Power Systems Optimal Placement And Sizing Of STATCOM in Multi-Objective Optimization Approach And Using NSGA-II Algorithm

Roozbeh Mohammadi[1*] , MEHDI MAHDAVIAN[2]
[1,2]Department of Power Electronic Engineering, Naein Branch, Islamic Azad University, Isfahan , Iran.

Abstract:
Current research plays a responsive role against the quaere of how could be possible to achieve high capacity in power line transmission of power grids(Networks) by means of placing Static Synchronous Compensator (STATCOM) within them without Construction of new transmission and distribution lines. For this bourgeon, we introduce Flexible AC Transmission Systems (FACTS) in intermittent, the priority of STATCOM, different manners of placement, FACTS components sizing, and multi-objective genetic algorithm NSGA-II rising in a multi-objective optimization approach in a 30 buses IEEE power system. By taking all project goals into account (voltage profile, power factor, active and reactive power capacity of each line), we designate the optimum position and size in order to setup STATCOM, and by setting two STATCOMs up, system will be gone through in proceeding and preceding status from the point view of implementing STATCOMs and current objective of this paper have been being improved.

Key indexes:
STATCOM, NSGA-II Algorithm, multi-objective optimization approach

1. Introduction

Nowadays we have got need which dramatically increases in demanding more electrical energy. For meeting the needs, generators of electrical energy have tried out constructing new power plants and increasing production capacity. For transmitting such amount of energy between generators and consumers, the capacity and power of transmission grid are in demands of raising for make this process possible. Furthermore, these energy transfer systems will face power transmission limitation. This finitude comes in for sustainability and supplying permissible level of voltage. So transmission lines practical exploitation capacity is much less than the actual capacity which will be taken as their own heat finitude.This results in transmission lines' non-optimum exploitation. One of the ways to multitude, power transmission lines capacity is constructing new lines, though implementing this method will take some more time and put cuts in spending in threaten. This loading increment and necessity of power transmission exploitation, have the associated companies use of maximum efficiency and possible loading in proceeding grids[1].

Introducing the concepts of FACTS

Further advances in semiconductors, the nominal capacity considerable increment of current and semiconductor switches create the idea of implementing them in power systems. On the current basis, new solutions of implementing power systems were proposed which is the concept of flexible grid transmission or FACTS. So the FACTS concept is associated with controllable components with semiconductors switches. What enables these components to control real or reactive power through lines or buses voltages connects to variable parameters, giving by these components. Unlike the mechanical components having stepwise variations in FACTS parts, these parameters vary thoroughly in continuous form and so fast rate which results for FACTS not to be finitude in steady state and these components will be having more extensive functional domain respect to mechanical ones. By noting to the main reason of voltage instability, disability of power system in supplying reactive power is in demand [4]. By the same token, compensating reactive power in power grids is in a high level of importance in preventing the breakdown voltage and reducing the losses. Among this, Flexible AC Transmission Systems (FACTS) could be taken as an appropriate solution in compensation of reactive power so as to establish a voltage stability [3]. A step further in choosing an element of FACTS, the first step will be system study, up to there by means of this, a specific and critical condition such as issues associated with system voltage, its breakdown probability, transmission line densities and undesirable power flow can be specified in systems. By supposing preceding issues, if there exists intended potential make sure to pick up proper element for functionality optimization of the system. On the basis of obtained information from preceding studies and associated economic consideration of new element accompanying related solutions, compare general component and at last select the proper element. Static synchronous compensator which is static synchronous compensator reactive power plays a vital role in making

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voltage stable and can be mentioned as one of the FACTS components. Supporting voltage in critical points is one of the SATACOM vital roles[5,9]. The basic functionality of STATCOM is that it will connect in shunt form to the power system. STATCOM will turn into a voltage controller by reactive power injection. According to diverse capabilities of this equipment, finding the proper position for embedding FACTS components into grids, is one of the major issues in power transmission. These components proper position depends on intended goal which is going to be meet[4,7]. The followings should be taken into account in FACTS components optimization placement:

