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TECHNICAL ANALYSIS OF DEMAND RESPONSE PROGRAM AND FACTS DEVICES IMPLEMENTATION USING MULTI-OBJECTIVE OPTIMIZATION

M.R. Shadmesgaran [1,3] A.M. Hashimov [1,2] N.R. Rahmanov [2] O.Z. Kerimov [2] I.I. Mustafayeva [1]

1. Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan
shadmesgaran@yahoo.com, arif@physics.ab.az, m_irade@hotmail.com
2. Azerbaijan Research Institute of Energetics and Energy Design, Azerenerji JSC, Baku, Azerbaijan
nariman@cpee.az, okerimov@yahoo.com
3. East Azarbaijan Communication Company, Tabriz, Iran

Abstract- Recently, the greatest need of power systems and consequently the most important consideration of scientists and specialists is maximum use of existing equipment capacity. This important issue is in direct relationship with power system stability increasing and power loss reduction. In recent years, the high performance of FACTS devices and demand response programs in improvement of the mentioned objective functions have been proved. In this paper, multi-objective function improvement has been carried out using simultaneous implementation of series and parallel FACTS devices and demand response program (DR). Also, optimal places and capacities of the three instruments are separately determined and displayed using various evolutionary algorithms named genetic algorithm and TLBO (Teaching Learning based optimization algorithm). Furthermore, optimization problem is solved in emergency condition of network. Simulations are carried out on 30 bus IEEE standard test system using MATLAB program and PSAT (Power System Analysis Toolbox). The results of numerical studies prove that simultaneous use of series and parallel FACTS devices and DR program can provide high performance in the network. Finally, simulation results through various evolutionary algorithms (GA and TLBO) have been compared.

Keywords: Parallel and Series FACTS Devices, Demand Response Program, Voltage Static Stability, Power Loss.

I. INTRODUCTION

The limitations of transmission capacity in the network have caused voltage instability and increased power loss problems. At first glance, in order to improve voltage stability, more investment for enhancement of network operation quality is required. On the other hand, for power loss reduction we need to use high technology and consider better solutions to change network characteristics. Thus, a large amount of investment is needed to spend for renovation of network infrastructures [1].

Voltage collapse is a process composed of sequences of events along with voltage instability causing the voltage profile to drop unacceptably in large area of network. On the other hand, increased power demand in the case of reserve absence may cause voltage instability and voltage collapse phenomenon is occurred. In the deregulated environment, system commonly is under stress [2] and aforementioned systems are more prone to voltage instability. Several voltage instability problems have already occurred in various points of the world, namely: France, Japan and the United State of America. These failures have attracted a great deal of attraction to the voltage instability problem.

Voltage stability is one of the most necessary factors that it has to be considered in various stages of power system planning, operation and control to avoid voltage collapse and wide blackouts [5]. In the recent decades, FACTS devices are recommended and applied to improve voltage stability. Moreover, emergency situation analysis in order to improve voltage stability has been done in some studies [6, 7]. Furthermore, other approaches are recommended like continuous power flow (CPF) approach that seems more practical [9].

In [10], two practical indexes are introduced to show severity of emergency condition. For the purpose of showing the amount of voltage stability, neural network method is used [11, 12]. In [13] the impact of fault occurrence on voltage stability is evaluated. In [14] a new approach is presented in terms of voltage stability evaluation. This approach deals with identifying weak lines and by this way it identifies the points with high voltage instability contingency. In order to evaluate the presented approach in this paper, 14 bus IEEE standard system is applied.

In [15], optimal location and adjustments of TCSC (Thyristor Controlled Series Capacitor) in power system are investigated. In this reference, by use of evolutionary algorithms, power loss reduction in transmission lines is studied. This reference has used the newest evolutionary algorithm named evolutionary-differential algorithm for solving the problem.

The simulations in reference [15] are carried out on 14 bus IEEE standard system. One of the approaches by which network loss is reduced is network reconfiguration. In [16], by this way under resource and network constraints, loss reduction in micro grid is dealt with. Furthermore, two-stage method [17, 18] has been used for loss reduction in smart distribution network.

In this paper, parallel and series FACTS devices and DR program are used in order to improve voltage static stability and power loss reduction. To improve technical indexes, the equipment is simultaneously optimized. Moreover, FACTCS devices are determined to achieve the certain amounts of objective functions. In section II, FACTS device models and demand response program are presented. Formulation of a study case is carried out in section III. Numerical studies and conclusions are presented in sections IV and V, respectively.

