10.2478/v10170-010-0027-2

Archives of Control Sciences
Volume 20(LVI), 2010
No. 4, *pages 473–489*

FACTS location and size for reactive power system compensation through the multi-objective optimization

MESSAOUD BELAZZOUG, MOHAMED BOUDOUR and KARIM SEBAA

The problem of the FACTS (Flexible Alternative Current Transmission System Devices) location and size for reactive power system compensation through the multi-objective optimization is presented in this paper. A new technique is proposed for the optimal setting, dimension and design of two kinds of FACTS namely: Static Volt Ampere reactive (VAR) Compensator (SVC) and Thyristor Controlled Series Compensator (TCSC) handling the minimization of transmission losses in electrical network. Using the proposed scheme, the type, the location and the rating of FACTS devices are optimized simultaneously. The problem to solve is multi criteria under constraints related to the load flow equations, the voltages, the transformer turn ratios, the active and reactive productions and the compensation devices. Its solution requires the the advanced algorithms to be applied. Thus, we propose an approach based on the evolutionary algorithms (EA) to solve multi-criterion problem. It is similar to the NSGA-II method (Ellitist Non Dominated Sorting Genetic Algorithm). The Pareto front is obtained for continuous, discrete and multiple of five MVArs (Mega Volt Ampere reactive) of compensator devices for the IEEE 57-bus test system (IEEE bus test is a standard network).

Key words: reactive dispatch, multi-objective optimization, NSGA-II, SVC, TCSC, FACTS

1. Introduction

One of the most important problem in the energy generation and transmission systems is the voltage profile maintenance of safe and optimally operating system by installation of compensation devices such as Flexible Alternative Current Transmission System ones (FACTS). In its most general description, the FACTS concept is based on the substantial incorporation of power electronic devices and methods into the high-voltage side of the network, to make it electronically controllable [1].

Many of the ideas upon which the foundation of FACTS rests evolved over a period of many decades. Nevertheless, FACTS, an integrated philosophy, is a novel concept that

---

M. Belazzoug is with Department of Electronic L.A.B.S.E.T, University of Saad Dahleb Road of Soumaa - Blida (Algeria), e-mail: m_belazzoug@yahoo.fr. M. Boudour is with Electrical and Industrial Systems Laboratory, USTHB, Algiers, Algeria, e-mail: m.boudour@ieee.org. K. Sebaa is with Laboratoire de Recherche en Electrotechnique et en Automatique, University of Medea, 26000, Medea, Algeria, e-mail: karim.sebaa@gmail.com.

Received 4.10.2010. Revised 5.12.2010.

was brought to fruition during the 1980s at the Electric Power Research Institute (EPRI), the utility arm of North American utilities [2]. FACTS looks at ways of capitalizing on the many breakthroughs taking place in the area of high-voltage and high current power electronics, aiming at increasing the control of power flows in the high voltage side of the network during both steady-state and transient conditions. The new reality of making the power network electronically controlled, altered the way of designing of the power plant equipment as well as the procedures that are undertaken in the planning and operation of transmission and distribution networks. These developments may also affect the way of energy transaction, as high-speed control of the path of the energy flow is now feasible. Owing to the many economical and technical benefits it promised, FACTS received the support of electrical equipment manufacturers, utilities, and research organizations around the world [3].

Several kinds of FACTS controllers have been commissioned in various parts of the world. The most popular are: load tap changers, phase-angle regulators, static VAR compensators, thyristor-controlled series compensators, inter phase power controllers, static compensators, and unified power flow controllers [1], [4].

An appropriate voltage profile can be maintained while minimizing two objective functions related to the total transmission active losses and the compensation devices amount (FACTS), which means that this problem is a multi-objective one (MO). Different methods have been presented in the literature to solve the MO dispatch problems. Let mention two families of these methods:

- New methods basing on the evolutionary techniques [5] as the NPGA (Niched Pareto Genetic Algorithm) [6,7], NSGA (Non dominated Sorting Genetic Algorithm) [8], SPEA (Strength Pareto Evolutionary Algorithm) [9], SPEA-II (Improving Strength Pareto Evolutionary Algorithm) [10], Improved Hybrid Evolutionary Programming Technique [11] and Ant Colony Optimization Method [12].

- The classic methods as the non linear programming technique [13], the weights aggregation method [14] and the ε-constraints method [15].

The classic methods present some inconveniences as long time of execution, non safety convergence, numerical complexity and generation of small number of non dominated solutions. There are also disadvantages of aggregated objectives as follows:

1. Requirement of a priori knowledge about the relative importance of the objectives, and the limits on the objectives that are converted into constraints.

2. The aggregated function leads to only one solution.

3. Trade-offs between objectives cannot be easily evaluated.

4. The solution may not be attainable unless the search space is convex.

The aggregation is not recommended for the systems with conflicted objectives. Also, in engineering areas, we need to know all possible optimization solutions for all objectives simultaneously. In the business world it is known as the tradeoff analysis. There are several areas in engineering where the trade-off analysis is necessary. Because of these inconveniences, the MO evolutionary algorithms looks more promising, thanks to their ability to exploit space of research without requirement of a pre-recognition of the problem.

