072	0.045	3.844
E-Un L	24	2.5	16	78.2	12	0.072	0.042	3.784
E-Un L	29	2.5	16	74.9	12	0.08	0.049	3.854
E-Un L	9	2.5	16	78.2	12	0.035	0.074	4.144
E-Un L	30	7.5	12	78	12	0.029	0.052	3.936
E-Un L	30	4.4	36	77.9	12	0.088	0.388	5.452
E-Un L	8	6.3	36	74.8	12	0.088	0.384	5.421
E-Un L	30	4.4	36	71.6	12	0.088	0.383	5.42
E-Un L	30	7.5	12	74.9	12	0.029	0.051	3.905

In other words, approaching the real conditions of the system allows better use of existing capacities. It is worth noting that, the optimal answer with the smallest system loadability index was obtained in operating condition (normal + fix loads) λ = 2.915, while the optimal solution with the largest system loadability index was attained in operating condition (normal + uncertainty loads) λ =5.57. Furthermore, the red curve shows that the lowest fluctuations in the system loadability index of the optimal solutions, is experienced in operating condition of (emergency + fix loads). Predominantly the importance of incorporating operating conditions into optimization processes in achieving more practical optimal solutions is proven.

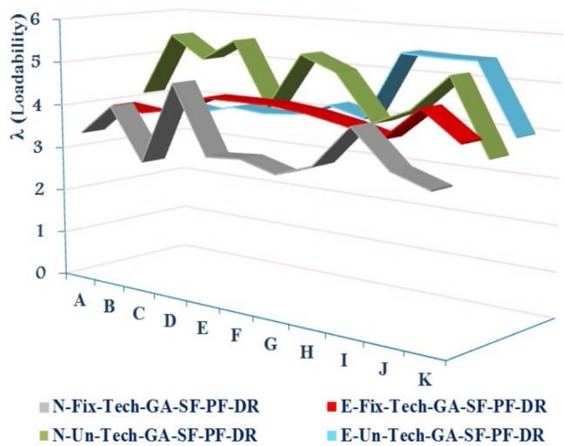

Figure 5. Comparison of investment cost and economic price of DR in different operating conditions

The optimal solutions obtained from the economic-technical optimization processes in different operation mode are demonstrated in Table 4.

The first column of the table shows that the optimization process is performed under eight different operation modes. The values set for the indicators of loss reduction and loadability enhancement by the system operator are shown in column 2. This column shows that the goals of losses reduction and system loadability increasing for each of the defined operation modes have been performed separately. Columns 3 through 6 show the compensation type, name, optimal location and capacity of applied compensators, respectively. The seventh column displays the dimension of quantities written in the sixth column. The eighth column shows the calculated cost of investment for optimal compensating equipment, determined by the technical optimization processes in dollars. Finally, in the ninth column, the economic prices calculated for the DR program in $/KVA calculated based on the lowest price obtained for the installation of compensating devices are displayed. As can be seen in Table 4, by analyzing the results of economic-technical simulation processes, the best locations for installing parallel compensating devices are buses 21 and 23, for series compensating devices, lines 10, 12 and 29 and for implementing DR programs, lines 2, 5 and 21 are revealed.

Table 4. Comparison of the effect of operating conditions on system economic indices optimization

Economic Optimization - GA							
Condition	Main Goal	Type Of Equipment	Optimal Location (Bus/Line)	Optimal Capacity	Dimension	Optimal cost (Dollar)	Economic Price of DR ($/MVA)
N_Fix L_PL	PL=0.0450	SF	12	0.28	kvar	43.05	-
		PF	10	10	kvar	1273.8	-
		DR	5	7.18	MVA	-	5.99
N_Fix L_λ	λ=2.6	SF	36	2.07	Mvar	315220	-
		PF	23	30	kvar	3821.1	-
		DR	21	2.01	MVA	-	1901.1
E_Fix L_PL	PL=0.0450	SF	12	140	kvar	21511	-
		PF	21	10	kvar	1273.8	-
		DR	21	1.72	MVA	-	740.58
E_Fix L_λ	λ=2.6	SF	10	1.36	Mvar	207790	-
		PF	9	9.77	Mvar	1215700	-
		DR	21	0.97	MVA	-	214216
N_Un L_PL	PL=0.0450	SF	10	0.572	Mvar	87681	-
		PF	29	9.43	Mvar	1163400	-
		DR	5	1.04	MVA	-	84309
N_Un L_λ	λ=2.6	SF	29	4.3	kvar	661	-
		PF	22	110	kvar	14008	-
		DR	2	0.49	MVA	-	1349
E_Un L_PL	PL=0.0450	SF	10	0.25	Mvar	38393	-
		PF	15	9.77	Mvar	1215700	-
		DR	5	8.52	MVA	-	4506.2
E_Un L_λ	λ=2.6	SF	29	4.3	kvar	661	-
		PF	9	10	Mvar	1243590	-
		DR	2	0.41	MVA	-	1612.2

