Static Var Compensator Allocation Considering Transient Stability, Voltage Profile and Losses

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***Abstract*--The purpose of this paper is to determine the optimal location, size and controller parameters of Static Var Compensator (SVC) to simultaneously improve static and dynamic objectives in a power system. Four goals are considered in this paper including transient stability, voltage profile, SVC investment cost and power loss reduction. Along with the SVC allocation for improving the system transient stability, an additional controller is used and adjusted to improve the SVC performance. Also, an estimated annual load profile including three load levels is utilized to accurately find the optimal location and capacity of SVC. By considering three load levels, the cost of power losses in the power system is decreased significantly. The combination of the active power loss cost and SVC investment cost is considered as a single objective to obtain an accurate and practical solution, while the improvement of transient stability and voltage profile of the system are considered as two separate objectives. The problem is therefore formulated as a multi-objective optimization problem, and Multi Objective Particle Swarm Optimization (MOPSO) algorithm is utilized to find the best solutions. The suggested technique is verified on a 10-generator 39-bus New England test system. The results of the nonlinear simulation indicate that the optimal sizing, location and controller parameters setting of SVC can improve significantly both static and dynamic performance of the system.**

***Index Terms*-- Static Var Compensator (SVC), Transient stability, Multi Objective Particle Swarm Optimization (MOPSO), Voltage profile.**

I. INTRODUCTION

A. Aims and Scope

In recent years, Flexible AC Transmission Systems (FACTS) devices have been utilized for various objectives to improve the power system operation [1]. The main objectives which are essential for the operation and security of power systems include: i) voltage profile, ii) power loss, and iii) transient stability [1]. Among the mentioned objectives, transient stability is an increasingly important issue in the power system, e.g., a weak transient stability may frequently cause the blackout during the system fault, and it can extremely damage the rotor of generators. In order to mitigate these difficulties, FACTS devices, which are fast responsive, can be utilized. In addition, FACTS devices can improve the voltage profile in the power system [2]. Electrical devices are designed to work within a specific range of voltage. Therefore, the deviation from this range reduces the efficiency of devices and can deteriorate their operation or even damage them. In this regard, FACTS devices can be used to provide voltage security constraints in the power systems under normal conditions. Consequently, the FACTS devices can improve the mentioned objectives in the power system. However, the effectiveness of the FACTS controllers is mainly dependent on their locations and capacity. Therefore, it is essential to propose practical method for determining the allocation and capacity of these devices in the power system.

B. Literature Review and Approach

A considerable amount of literature has been published to evaluate the impacts of FACTS devices in the power system and determine their optimal allocations. To this end, different criteria have been proposed in the literature for the allocation problem. For example, Ref. [3] considers the static voltage stability enhancement as an objective for the allocation problem. Loss reduction is the main criterion which is considered for the allocation problem in [4]. Power plants fuel cost reduction using optimal power flow and voltage profile improvement are the other objectives proposed in [2]. In order to cope with the small signal stability problem, Ref. [5] proposes the best assignment and parameter setting of FACTS devices. In [6], the Static Var Compensator (SVC) has been allocated to enhance the first swing stability boundary of the power system. In order to advance the transient stability of the system and SVC cost, the optimal location, size and setting parameters of SVC controller are evaluated in [7]. Also, Ref. [8] determines the optimal location, size and parameter setting of SVC in long transmission lines to improve transient stability of the system and reduce the SVC cost. It should be noted that each of the mentioned objectives improves the power system network operation, but improvement in one objective does not guarantee the same improvement in others.

In addition, some assumptions, e.g., using single objective optimization, ignoring the investment budget as a part of the objective function, and allocation in the presence of a multi-objective function [9], have been considered in the literature to implement these objectives. These assumptions can result in some problems such as, an inability to use the powerful advantages of FACTS devices in the static and dynamic conditions and impractical allocation results. Note that, each of the mentioned objectives can enhance the operation of the power system from its own viewpoint and therefore, none of them can be neglected for allocation of FACTS devices. Furthermore, It is essential to consider the cost of devices since neglecting it cannot be justified in the allocation of FACTS devices [7, 9]. The current paper considers the transient stability improvement, power loss reduction, voltage profile, and the investment costs of FACTS devices to improve previous researches in the field of FACTS devices allocation in the power systems. Despite previous studies, the alleviation of both cost factors is considered in the proposed model. In an effort to approach a practical solution, an estimated annual load profile has been considered. It should be mentioned that, in this study, the FACTS device is assumed to be SVC.

