International Journal of Control and Automation
Vol.7, No.7 (2014), pp.383-396
http://dx.doi.org/10.14257/ijca.2014.7.7.31

Optimal SVC Placement in Electric Power System Using NSGA-II

Shishir Dixit[1], Ganga Agnihotri[2] and Laxmi Srivastava[3]

[1,3]Department of Electrical Engineering,MITS, Gwalior,India
[2]Department of Electrical Engineering,MANIT, Bhopal,India
[1]shishir.dixit1@gmail.com, [2]ganga1949@gmail.com, [3]srivastaval@hotmail.com

Abstract

This paper proposes non dominated sorting genetic algorithm (NSGA-II) with a feature of adaptive crowding distance for obtaining optimal location and sizing of Static Var Compensators (SVC) to minimize real power losses (RPL) and load bus voltage deviation (VD) considering critical contingencies. The voltage security of the power system is also analyzed for all placements of SVCs at respective location computed. Finally, after compression of optimal power loss, load bus voltage deviation along with voltage security following by simulation of critical contingency the most appropriate location and sizing of SVC is determined. While obtaining the optimal location and sizing of SVC, single line outages are considered as contingencies and voltage limits for the load buses are considered as security constraints. The effectiveness of proposed approach has been demonstrated on IEEE 30-bus test system. The results obtained for proposed algorithm are optimistic and reveal the capability of the NSGA-II to generate well-distributed non-dominated Pareto front.

Keywords: *NSGA-II; SVC; real power losses (RPL); voltage deviations (VD)*

1. Introduction

One of the foremost problems in the emerging power system operation and control is to maintain the voltage security with optimal operating and the security of the system while minimizing system power losses and voltage deviation. Application of FACTS devices may lead to maintaining suitable voltage profile while minimizing power losses and load voltage deviation. Owing to huge investment of FACTS devices researchers have reported numerous approaches with intensive exploration at planning stage to acquire maximum benefit of these devices.

The different methodologies, approaches, and algorithms have been suggested in the literature to solve the problems of dispatch. This reported work can broadly be classified under following headings: classic methodologies such as the the weights method [1], non linear programming technique [2], and the ϵ-constraints method [3]. The classic methods reported in the literature presents some inconveniences like the extensive execution time, the uncertainty of convergence, the intricacy of algorithmic and the creation of a weak number of non dominated solutions. Owing to these limitations of classical methods, the evolutionary algorithms have gained more popularity recently because of their capability to exploit huge spaces of search and ease of requirement for pre identification of the problem. The evolutionary techniques [4] as NSGA (Non Dominated Sorting Genetic Algorithm) [5], NPGA method (Niched Pareto Genetic Algorithm) [6-7], SPEA (Strength Pareto Evolutionary Algorithm) [8], ISPEA-II (Improving Strength Pareto Evolutionary Algorithm) [9], Ant Colony Optimization Method [10], an Improved Hybrid Evolutionary Programming Technique [11]. The

ISSN: 2005-4297 IJCA

SVC is a shunt connected static Var generator or consumer whose output can be adjusted to exchange inductive or capacitive to maintain or control specific parameters of electrical power system, such as bus voltage etc. [12]. The SVC is basically combination of a series capacitor bank shunted by thyristor controlled reactor. In [13] mathematical modeling of FACTS has been discussed. Srinivas and Deb introduced NSGA [14]. NSGA has shown its limitation for complexity in computational, lack of elitism and for choosing the optimal parameter value for sharing parameter. Therefore, a modified version, NSGA-II was developed.

In this paper, the problem of obtaining optimal sizing and location is formulated as multi-objective optimization, mixed continuous-discreet problem by combining two objective functions. A new methodology has been implemented to solve multi-objective optimization which basically consists of two parts. In first part severe lines are identified using voltage power index (*VPI*) whereas in second part NSGA-II have been implemented following by outage of these critical lines to obtain optimal location and sizing of SVC for minimizing real power loss and voltage deviation.

2. Problem Formulation

In this paper, outage of single line in a power system is considered as contingencies for optimal location and sizing of SVC. The severity of a single line outage contingency is estimated using Voltage Power Index (*VPI*) [15] as:

$$VPI = \sum_{i=1}^{NB} (\Delta|V_i|/\Delta|V_i^{max}|)^{2m} \tag{1}$$

where, $\Delta|V_i|$ is absolute difference between the voltage magnitude under line outage and base case condition; $\Delta|V_i^{max}|$ is bus voltage magnitude chosen by the utility engineers to indicate acceptable limit for an outage case. In this paper, the value of the exponent m has been taken as 2 and $\Delta|V_i^{max}|$ has been considered as 0.2 p.u. the no. of buses are 30.

2.1 Minimization of Real Power Loss

The real power loss (RPL) as first objective function $F_1(u,v)$ is defined as:

$$RPL_1 = \sum_{k=1}^{NTL}[g_k[V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)] \tag{2}$$

where, NTL and g_k are the number of transmission lines and conductance of k^{th} line respectively. The bus voltages at the both ends of k^{th} line are represented by $V_i \angle\delta_i$ and $V_j \angle\delta_j$, respectively.

