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Optimization of the Reactive Power Injection to Control Voltage Profile by Using Artificial Bee Colony Algorithm

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Abstract— **The increasing demand for electric power requires the power system utility to continuously adapt the network system, both on the transmission line and the distribution systems. It may cause a voltage drop and other impact related to power losses because of the limited availability of reactive power source in the system. Therefore, implementation of compensation devices such as capacitor bank, Static VAR Compensator (SVC), and other Flexible AC Transmission System (FACTS) devices to inject reactive power to the network are needed. The optimum location and size of the compensation device must be determined appropriately. This paper presents two optimization approaches, including both deterministic and nondeterministic methods. Artificial bee colony (ABC) algorithm is applied to acquire the most optimum size and location of SVC. It is an optimization method using metaheuristic techniques which have been developed based on the intelligent behavior of honey bee. The IEEE standard 30-bus system data has been used to determine the performance of the ABC algorithm to control the voltage profile and power losses. Comparison of the voltage profile and power losses without and with an injection of SVC of the power system has been determined by using the ABC algorithm optimization method. Based on the analysis results, it was known that the SVC optimization could boost the voltage profile at all buses under consideration to the value higher than its minimum allowed voltage. Besides, the power losses condition has also been improved, with 35.36% active power improvement and 40.90% reactive power improvement subsequently.**

Keywords—reactive power injection, artificial bee colony algorithm, power losses, SVC, voltage control

I. INTRODUCTION

The demands for electric power continuously increase that the adaptation of network systems both on the transmission line and distribution systems is needed. If anticipation measures are not taken properly, it may cause a voltage drop and further impact on the network power losses [1]. The voltage drops and power losses are commonly caused by the limited availability of reactive power sources in the system. Some compensation devices such as capacitor bank, Static VAR Compensator (SVC), Flexible AC Transmission System (FACTS) devices or customized devices are required for injecting reactive power to the network in both transmission and distribution systems [2-3]. Other alternatives to improve and increase the efficiency of the distribution system have been done using the embedded generation injection [4-7]. It has been researched to enhance the power system distribution performances in term of the system quality, security, reliability, stability, power losses, and voltage profile.

The placement and size of the compensation device need to be determined properly. Both deterministic and nondeterministic methods can be used to optimize the location and sizing of reactive power injection. The deterministic method is based on mathematical approach, covering the mixed integer nonlinear programming [8], dynamic programming [9], simplex and linear programming, and many others. While, the nondeterministic method is based on the probabilistic and random approach, for example the simulated annealing [10], ant colony algorithm, genetic algorithms [4], fuzzy EP algorithm [11], artificial bee colony [12], and many others.

Artificial bee colony (ABC) algorithm is based on the metaheuristic techniques to acquire optimum results. This method was developed based on the intelligent behavior of honey bees in a colony, and its performance is used as a benchmark to calculate the parameter value of an optimization function. The main advantage of the ABC algorithm includes its simplicity, flexibility, and robustness. It requires less parameter to control and easy to be hybridized with other optimization algorithms, while being adaptable to the use of basic math and logic operations [13]. Considering all the advantages of the ABC algorithm, this paper discusses its implementation to optimize the location and sizing of reactive power injection using an SVC device in the power system. The IEEE standard 30-bus system data is used to determine the performance of the ABC algorithm to control the voltage profile and power losses.

II. REACTIVE POWER CONTROL AND COMPENSATION

A. *Reactive Power and Voltage Regulation*

A reliable and efficient power system operation can be obtained through some condition requirements [14-15]:

1. The voltage values on the whole parts of the system must be in the allowable limit range.
2. Power system stability can be improved by maximizing transmission system utilization.
3. Minimizing reactive power can reduce both active and reactive power losses.

Series and shunt compensations can also be implemented to improve the performance of transmission system. These measures require the compensator to be permanently connected to the transmission system to control and modify the system characteristics. SVC is a shunt-type compensator using thyristor and switched reactors which are mounted in parallel. SVC provides active compensation by absorbing reactive power or injecting reactive power during peak load automatically.

B. *Satic Var Compensator Model*

Flexible AC Transmission System (FACTS) device is a power electronic–based static device which can provide some control on the variables of transmission system [16]. There are two well-known categories of this device.

1. Impedance Variable – Type, which includes Static VAR Compensator (SVC), Thyristor Controlled Series Compensator (TCSC), and Thyristor Controlled Phase Shifting Transformer (TCPST).
2. Voltage Source Converter – Type, which includes Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Interline Power Flow Controller (IPFC), Unified Power Flow Controller (UPFC).