One additional controller is required, when a SVC is utilized to improve the voltage of buses in a power system. This kind of controller can be used to adjust the bus voltage of SVC to improve the damping procedure of the system oscillations [7-9]. In this situation, the interaction between the power system and this controller (SVC-based controller) can affect the system oscillations. Accordingly, the optimum parameter setting of this kind of controller is essential and it should be selected properly. A lot of approaches, for example stochastic exploration, have been proposed and advanced to find global optimization solutions [10, 11]. In order to improve the system transient stability, this paper determines the optimal location of the SVC by considering and adjusting an extra controller to enhance its performance.

Considering more than one objective function increases complexity of the optimization model [12-14]. In order to solve this kind of problems, multi-objective optimization methods can be employed. In the Multi-Objective Problem (MOP) unlike the single one, a set of solutions obtained instead of only one answer. In this paper, Pareto method has been used to solve the mentioned problem. The Pareto optimal solution is the solution that improvement in one of the objective function begins to deteriorate its performance in at least one of the rest. The Pareto method allows the system designer to choose among the available solutions with respect to the network's conditions and requirements for determining the placement and capacity of SVC. Due to the simple concept, easy implementation, modifiable parameters and rapid convergence, Multi-Objective Particle Swarm Optimization (MOPSO) algorithm has been utilized for solving various optimization problems [15-17]. In order to solve the mentioned MOP, this paper employs MOPSO as a promising evolutionary technique. In addition, a Sequential Quadratic Programming (SQP) optimization sub-problem has been utilized to implement an estimated annual load profile to accurately find the optimum location and capacity of SVC.

C. Paper Organization

The remainder of the paper is organized as follows. Section II formulates the optimal location and size of SVC as a multi-objective optimization problem. Next, a brief overview of SVC-based controller is presented in Section III. Section VI provides results for a case study. Finally, Section V summarizes the results of this work and draws conclusions.

II. PROBLEM FORMULATION AND OBJECTIVE FUNCTION

The first objective function in this paper is related to minimization of the investment cost of SVC and active power loss. This objective function is as follows [7],

$$\begin{aligned} f_1(x,u,w) &= K_i C_{investment}(w) \\ &\quad + K_e \sum_i (P_{loss\,i}(x,u,w) T_i) \end{aligned} \tag{1}$$

where K_e is the active power cost in \$/kWh; T_i represents the time length of the i^{th} load level in hours; $P_{lossi}(x,u,w)$ is the active power loss of i^{th} load level; $C_{investment}(w)$ can be written as follows [7]:

$$C_{investment}(w) = C_{M\text{var}\_SVC} S_{SVC} \tag{2}$$

where S_{SVC} represents the apparent power of SVC; $C_{M\text{var}\_SVC}$ is the MVar cost of SVC [7].

$$\begin{aligned} C_{M\text{var}\_SVC} &= 0.3 S_{SVC}^2 - 305 S_{SVC} \\ &\quad + 127380 (\$/\text{MVar}) \end{aligned} \tag{3}$$

Note that, the investment cost needs to be accomplished in the same year of the allocation study. After calculating the investment cost of SVC based on the interest rate, the life time of SVC can be combined in a single objective function. The following K_i factor can be defined to do this [7].

$$K_i = \frac{(1+B)^{n_{SVC}} B}{(1+B)^{n_{SVC}} - 1} \tag{4}$$

where B presents the refundable investment rate in percentage; n_{SVC} is the SVC life time. B and n_{SVC} are assumed to be 15 percent and 30 years, respectively.