II. MODELS OF FACTS DEVICE AND DR

In this paper, series FACTS devices like TCSC and DVR and parallel FACTS devices like SVC and DSTATCOM are used in order to improve objective functions including voltage static stability and power loss reduction. Series and parallel FACTS devices by active and reactive power injecting to the network lines and buses respectively, have impact on the network parameters and lead to improving objective functions. Among the series FACTS devices, TCSC is used in transmission network and DVR in distribution network. Besides, if parallel FACTS devices are installed, SVC is used in transmission network and DSTATCOM is applied in distribution network. The capacity restricts of these devices are described in Equations (1) to (3) [19].

$$-2\text{ pu} \le Q_{SVC} \le 2\text{ pu} \tag{1}$$

$$-0.1\text{ pu} \le Q_{DSTATCOM} \le 0.1\text{ pu} \tag{2}$$

$$-0.8X_{Line} \le X_{FACTS\_SE} \le 0.2X_{Line} \tag{3}$$

Furthermore, DR program is applied along with FACTS devices. The purpose of DR program is customer loads reduction in network buses. Customer participation in DR program is optional and in the form of contract with network operator and this is what distinguishes it from mandatory load cut in emergency conditions. Reasonable technical limit for this program has not been presented in the papers; however, amount of its applications regularly follow Equation (4) [20].

$$0 \le S_{DR} \le 0.1S_{Load} \tag{4}$$

As it is clear in Equations (1) and (2), the injection limits of active and reactive powers by parallel FACTS devices in both inductive and capacitive states are indicated. In both equations, positive amounts show inductive state and negative amounts show capacitive state. Equation (3) shows that the reactance of series FACTS devices is a factor of the line reactance on which these devices are installed. Thus, the reactances of these devices are variable between -80 percent in capacitive state up to 20 percent in inductive state. Equation (4) shows that maximum amount of demand response capacity in each load bus is 10 percent of its load.

The parameters of Equations (1) to (4) are described as:

QSVC: Reactive power of SVC
QDSTATCOM: Reactive power of DSTACOM
XFACTS_SERIES: Reactance of series FACTS device
XLINE: Reactance of candidate line for installing series FACTS device
SDR: The participating amount of load
SLOAD: The load of bus which is candidate for implementing DR program

The buses of the network that do not have the ability of parallel FACTS devices or DR installation are shown in Table 1. These buses don't have implementation ability because of technical reasons or their customers are not willing to participate in demand response programs either.

Table 1. The buses which have limitations in use of parallel FACTS devices and demand response programs

	Parallel FACTS device can't be used in these buses	DR program can't be implemented in these buses
Bus Numbers	6-7-8-25-27	11-13-15-18-22

III. SOLUTION METHODS

A. Formulation of the Problem

Optimization problem in technical approach is the optimal location and capacity of parallel and series FACTS devices and demand response program in order for the maximization of voltage static stability objective function and minimization of power loss presented in Equations (5) to (7) [21], [22]. Multi-objective function is defined as equation (5).

$$F_{MO} = \min(F_1)\,\&\,\max(F_2) \tag{5}$$

$$F_2 = \lambda \tag{6}$$

$$F_1 = \sum_{i=1}^{L} R_i \left|I_i\right|^2 \tag{7}$$

Equation (7) shows power loss objective function. In this equation L shows the line set of network, R is line resistance, I is the line currents and λ is the factor indicating bus load ability. This factor is the output of continuous power flow program presented in Equation (8).

$$P_D = \lambda \times P_{D0} \tag{8}$$

where, P_{D0} is the amount of bus load in normal condition and P_D shows maximum load ability of bus. FACTS devices and DR program increase the difference of these two parameters. The constraints of the problem are shown in Equations (9) to (14). The constraint in Equation (9) represents the balance of power in each bus of network, the constraint in Equation (10) represents the balance of power in total network, the constraints in (11) and (12) represent active and reactive power of generators, constraint in Equation (13) represents acceptable range of voltage and constraint in equation (14) shows power flow limit from network lines.

$$P_{G_i} = P_{D_i} + \sum_{j=1}^{n} P_{ij} \quad (9)$$

$$\sum_{i=1}^{n} P_{G_i} = \sum_{i=1}^{n} P_{D_i} + P_{loss} \quad (10)$$

$$P_{G_{i\min}} \le P_{G_i} \le P_{G_{i\max}} \quad (11)$$

$$Q_{G_{i\min}} \le Q_{G_i} \le Q_{G_{i\max}} \quad (12)$$

$$V_{\min} \le V_i \le V_{\max} \quad (13)$$

$$P_{ij} \le P_{ij\max} \quad (14)$$

B. Optimization Algorithms

The characteristics of genetic algorithm are shown in Table 2. As shown in Table 2, number of initial population for evolutionary algorithms is 80 and number of iteration is 100.