2.2 Minimization of Voltage Deviations

The load bus voltage deviation (VD) as second objective function $F_2(u,v)$ is defined as:

$$VD = \sum_{k=1}^{NL} |(V_k - V_k^{ref})| \tag{3}$$

where, NL represents number of buses. In this paper, V_k^{ref} is considered as 1.0 p.u. In a power system it is accustomed to maintain the load bus voltage within ±5% of its nominal value.

In both objective functions $F_1(u,v)$ and $F_2(u,v)$, u is the vector of dependent variable consisting of load voltages (V_{L_1} . . . $V_{L_{NL}}$), generators' reactive powers (Q_{g_1}.....$Q_{g_{NG}}$) and transmission lines' loadings (S_{L_1} . . . $S_{L_{NTL}}$), and v is the vector of independent variables consisting of generators' voltages (V_{g_1} ...$V_{g_{NG}}$), transformers' tap settings (T_1 . . .T_{NT}) and reactive power injections (Q_{c_1} . . . $Q_{c_{NC}}$).Therefore u and v can be expressed as:

$$u = [V_{L_1} \ldots V_{L_{NL}};\ Q_{g_1} \ldots Q_{g_{NG}};\ S_{L_1} \ldots S_{L_{NTL}}] \tag{4}$$

$$v = [V_{g_1} \ldots V_{g_{NG}};\ T_1 \ldots\ T_{NT};\ \ Q_{c_1} \ldots Q_{c_{NC}}] \tag{5}$$

2.3 Multi- Objective Fnction

The objective function for the optimization problem can be obtained by combining all objectives mentioned above as:

$$Ƒ\,(u,v) = F_1(u,v) + F_2(u,v) \tag{6}$$

Now, the optimization will be carried out for minimizing the objective function $Ƒ\,(u,v)$, subject to equality and inequality constraints.

2.4 Constraints

1) Equality Constraints

The equality constraints represent the typical load flow equations as follows:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NB} V_j [G_{ij}\ \cos(\delta_i - \delta_j) + B_{ij}\ \sin(\delta_i - \delta_j))] = 0 \tag{7}$$

for i = 1,……., *NB*

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{NB} V_j [G_{ij}\ \sin(\delta_i - \delta_j) - B_{ij}\ \cos(\delta_i - \delta_j)] = 0 \tag{8}$$

for i = 1,……., *NB*

where, NB represents number of total buses. P_{Gi},, Q_{Gi} are the generator real and reactive powers and P_{Di}, Q_{Di} are the active and reactive power load at bus i respectively; G_{ij} and B_{ij} are the transfer conductance and susceptance of the line between bus i and bus j, respectively.

2) Inequality Constraints

Inequality constraints are the upper and lower limits of reactive power of a generator. The reactive power of i^{th} generator must lie within its minimum ($Q_{g_i}^{min}$) and maximum ($Q_{g_i}^{max}$) limits as:

$$Q_{g_i}^{min} \le Q_{g_i} \le Q_{g_i}^{max} \qquad i = 1,2 \ldots NG \tag{9}$$

3. Implementation OF NSGA-II

3.1. Initial Population

Initially in first step of algorithm an initial population P is generated randomly. The size of initial population is $N' \times n'$, where N', n' represents the number of individuals (chromosomes) and the number of continuous and discrete variables respectively. At the start, a gene of each individual is determined by assigning its value randomly between the upper and lower limits.

3.2. Non-dominated Sort

After generation of the initial population P', a non-dominated sorting of the population is done into different fronts [16]. For clarity, description of a naive and slow sorting procedure of a population into different non-domination levels is presented here. Thereafter, a fast approach is addopted [16]. In a naive approach, identification of solutions for the first non-dominated front in a population is done by comparing each solution with every other solution in the population to find its dominance. This requires comparisons for each solution for all objectives. At this stage, all individuals in the first nondominated front are found. In order to find the individuals of the next nondominated front, the solutions of the first front are discounted temporarily and the above procedure is repeated.

3.3 Density Estimation

To attain an estimate of the density of solutions in surrounding of a particular solution in the population, the average distance of two points of either side of the point under consideration is calculated for each of the objectives. A cuboid is so created by considering the nearest solutions on either side. The magnitude $i_{distance}$ provides as an estimate of the perimeter of the cuboid and is called the crowding distance [16].

3.4 Selection Algorithm

The Non-dominated sorting based selection approach as given in [17] has been used for selecting the population of the next generation. In this selection process, as a first step, a combined population $R_t = P_t \cup Q_t$ is created, where P_t represents the parent population while Q_t stands for the new population formed after implementation of genetic operators. The size of population R_t is as 2N. The population R_t is sorted in accordance of non-domination. Thereafter, crowding distance is calculated for each individual. As the only N chromosomes are selected for next generation P_{t+1} from 2N chromosomes of population R_t, an ensured elitism is predicted. Now, solutions of the non-dominated set F_1 are considered as the best solutions of the combined population and they must be given higher precedence than any other solution during the process of selection. During the process of selection of N solutions from non-dominated set *i.e.*, from F_1 starting fronts the following cases are considered for selecting a front:

a) There should be attest more than one chromosome having zero crowding distance and/or

b) The different solutions that have a crowding distance which is less than $\in$ the threshold value.