The transient stability of the system is considered as the second objective function as follows [7].

$$f_2(x,u,w) = \int_0^{t=t_{sim}} \left(\sum_{i=1}^{4} |J_i|\right) t\,dt, \tag{5}$$

where J_i are chosen as the maximum selected values of speed deviations from the set of J^k as follow [7]:

$$J^k = \int_0^{t=t_{sim}} \left(\sum_{i=1}^{N_G} \sum_{j=i+1}^{N_G} \left(\left|\Delta\omega_{i,j}{}^k\right|\right)\right) t\,dt, \tag{6}$$

where $\Delta\omega_{i,j}$ represents the speed deviation among generators i and j ($\Delta\omega_i - \Delta\omega_j$); N_G is the total number of generators in the system; t_{sim} is the time of simulation horizon. The J^k set is generated in case that there is no SVC in the system. As the Integral of Time multiple Absolute Error (ITAE) is used to derive the objective, the advantage of the minimal requirements of dynamic plant information can be preserved. Also, to compute this objective function, the time-domain simulation is used. The aim is minimizing the objective function f_2 to improve the overshoots and settling time of the response [7].

The third objective function is the voltage limitations and violations in the system. The voltage violation can be defined as follows for each bus.

$$VD_i = \frac{\Phi(|V_i - V_i^{ideal}| - dv_i)}{v_i} \quad , \Phi(x) = \begin{cases} 0 & if \;\; x < 0 \\ x & otherwise \end{cases} \qquad (7)$$

where V_i, V_i^{ideal} are the voltage and ideal voltage (i.e. 1 pu); dv_i represents the maximum voltage deviation tolerance. Accordingly, the third objective function can be written as follows.

$$f_3(x, u, w) = \sum_{i \in J_L} VD_i = \sum_{i \in J_L} \frac{\Phi(|V_i - V_i^{ideal}| - dv_i)}{v_i} \qquad (8)$$

where J_L is the number of buses. Note that, by minimizing this objective function, the bus voltages will remain in the specified limits.

To solve the multi-objective optimization problem, some constraints such as the bound of location, capacity of SVC and limits of the controller parameters have been considered. Therefore, the multi-objective optimization problem can be presented as follows:

$$\begin{aligned} &\min_{u,w \in \chi} f_1(x, u, w) \\ &\min_{u,w \in \chi} f_2(x, u, w) \\ &\min_{u,w \in \chi} f_3(x, u, w) \end{aligned} \qquad (9)$$

Subject to

$$\begin{aligned} &N_{loc}^{\min} \le N_{loc} \le N_{loc}^{\max} \\ &B_{SVC}^{\min} \le B_{SVC} \le B_{SVC}^{\max} \\ &K_S^{\min} \le K_S \le K_S^{\max} \\ &T_{1S}^{\min} \le T_{1S} \le T_{1S}^{\max} \\ &T_{3S}^{\min} \le T_{3S} \le T_{3S}^{\max} \end{aligned} \qquad (10)$$

where B_{SVC} and N_{loc} are the capacity and location number the SVC, respectively. K_S, T_{1S}, T_{2S} are the SVC controller parameters. The MOPSO technique is taken from [8] to solve the multi-objective optimization problem in this paper.

III. SVC-BASED CONTROLLER

The structure of the SVC-based controller is shown in Fig. 1. As it can be seen, the common lead-lag structure with gain, washout and two-stage phase-compensation blocks is used.

The washout block, which is a high-pass filter, is used to allow the passing of oscillations in the input signal without variation. This block cannot affect the steady changes in the input. The washout time constant can have a range between 1 to 20 seconds [18]. To provide the phase-lead behavior to compensate the phase-lag between input and output signals, the phase-compensation block is used.

TABLE I
INFORMATION FOR ECONOMIC STUDY

Parameter	Values
Factor and duration of load level 1	0.81, 2136 hours
Factor and duration of load level 2	1.00, 2832 hours
Factor and duration of load level 3	0.90, 3792 hours
K_e	0.16 $/kWh

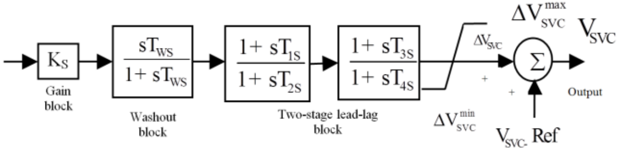

Fig. 1 SVC-based controller.