Table 2. Characteristics of the used genetic algorithm

Number of Population	80
number of generation times	100
Length of chromosomes	60
Chromosomes input	Location and capacity of FACTS device and DR Program
The objective functions	The value of λ index and power losses

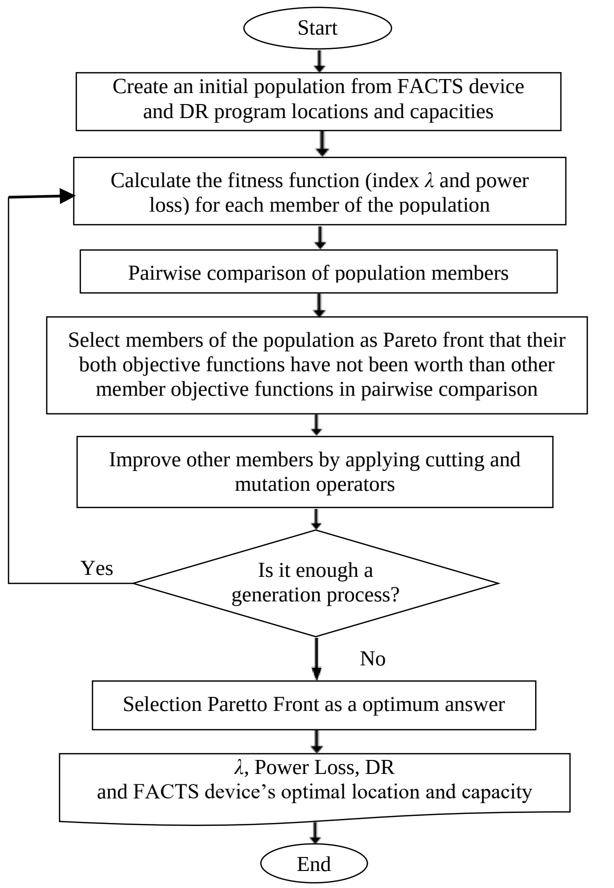

Figure 1. Flow chart of FACTS device and demand response location program to improve the static voltage stability using genetic algorithms

Also the length of each variable is 10, so the length of each chromosome is equal to 60. Each of these chromosomes includes the information about location and capacity of series and parallel FACTS devices and DR program. In this section, in order to carry out simulation, genetic algorithm is used. The flow chart of this program is shown in Figure 1. The inputs of this program (primary population) are place and capacity of FACTS devices and demand response program and the outputs of the program are the optimal location and capacity of these devices and objective functions are power loss and voltage static stability.

IV. NUMERICAL STUDIES

In this section, in a technical approach optimal allocation of parallel and series FACTS devices and demand response program in order to improve voltage static stability and power loss reduction in normal and emergency conditions of network are solved. The simulations are carried out on the 30-bus IEEE standard system as shown in Figure 2.

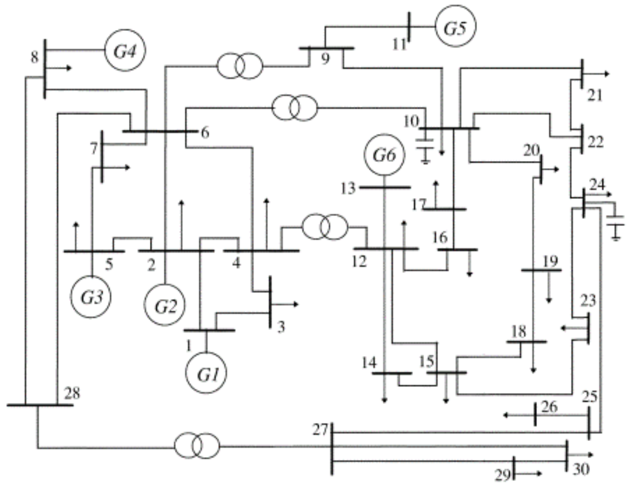

Figure 2. IEEE 30-bus standard network

Simulations are carried out using genetic algorithm and TLBO algorithm separately. The results of simulations using genetic algorithm in normal and emergency conditions are shown in Figures 3 and 4, and Tables 3 and 4, respectively. Emergency condition is considered with exiting line 8 connecting buses 5 and 7.

Table 3 presents simulation program outputs as Pareto Front members using genetic algorithms in normal condition of the network. As seen in Table 3 in this case set of Pareto front is composed from 11 members. All of these solutions are optimal location and capacity of series and parallel FACTS devices and DR program that have improved multi-objective function. According to the needs and conditions of the network and available equipment, operator can select one of the answers. For example, in the load peak condition of network that loadability is very important, the answer with the biggest lambda can be selected. In this case, economic issues are placed in the second priority. At low load situation, the network does not need high loadability, so the answer with minimal power losses would be appropriate.