In [1], placement and STATCOM optimized capacity are considered so as to voltage profile is improved and loss is reduced. For this purpose, genetic algorithm and ant optimization algorithm are implemented. Simulation has been run over 30 busses IEEE sample grid. Results in simulation illustrate that with placement and STATCOM optimized capacity determination, results such as energy losses reduction, voltage profile improvement and current reduction through feeder are achievable. In research [2], to find the STATCOM optimum location over different transmission test grids, an evolutionary algorithm like PSO (Particle Swarm Optimization), BFO (Bacterial Foraging Optimization) and optimization techniques in plant growth can be used. In this paper, transmission losses minimization is taken as goal function by identifying STATCOM location in grid minimum losses status, a grid with safe voltage profile, lower transmission losses, and high efficiency is created. In [3] to examine and prevent line densities, the power system has gone through load and output steady rise. Also, for line densities and voltage deviation reduction, the multi-objective optimization methods were implemented for transistor controlled series compensator components type, location, optimization size and static var compensator designation. To lower down the interaction between the components of the goal function, the multi-objective NSGA-II algorithm is fulfilled for simultaneous optimization of dense, power reduction and voltage deviation. In the research [4] FACTS components optimum assignment has been fulfilled and implemented with regard to security constraints of the power system. Security constraints include the network buses voltage deviation from the specified value and the network transmission line loading rate. For the reason of numerous parameters, the problem complexity and the constraints dependency to dependent variables, multi-objective non-dominated sorting genetic algorithm optimization is used. As well as the basic grid conditions for simulations, the underlying multi-line output is also considered in order to maintain the security of the network after the random outcomes. In research [5] to enhance the voltage stability and reduce losses a useful way has been proposed to locate several different types of FACTS components with equipment installation costs and power system utilization total cost. To this end, for simultaneous placement and size designation of the shunt and series components (TCSC, SVC) in a multi-objective structure, Shuffled Frog Leaping algorithm (SFLA) has been run which is the augmentation of genetic algorithm and Breadth-first search algorithm. In research [8] static synchronous compensator reactive power effect (STATCOM) has been investigated over a power grid with static voltage stability improvement and reduce losses approach. 9-bus system is tested in this experiment. The first step for voltage stability static analysis, STATCOM has been modeled in Newton-Raphson equation. The voltage static analysis was performed using analysis model. By this method, the critical areas of the grid (network) and thus the best place to install STATCOM have been detected. Many ways in FACTS components Placement have been testified in an optimized manner whose certain advantage and disadvantage are clear. But perhaps the newest conception entered into the calculation of the optimal placement of FACTS components, is Pareto Optimum. It can use a Non-dominated Sorting Genetic Algorithm (NSGA-II) with underpinnings of the principle of Pareto optimum, so as FACTS components optimized placement. According to this principle, in a multi-objective optimization, optimal responses set are those which, any improvement in the goal function, results in at least one other goal function to be weakened. This optimization presents a batch of optimal responses and the user selects the interest response with empirical considerations.

Optimal placement of STATCOM in power systems

STATCOM is FACTS components the second generation for reactive power compensation to be installed in shunt. STATCOM will cause voltage control with reactive power injection. STATCOM is voltage source converter and a reactance that can be installed in shunt with the system. Pre-phase current converter is injected into the AC system if the converter output voltage becomes more than AC system bus voltage So, in this case, the reactive power is injected into the system in capacitive performance. On the contrary, it absorbs the system lagging current converter if the converter output voltage is less than the AC system bus voltage. In such a circumstances, it absorbs reactive power in reactor performance. If the output voltage equals system AC voltage, no reactive power would be exchanged. In general series controller, the voltage will be injected into the circuit in shunt form and shunt controllers inject current into the system at the point of connection. Series and parallel controllers will inject current into the system by means of controller shunt part and voltage by series controller part. Traditional optimization techniques such as composite integer linear and non-linear programming are utilized for this kind of problems. Although increase local optimizations and severe computational methods, optimization becomes more difficult.

2. NSGA-II Meta-heuristic algorithm

NSGA-II meta-heuristic algorithm is one of the most versatile and powerful algorithms for solving multi-objective optimizations and whose functionality in solving various problems has been proven. Deb (1995) proposed NSGA optimization method to solve multi-objective optimization problems [3].There may be Highlights of this optimization method which are as follows:

- The answer which certainly no other one can proceed has got more score. The answers are going to be sorted on basis of other better solutions existence.
- Answers fit goodness, will be assigned based on their ranks and lack of other answers dominance. Shared fitness will be used for answers in the small vicinity so in order to answers intermittency can be adjusted in high desirable level for uniform distribution of answers in search space.