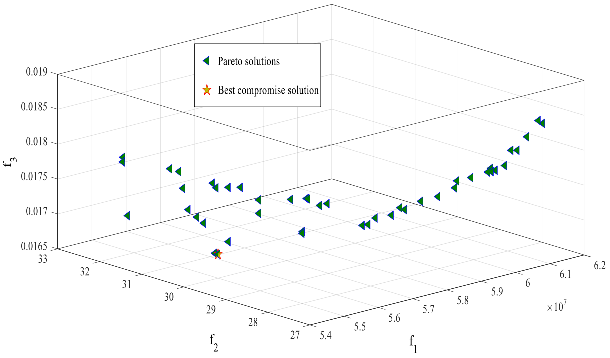

Fig. 2 Non–dominated and the finest cooperation answers.

Generally, in the SVC-based controller structure the time constants need to be pre-specified. In this paper, T_W=10*s* and T_{2S}=T_{4S}=0.3*s* are assumed. To determine the time constants T_{1S}, T_{3S} and the gain K_S, the MOPSO technique is used.

IV. RESULTS AND DISCUSSIONS

The 10-machine 39-bus New England power system is utilized to define the optimum location and size of SVC and determine the parameters of the SVC-based controller [7, 19]. Generator 1 (bus 39) represents parts of the U.S.-Canadian interconnection system [7]. It is expected here that SVC can be installed at all buses excepting bus 39. Table I lists the necessary information for economic study, and the forecasted load curve with three load levels and their durations. The fault is set to happen at 2.0 s from the beginning of the simulation and be cleared after 1.0 s at bus 29 at the end of line 26-29, which is enormously severe from the stability viewpoint [7, 20].

The subsequent objective function is recommended to calculate the transient stability of the system [7]:

$$f_2(x, u, w) = \int_0^{t=t_{sim}} \left(|J_1| + |J_2| + |J_3| + |J_4|\right) t\,dt, \qquad (11)$$

where $j_1 = \Delta\omega_4 - \Delta\omega_{10}$, $j_2 = \Delta\omega_6 - \Delta\omega_{10}$, $j_3 = \Delta\omega_7 - \Delta\omega_{10}$ and $j_4 = \Delta\omega_8 - \Delta\omega_{10}$. The voltage magnitude of the buses should vary in the band between 0.97 and 1.03 *pu*. The ranges of the optimized parameters are 0.01 - 10 *pu* for B_{SVC}, 0.01 - 1 for T_{1S} and T_{3S}, 0.01 - 200 for K_S and all load bus numbers for N_{loc}. In all MOPSO runs, the number of population is selected to be 100 and the maximum number of iterations is set to 50 [7].

Fig. 2 shows the non-dominated answers of optimum position, size and controller parameters of SVC that are obtained from MOPSO algorithm. Also, Tables II and III show the results acquired by MOPSO and the best compromise solution (Pareto number 43), which are also highlighted in Tables II and III. As it can be seen in these tables, there are 50 responses for the problem. All responses find the installation place of SVC between buses 25 to 29 with different sizes. 70% of all found responses specify the installation place of SVC at bus 25, and also 18% at bus 26, 8% at bus 27, and 4% at bus 29. It can be seen in these tables that the obtained optimal installation place of SVC varies upon different objective functions. For example, the best place for the objective function involving transient stability is bus 25 while for the one involving voltage deviation is buses 26 and 29. The best installation place of SVC for the total cost objective function is bus 27. Also, Table III indicates the comparison of the cost of power losses in two modes: considering three load levels and one load level. This table shows that with considering three load levels, the power losses in power system are significantly reduced.

TABLE II
NON –DOMINATED SOLUTIONS ACQUIRED BY MEANS OF MOPSO (OPTIMAL POSITION, SIZE, AND CONTROLLER PARAMETERS OF SVC, SVC COST AND THE FIRST OBJECTIVE).