In this paper, the problem is formulated with two objective functions. The evolutionary optimization method used is NSGA-II.

2. FACTS modeling

Similarly to the TCSC, the SVC combines a series capacitor bank shunted by thyristor controlled reactor in order to provide smooth variable compensation (Fig. 1). The first one is installed in series with transmission line and the second one is branched in shunt at load node.

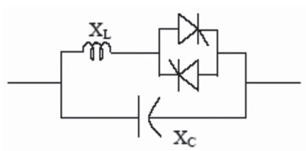

Figure 1. Structure of TCSC and SVC.

2.1. Model of TCSC

TCSCs vary the electrical length of the compensated transmission line with small delay. This characteristic enables the TCSC to be used to provide fast active power flow regulation. The basic idea behind power flow control with the TCSC is to decrease or increase the overall lines effective series transmission impedance, by adding a capacitive or inductive reactive correspondingly.

Fig. 2 shows the implementation of TCSC in the electric line.

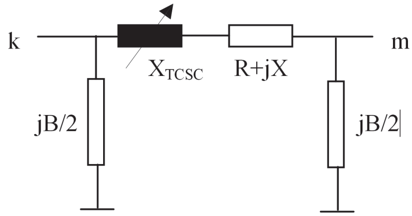

Figure 2. Equivalent model of TCSC.

The TCSC is modeled as variable impedance X_{TCSC}, where the equivalent reactance of line is defined as:

$$X_{ij} = X_{line} + X_{TCSC} \tag{1}$$

where $R + jX$ is the transmission line impedance, and $jB/2$ is the susceptance of line between nodes k and m. The level of the applied compensation of the TCSC usually varies between 20% inductive and 80% capacitive [16].

2.2. Model of SVC

The SVC is defined as a shunt connected static Var generator or consumer whose output is adjusted to exchange inductive or capacitive so as to maintain or control specific parameters of electrical power system, typically a bus voltage [16]. In this paper, the SVC is modeled as a variable shunt reactive susceptance jB_{SVC} installed at node i under voltage V_i as shown in Fig. 3.

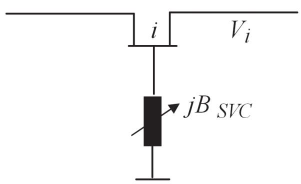

Figure 3. Equivalent model of SVC.

The reactive power Q_{SVC} provided (or absorbed) by the SVC at node i is given by the following equation:

$$Q_{SVC} = -B_{SVC}V_i^2. \tag{2}$$

3. Problem formulation

The solution of multi-objective problem of the optimal reactive dispatch minimizes two objective functions under constraints. These functions represent the compensation devices amount ($f(SVC)$, $f(TCSC)$ or $f(FACTS)$) as the first function and the transmission losses ($f(LOSSES)$), as the second one.

3.1. Compensation devices amount (f_1)

The objective function which corresponds to SVC amount is represented by the following function [17]:

$$f(SVC) = \sum_{I=1}^{N_{PQ}} |Q_{SVC}| \tag{3}$$

where N_{PQ} is the number of load nodes.

The objective function of TCSC amount is represented by the following relation:

$$f(TCSC) = \sum_{I=1}^{N_L} |X_{TCSC}| \tag{4}$$

where N_L is the number of transmission lines.

The combination of both SVC and TCSC amounts is represented by the following function:

$$f(FACT) = f(SVC) + \rho f(TCSC) \tag{5}$$

with ρ is a weighting parameter.

3.2. Total transmission active losses (f_2)

The total losses in the transmission lines are given by the following function:

$$f(LOSSES) = \sum_{I=1}^{N_G} P_{GI} - \sum_{I=1}^{N_{PQ}} P_{DI} \tag{6}$$

where N_G is the number of generator buses, N_{PQ} is the number of load buses and P_{GI} is the real power of generator at node i. P_{DI} is the load real power at node i.

3.3. Equality constraints

Equality constraints represent typical load flow equations as follows:

$$\begin{aligned}
&P_{GI} - P_{DI} = V_I \sum_{K=1}^{N} V_K (G_{IK} \cos(\sigma_I - \sigma_K) + B_{IK} \sin(\sigma_I - \sigma_K)) \\
&Q_{GI} + Q_{SVCI}.V_I^2 - Q_{DI} = V_I. \sum_{K=1}^{N} V_K (G_{IK} \sin(\sigma_I - \sigma_K) - B_{IK} \cos(\sigma_I - \sigma_K)) \\
&I = 1, \ldots, N
\end{aligned} \tag{7}$$

where N is the number of buses, P_{GI} and Q_{GI} are the generator real and reactive power, respectively, P_{DI} and Q_{DI} are the load real and reactive power, respectively, G_{ij} and B_{ij} are the transfer conductance and susceptance between bus i and bus j, respectively. σ_I is the phase and V_I is the voltage magnitude of the ith bus.