Due to the performance and quality of the NSGA algorithm results and shared fitness and the other parameters relatively high sensitivity, the second version of the NSGA algorithm, which is so-called NSGA-II Algorithm was introduced in 2000 by Deb et al [3]. Besides to all the functionality that NSGA-II Algorithm has got, it can be taken into account as many pattern formation of multi-objective optimization algorithms. This algorithm and its unique way of dealing with multi-objective optimization problems over and over have been used by different individuals to create new multi-objective optimization algorithms. [6] NSGA-II algorithm of the each generation results, some of them are selected by using binary tournament selection. In Binary selection Option, two answers are chosen among the random population and then between these two answers, a comparison is done, and each one is better, will be chosen eventually. Primarily criteria for selection in the NSGA-II algorithm are the answers ranking, and ulterior Crowding distance is related to answers. The less answer ranking and the more Crowding distance, the more desirable answer in hand is. In the NSGA-II algorithm among each generation answers, some of them will be selected using binary tournament selection. In the binary method selection, two answers will be chosen randomly from the population and then between the two solutions, a comparison is run and each one is better, eventually will be elected. Primarily selection criteria in the NSGA-II algorithm are answers ranking and ulterior Crowding distance is related to the answer. The less answer ranking and the more crowding distance, the more desirable answer in hand is [6]. By repeating the binary operator over each generation population, a set of individual generation is selected to participate in the Crossover and Mutation. Crossover action is implemented on the selected population, and on the other, mutation action, descendants and mutants will be created in results. In addition, this population will be merged with the original population. Members of the newly formed population, are sorted in ascending order first in terms of rank. Rated members of the population which are the same, are sorted in descending order in terms crowding distance. Now the population is sorted primarily based on their ranks, and ulterior, in terms of crowding distance. The same number of the original population, members are selected at the top of the sorted list and the rest of the population will be erased. Selected members make up the population next generation. And the cycle on this part will be repeated, to meet termination condition [6]. Non-dominant answers obtained from multi-objective optimization problems, often known as the Pareto front. None of the Pareto front answers are preferred over the other one, and depending on the condition, can be considered either as an optimal decision. The Fitness Sharing method used for answers in the small vicinity of interest point, in order to have answers adjusted in cumulative order and distributed uniformly in the search space.

Major features of this algorithm are as follows:

- Has got a faster solution respect to other methods in tanking, and computational complexities of previous algorithms are gone.
- Crowding distance definition as alternative features for methods such as fitness sharing

Using binary tournament selection operator

- Non-dominant solutions storing and archiving which obtained in the previous steps of the algorithm (elitism)

STATCOM modeling using NSGA-II multi-objective algorithm for optimum placement and transmission lines sizing

In this problem load flow calculations are implemented in no STATCOM status using the Matlab software, first over a 30 buses IEEE power grid transmission system using Newton-Raphson method

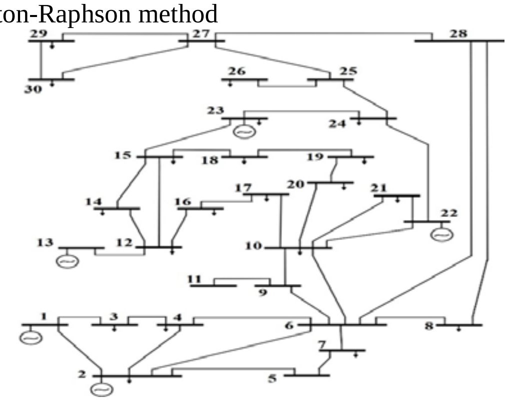

Figure 1: The 30 buses IEEE power transmission grid (network)

Then, according to these results and the multi-objective NSGA-II algorithm using, we take action to placement and sizing of 2 STATCOM devices, and load flow computations will be done once more in the presence of STATCOM and finally, we compare obtained results in this two stages. This system buses profile is given in Table 1. Buss (1) is a Slack bus, bus No. 2, 4, 5, 8, 13, 30 are of PV buses and rest of busses are of PQ buses, which are distinguished at the table by Type 1, Type 2 type 3 respectively. 30 buses losses between transmission lines profile are illustrated in Table 2.