The Case 1 is a suggestion of duplicate chromosomes and in case 2 where chromosomes are having a crowding distance less than $\in$ is an indication of close proximity of solutions *i.e.*, threshold value which, if accepted, may result into cluster of solutions which are not desired.

The algorithm selects only one solution in case of duplicate chromosomes and rejects all that chromosomes which have crowding distance less than ∈. If the number of solutions so selected from front F_1 is less than N, the remaining (y) members of the population P_{t+1} are chosen from next succeeding non-dominated fronts in the order of their ranking. As a result, solutions from the set F_2 are chosen next to F_1, followed by solutions from the set F_3 and so on till N number of solutions is selected. During the selection, the solutions are received from best to worst front (F_1, F_2, …..), but due to non acceptance of all solutions of any particular front, there may be a chance for not getting all N chromosomes even from all the fronts (having 2N chromosomes). In all these cases, population will be filled up by duplicating the acceptable solutions. The new population size N of P_{t+1} will now used for genetic operator like selection, crossover, and mutation to create a new population Q_{t+1} of size N.

3.5 Adaptable Threshold for Crowding Distance

The threshold value for crowding distance is adapted as proposed in [17] for creating prospective solutions like creating diverse solutions, avoiding too proximate solutions etc. If, for a particular value of ∈, all N solutions are selected from F_1 only, it may happen that all N accepted solutions are clustered in a particular region. In that case the algorithm adapts the value of ∈ to a greater value so that, to have a total of N solutions, the algorithm is bound to go to at least F_2, if not to F_3. Going to F_2 guarantees that all solutions of F_1 are accepted, which are spread over the Pareto Front. However, if *N* solutions are not obtained even after accepting non-violated chromosomes from all the fronts, ∈ value will be decreased to enable the algorithm to have more solutions from F_1, F_2 *etc*.

3.6 Creation of Offspring

In this paper, real-coded GA (SBX- Simulated Binary Crossover) has been used for crossover and Polynomial mutation is used for mutation [19].

3.7 Stopping Rule

The iterative procedure for generating new trials by selecting those having minimum function values from the set of competing pool is terminated when there is no considerable improvement in the solution. The procedure can also be terminated when a given maximum number of generations are reached. In this paper, the maximum number of generations has been considered as the stopping criterion.

Implementation Summary of NSGA-I1

1: Formulate NSGA-I1 (N, G, $fi(x_i)$)) → N members evolve G generations to solve $fi(x_i)$)

2: Initialize Population

3: Generate random population

4: Compute Objective Values

5: Assign rank (level) based on Pareto dominance

- sort

```
Apply Binary Tournament Selection
Performore recombination and mutation
Generate child population
for each Parent and Child in Population do
    Assign Rank (level) based on Pareto - sort
    Generate sets of non dominated vectors along PF
    known
    Loop (inside) by adding solutions to next generation starting from the first front until N individuals found determine crowding distance between points on each front
end for
Select points (elitist) on the lower front (with lower rank) and are outside a crowding distance
Create next generation
Binary Tournament Selection
Recombination and Mutation
end for
end formulation
```

4. Simulations Results

NSGA-II has been applied for obtaining optimal location and sizing of SVC in IEEE 30-test bus system [20] in order to minimize real power losses and load bus voltage deviation. The test bus system has one slack bus, 5 *PV* buses, 24 *PQ* buses and 41 transmission lines. For optimal placement of SVC, single line outages contingencies are created in the test power system and to determine the severity of a contingency, *VPI* is calculated for all possible line outage contingencies. It has been found that developed NR load flow program converges only for 37 single line outages out of 41 single line outages. The objective function is formulated as a multi objective optimization problem. The placement of SVC is considered as a discreet decision variable, where any of 24 *PQ* buses may be the possible optimal location for SVC placement.

For some of the single line outage contingencies, the voltage magnitude of some buses violated the permissible voltage limit in viewpoint of voltage security, which is indicated by *VPI* in this paper. On the basis of *VPI*, the ranking of critical contingencies is done as shown in Table 1. As can be seen from Table 1, severity of line outages on the basis of *VPI* are as 36, 5, 15, 37, 38, and 25 and so on. In this paper, only first three severe contingencies *i.e.*, outage of line nos. 36, 5, and 15 have been considered for SVC placement.