3.4. Inequality constraints

Inequality constraints represent the system operating limits as follows:

$$\begin{aligned}
& V_{I\,\min} \leqslant V_I \leqslant V_{I\,\max} \qquad I = 1,\ldots,N \\
& -0.8X_{ILINE} \leqslant X_{ITSCS} \leqslant 0.2X_{ILINE} \qquad I = 1,\ldots,N_L \\
& P_{GI\min} \leqslant P_{GI} \leqslant P_{GI\max} \\
& Q_{GI\min} \leqslant Q_{GI} \leqslant Q_{GI\max} \\
& T_{K\min} \leqslant T_K \leqslant T_{K\max} \quad I = 1,\ldots,N_G; \;\; K = 1,\ldots,N_T \\
& 0 \leqslant Q_{SVCI} \leqslant Q_{SVCI\max}\, I = 1,\ldots,N_{PQ}
\end{aligned} \tag{8}$$

with N_T is the number of transformers, T_K is the transformer turn ratio at the kth bus ad N_L is the number of lines.

4. NSGA-II (ELITIST non-dominated sorting genetic algorithm)

NSGA was introduced by Srinivas and Deb [18]. NSGA implements the idea of a selection method based on classes of dominance of all solutions. This algorithm identifies non-dominated solutions in the population, at each generation, to form non-dominated fronts, based on the concept of non-dominance of Pareto. After this, the usual selection, crossover, and mutation operators are performed. However, there are some faults in NSGA. It has been generally criticized for its computational complexity, lack of elitism and necessity of choosing the optimal value of sharing parameter.

A modified version, NSGA-II was developed, which has better sorting algorithm, incorporates elitism and no sharing parameter is needed to be chosen a priori. In this algorithm, the population is initialized as random, and the number of population is N. After initialization, the population is sorted based on non-domination into each front. Each individual in each front are assigned with a rank values based on front in which they belong to. Then, crowding distance is calculated for each individual. The crowding distance is a measure of how close an individual is to its neighbors. Large average crowding distance will result in better diversity in the population. Parents are selected from the population by using binary tournament selection based on the rank and crowding distance. The individual with smaller rank or greater crowding distance is selected. The selected population generates offspring from crossover and mutation operators. The population and the current offspring is sorted again based on non-domination and only the best N individuals are selected. The selection is based on the rank and on the crowding distance calculated for the last front. Then the new population is selected as parents at the next round. The pseudo code of the NSGA-II is as follows.

- For each iteration t do:

1. $R_t = P_t \cup Q_t$ (combine parent and offspring population)
2. $F = fast\_nondominated\_sort(R_t)$ (evaluation of non-dominated fronts in R_t)
3. $P_{t+1} = \varnothing$ & $i = 1$
4. until $|P_{t+1}| + |F_i| \leqslant N$ (until the parent population is filled)

    4.1 $i = i + 1$
    4.2 $crowding\_distance\_assignement(F_i)$ (calculate crowding distance in F_i)
    4.3 $P_{t+1} = P_t \cup F_i$ (include ith non-dominated front in the parent population)

5. $sort(F_i, \prec_n)$ (sort in descending order using $\prec_n$)
6. $|P_{t+1}| = |P_i| \cup F_i(N - |P_{t+1}|)$ (choose the first $N - |P_{t+1}|$ elements of F_i)
7. Q_{t+1} (use selection, crossover and mutation to create a new population using P_{t+1})

- $t = t + 1$

The NSGA-II procedure is summarized in Fig. 4.

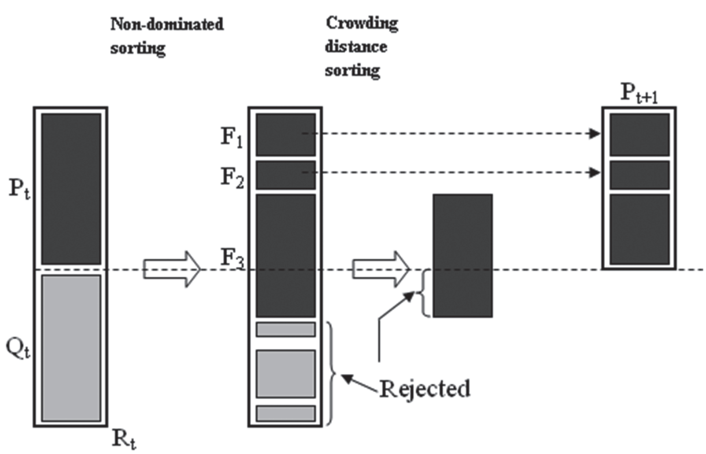

Figure 4. NSGA-II procedure.