Pareto Solutions	N_{loc}	B (pu)	K_S	T_{1S}	T_{3S}	SVC cost (M$)	$f1$ (M$)
1	25	3.395	192.66	1.0000	0.010	3.042	60.663
2	25	3.693	196.21	0.9701	0.107	3.074	60.840
3	25	3.778	200.00	0.8535	0.134	3.113	61.057
4	26	0.327	199.12	1.0000	0.076	0.682	55.103
5	25	2.170	200.00	0.9516	0.010	2.677	58.973
6	25	0.404	196.27	1.0000	0.010	0.858	55.306
7	29	1.580	198.43	0.7956	0.064	2.373	58.041
8	29	1.458	200.00	0.9928	0.198	2.339	57.955
9	25	1.810	197.11	1.0000	0.010	2.489	58.358
10	25	1.665	200.00	0.8853	0.108	2.439	58.216
11	26	0.971	199.01	0.8161	0.010	1.573	56.478
12	25	0.470	198.12	1.0000	0.154	0.892	55.519
13	26	0.498	195.12	0.1207	0.010	0.893	55.521
14	26	1.022	200.00	1.0000	0.010	2.064	57.341
15	26	0.257	198.98	0.0382	0.977	0.491	54.932
16	25	0.532	200.00	1.0000	0.320	1.056	55.734
17	25	3.259	199.10	1.0000	0.295	3.039	60.651
18	25	2.431	197.53	0.4083	1.000	2.876	59.810
19	26	0.215	196.23	0.9361	0.010	0.380	54.822
20	25	1.812	200.00	0.5487	0.010	2.519	58.447
21	25	3.238	200.00	1.0000	0.010	3.013	60.509
22	25	3.816	195.64	0.2050	0.924	3.221	61.668
23	25	3.696	198.03	1.0000	0.010	3.093	60.947
24	25	3.202	200.00	0.1030	0.939	2.999	60.433
25	25	4.000	198.23	1.0000	0.010	3.251	61.835
26	25	2.258	194.45	0.0100	1.000	2.684	58.998
27	25	3.807	200.00	1.0000	0.103	3.167	61.366
28	25	4.000	200.00	0.9127	0.010	3.251	61.835
29	25	3.049	196.12	0.4960	0.364	2.964	60.250
30	25	0.010	199.54	0.3070	0.514	0.019	54.473
31	27	0.010	161.13	1.0000	0.010	0.019	54.476
32	25	1.969	198.21	1.0000	0.643	2.641	58.842
33	25	0.738	200.00	0.7242	0.010	1.549	56.081
34	25	1.238	196.98	1.0000	0.675	2.237	57.712
35	25	2.927	198.33	0.8209	0.010	2.877	59.815
36	25	2.311	200.00	0.7276	0.180	2.761	59.298
37	27	0.251	150.12	1.0000	0.010	0.486	55.016
38	25	0.992	200.00	1.0000	0.098	2.025	57.264
39	25	1.197	198.19	1.0000	0.010	2.132	57.481
40	25	3.531	199.21	1.0000	0.010	3.042	60.667
41	26	0.010	193.20	0.9635	0.084	0.019	54.476
42	26	0.585	193.12	0.6186	0.178	1.235	55.979
43	26	0.500	197.23	1.0000	0.028	0.901	55.530
44	25	4.000	200.00	0.8294	0.010	3.251	61.835
45	25	4.000	200.00	1.0000	0.359	3.251	61.835
46	25	3.031	196.52	1.0000	0.010	2.884	59.847
47	27	0.010	156.13	1.0000	0.426	0.219	54.704
48	27	0.713	155.78	0.9589	0.103	1.411	56.232
49	25	1.007	198.21	0.8122	0.344	2.028	57.270
50	25	0.355	199.32	0.8788	0.387	0.696	55.138

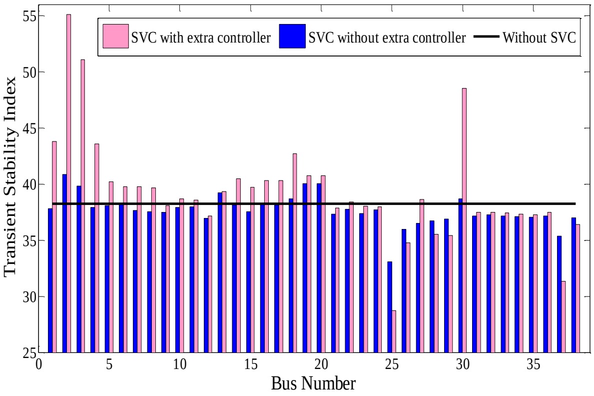

Fig. 3 Transient Stability index of the system for all buses.