Figure 6 compares the optimal results obtained from the economic-technical optimization processes in eight different operating conditions using radar diagram. In this figure, the green dash dotted curve, comparisons the optimal costs for compensators installation in different operating conditions. As well as, Comparison of economic price obtained for DR in different operating conditions based on the minimum cost of FACTS equipment resulting from economic-technical optimization processes is carried out by the red dash-line. The asymmetry of these curves reaffirms the importance of incorporating operating conditions into economic-technical optimization processes. According to the choice of logarithmic axes, the corresponding points at very high cost of compensation are identified as system risk points in the diagram, which the operator always tries to keep the system away from.

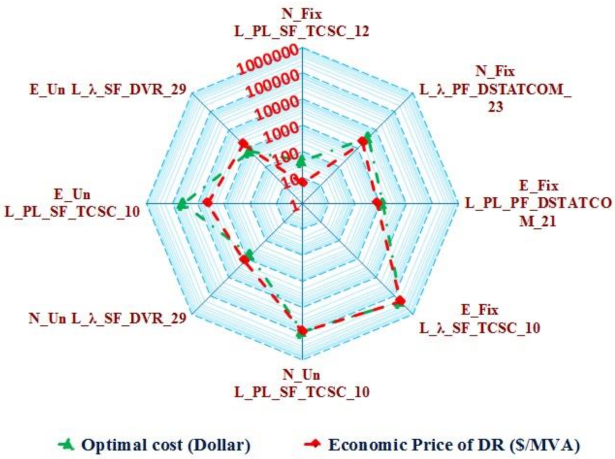

Figure 6. Comparison of investment cost and economic price of DR in different operating conditions

6. CONCLUSIONS

Flexible optimization process is presented in which the optimization approach and multi-objective function are selected in accordance with the operating conditions. By considering the operating conditions in the optimization process, approaching to the real system is realized. In low-load conditions, the maximum loss reduction with the lowest possible investment cost is emphasized using the economic-technical optimization process. In peak load conditions, in order to prevent blackout, regardless of economic indicators, increasing loadability of power system is provided by the technical optimization process using evolutionary algorithm and Pareto Front selection method.

In the next stage, data analysis is performed on optimal solutions to obtain more valuable information. As a result, the most suitable locations for installing series and parallel compensating devices and implementing DR programs that have the best technical and economic indices in different operating conditions are revealed. Furthermore, non-economic operating conditions were identified as system risk points. The results of data analysis in a wide range prove the effectiveness of the flexible optimization process offered to achieve the technical and economic goals, as well as helping the system operator to make the best decision.

NOMENCLATURES

1. Acronyms

DR	Demand Response
FACTS	Flexible AC Transmission System
TCSC	Tiristor Controlled Series Capacitor

SVC Static VAR Compensator
DVR Dynamic Voltage Restoration
DSTATCOM Distribution Static Synchronous Compensator
GA Genetic Algorithm
CPF Continuous Power Flow

2. Symbols / Parameters

n: The number of coefficients considered for the scenario method

KS_i : The *i*-th coefficient of the method is scenario which is multiplied in loads.

$C_{compensator}$: The capacity of compensator

L_x : The location of the compensator

X_x : The reactance of compensator

S_x : The Apparent power of implemented DR

PL : Power loss index

PL_0 : The system power loss before compensating

PL_{New} : The system power loss after compensating

PL_m : Average of optimal power loss index for different coefficients of loads.

PL_{Set} : The power loss set by system operator

PL_i : The system power loss for KS_i percentage of *system loads.*

$PL_{OPT}(Loads \times KS_i)$: The optimal power loss for coefficient KS_i

λ : The system loadability index

λ_0 : The system loadability before compensating

λ_{New} : The system loadability after compensating

λ_m : Average optimal loadability obtained for different coefficients of loads.

λ_{Set} : The system loadability set by system operator

λ_i : The system loadability for KS_i percentage of system loads.

$\lambda_{OPT}[Loads \times KS_i]$: The optimal system loadability for coefficient KS_i

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