Table 1. IEEE system 30 buses profile

BUS Data of IEEE-30 Bus System									
Bus	Type	Vsp	theta	Pgi	QGi	PLi	Qli	Qmin	Qmax
1	1	1	0	0	0	0	0	0	0
2	2	1.043	0	40	50	21.7	12.7	-40	50
3	3	1	0	0	0	2.4	1.2	0	0
4	2	1	0	0	20	7.6	1.6	0	0
5	2	1.01	0	0	37	94.2	19	-40	40
6	3	0.98	0	0	0	10.6	1.9	0	0
7	3	0.95	0	0	0	0	0	0	0
8	2	1.01	0	0	37.3	30	30	-10	40
9	3	1	0	0	0	0	0	0	0
10	3	1	0	0	0	5.8	2	0	0
11	3	0.982	0	0	16.2	0	0	-6	24
12	3	1	0	0	0	11.2	7.5	0	0
13	2	1.071	0	0	10.6	0	0	-6	24
14	3	1	0	0	0	6.2	1.6	0	0
15	3	1	0	0	0	8.2	2.5	0	0
16	3	1	0	0	0	3.5	1.8	0	0
17	3	1	0	0	0	9	5.8	0	0
18	3	0.99	0	0	0	3.2	0.9	0	0
19	3	1	0	0	0	9.5	3.4	0	0
20	3	1	0	0	0	2.2	0.7	0	0
21	3	1	0	0	0	17.5	11.2	0	0
22	3	1	0	0	0	0	0	0	0
23	3	0.98	0	0	0	3.2	1.6	0	0
24	3	1	0	0	0	8.7	6.7	0	0
25	3	1	0	0	0	0	0	0	0
26	3	1	0	0	0	3.5	2.3	0	0
27	3	1	0	0	0	22.8	10.9	0	0
28	3	1	0	0	0	0	0	0	0
29	3	1	0	0	0	2.4	0.9	0	0
30	2	1	0	0	0	0	0	0	0

Table 2. IEEE system 30 buses losses between transmission lines

Line Data of IEEE-30 Bus System											
From	To	R	X	B/2	X'mer	From	To	R	X	B/2	X'mer
Bus	Bus	pu	pu	pu	TAP (a)	Bus	Bus	pu	pu	pu	TAP (a)
1	2	0.0192	0.0575	0.0264	1	15	18	0.1073	0.2185	0	1
1	3	0.0452	0.1652	0.0204	1	18	19	0.0639	0.1292	0	1
2	4	0.057	0.1737	0.0184	1	19	20	0.034	0.068	0	1
3	4	0.0132	0.0379	0.0042	1	10	20	0.0936	0.209	0	1
2	5	0.0472	0.1983	0.0209	1	10	17	0.0324	0.0845	0	1
2	6	0.0581	0.1763	0.0187	1	10	21	0.0348	0.0749	0	1
4	6	0.0119	0.0414	0.0045	1	10	22	0.0727	0.1499	0	1
5	7	0.046	0.116	0.0102	1	21	23	0.0116	0.0236	0	1
6	7	0.0267	0.082	0.0085	1	15	23	0.1	0.202	0	1
6	8	0.012	0.042	0.0045	1	22	24	0.115	0.179	0	1
6	9	0.0321	0.208	0	0.978	23	24	0.132	0.27	0	1
6	10	0.0218	0.556	0	0.969	24	25	0.1885	0.3292	0	1
9	11	0.0159	0.208	0	1	25	26	0.2544	0.38	0	1
9	10	0.0234	0.11	0	1	25	27	0.1093	0.2087	0	1
4	12	0.0817	0.256	0	0.932	28	27	0	0.396	0	0.968
12	13	0.0391	0.14	0	1	27	29	0.2198	0.4153	0	1
12	14	0.1231	0.2559	0	1	27	30	0.3202	0.6027	0	1
12	15	0.0662	0.1304	0	1	29	30	0.2399	0.4533	0	1
12	16	0.0945	0.1987	0	1	8	28	0.0636	0.2	0.0214	1
14	15	0.221	0.1997	0	1	6	28	0.0169	0.0599	0.065	1
16	17	0.0824	0.1923	0	1						

First phase (Opening)

After all system data entry into Matlab software using Newton-Raphson load flow equations Voltage values (V), angle (degrees), injected power (Watt and Var), power generators (Watt and Var), load (watts and Var) over each bus and the power losses rate can be achieved between each bus.

The results obtained in the first phase

The results are given in Table 3 according to goal function definitions:

- The total active and reactive grid power are 45.278 and 177.803 MW, respectively.
- Bass (30), has got the lowest power factor of 0.8682.
- Bus (7), has the capability the of the highest voltage sustainability.