Table 3. Optimization program results, maximization of objective function λ and Power losses minimization in normal conditions of network

Optimal location of DR program	Optimal capacity of DR (%)	Optimal location of series FACTS devices (Line Number)	Optimal capacity of series FACTS devices (%)	Type of series FACTS devices	Optimal location of Parallel FACTS devices (Bus Number)	Optimal capacity of parallel FACTS devices (pu)	Type of parallel FACTS devices	Power Loss (pu)	λ Index
24	7.51	12	55.76	TCSC	12	0.0450	DSTATCOM	0.0958	3.3941
24	8.76	16	72.18	DVR	12	0.1750	DSTATCOM	0.2020	4.0816
5	8.76	12	64.95	TCSC	9	0.0945	DSTATCOM	0.0411	2.9152
16	7.51	16	72.18	DVR	12	0.2366	DSTATCOM	0.4649	4.7638
23	7.51	12	55.76	TCSC	12	0.0371	DSTATCOM	0.0754	3.2454
3	9.38	16	52.73	DVR	12	0.0645	DSTATCOM	0.0791	3.3069
24	5.63	12	68.27	TCSC	12	0.0137	DSTATCOM	0.0450	3.0891
28	3.75	12	79.71	TCSC	12	0.0371	DSTATCOM	0.0802	3.3780
29	8.76	16	67.00	DVR	12	0.1740	DSTATCOM	0.2867	4.2868
3	9.38	16	37.09	DVR	12	0.0723	DSTATCOM	0.1227	3.4979
21	3.75	12	79.71	TCSC	12	0.0215	DSTATCOM	0.0510	3.2309

Figure 3 shows the simulation program outputs as Pareto Front members using genetic algorithms in normal condition of the network. The points marked with stars are members of the Pareto front. Both of objective functions of these points did not fail in comparison with other solutions. Thus, each of these points can be selected by system operator as an optimal response according to the needs and conditions of the network. The points marked with circles are members of the non-Pareto front. Both of objective functions of these points failed in comparison with at least one another solution. These points illustrate the path of evolutionary algorithm in finding Pareto front members.

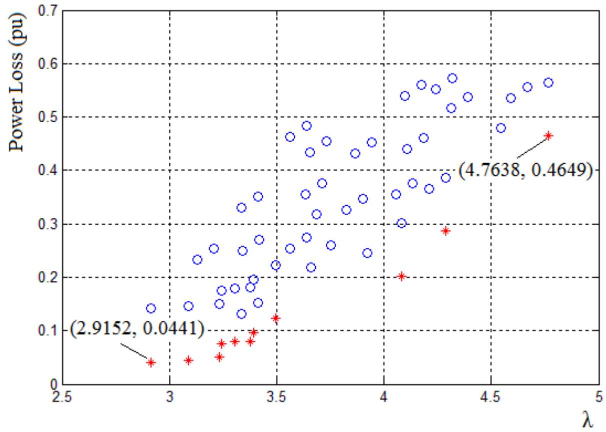

Figure 3. Genetic algorithm output with objective functions λ and power losses in normal condition of network

Figure 3 shows that the biggest Lambda is λ= 4.7638. According to Table 3, the maximum loadability of network can be achieved by simultaneous installing of DSTATCOM with capacity of 0.2366 pu in bus 12 and DVR with capacity of 72.18% in line 16 and DR program with capacity of 7.51% in bus 16. Also, the lowest power losses P_L=0.0411 can be achieved by simultaneous installing of the DSTATCOM with capacity of 0.0945 pu in bus 9 and TCSC with capacity of 64.95% in line 12 and DR program with capacity of 8.76% in bus 5.

As in Tables 3 and 4 presents simulation program outputs as Pareto Front members using genetic algorithms in emergency condition of the network. As seen in Table 4, in this case, set of Pareto front is composed of 19 members. Figure 4 shows that the biggest Lambda is λ= 4.6310.

Table 4. Optimization program results, maximization of objective function λ and Power losses minimization in emergency conditions of network