The static VAR compensation system is a combination of mechanically or electrically switched reactors and capacitors and a static VAR compensator [17]. The main purpose of the SVC implementation is to maintain the voltage levels at the weak buses in the transmission network to its allowed value and to improve voltage stability by injecting a controlled capacitive or inductive current through the control of a specific variable [17-18]. SVC is commonly installed in the middle part of the transmission system.

In its simplest form, SVC consists of Thyristor controlled reactor (TCR) mounted with capacitor bank in parallel. SVC generally compensates reactive power by adjusting the firing angle of thyristor so as to regulate the output reactive power of SVC. Model representation of SVC is shown in Figure 1. The configuration of the basic SVC can be represented as a fixed capacitor (FC) with a thyristor controlled reactor (TCR), or the SVC with thyristor switched capacitor (TSC) and TCR [17]. Figures 1 and 2 show a basic configuration of a SVC with voltage control and its steady-state control characteristic, respectively, for an FC-TCR type SVC.

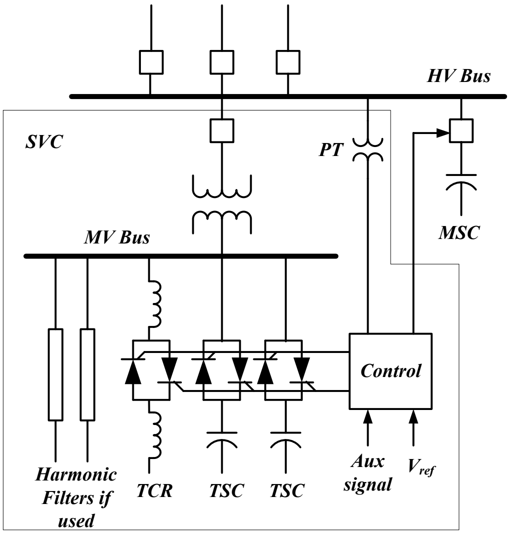

Fig. 1. Typical static VAR compensator system

In Figure 1, the SVC is modeled using a variable reactance with maximum inductive and capacitive limits directly corresponding to the limits of the firing angles of the thyristor. In the load flow analysis, the SVC can be modeled as PV-bus with reactive power limit. In this case, the SVC is represented as a thyristor-controlled reactor and fixed capacitor (TCR-FC). In other words, the SVC is modeled as a PV bus with shunt capacitor.

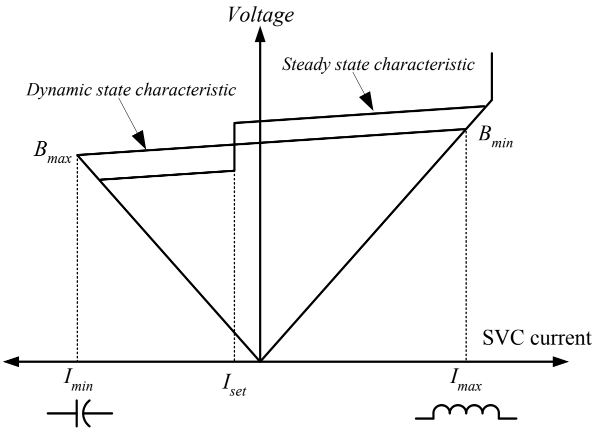

Fig. 2. SVC characteristic, steady state and dynamic characteristics

The injected reactive power at point *j* is written in following equation:

$$Q_j = -V^2{}_j B_{SVC} \tag{1}$$

$$B_{SVC} = B_C - B_L \tag{2}$$

where Q_j : reactive power injection (MVAR), and B_{SVC} : Shunt injection (Ω)

III. ARTIFICIAL BEE COLONY (ABC) ALGORITHM

To implement the ABC algorithm, the colony of bees is considered as consisting of three groups of bees: employed bees, onlooker bees, and scout bees [19]. The sequence in implementing the ABC algorithm is explained as follows:

1. Initializing randomly the food source, as given in the following equation:

$$\theta_{ij} = \theta_{imin} + r(\theta_{imax} - \theta_{imin}) \quad (3)$$

where:

θ_i = employed bees's position

i = 1: SN (food source)

j = 1: N (number of colony)

r = random value [0,1]