Table 1. VPI Values for Outage of Line Outage

Sr. No.	LO	VPI	Ranking
1.	36	0.1541	I
2.	5	0.0063	II
3.	15	0.0023	III
4.	37	0.0018	IIII
5.	38	0.0015	IIV
6.	25	0.0011	IV
7.	18	0.0004	IVI
8.	4	0.0004	IVII
9.	14	0.0003	IVIII
10.	26	0.0002	IIX
11.	24	0.0002	IX
12.	30	0.0001	IXI

4.1. Outage of Line no. 36

The highest value of *VPI* is computed for outage of line no. 36 as 0.1541, therefore, from the viewpoint of voltage security it is the most severe line outage. NSGA-II is implemented for five trials following outage of line no. 36. The population size and number of generations are chosen as 10 and 180 to determine the optimal location and sizing of SVC. The simulation results of five trials are shown in Table 2. It offers several solutions to multi objective optimization problem and permits the operator to select adequate one. These results provide two optimal locations i.e. bus no. 27 for three times and bus no. 30 for two times. The power loss and voltage deviations are found 0.1930 p.u. and 0.6562 p.u., when SVC was placed at bus no. 27 whereas power loss and voltage deviations are computed 0.1943 p.u., and 0.6207 p.u, when SVC is placed at bus no. 30. The best optimal location for SVC may be considered as bus no. 27 due repeatedly computing with minimum value of power loss and voltage deviation. Figure 1 shows the Pareto optimal front for outage of line no. 36. The best compromising solution for optimal values of power loss and voltage deviation are compiled in Table 5. Figure 2 illustrates the voltage profile of the test system without and with SVC at bus no. 27. It can be observed from Figure 2 that with outage of line no. 36, the voltage magnitude at bus nos. 25, 26, 27, 29 and 30 was below 0.95 p.u., which after placement of SVC at bus no. 27 significantly increased.

Table 2. SVC Placement Results for LO 36

Trials	Optimal Location	Optimal Size (p.u)	Real Power Loss (p.u)	Voltage Deviation in (p.u.)
T1	27	0.1180	0.1930	0.6562
T2	30	0.1093	0.1943	0.6207
T3	27	0.1180	0.1929	0.6562
T4	27	0.1180	0.1929	0.6562
T 5	30	0.1093	0.1943	0.6207

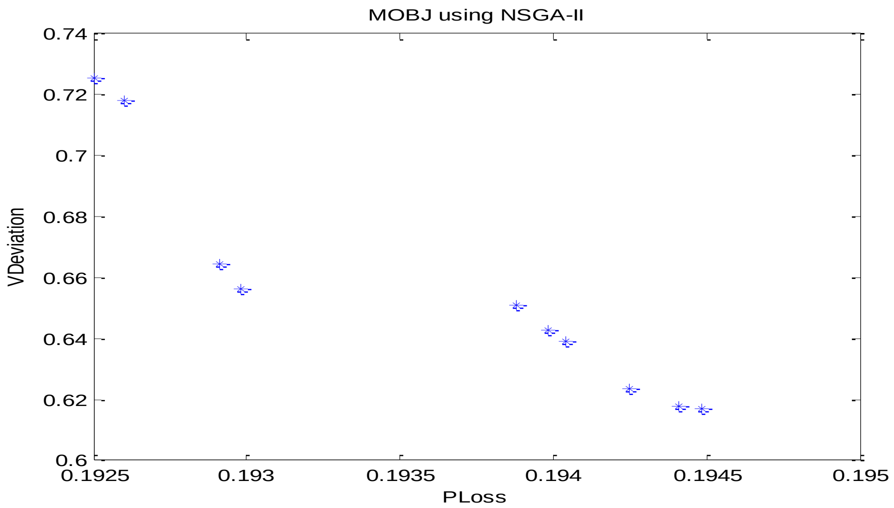

Figure 1. Pareto Front for LO 36

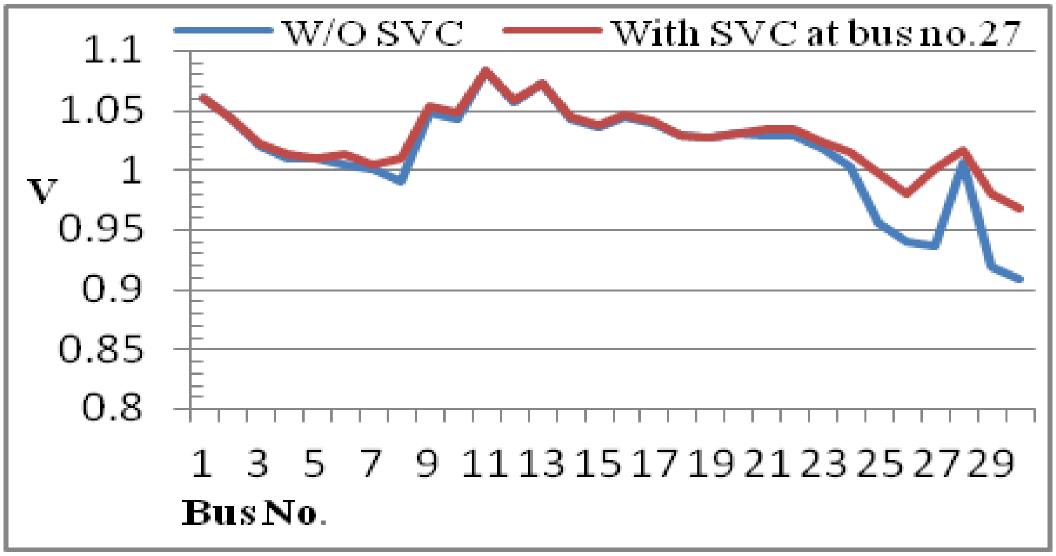

Figure 2. Voltage Profile for Outage of Line no. 36 without and with SVC at Bus No. 27