5. Numerical simulations and comments

The elaborated program was validated and tested for various networks. For example the results obtained for the IEEE 57 nodes network which contains 57 buses, 7 thermal generators, 80 lines and 17 transformers [19] confirmed its usefulness. In this study, full load nodes are considered as compensation nodes candidates for SVC and also all lines for TCSC. The voltage limits at load nodes and generating nodes are respectively:

$$0.9pu \leqslant V_L \leqslant 1.1pu$$

$$0.94pu \leqslant V_G \leqslant 1.06pu$$

For all tests, the maximum limit of capacitive compensation (SVC) to install is equal to 50 MVArs. The limits on tap changers under load transformers are 0.90 and 1.10. The convergence tolerance for load flow is 10^{-4} p.u. for active and reactive powers. The optimization program presents a feasibility and optimality tolerance of 10^{-6} p.u. Initial compensator devices installed at nodes 18, 25 and 53 are 10, 5.9 and 6.3 MVArs respectively.

Two cases have been considered: in the first case we kept the devices on their nodes, in the second case we considered the network without its compensation reactive system.

The mono-objective optimization of losses allows for installing 122.82 MVArs in order to reduce 59.91% of them for the first case and installing 152.85 MVArs on several nodes with the intention to decrease 60.77% of them for the second case. This optimal reactive power flow gives one extremal solution to the problem. With applying multi-objective optimization we obtain several solutions which permit the operator to choose the adequate one.

The optimal Pareto set for bi-objectives optimization of the compensation devices and active power losses: SVCs/Losses (discrete, multiple of 5 MVArs, continuous and with 10% of precision), TCSCs/Losses, FACTSs/Losses are shown in Figs 5 to 9, respectively. Inside each figure, a comparison between two cases is shown: one corresponds to investment of new FACTS (case 1) and in the other one (case 2) refers to the existing SVCs in the network being set to zero.

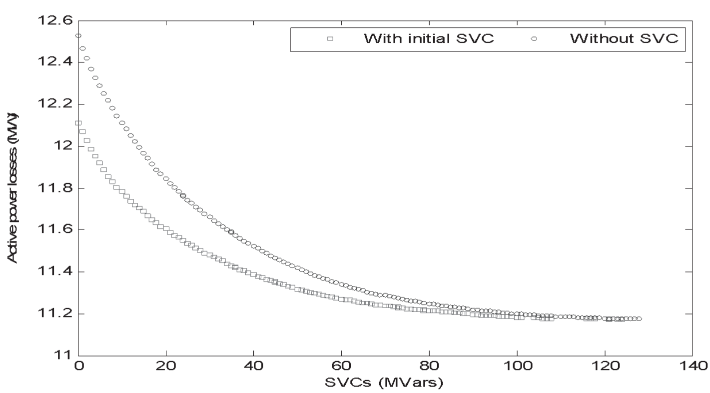

Figure 5. Pareto set SVCs(discrete)/losses.

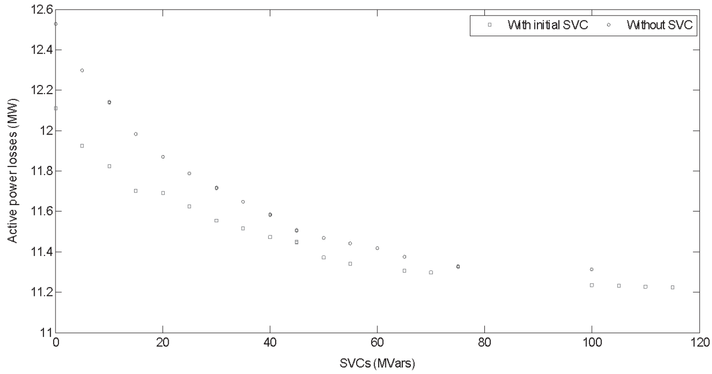

Figure 6. Pareto set SVCs(multiple of 5)/losses.

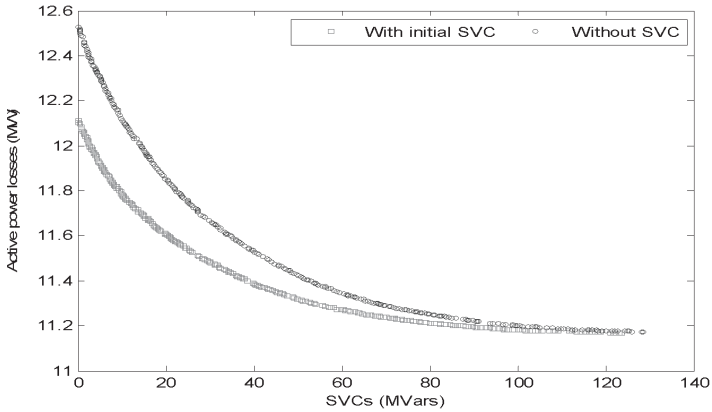

Figure 7. Pareto set SVCs(continuous)/losses.