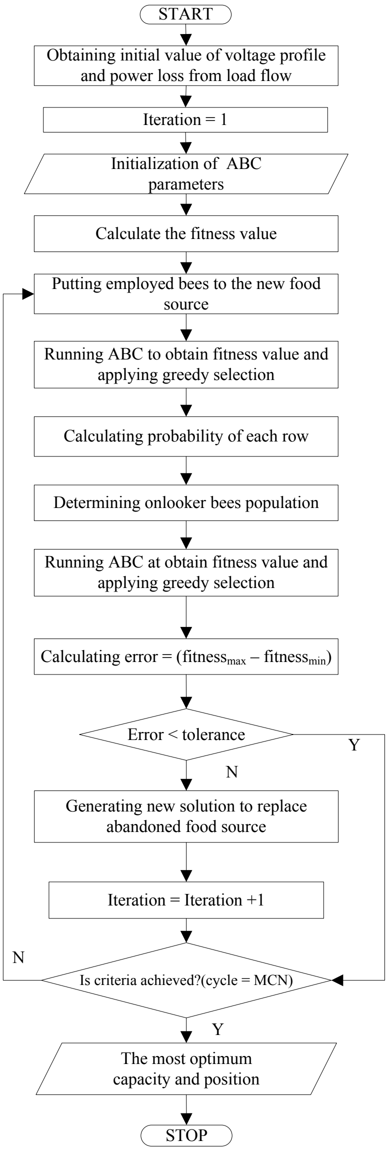

Fig. 3. Artificial Bee Colony (ABC) Algorithm

2. Repeating the following steps until the requirement is achieved.
   - Sending onlooker bees to the food source based on nectar's quantity (employed bees phase), with the following equation:

$$x_{ij}(t+1) = \theta_{ij}(t) + \emptyset(\theta_{ij}(t) - \theta_{kj}(t)) \quad (4)$$

where:

x = employed bees's position

t = number of iteration

θ_k = randomly selected bee $k \neq i$

$\emptyset$ = random value [0,1]

   - Putting onlooker bees to the food source based on probability equation as follows: (onlooker bees phase).

$$P_i = \frac{F(\theta_i)}{\sum_{k=1}^{SN} F(\theta_k)} \quad (5)$$

where:

P_i= probability of selection,

SN = food source,

θ_i = position of the employed bees,

$F(\theta_i)$ = fitness value

   - Terminating the food source exploitation process abandoned by employed bees.
   - Sending scout bees to find new food source randomly:

$$\theta_{ij} = \theta_{jmin} + r(\theta_{jmax} - \theta_{jmin}) \quad (6)$$

   - Remembering the best food source.

There are three main control parameters used in ABC algorithm; the number of food sources, which is equal to the number of employed bees or onlooker bees (SN), the limit value, and the maximum number of cycles (MCN). The flowchart to determine the optimal size and location of the SVC reactive power injection by using the ABC algorithm is shown in Figure 3. The constraint equality used to solve the optimization problem is written as follows:

$$V^{min}{}_i \leq V_i \leq V^{max}{}_i \quad (7)$$

where: i = bus number; V_{min} = 0.95 p.u.; V_{max} = 1.05 p.u.

IV. RESULT AND DISCUSSION

A. *IEEE 30 Bus System and Load Flow Result*

The considered parameters consist of the 150kV base-voltage, 100MVA base-power, 0.001 power mismatch, and the maximum number of iteration is 20. The bus classifications are given as follows: 1) Slack bus: bus#1; 2) Generator bus: bus#2,13, 22, 23, and 27; and 3) Load bus: bus# 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 24, 25, 26, 28, 29, and 30. The voltage magnitudes of PV and slack nodes have been assigned to 1.0 pu. Total load in the system were about 201.43 MW and 137.8 MVAR.

Table I shows the results of power-flow analysis before implementing any reactive power compensation in the system. The power-flow result could be obtained using full Newton-Raphson method after all criteria had converged in the third iteration. The generated power supply indicates the values of about 205.70 MW and 126.89 MVAR respectively for the active and reactive power. The voltage magnitudes of all nodes are above the acceptable minimum limit, except the three nodes which violate the standard, which experiencing under voltage problem (0.95pu) i.e. bus#18, 19, and 20 with the voltage magnitude are 0.91, 0.89, and 0.90 respectively.