Table 3: goal functions results without STATCOM

F1:Total Loss		
MW	Mvar	
46.278	177.803	
F2: Minimum Power Factor		
Bus Number	Min Cos(Phi)	
30	0.8682	
F3: Voltage Deviation Index (VDI)		
Bus Number	Max VDI	Total VDI
30	0.1111	1.5869
F4: Voltage Stability Index (VSI)		
Bus Number	Max VSI	
5	1.2432	

The second phase optimization using multi-objective NSGA-II algorithm

The multi-objective optimization problem is sub-branch of a multi-criteria decision making (MCDM) which will be considered among an unlimited set of possible solutions. The multi-objective optimization problem arose from the decision-making methods in the real world that one decision maker is facing with a set of goals and conflicting and contradictory criteria. In these types of issues, unlike the single-objective optimization problems, and for several conflicting objectives, rather than just one answer, a set of answers is obtained. In further steps, by means of implementing the multi-objective NSGA-II algorithm, places and STATCOM sizes are calculated. And with several times iteration at the end of the multi-objective algorithm process, a set of quiescent points are obtained, as already mentioned these points should be compared with the stage in which the STATCOM is out of network. In NSGA-II multi-objective algorithm, the comparison between objectives is not implemented. But instead on a single target, target allocation is done on multiple targets simultaneously. In such a situation a multi-objective algorithm finds series of points which play a better role in voltage stabilization, losses, grid losses and grid voltage stability. This results in a compromise between the goals to find the answers. Now we have to compare answers obtained in this section with the status STATCOM has not been identified. In the current program, two STATCOM devices are supposed for the placement and sizing and next, after the multi-objective NSGA-II algorithm calculations process with the following characteristics, it takes the turn to choose the most appropriate answer among obtained ones.

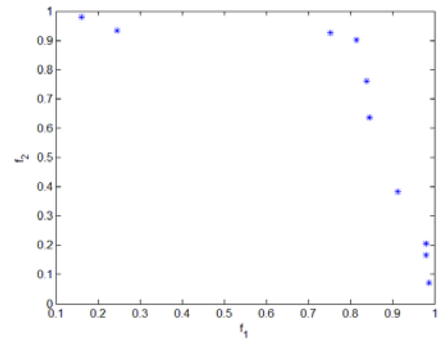

Figure 1: NSGA-II algorithm iterations reach up to 5

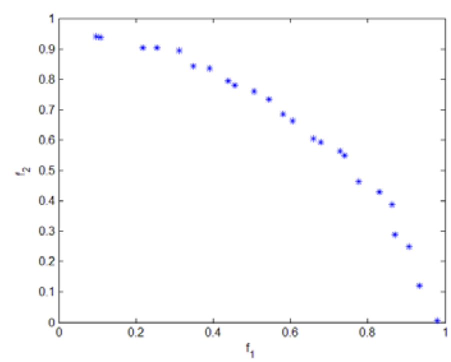

Figure 2: NSGA-II algorithm iterations reach up to 15

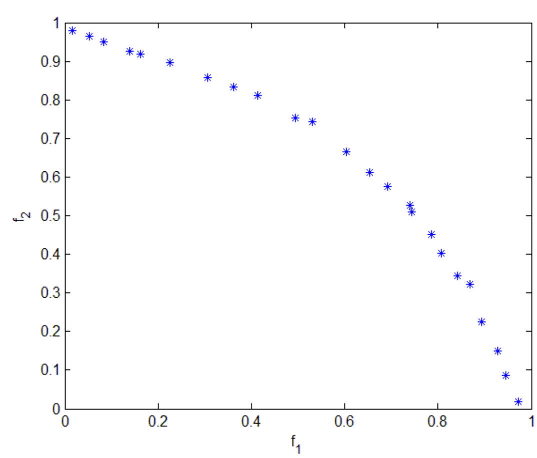

Figure 3 : NSGA-II algorithm iterations reach up to 20

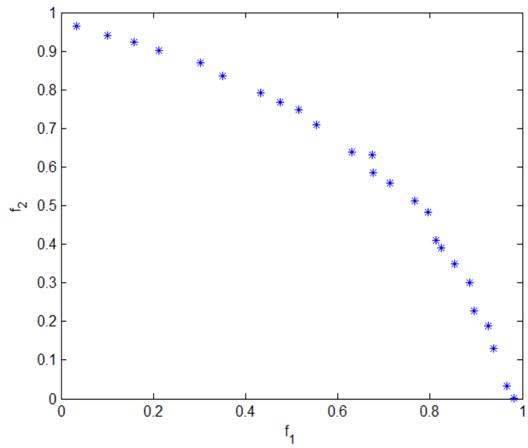

Figure 4: NSGA-II algorithm iterations reach up to 25

- Placement algorithm iteration 25 times
- Initial population algorithm number equals to 25
- Crossover factor of 0.35
- Mutation rate of 0.02
- 0.15 percent mutation