Fig. 3 displays the comparison of the transient stability objective over the SVC locations at the entire buses by using the values of the 43rd Pareto answer in Tables II and III. In this figure, the black line indicates the transient stability index when there is no SVC. As shown in this figure, the SVC location to attain the minimum transient stability objective is the bus number 25.

The other significant point is related to the responses with the weak transient stability of power system such as responses with Pareto solution number 31, 37, 47, 48. In these responses, the SVC installation place is at bus 27, and the gain of SVC controller has lower amount. These values of gain can help the SVC controller not to deteriorate the transient stability of the system. Fig. 4 to Fig. 7 show the speed deviation and the variation of rotor angle deviations of generators 8 and 5 (generator 10 is the reference), respectively. In these figures, the dash line displays the result without SVC, the spotted line indicates the result using SVC without optimized position and the solid line demonstrates the result using SVC with optimized position.

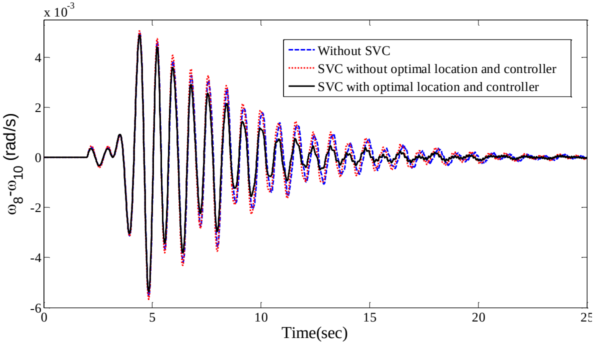

Fig. 4 Generator 8 speed deviation considering both controller and location.

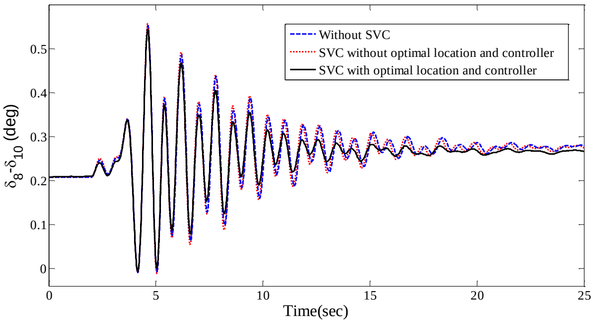

Fig. 5 Generator 8 variation of rotor angle difference considering both controller and location.

Note that, in the case without of the optimized position, the SVC is located at bus 17, and in the case without enhanced controller, the SVC has no controller and its V_{ref} is 1 pu. These figures verify the results obtained from MOPSO method. Fig. 8 and Fig. 9 show the change of rotor angle deviations and speed deviation of generator 8 for optimal location and size of SVC with and without using the best controller based on the 43rd Pareto solution. It is evident that using SVC with enhanced controller can settle down faster and have more damping.

TABLE III

NON –DOMINATED SOLUTION OBTAINED USING MOPSO (THE SECOND AND THIRD OBJECTIVES VALUES, POWER LOSSES IN THREE INDIVIDUAL LOAD LEVELS AND POWER LOSS COST USING 1 AND 3 LOAD LEVELS)