The power difference between the required load and the supplied generation composing the power loss shows the values of about 4.321 MW and -10.794 MVAR for active and reactive power losses respectively. The negative sign of the reactive power indicates that the system needs more reactive power which cannot be provided by the system. As a consequence, some nodes will experience under voltage problem, since the voltage magnitude cannot be controlled by the lack of the reactive power availability.

TABLE I. LOAD-FLOW ANALYSYS RESULT FOR 30-BUS SYSTEM WITHOUT SVC

NO	Voltage (pu)	Angle (degree)	Load MW	Load MVAR	Generation MW	Generation MVAR
1	1.00	0.00	0.00	0.00	25.03	-1.89
2	1.00	-0.40	21.70	12.70	60.97	35.89
3	0.98	-1.50	2.40	1.20	0.00	0.00
4	0.98	-1.75	7.60	1.60	0.00	0.00
5	0.98	-1.82	0.00	0.00	0.00	0.00
6	0.97	-2.19	0.00	0.00	0.00	0.00
7	0.96	-2.59	22.80	10.90	0.00	0.00
8	0.96	-2.68	30.00	30.00	0.00	0.00
9	0.96	-2.80	0.00	0.00	0.00	0.00
10	0.96	-3.13	5.90	2.00	0.00	0.00
11	0.96	-2.80	0.00	0.00	0.00	0.00
12	0.97	-2.45	11.20	7.50	0.00	0.00
13	1.00	1.55	0.00	0.00	37.00	19.77
14	0.96	-2.19	6.20	1.60	0.00	0.00
15	0.96	-1.98	8.20	2.50	0.00	0.00
16	0.96	-2.52	3.50	1.80	0.00	0.00
17	0.95	-3.20	9.00	5.80	0.00	0.00
18	0.91	-2.31	3.20	0.90	0.00	0.00
19	0.89	-2.32	9.50	34.00	0.00	0.00
20	0.90	-2.51	2.20	0.70	0.00	0.00
21	0.96	-3.70	19.67	11.20	0.00	0.00
22	1.00	-2.44	0.00	0.00	31.59	43.89
23	1.00	-1.34	3.20	1.60	22.20	16.54
24	0.98	-2.49	15.00	6.70	0.00	0.00
25	0.99	-1.86	1.00	0.00	0.00	0.00
26	0.97	-2.31	3.50	2.30	0.00	0.00
27	1.00	-1.06	0.00	0.00	28.91	12.69
28	0.97	-2.33	0.00	0.00	0.00	0.00
29	0.98	-2.67	3.66	0.90	0.00	0.00
30	0.96	-3.67	12.00	1.90	0.00	0.00
Total Load/Generation			**201.43**	**137.80**	**205.70**	**126.89**
Total Power Losses			**4.32**	**MW**	**-10.74**	**MVAR**

Based on the power losses calculation, the maximum active power loss is experienced in the line between bus#10 - bus#20 with the amount of 0.524 MW. In addition, the maximum absorbed and supplied reactive power losses are about 2.465 MVAR and -5.926 MVAR, being encountered in the line between bus#12- bus#13 and bus#1-bus#2 respectively.

B. *Static VAR Compensastion (SVC) Optimization Result*

To determine the optimum size and location for injecting Static VAR Compensation (SVC) requirement in the system, the Artificial Bee Colony (ABC) Algorithm has been performed by using the following parameters: a) number of food sources (SN): 20; 2) the minimum capacity of SVC: 0; 2) the maximum capacity of SVC: 100; and 3) maximum cycles (MCN): 100. To achieve valid and accurate results, some testing has been performed. The performance of ABC in calculating the best objective function (fitness) is shown in Figure 4. The fitness value used in this case is to determine the allowable voltage for each node with minimum active power losses in the system. In initial state, the active power loss shows a high value (4.562 MW) and dramatically decreases in 2-4 iterations. The power losses will start to converge in iteration-5 (2.406 MW) and keep constant until reaching the minimum fitness in iteration- 30 (2.316 MW).