The Pareto front of various optimization cases are illustrated in Figs 5 to 9. We can observe that the NSGA-II provides a well distributed Pareto front for both cases. It is clear that the Pareto fronts of the second case (without initial SVC) are under of those that corresponds to the first case. Unfortunately, the power losses are also decreased because of the reduction of power transition in the lines. In the TCSC case, it is clear that the reduction on losses is more significant until 20 MVArs is installed. Compared with TCSC, the SVC provides lowest power losses. In the last case, TCSC and SVC are both installed at the same time. They provided the highest reduction of losses which is illustrated in Figs 10 and 11.

In Tabs 1, 2 and 3, we represent the installation of FACTS for the two cases and two points: the first point is chosen so that the sum of FACTS is near 22.2 MVArs (this sum is of the initial devices already installed); the second point corresponds to the extreme point. From the Figs 5 to 9, we can pull the values of two points for every case. These

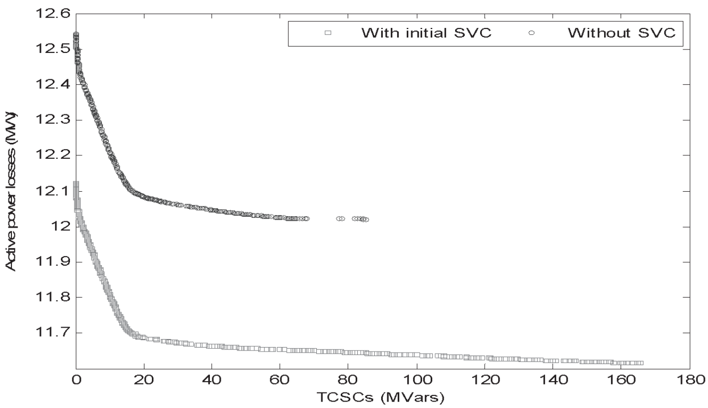

Figure 8. Pareto set TCSCs/losses.

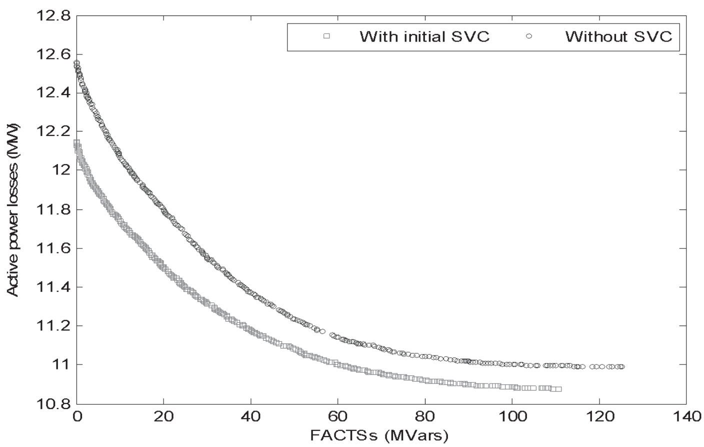

Figure 9. Pareto set FACTSs/losses.

values are summarized to the tables. The table 2 shows that by having 5 MVArs on nodes 31, 42, 50 and 53 with the use of all the controllers of a reactive energy, the losses are reduced by 58.04%. Figs 12 and 13 display the load nodes voltage values corresponding to point 2. It can be noticed that all voltages lie between their permitted limits.

Another case to be studied follows from movement of the existing capacitor batteries of the nodes 18, 25 and 53 towards nodes 31, 32, 42 and 53 with the quantities indicated in Tab. 2. This makes possible the reduction of the active power losses of 58.30%, and readjusted all the control variables (generation voltages and transformer turn ratios) and the state variables (load voltages, active and reactive power generation).

Table 2 shows that for minimal losses, the transformer between 13 and 49 node is the weakest one and it needs an installation of the biggest TCSC. The table shows also

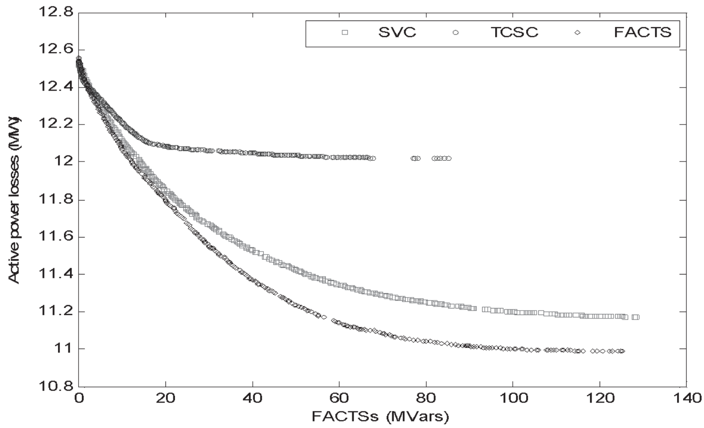

Figure 10. Pareto set FACTSs/losses without initial SVC.