Pareto Solutions	*f2*	*f3*	P_{loss} cost in 1st load level	P_{loss} cost in 2nd load level	P_{loss} cost in 3rd load level	All P_{loss} cost using 3 load levels (M$)	All P_{loss} cost using 1 load level (M$)
1	28.13	0.0177	13.029	19.910	24.683	57.621	63.083
2	27.79	0.0180	13.064	19.957	24.746	57.766	63.486
3	27.59	0.0182	13.107	20.015	24.823	57.944	64.444
4	30.43	0.0172	12.261	18.859	23.301	54.420	58.677
5	28.80	0.0172	12.708	19.477	24.110	56.296	60.691
6	30.29	0.0177	12.268	18.866	23.312	54.447	59.002
7	30.47	0.0167	12.557	19.272	23.839	55.668	60.620
8	30.41	0.0167	12.545	19.255	23.816	55.616	60.376
9	29.17	0.0170	12.606	19.338	23.926	55.869	60.889
10	29.19	0.0170	12.583	19.308	23.886	55.777	60.314
11	30.23	0.0172	12.374	19.021	23.510	54.904	59.608
12	30.18	0.0177	12.309	18.928	23.390	54.627	58.886
13	30.50	0.0167	12.309	18.928	23.390	54.627	58.981
14	30.18	0.0173	12.463	19.143	23.670	55.277	59.882
15	30.45	0.0173	12.266	18.865	23.310	54.440	58.628
16	30.06	0.0177	12.321	18.945	23.412	54.678	59.140
17	28.01	0.0177	13.026	19.907	24.678	57.611	62.999
18	28.69	0.0173	12.862	19.686	24.386	56.933	61.751
19	30.56	0.0174	12.266	18.865	23.310	54.442	58.386
20	29.07	0.0171	12.620	19.357	23.951	55.928	60.465
21	27.99	0.0177	12.998	19.869	24.629	57.495	62.951
22	27.71	0.0183	13.228	20.178	25.040	58.446	64.685
23	27.73	0.0180	13.084	19.986	24.783	57.853	63.671
24	28.01	0.0177	12.983	19.848	24.602	57.433	62.922
25	27.49	0.0191	13.261	20.223	25.099	58.583	65.129
26	28.93	0.0172	12.713	19.483	24.118	56.314	60.749
27	27.57	0.0184	13.168	20.097	24.932	58.198	64.639
28	27.42	0.0191	13.261	20.223	25.099	58.583	65.567
29	28.26	0.0176	12.947	19.800	24.538	57.285	62.801
30	30.50	0.0180	12.269	18.869	23.316	54.454	58.386
31	31.84	0.0179	12.270	18.870	23.317	54.457	58.386
32	29.01	0.0171	12.685	19.447	24.069	56.201	60.643
33	29.91	0.0175	12.290	18.892	23.349	54.531	59.584
34	29.61	0.0173	12.511	19.208	23.755	55.474	60.304
35	28.29	0.0175	12.863	19.687	24.387	56.937	61.924
36	28.68	0.0173	12.766	19.556	24.214	56.537	61.698
37	32.16	0.0170	12.286	18.895	23.348	54.530	58.477
38	29.71	0.0174	12.454	19.131	23.654	55.239	59.627
39	29.60	0.0173	12.481	19.167	23.701	55.349	60.271
40	27.80	0.0178	13.029	19.911	24.684	57.625	63.220
41	30.72	0.0180	12.270	18.870	23.317	54.457	58.386
42	30.55	0.0168	12.336	18.967	23.440	54.744	59.050
43	30.43	0.0167	12.309	18.929	23.391	54.629	59.007
44	27.42	0.0191	13.261	20.223	25.099	58.583	65.806
45	27.42	0.0191	13.261	20.223	25.099	58.583	65.806
46	28.27	0.0176	12.869	19.695	24.398	56.962	62.475
47	32.02	0.0179	12.276	18.880	23.329	54.484	58.390
48	31.84	0.0173	12.355	18.993	23.473	54.821	59.281
49	29.75	0.0174	12.455	19.132	23.655	55.242	59.779
50	30.24	0.0178	12.267	18.865	23.310	54.442	58.813

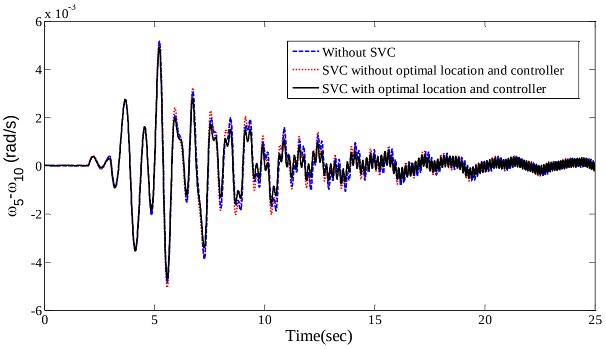

Fig. 6 Generator 5 speed deviation considering both controller and location.