4.2. Outage of Line No. 5

The value of *VPI* is 0.0063 for second most severe contingency which is outage of line no. 5. NSGA-II has been implemented to find the optimal location and sizing of SVC following the outage of line no. 5 for five trials keeping the same fixed number of generations and population size *i.e.*, 180 and 10 respectively. The simulation results obtained are compiled in Table 3. It is observed from Table 3 that bus no. 6 is repeatedly obtained optimal location for four trials of SVC placement. The Pareto optimal front obtained as simulation result of NSGA-II is shown in Figure 3 which provides several solutions for power loss and voltage deviation for multi-objective function (6). The best compromising solution for optimal values of power loss and voltage deviation are summarized in Table 5. The voltage profile before and after placement of SVC at bus no. 6 is shown in Figure 4.

Table 3. SVC Placement Results for LO 5

Trials	Optimal Location	Optimal Size (p.u)	Real Power Loss (p.u)	Voltage Deviation (p.u)
T1	6	0.4269	0.3192	0.6013
T2	6	0.4269	0.3192	0.6013
T3	6	0.4269	0.3192	0.6013
T4	6	0.4269	0.3192	0.6013
T 5	6	0.4269	0.3192	0.6013

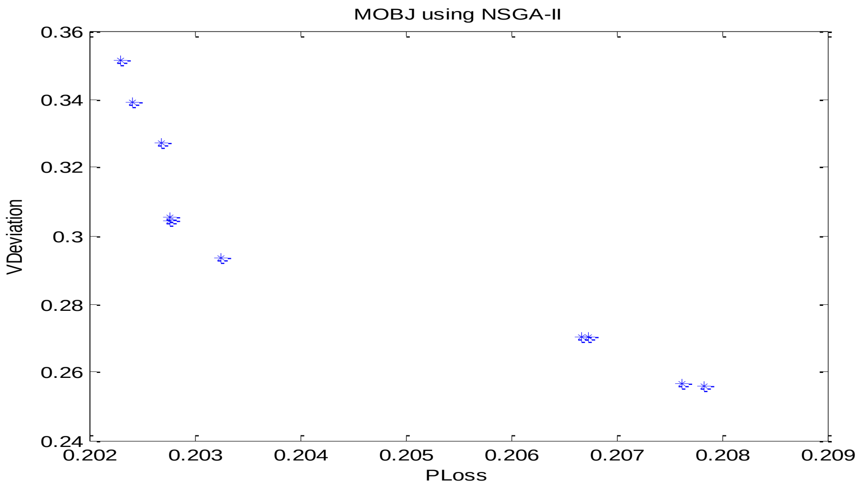

Figure 3. Pareto Front for LO 5.

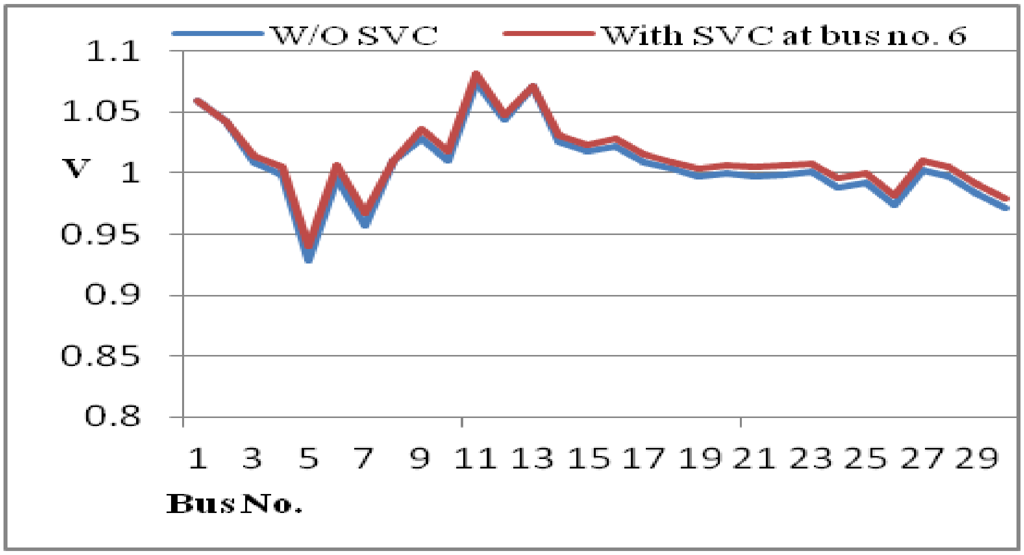

Figure 4. Voltage Profile for Outage of Line no. 5 without and with SVC at Bus no. 6

4.3. Outage of Line no. 15

The developed NSGA-II has been applied maintaining the same population size and generations *i.e.*, 10 and 180 respectively for third most severe contingency *i.e.*, outage of line no. 15 having *VPI* value as 0.0023. The simulation results for five trials are summarized in Table 4. The optimal location for SVC placement is found to be bus no. 24 with rating of -0.2033 p.u. for three trials. Figure 5 shows the Pareto optimal front obtained as a result of NGSA-II implementation when line number 5 is out. The best compromising solution for optimal values of power loss and voltage deviation are given in Table 5. The voltage magnitude of all the buses with and without SVC is illustrated in Figure 6.