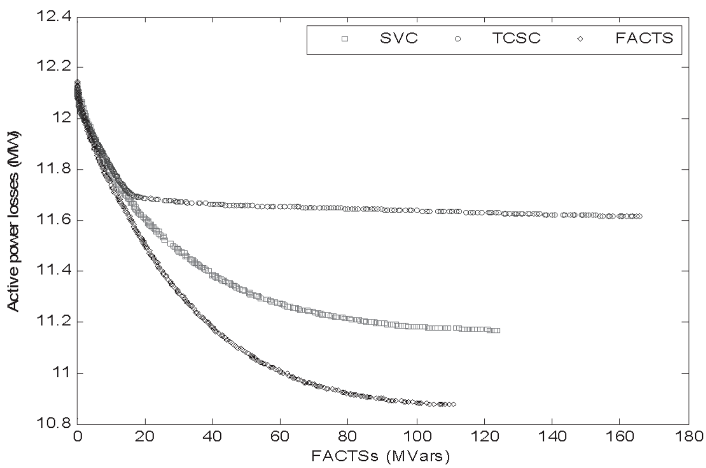

Figure 11. Pareto set FACTSs/losses with initial SVC.

that, minimal losses are limited: they are equal to 12.02 MVArs and 11.62 MVArs for case 1 and 2 respectively.

Tab. 3 shows that for minimal losses, the lines (12,17), (41,42), (13,49) and (39,57) are the most important locations for the installation of TCSC. The nodes candidates to installing SVC are 31, 32, 33, 42 and 53. In addition, minimal losses are extremal: they are equal to 10.95 MVArs and 11.05 MVArs for case 1 and 2 respectively.

For both cases, the determination of the nodes candidates to the compensation is made on closely situated nodes, which reflects the lack of reactive energy on the level of the zone of nodes 30 and 31. This table illustrates the results of a minimization of the active losses of each case of the network, which presents a reduction of 60.68% for case

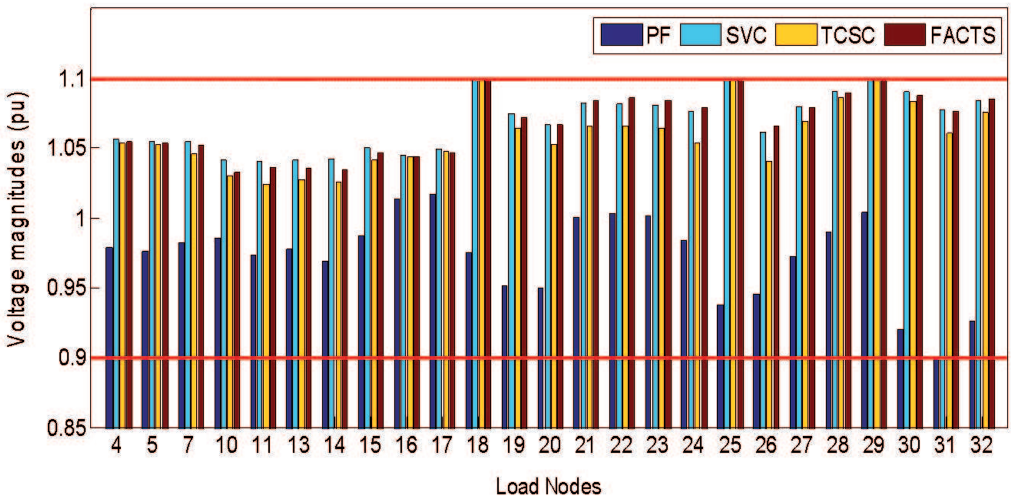

Figure 12. Load voltages.

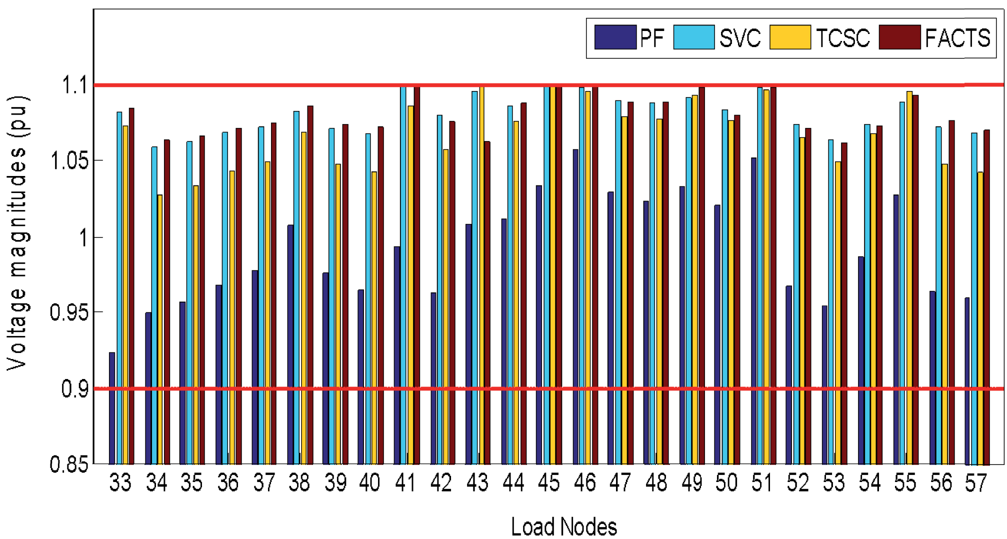

Figure 13. Load voltages.