Optimal location of DR program	Optimal capacity of DR (%)	Optimal location of series FACTS devices (Line Number)	Optimal capacity of series FACTS devices (%)	Type of series FACTS devices	Optimal location of Parallel FACTS devices (Bus Number)	Optimal capacity of parallel FACTS devices (pu)	Type of parallel FACTS devices	Power Loss (pu)	λ Index
24	8.76	12	78.83	TCSC	9	0.0912	DSTATCOM	0.0434	3.0233
24	9.19	12	79.61	TCSC	1	1.2023	SVC	0.0434	3.0279
24	6.26	19	05.63	DVR	12	0.0802	DSTATCOM	0.2915	3.9177
30	5.63	12	44.91	TCSC	12	0.0723	DSTATCOM	0.2365	3.8368
30	7.51	38	03.66	DVR	12	0.0802	DSTATCOM	0.2920	3.9968
30	6.26	34	57.22	DVR	12	0.0919	DSTATCOM	0.4326	4.3456
30	8.76	3	33.18	TCSC	12	0.0919	DSTATCOM	0.4375	4.3537
21	7.51	13	25.36	TCSC	12	0.0723	DSTATCOM	0.2241	3.7352
23	6.26	16	56.83	DVR	12	0.0802	DSTATCOM	0.0961	3.4066
26	5.00	16	47.25	DVR	12	0.0919	DSTATCOM	0.1534	3.6611
30	6.26	34	73.26	DVR	12	0.0919	DSTATCOM	0.4326	4.3494
9	5.00	16	44.13	DVR	12	0.0919	DSTATCOM	0.1670	3.6842
24	5.00	16	44.13	DVR	12	0.0232	DSTATCOM	0.3374	4.2638
30	8.76	34	73.06	DVR	12	0.0841	DSTATCOM	0.3325	4.1123
30	8.76	7	58.59	TCSC	12	0.0762	DSTATCOM	0.2541	3.9072
16	8.76	16	57.61	DVR	12	0.0880	DSTATCOM	0.1074	3.4781
24	5.00	37	70.03	DVR	12	0.0723	DSTATCOM	0.2256	3.8008
2	5.00	16	69.93	DVR	12	0.0170	DSTATCOM	0.4397	4.6310
29	7.51	38	53.70	DVR	12	0.0802	DSTATCOM	0.2931	4.0213

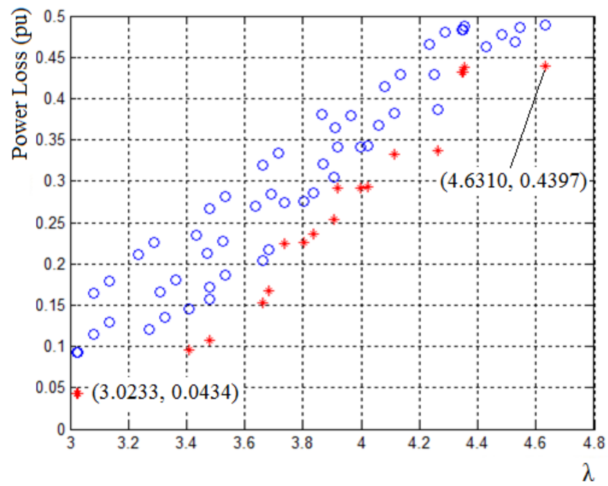

Figure 4. Genetic algorithm output with objective functions λ and power loss in emergency condition of network

According to Table 4, the maximum loadability of network can be achieved by simultaneous installing of DSTATCOM with capacity of 0.0170 pu in bus 12 and DVR with capacity of 69.93% in line 16 and DR program with capacity of 5.00% in bus 16.

Also, the lowest power losses P_L=0.0434 can be achieved by simultaneous installing of DSTATCOM with capacity of 0.0912 pu in bus 9 and TCSC with capacity of 78.83% in line 12 and DR program with capacity of 8.76% in bus 24.

Table 5 presents simulation program outputs as Pareto Front members using TLBO algorithms in normal condition of the network.

Table 5. Optimization program results, maximization of objective function λ and Power losses minimization in normal conditions of network TLBO

Optimal location of DR program	Optimal capacity of DR (%)	Optimal location of series FACTS devices (Line Number)	Optimal capacity of series FACTS devices (%)	Type of series FACTS devices	Optimal location of Parallel FACTS devices (Bus Number)	Optimal capacity of parallel FACTS devices (pu)	Type of parallel FACTS devices	Power Loss (pu)	λ Index
5	3.75	12	79.02	TCSC	9	0.0226	DSTATCOM	0.0416	3.0336
5	4.38	12	79.02	TCSC	13	0.0723	DSTATCOM	0.0414	3.0331
30	9.38	36	72.47	TCSC	12	0.0880	DSTATCOM	0.4085	4.7752
19	7.51	36	67.49	TCSC	12	0.0880	DSTATCOM	0.4054	4.7342
2	7.51	16	79.71	DVR	12	0.0958	DSTATCOM	0.0612	3.2893
6	6.26	36	66.80	TCSC	12	0.0762	DSTATCOM	0.2733	4.2774
6	8.24	36	70.08	TCSC	12	0.0652	DSTATCOM	0.3320	4.5025
6	4.69	36	64.47	TCSC	12	0.0898	DSTATCOM	0.1863	3.9125
6	6.52	36	61.02	TCSC	12	0.0901	DSTATCOM	0.1251	3.6821

As seen in Table 5 in this case set of Pareto front is composed from 9 members. All of these solutions are optimal location and capacity of series and parallel FACTS devices and DR program that have improved multi-objective function. Conclusion as Table 3 also applies here. Figure 5 shows the simulation program outputs as Pareto Front members using TLBO algorithms in normal condition of the network. The points marked with stars are members of the Pareto front. Both of objective functions of these points did not fail in comparison with other solutions.