Table 4. SVC Placement Results for LO 15

Trials	Optimal Location	Optimal Size (p.u)	Real Power Loss (p.u)	Voltage Deviation(p.u)
T1	24	-0.2033	0.2933	0.2935
T2	24	-0.2033	0.2933	0.2935
T3	10	-0.7805	0.1640	0.2556
T4	10	-0.7805	0.1640	0.2556
T 5	24	-0.2033	0.2933	0.2935

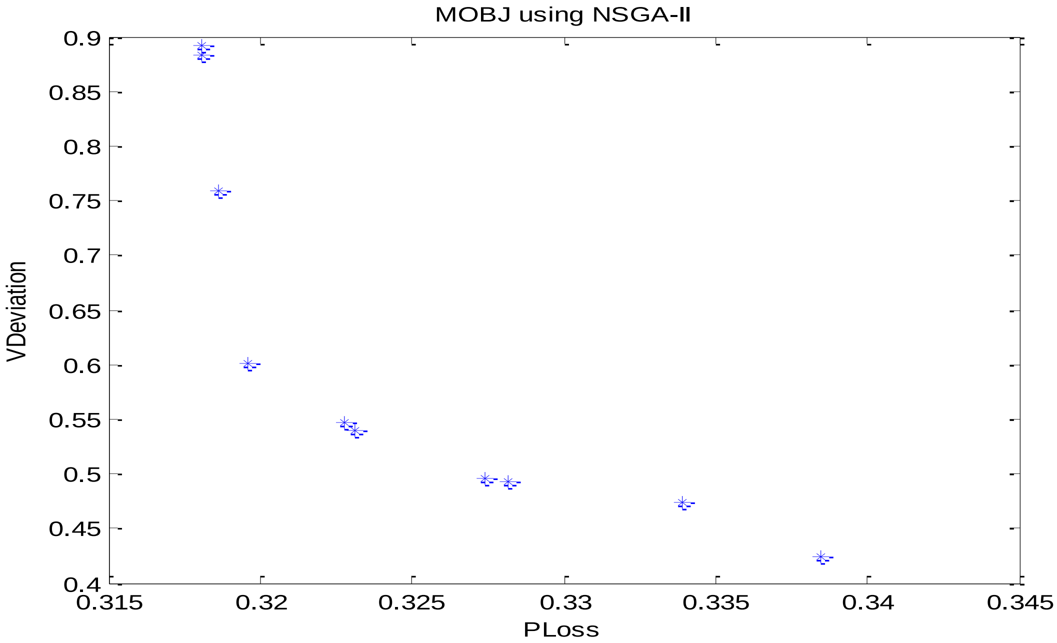

Figure 5. Pareto Front for LO 15 when SVC Placed at Bus no 24

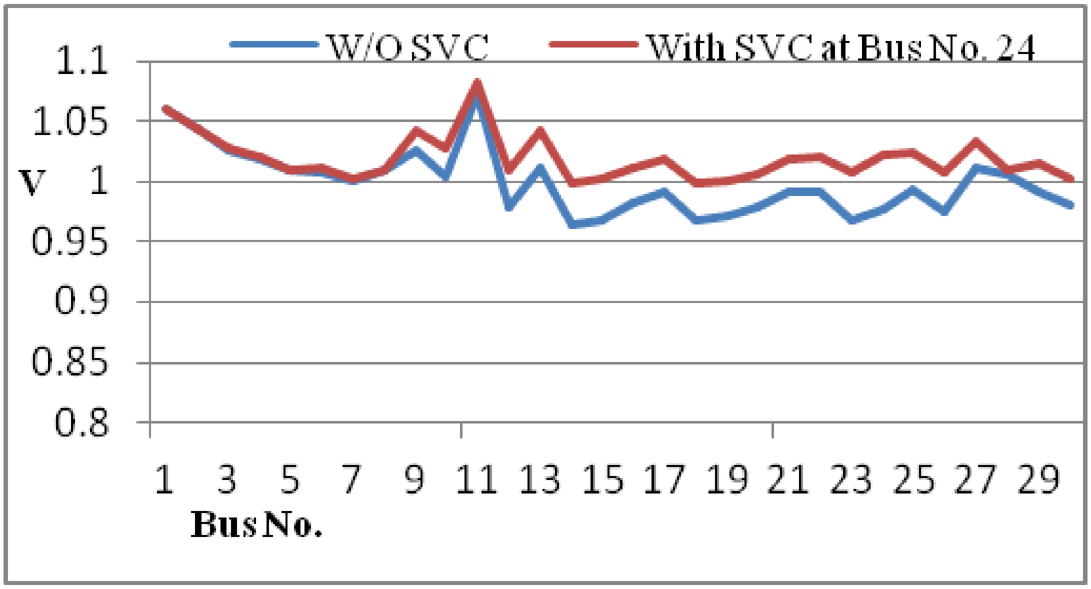

Figure 6. Voltage Profile for Outage of Line no. 15 without and with SVC at Bus no. 24