1 and 61.16% for case 2. The commutation of the bank capacitors is more significant for the losses while the objectives are reached. In general, the use of FACTS is necessary to stabilize the network. The combination of SVC and TCSC provides an important state of compensation.

Table 9. Optimization results - installing only SVC.

Only SVC (multiple of 5 MVArs)				
Variables	with initial SVC (MVArs@node) (10@18 5.9@25 6.3@53)		without SVC	
	Point1	Point2	Point1	Point2
SVC (10)	-	5	-	-
SVC (13)	-	5	-	-
SVC (14)	-	5	-	-
SVC (17)	-	5	-	5
SVC (25)	-	-	-	5
SVC (28)	-	5	-	5
SVC (31)	5	5	5	5
SVC (32)	-	-	5	-
SVC (35)	-	5	-	-
SVC (38)	-	5	-	10
SVC (41)	-	5	-	-
SVC (42)	5	5	5	5
SVC (43)	-	-	-	5
SVC (44)	-	5	-	5
SVC (46)	-	5	-	5
SVC (47)	-	15	-	10
SVC (50)	5	10	-	10
SVC (51)	-	5	-	5
SVC (52)	-	5	-	5
SVC (53)	5	5	5	10
SVC (55)	-	15	-	10
SVCs(MVArs)	20	115	20	100
Losses (Mega Watts-MW)	11.6901	11.2249	11.8690	11.3133

It is true that the regulation of control variables such as generation voltages and tap turn ratios transformers ensure the realisability of power system but stills insufficient in economic perspective.

Table 10. Optimization results - Installing only TCSC.

TCSC(i,j) (pu)	with initial SVC		without SVC	
	Point1	Point2	Point1	Point2
TCSC(8, 9)	-0.0164	-0.0182	-0.0169	-0.0199
TCSC(1,15)	-0.0200	-0.0256	-0.0244	-0.0313
TCSC(1,16)	-	-	-0.0172	-0.0513
TCSC(12,17)	-0.0105	-0.1077	-0.0021	-0.1430
TCSC(23,24)	-	-	-	-0.1103
TCSC(24,25)	-	-	-	-0.0165
TCSC(30,31)	-0.0004	-0.0002	-	-
TCSC(31,32)	-	-	-	0.0019
TCSC(41,42)	-0.0324	-0.2328	-0.0129	-0.1882
TCSC(13,49)	-0.1414	-0.1377	-0.1418	-0.1393
TCSC(29,52)	-	-	-0.0073	-0.0803
TCSC(52,53)	-0.0004	-0.0495	-	-
TCSC(40,56)	-	-	-	0.0425
TCSC(56,41)	-	-	-	0.0281
TCSC(39,57)	-0.0018	-1.0840	-	0.0005
TCSCs(MVArs)	22.3300	165.5700	22.2600	85.3100
Losses(MW)	11.6836	11.6161	12.0781	12.0209

6. Conclusion

In this paper, an approach based on the NSGA-II method has been presented and applied to the multi-objectives reactive dispatch problem of an electric network.

The problem has been solved as a multi-objectives problem, with taking into account the active power losses, compensation devices amount such as SVC, TCSC and FACTS. The results illustrate that the proposed approach is efficient for solving the multi-objective reactive dispatch problem. The non-dominated solutions obtained are well distributed and have satisfactory range characteristics.

Based on the above observation, we can conclude that the simultaneously use of TCSC and SVC provides the best optimization of losses. The TCSC allows equilibrating the weakness of lines and transformers on their susceptances. Therefore, the use of SVC is better when we search for reducing considerably losses. The combination of both SVC and TCSC gives an important state of compensation.

Table 11. Optimization results - Installing FACTS.