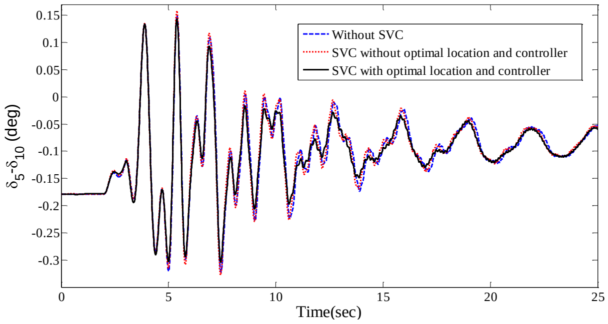

Fig. 7 Generator 5 variation of rotor angle difference considering both controller and location.

Fig. 10 indicates the voltage profile for the 2nd load level. This figure has three response forms: the response without SVC installation, the best and the worst voltage deviation responses. As it can be seen from this figure, even in the worst voltage deviation response, most bus voltages have been improved; but due to bus voltage limits, they are not noticeable.

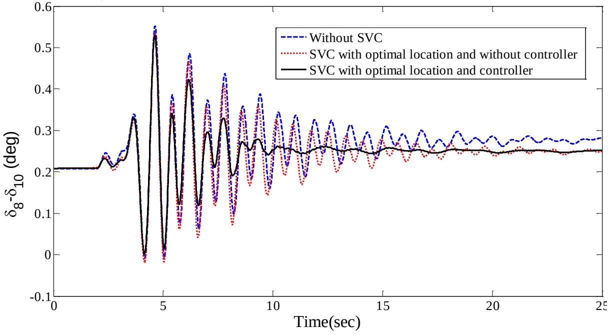

Fig. 8 Generator 8 variation of rotor angle difference considering both only controller.

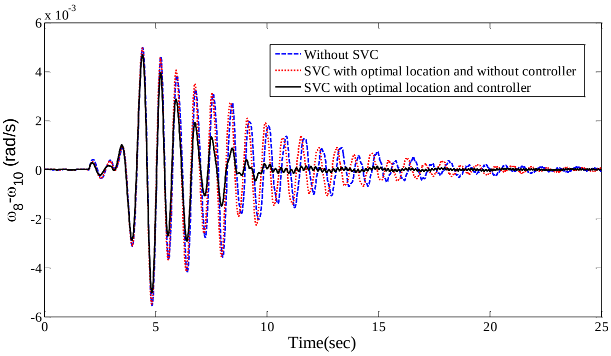

Fig. 9 Generator 8 speed deviation considering both only controller.

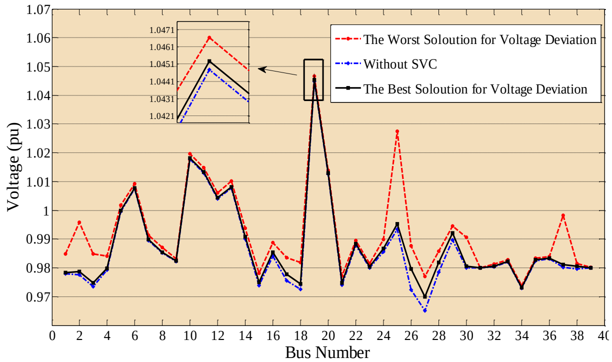

Fig. 10 System voltage profile for 2nd load level.

Another point is related to bus 19 as indicated in the enlarged insertion in Fig. 10. At this bus, the voltage is significantly increased by using the transformer tap value of 1.06. The MOPSO algorithm tries to find the responses which have no increased voltage at this bus. This bus has no electrical load.

V. CONCLUSION

In this study, the MOPSO has been utilized as a multi objective optimization technique to define the optimum position, size and parameter setting of SVC in a system with multiple machines. In this research, four objectives have been considered to improve both the static and dynamic conditions. The combination of the active power loss cost and SVC investment cost has been considered as an objective to reach an accurate and practical solution. Improvement of the transient stability and voltage profile of the system have been considered as two separate objectives. Also, an additional controller has been utilized and improved to enhance the performance of SVC in refining the power system transient stability. A 10-machine 39-bus New England test system has been utilized to validate the efficacy of suggested MOPSO-optimized size, position and controller parameter setting of the SVC. The nonlinear simulations have revealed that the suggested size, position and controller parameter setting of SVC are different in dynamic and static conditions.

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