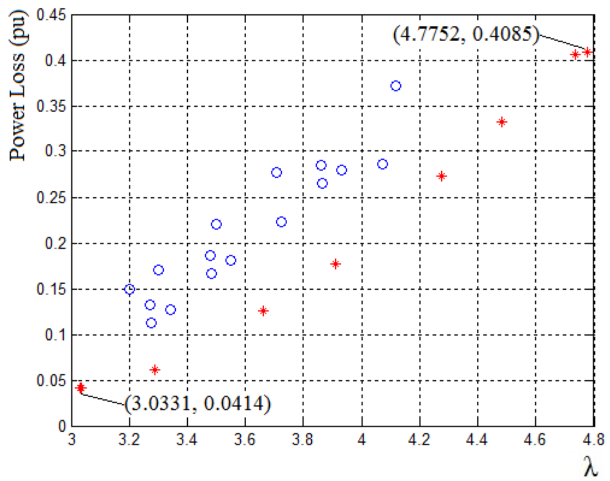

Figure 5. TLBO algorithm output with objective functions λ and power losses in normal condition of network

Figure 5 shows that the biggest Lambda is λ= 4.7752. According to Table 5, the maximum loadability of network can be achieved by simultaneous installing of DSTATCOM with capacity of 0.0880 pu in bus 12 and TCSC with capacity of 72.47% in line 36 and DR program with capacity of 9.38% in bus 30. Also the lowest power losses P_L=0.0414 can be achieved by simultaneous installing of the DSTATCOM with capacity of 0.0723 pu in bus 13 and TCSC with capacity of 72.47% in line 36 and DR program with capacity of 9.38% in bus 30.

Table 6 presents simulation program outputs as Pareto Front members using TLBO algorithms in normal condition of the network. As seen in Table 6 in this case set of Pareto front is composed from 9 members. All of these solutions are optimal location and capacity of series and parallel FACTS devices and DR program that have improved multi-objective function. Conclusion as Table 3 also applies here.

Table 6. Optimization program results, maximization of objective function λ and Power losses minimization in emergency conditions of network TLBO

Optimal location of DR program	Optimal capacity of DR (%)	Optimal location of series FACTS devices (Line Number)	Optimal capacity of series FACTS devices (%)	Type of series FACTS devices	Optimal location of Parallel FACTS devices (Bus Number)	Optimal capacity of parallel FACTS devices (pu)	Type of parallel FACTS devices	Power Loss (pu)	λ Index
10	3.75	16	67.49	DVR	12	0.0567	DSTATCOM	0.0575	3.1219
19	9.38	12	79.71	TCSC	9	0.0248	DSTATCOM	0.0434	2.9961
22	6.88	36	79.51	TCSC	12	0.0880	DSTATCOM	0.4205	4.6955
14	6.88	36	63.87	TCSC	12	0.0880	DSTATCOM	0.4099	4.6015
12	4.38	36	54.49	TCSC	12	0.0489	DSTATCOM	0.1098	3.4634
5	4.38	36	76.38	TCSC	12	0.0489	DSTATCOM	0.1110	3.5286
17	5.00	16	59.67	DVR	12	0.0997	DSTATCOM	0.1232	3.5666
17	9.97	16	69.21	DVR	12	0.0857	DSTATCOM	0.1650	4.2012

Figure 6 shows the simulation program outputs as Pareto Front members using TLBO algorithms in emergency condition of the network. The points marked with stars are members of the Pareto front. Both of objective functions of these points did not fail in comparison with other solutions.

Figure 6 shows the biggest Lambda is λ= 4.6955. According to Table 6, the maximum loadability of network can be achieved by simultaneous installing of DSTATCOM with capacity of 0.0880 pu in bus 12 and TCSC with capacity of 79.51% in line 36 and DR program with capacity of 6.88% in bus 22. Also the lowest power losses P_L=0.0434 can be achieved by simultaneous installing of the DSTATCOM with capacity of 0.0248 pu in bus 9 and TCSC with capacity of 79.71% in line 12 and DR program with capacity of 9.38% in bus 19. Table 7 is formed from the combination of the obtained results from the evolutionary algorithms. This table is sorted based on power loss. As it is shown in the table, in normal condition, the best answer in terms of loss reduction is achieved using genetic algorithm.