Only SVC 5 MVArs				
Variables	with initial SVC		without SVC	
	Point1	Point2	Point1	Point2
SVC(10)	-	5	-	-
SVC(14)	-	5	-	-
SVC(17)	-	5	-	-
SVC(23)	-	5	-	-
SVC(31)	-	-	5	5
SVC(33)	5	5	-	5
SVC(35)	-	-	5	5
SVC(38)	-	-	-	10
SVC(41)	-	-	-	10
SVC(42)	5	5	-	-
SVC(44)	-	5	-	-
SVC(47)	-	10	-	-
SVC(48)	-	5	-	-
SVC(49)	-	5	-	-
SVC(50)	-	10	-	-
SVC(53)	-	5	5	10
SVC(56)	-	-	-	5
TCSC(8, 9)	-0.0164	-0.0182	-0.0169	-0.0199
TCSC(1,15)	-0.0200	-0.0256	-0.0244	-0.0313
TCSC(1,16)	-	-	-0.0172	-0.0513
TCSC(12,17)	-0.0105	-0.1077	-0.0021	-0.1430
TCSC(23,24)	-	-	-	-0.1103
TCSC(24,25)	-	-	-	-0.0165
TCSC(41,42)	-0.0324	-0.2328	-0.0129	-0.1882
TCSC(13,49)	-0.1414	-0.1377	-0.1418	-0.1393
TCSC(29,52)	-	-	-0.0073	-0.0803
TCSC(52,53)	-0.0004	-0.0495	-	-
TCSC(40,56)	-	-	-	0.0425
TCSC(56,41)	-	-	-	0.0281
TCSC(39,57)	-0.0018	-1.0840	-	0.0005
SVCs(MVArs)	22.2100	96.4800	22.1900	91.6800
Losses (MW)	11.4861	10.9549	11.7582	11.0552

References

[1] IEEE/CIGRE' (Institute of Electrical and Electronic Engineers / Conseil International des Grands Réseaux Électriques) FACTS overview. Special issue, TP108,

IEEE Service Center, Oiscataway, NJ, 1995.

[2] N.G. Hingorani and L. Gyugyi: Understanding FACTS, Concepts and technology of flexible AC transmission systems. IEEE Press, 2000.

[3] Y.B. Song and A.T. Johns: Applications of fuzzy logic in power systems. III. Example applications. *Power Engineering J.*, **13**(2), (1999), 97-103.

[4] K. Deb: Evolutionary algorithms for multi-criterion optimization in engineering design. Evolutionary Algorithms in Engineering and Computer Science, Chapter 8, 1999, 135-161.

[5] C. Fonseca: Multiobjective genetic algorithms with application to control engineering problems. PhD Thesis, Department of Automatic Control and Systems Engineering, The University of Sheffild, September, 1995.

[6] J. Horn, N. Nafpliotis and D.E. Goldberg: A niched Pareto genetic algorithm for multi-objectives optimization. *Proc. of the First IEEE Conf. on Evolutionary Computation, IEEE World Congress on Computational Intelligence*, **1** (1994), 82-87.

[7] M.A. Abido: A niched Pareto genetic algorithm for multi objectives environmental / economic dispatch. *Electrical Power and Energy Systems*, (2003), 97-105.

[8] H. Alexandre, F. Dias and J.A. de Vasconcelos: Multiobjective genetic algorithms applied to solve optimization problems. *IEEE Trans. Magnetics*, **38**(2), (2002), 1133-1136.

[9] E. Zitzler and L. Thiele: An evolutionary algorithm for multi-objectives optimization: The strength Pareto approach. TIK-Report no. 43, 1998.

[10] E. Zitzler, M. Laumanns and L. Thiele: SPEA2: Improving the strength Pareto evolutionary algorithm. TIK-Report no. 103, 2001.

[11] W. Yan, S. Lu and D.C. Yu: A novel optimal reactive power dispatch method based on an improved hybrid evolutionary programming technique. *IEEE Trans. Power Systems*, **19**(2), (2004).

[12] T. Bouktir and L. Slimani: Optimal power flow of the algerian electrical network using an ant colony optimization method. *Leonardo J. of Sciences*, **6** (2005), 43-57.

[13] M.O. Mansour and T.M. Abdel-Rahman: Non-linear VAR optimization using decomposition and coordination. *IEEE Trans. Power Apparat. Systems*, **103**(2), (1984), 246-255.

[14] I.P. ABRIL and J.A. GONZÁLEZ: VAR compensation by sequential quadratic programming. *IEEE Trans. Power Systems*, **18**(1), (2003), 36-41.

[15] Y.T. HSIAO, H.D. CHIANG, C.C. LIU and Y.L. CHEN: A vomputer package for optimal multi-objective VAR planning in large scale power systems. *IEEE Trans. Power Systems*, **9**(2), (1994), 668-676.

[16] J.T. MA, and L.L. LAI: Evolutionary programming approach to reactive power planning. *IEE Proc. - Gener. Transm. Distrib.*, **143**(4), (1996), 365-370.

[17] A. FARAG, S. AL-BAIYAT and T.C. CHENG: Economic load dispatch multi-objectives optimization procedures using linear programming techniques. *IEEE Trans. Power Systems*, **10**(2), (1995), 731-738.

[18] M. BELAZZOUG, M. BOUDOUR and A. HELLAL: New reactive power sources dispatch applied to the IEEE 57 nodes. *The Int. J. for Computation and Mathematics in Electrical and Electronic Engineering*, **27**(5), (2008), 1192-1211.

[19] E. ACHA and C.FUERTE ESQUIVEL: FACTS, modelling and simulation in power network. John Wiley & Sons Ltd., England, 2004.