Election or appropriate answers selection among the Pareto optimal solution set

After goal function normalization values, first the minimum goal functions values of each non-dominant answers are calculated and then the desired option (final solution) with a maximum value is selected.

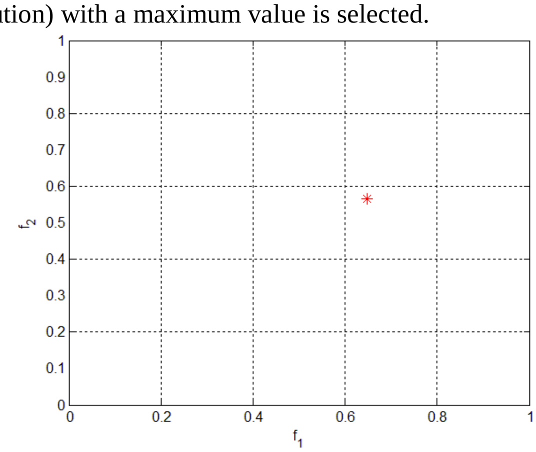

Figure 5: The final answer from Max-Min method

$$\max\{\, min_k\{f_{1,k}‘\ f_{2,k}‘\ \dots ‘\ f_{Np,k}\}\,\}$$

According to table 4 results, bus number 10 of a STATCOM with voltage of 1.0693 per unit, angle of -30.2681 and reactive power of -0.693 per unit, and in other STATCOM in bus number 27 with voltage of 1.0316 per unit, angle of 32.4861 and reactive power of 0.316 per unit can cause voltage profile stabilization, transmission lines losses reduction and 30 buses system power factor, in the most optimized mode.

Table 4: placement and sizing of the STATCOM results using the algorithm NSGA-II

STATCOM	Vsh	Thst	Qsh
Bus	pu	Degree	pu
27	1.0316	-32.4861	-0.316
10	1.0693	-30.2681	-0.693

Third phase

At this point, once again we step further to carry out Newton-Raphson calculations in the presence of two STATCOMs, with obtained position and values (sizes) in the previous step.
The results within objective function definition hypothesis are given in Table 5:
- The total active and reactive grid power are 55.4741 and 196.1210 respectively.
- Bass (26), the lowest power factor is capable of 0.8395.
- Bus (26), the highest voltage deviation is assigned to buses voltage.
- Bus (5), is capable of the voltage highest level sustainability.

Table 5: goal functions results with STATCOM

F1:Total Loss		
MW	Mvar	
55.4741	196.1210	
F2: Minimum Power Factor		
Bus Number	Min Cos(Phi)	
26	0.8395	
F3: Voltage Deviation Index (VDI)		
Bus Number	Max VDI	Total VDI
26	0.0506	0.8233
F4: Voltage Stability Index (VSI)		
Bus Number	Max VSI	
5	1.1779	

3. Conclusion

Using traditional optimization methods such as non-linear and linear programming, integer, complex and cumbersome calculations, optimization problems become difficult and to overcome such problems, evolutionary computation methods and optimization algorithms are utilized to locate and optimized sizing of this equipment. By means of obtained Newton-Raphson calculations in the first phase (before connecting STATCOM to the network) and the third phase (after connecting STATCOM to the network) comparison between the voltage buses in Figure 6 is understandable.