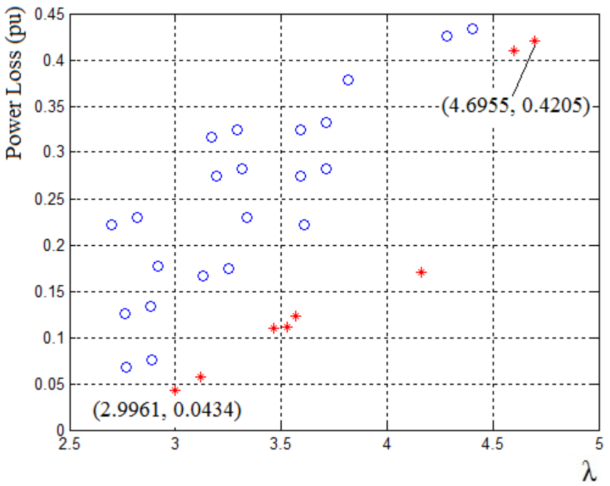

Figure 6. Genetic algorithm output with objective functions λ and power loss in emergency condition of network

Table 7. Comparison the effectiveness of two used evolutionary algorithms through comparing the obtained responses based on minimum power loss reduction in normal conditions of network

Power Loss	Loadability λ	Evolutionary Algorithm Type
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

Table 8 is formed from the combination of the obtained results from the evolutionary algorithms. This table is sorted based on the network loadability. As it's shown from the table in normal condition the best answer in terms of loadability is achieved using TLBO algorithm.

Table 9 is formed from the combination of the obtained results from the evolutionary algorithms. This table is sorted based on power loss. As it is shown in the table, in normal condition, the best answer in terms of loss reduction is achieved using genetic algorithm.

Table 10 is formed from the combination of the obtained results from the evolutionary algorithms. This table is sorted based on the network loadability. As it is shown in the table, in emergency condition, the best answer in terms of loadability is achieved using TLBO algorithm.

Table 8. Comparison the effectiveness of two used evolutionary algorithms through comparing the obtained responses based on maximum loadability of network in normal conditions of network

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

Table 9. Comparison the effectiveness of two used evolutionary algorithms through comparing the obtained responses based on minimum power loss reduction in emergency conditions of network

Power Loss	Loadability λ	Evolutionary Algorithm Type
0.0434	3.0233	GA
0.0434	3.0279	GA
0.0434	2.9961	TLBO
0.0575	3.1219	TLBO
0.0961	3.4066	GA
0.1074	3.4781	GA
0.1098	3.4634	TLBO
0.1110	3.5286	TLBO
0.1232	3.5666	TLBO
0.1534	3.6611	GA
0.1650	4.2012	TLBO
0.1670	3.6842	GA
0.2241	3.7352	GA
0.2256	3.8008	GA
0.2365	3.8368	GA
0.2541	3.9072	GA
0.2915	3.9177	GA
0.2920	3.9968	GA
0.2931	4.0213	GA
0.3325	4.1123	GA
0.3374	4.2638	GA
0.4099	4.6015	TLBO
0.4205	4.6955	TLBO
0.4326	4.3456	GA
0.4326	4.3494	GA
0.4375	4.3537	GA
0.4397	4.6310	GA

Table 10. Comparison the effectiveness of two used evolutionary algorithms through comparing the obtained responses based on maximum loadability of network in emergency conditions of network

Power Loss	Loadability λ	Evolutionary Algorithm Type
0.4205	4.6955	TLBO
0.4397	4.6310	GA
0.4099	4.6015	TLBO
0.4375	4.3537	GA
0.4326	4.3494	GA
0.4326	4.3456	GA
0.3374	4.2638	GA
0.1650	4.2012	TLBO
0.3325	4.1123	GA
0.2931	4.0213	GA

0.2920	3.9968	GA
0.2915	3.9177	GA
0.2541	3.9072	GA
0.2365	3.8368	GA
0.2256	3.8008	GA
0.2241	3.7352	GA
0.1670	3.6842	GA
0.1534	3.6611	GA
0.1232	3.5666	TLBO
0.1110	3.5286	TLBO
0.1074	3.4781	GA
0.1098	3.4634	TLBO
0.0961	3.4066	GA
0.0575	3.1219	TLBO
0.0434	3.0279	GA
0.0434	3.0230	GA
0.0434	2.9961	TLBO

V. CONCLUSIONS

In this paper, the impact of simultaneous implementation of series and parallel FACTS devices on multi-objective function improvement are investigated. To clarify the issue, in the beginning, optimal location and capacity of three instruments using evolutionary algorithms have been set. In this section, for solving the optimization problem, Genetic algorithm and TBLO (Teaching Learning Based Optimization) algorithm have been used. Due to the use of multi-objective function, instead of an optimal solution, a set of optimal solutions as Pareto front are achieved. Furthermore, optimization problem has been solved in both normal and emergency condition of network. All simulations are carried out using Matlab program and PSAT toolbox on 30 bus IEEE standard test system. The results show that simultaneous implementation of series and parallel FACTS devices and demand response program is an efficient method and has been able to significantly increase the efficiency of the network was exposed to random variation of operation condition and network structure.