Table 5. BEST Compromising Results of NSGA-II

LO	Optimal Location	Optimal Size in p.u	Real Power Loss in p.u
Base case	-	-	0.1803
LO 36	27	0.1180	0.1930
LO 5	6	0.4269	0.3192
LO 15	24	-0.2033	0.2933

The optimal location and sizing of SVC computed for outage of line no. 36 is found to be self-sufficient for maintaining voltage security of the test power system when outage of the first three most critical lines occur one at a time. Table 6 presents voltage scenario of test power system without placement of SVC. It is observed from Table 6, there is no need of SVC placement for base case condition. Table 7 presents voltage profile of the test system when SVC of 0.1180 p.u. is placed at bus no. 27 and outage of the tree most critical lines *i.e.*, outage of line no. 36, 5, and 15 are simulated considering one at a time.

Table 6. VOLTAGE Profile without SVC

Bus No.	Base Case	LO 36	LO 5	LO 15
1.	1.06	1.06	1.06	1.06
2.	1.043	1.043	1.043	1.043
3.	1.0215	1.0201	1.0111	1.0274
4.	1.0129	1.0112	1.0012	1.0199
5.	1.01	1.01	0.9323	1.01
6.	1.0121	1.0115	0.9993	1.0112
7.	1.0034	1.0031	0.9601	1.0029
8.	1.01	1.01	1.01	1.01

9.	1.051	1.0461	1.0437	1.0454
10.	1.0444	1.0354	1.036	1.0362
11.	1.082	1.082	1.082	1.082
12.	1.0574	1.053	1.0524	1.0097
13.	1.071	1.071	1.071	1.0419
14.	1.0424	1.0353	1.0371	0.997
15.	1.0378	1.027	1.0317	1.0002
16.	1.0447	1.0382	1.0381	1.014
17.	1.0391	1.0309	1.0312	1.0242
18.	1.0279	1.0177	1.021	1.0001
19.	1.0253	1.0154	1.0178	1.0035
20.	1.0293	1.0196	1.0215	1.0109
21.	1.0321	1.0182	1.0237	1.0225
22.	1.0327	1.0173	1.0243	1.0227
23.	1.0272	1.0045	1.0202	0.9984
24.	1.0216	0.9835	1.0133	1.0052
25.	1.0189	0.9246	1.0093	1.0124
26.	1.0012	0.9051	0.9915	0.9946
27.	1.0257	0.8999	1.0155	1.0254
28.	1.0107	1.0153	1.0009	1.0088
29.	1.0059	0.877	0.9955	1.0056
30.	0.9945	0.8637	0.9839	0.9942

Table 7. VOLTAGE Profile with SVC at Bus no. 27

Bus No.	LO 36	LO 5	LO 15
1.	1.0600	1.0600	1.0600
2.	1.0430	1.0430	1.0430
3.	1.0213	1.0124	1.0285
4.	1.0126	1.0027	1.0212
5.	1.0100	0.9344	1.0100
6.	1.0127	1.0011	1.0131
7.	1.0038	0.9621	1.0041
8.	1.0100	1.0100	1.0100
9.	1.0520	1.0463	1.0495
10.	1.0467	1.0405	1.0433
11.	1.0820	1.0820	1.0820
12.	1.0586	1.0548	1.0195
13.	1.0710	1.0710	1.0515
14.	1.0435	1.0403	1.0072
15.	1.0373	1.0358	1.0107
16.	1.0463	1.0413	1.0228
17.	1.0413	1.0353	1.0319
18.	1.0285	1.0252	1.0096
19.	1.0264	1.0221	1.0123
20.	1.0307	1.0259	1.0193
21.	1.0333	1.0295	1.0312
22.	1.0335	1.0305	1.0318

23.	1.0238	1.0275	1.0109
24.	1.0147	1.0249	1.0203
25.	0.9985	1.0356	1.0408
26.	0.9805	1.0183	1.0235
27.	1.0009	1.0508	1.0618
28.	1.0162	1.0058	1.0139
29.	0.9806	1.0315	1.0428
30.	0.9688	1.0204	1.0317

5. Conclusion

In this paper, non dominated sorting genetic algorithm has been successfully implemented for obtaining optimal location and sizing of SVC to minimize real power loss and load bus voltage deviation. The voltage security of the system is also ensured with placement of SVC. It is concluded that optimal placement of SVC can enhance voltage security significantly in a power system. Implementation performed on IEEE 30-bus test system indicates that proposed NGSA-II is capable to provide optimal location and sizing of FACTS devices. Though, the proposed approach has been implemented on IEEE 30-bus test system, the same can be implemented on practical power system as well.

Acknowledgements

The authors sincerely acknowledge the financial support provided by University Grants Commission (UGC), New Delhi, India under Major Research Project received vide F. No. 41-657/2012[SR] dated 26-07-2012 and the Director, MITS Gwalior, India to carry out this work.