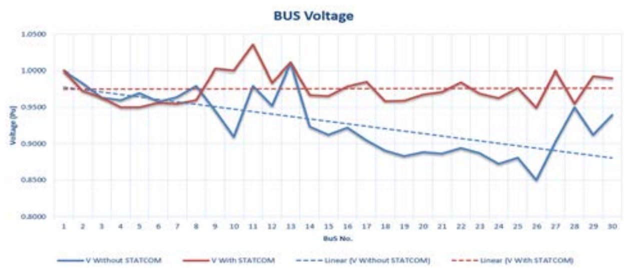

Figure 6: buses voltage comparison without and with STATCOM

In terms of unit, blue line is assigned to buses voltage from 1 up to 30 in the first phase and red line to buses voltage from1 to 30 in second phase, dotted lines are each phase regression. According to illustration, the voltage level using STATCOM will cause too much improvement and small vicinity to per unit band with (limit). Only in buses No. 2 up to 8, voltage level slightly lowers due to the multi-objective NSGA-II algorithm, it is explainable. As seen, as the blue line (first phase) approaches to the bus No.30, the network bus voltage level is reduced and the regression line slope is increased which expresses the system instability in terminal buses, But the red line which is assign to buses voltage level, after STATCOM connection to the network, will have risen thoroughly and regression line in per unit regime will vary slightly and this represents an increase in the network voltage level sustainability. In Figure 7, we compare the power factor between buses, as illustrated ,the power factor on buses besides to being preserved without a drop have a rise in the buses No. 12, 13, 14, 15, 16, 18, 25, 26, 27, 29, 30 and that results in system power factor promotion. It should be noted in cases which multi-objective optimization is not included or selection of answers is not done properly, by slightly changing system parameters, negative changes in other parameters are tangible, but in this issue, we are not faced with such a case.

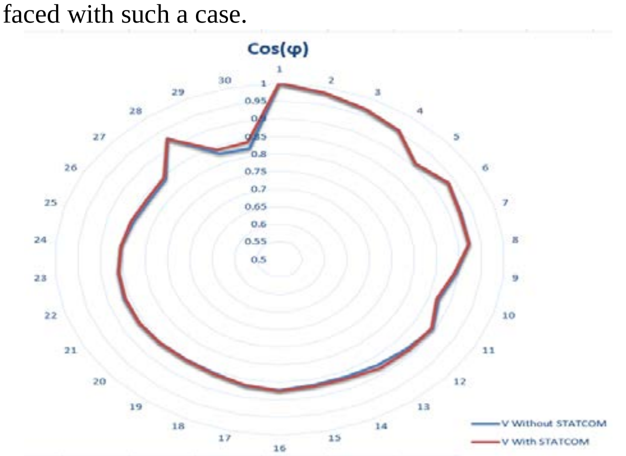

Figure 7: networks buses power factor with and without the STATCOM

Figure (8) compares the network total active power losses without STATCOM (blue columns) and in status STATCOM connected to the network (red columns), As can be seen after STATCOMs installation in network at a rate of 2.1292 megawatts, total active power losses reduces.

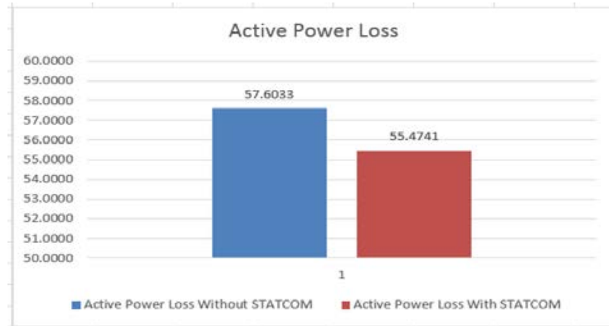

Figure 8: The total active power comparison without and with STATCOM

Figure 9 Compares grid total reactive power losses in the none-STATCOM (blue columns) and STATCOM connected status (red columns), As can be seen on the network after STATCOM installing at a rate of 5.5025 mega-vat, total reactive power losses decrease.

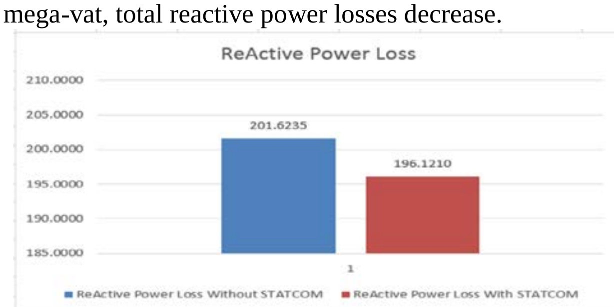

Figure 9: total reactive power comparison without and with STATCOM

Using intelligent multi-objective optimization NSGA-II algorithms is one of the most effective tools for placement and sizing of STATCOM in power systems. therefore STATCOM optimum placement and sizing using non-dominated multi-objective sorting genetic NSGA-II algorithm, voltage, power factor, voltage deviation, active and reactive power grid are improved compared to the standard mode.

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