Finally, the obtained answers by using evolutionary algorithms (GA and TLBO) have been compared. The comparisons show that in both normal and emergency condition of the network, the best answer in terms of loss reduction is achieved using genetic algorithm. While from the perspective of loadability enhancement, in both normal and emergency conditions of the network, the best solution is achieved using TLBO algorithms. Totally by combining the obtained solutions through the two algorithms, more choices are provided for network operators. So, the operator, according to requirements and conditions of the network, will be able to choose better solutions to gain maximum productivity. Consequently, it can be said that the two algorithms have complemented each other and have considerably increased power system efficiency.

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BIOGRAPHIES

Mohammad Reza Shadmesgaran was born in Tabriz, Iran, in 1967. He received his M.Sc. degree in Electrical Engineering from Iran University of Science and Technology, Tehran, Iran in 2008. He is currently a Ph.D. student at Institute of Physics, Azerbaijan National Academy of Sciences, Baku, Azerbaijan and works as Deputy Director of Telecom Company in Tabriz, Iran. His research interests are increasing efficiency in power systems, demand response, power system dynamics, stability and control and FACTS devices.

Arif Mamed Hashimov was born in Shahbuz, Nakhchivan, Azerbaijan on September 28, 1949. He is a Professor of Power Engineering (1993); Chief Editor of Scientific Journal of "Power Engineering Problems" from 2000; Director of Institute of Physics of Azerbaijan National Academy of Sciences (Baku, Azerbaijan) from 2002 up to 2009; Academician from 2007; the First Vice-President of Azerbaijan National Academy of Sciences from 2007 up to 2013; and Director of Azerbaijan Research Institute of Energetics and Energy Design from 2014 till now. He is laureate of Azerbaijan State Prize (1978); Honored Scientist of Azerbaijan (2005); Cochairman of International Conferences on "Technical and Physical Problems of Power Engineering" (ICTPE) and Editor in Chief of International Journal on "Technical and Physical Problems of Engineering" (IJTPE). Now he is a High Consultant in "Azerenerji" JSC, Baku, Azerbaijan. His research areas are theory of non-linear electrical Networks with distributed parameters, neutral earthing and ferroresonant processes, alternative energy sources, high voltage physics and techniques, electrical physics. His publications are 300 articles and patents and 5 monographs.

Nariman R. Rahmanov received the M.Sc. and Ph.D. degrees from Azerbaijan State Oil and Chemistry Institute (Baku, Azerbaijan) in 1960 and 1968, respectively. He received the Doctor of Technical Sciences in Power Engineering from Novosibirsk Electro Technical Institute, Russia in 1990. He is a Professor since 1990 and Director of Azerbaijan Scientific Research Institute of Energetic and Energy Design (Baku, Azerbaijan) from 2007 up to 2009, and Deputy Director of the same institute and SPII from 2009 up to present. He is Director of Azerbaijan-Norway Center of Cleaner Production and Energy Efficiency (CPEE Center). He is the member of IEEE, Academician of International Eco-Energy Academy (Baku, Azerbaijan), Co-Chairman of International Conference on "Technical and Physical Problems of Electrical Engineering" (ICTPE), member of Editorial Boards of International Journal on "Technical and Physical Problems of Engineering" (IJTPE) and Journal of Power Engineering Problems. His research areas are power systems operation and control, distributed systems, alternative energy sources. His publications are more than 210 articles and patents, and also 3 monographs.

Oktay Z. Kerimov graduated from Azerbaijan Industrial Institute (Baku, Azerbaijan) as a Mechanical Engineer in Automation Control. He received the Ph.D. degree from Moscow Institute of Power, Russia in 1970. He was Senior Researcher in Azerbaijan Institute of Power (Baku, Azerbaijan) from 1962 till 1981. He was a Visiting Scholar in UC Berkeley, CA, USA from 1977 till 1978. He also was an advisor on Power Systems in Park Holding, Turkey at the period of 1993-2004. He joined again to Azerbaijan Institute of Power as the Head of Energy Saving and Efficiency Laboratory since 2005.

Irade Isfendiyar Mustafayeva was born on May 22, 1986. She received the B.Sc. degree from Baku State University (Baku, Azerbaijan) and the M.Sc. degree from Azerbaijan State Pedagogical University (Baku, Azerbaijan) both in Physics in 2005, 2011, respectively. Currently, she is a Research Engineer at Institute of Physics, Azerbaijan National Academy of Sciences (Baku, Azerbaijan).