References

[1] P. Abril and J. A. GonzaJez, “VAR Compensation by Sequential Quadratic Programming”, IEEE Trans. Power Systems, vol. 18, no. 1, **(2003)** February, pp. 36-41.

[2] M. O. Mansour and T. M. Abdel-Rahman, “Non-linear VAR Optimization using Decomposition and Coordination”, IEEE Trans. Power Apparat. Systems, PAS-103, no. 2, **(1984)**, pp. 246-255.

[3] Y. T. Hsiao, H. D. Chiang, C. C. Liu and Y. L. Chen, “A Computer Package for Optimal Multiobjective V AR Planning in Large Scale Power Systems”, IEEE Trans. Power Systems, vol. 9, no. 2, **(1994)** May, pp. 668-676.

[4] C. Fonseca, “Multiobjective Genetic Algorithms with Application to Control Engineering Problems”, PhD Thesis, Department of Automatic Control and Systems Engineering. The University of Sheffild, **(1995)** September.

[5] H. Alexandre, F. Dias and A. de Vasconcelos, “Multi objective Genetic Algorithms Applied to Solve Optimization Problems”, IEEE Trans.Magnetics, vol. 38, no. 2, **(2002)** March, pp. 1133-1136.

[6] E. Zitzler, M. Laumanns and L. Thiele, “SPEA2: Improving the Strength Pareto Evolutionary Algorithm”, TIK-Report no. 103, **(2001)** May.

[7] 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, vol. 19, no. 2, May **(2004)**.

[8] E. Zitzler and L. Thiele, “An Evolutionary Algorithm for Multi objectives Optimization: The Strength Pareto Approach”, TIK-Report no. 43, **(1998)**.

[9] E. Zitzler, M. Laumanns and L. Thiele, “SPEA2: Improving the Strength Pareto Evolutionary Algorithm”, TIK-Report no. 103, **(2001)** May.

[10] T. Bouktir and L. Slimani, “Optimal Power Flow of the Algerian Electrical Network using an Ant Colony Optimization Method”, Leonardo Journal of Sciences, vol. 6, **(2005)**, pp. 43-57.

[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, vol. 19, no. 2, **(2004)** May.

[12] J. T. Ma and L. L. Lai, “Evolutionary Programming Approach to Reactive Power Planning”, lEE Proc. - Gener. Transm. Distrib., vol. 143, no. 4, **(1996)** July, pp. 365- 370.
[13] A. Farag, S. Al-Baiyat and T. C. Cheng, “Economic load dispatch multi objectives optimization procedures using linear programming techniques”, IEEE Trans. Power Systems, vol. 10, no. 2, **(1995)**, pp. 731-738.
[14] M. Belazzoug, M. Boudour and A. Hellal, “'New reactive power sources dispatch applied to the IEEE 57 nodes”, COMPEL PES-SSD07-03, The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, vol. 27, no. 5, **(2008)**, pp. 1192-1211.
[15] A. J. Wood and B. F. Wollenberg, “Power Generation Operation and Control”, IIEd., John Willey & Sons, Inc, **(2004)**.
[16] K. Deb, A. Pratap, S. Agarwal and T. Meyarivan, “A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II”, IEEE Transaction on Evolutionary Computation, vol. 6, no. 2, **(2002)**, pp 182-197.
[17] B. Purkayastha, N. Sinha and B. Syam Purkayastha, “Optimal Combined Economic and Emission Load Dispatch using modified NSGA-II with Adaptive Crowding Distance”, International Journal of Information Technology & Knowledge Management, vol. III, no. I, **(2010)** June.
[18] K. Deb, “Evolutionary Algorithms for Multicriterion Optimization in Engineering Design”, Evolutionary Algorithms in Engineering and Computer Science, Chapter 8, **(1999)**, pp. 135-161.
[19] K. Deb and R. B. Agarwal, “Simulated Binary Crossover for continues Search Space”, Complex Systems, vol. 9, **(1995)** April, pp. 115-148.
[20] H. Saadat, “Power System Analysis”, Tata McGRAW-HILL Edition.

Authors

Shishir Dixit, obtained his M. Tech. degree in Electrical Engineering from MANIT, Bhopal, India in 2003. Presently he is working as Assistant Professor in the department of Electrical Engineering, MITS, Gwalior, India. His area of interest is FACTS placement in power system, power system optimization and control.

Ganga Agnihotri, received BE degree in Electrical engineering from MACT, Bhopal (1972), the ME degree (1974) and Ph. D. degree (1989) from University of Roorkee, India. Since 1976 she is with Maulana Azad College of Technology, Bhopal in various positions. Currently she is professor. Her research interest includes Power System Analysis, Power System Optimization and Distribution Operation.

Laxmi Srivastva, obtained her M. Tech. degree in Elecctrical Engineering from Indian Institute of Technology, Kanpur, India in 1990 and her Ph. D. form University of Roorkee (presently known as IIT Roorkee), India in 1998. She is working as Professor in the department of Electrical Engineering, MITS, Gwalior, India. She is currently involved in research in power system optimization and control, security analysis and ANN and fuzzy neural application to power system.