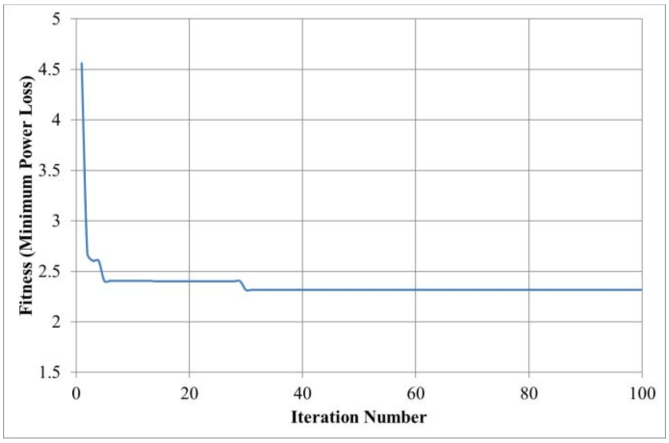

Fig. 4. ABC Algorithm performance

Based on the ABC optimization result, the size and location optimal of the SVC can be determined in two locations as follows:

1) Bus#5 with SVC capacity of 36.996 MVAR
2) Bus#19 with SVC capacity of 36.971 MVAR

The load-flow calculation can then be continued with implementation of the SVC with size and location given above. The load-flow result with the SVC compensation is shown in Table II. The power supply from generation is about 204.21 MW and 48.40 MVAR for the active and reactive power. The reactive power supply from the generating units has decreases since the SVC has injected the system with the total compensation of about 72.97 MVAR. As a result, voltage magnitude of all nodes is above the acceptable minimum limit, including bus#18, 19, and 20 which improve to 0.97 p.u.

Based on the power losses calculation, the maximum active power loss has been experienced in the line between bus#5 - bus#7 with the amount of 0.35 MW. In addition, the maximum absorbed and supplied reactive power losses of about 2.08 MVAR and -5.94 MVAR have been encountered in the line between bus#12- bus#13 and bus#1-bus#2 respectively.

TABLE II. LOAD-FLOW ANALYSIS RESULT FOR 30-BUS SYSTEM WITH SVC

NO	Voltage	Angle	Load		Generation	
	(pu)	(degree)	MW	MVAR	MW	MVAR
1	1.00	0.00	0.00	0.00	23.54	-5.64
2	1.00	-0.37	21.70	12.70	60.97	1.60
3	0.99	-1.54	2.40	1.20	0.00	0.00
4	0.99	-1.79	7.60	1.60	0.00	0.00
5	1.02	-2.47	0.00	0.00	0.00	0.00
6	0.98	-2.25	0.00	0.00	0.00	0.00
7	0.99	-2.85	22.80	10.90	0.00	0.00
8	0.97	-2.71	30.00	30.00	0.00	0.00
9	0.98	-2.82	0.00	0.00	0.00	0.00
10	0.98	-3.13	5.90	2.00	0.00	0.00
11	0.98	-2.82	0.00	0.00	0.00	0.00
12	0.99	-1.41	11.20	7.50	0.00	0.00
13	1.00	1.60	0.00	0.00	37.00	10.95
14	0.98	-2.14	6.20	1.60	0.00	0.00
15	0.98	-2.11	8.20	2.50	0.00	0.00
16	0.97	-2.47	3.50	1.80	0.00	0.00
17	0.97	-3.18	9.00	5.80	0.00	0.00
18	0.97	-3.43	3.20	0.90	0.00	0.00
19	0.97	-3.99	9.50	34.00	0.00	0.00
20	0.97	-3.83	2.20	0.70	0.00	0.00
21	0.97	-3.51	19.67	11.20	0.00	0.00
22	1.00	-2.07	0.00	0.00	31.59	24.64
23	1.00	-0.96	3.20	1.60	22.20	6.94
24	0.98	-2.16	15.00	6.70	0.00	0.00
25	0.99	-1.65	1.00	0.00	0.00	0.00
26	0.97	-2.10	3.50	2.30	0.00	0.00
27	1.00	-0.93	0.00	0.00	28.91	9.92
28	0.98	-2.29	0.00	0.00	0.00	0.00
29	0.98	-2.53	3.66	0.90	0.00	0.00
30	0.96	-3.54	12.00	1.90	0.00	0.00
Total Load/Generation			**201.43**	**137.80**	**204.21**	**48.40**
Total Power Losses			**2.793**	**MW**	**-15.21**	**MVAR**

The voltage profile comparison for both cases, with and without SVC compensation in the system, is given in Figure 5. The voltage profile with SVC indicates a good performance since the magnitude of all bus-voltages is above the minimum allowable value, i.e. 0.95 pu. On the other hand, without any compensation of SVC, the power system shows a poor performance. The power generation as the only source of reactive power cannot fulfill the reactive requirement since the output of the reactive power depends on the output of the active power supplied by the generation unit. The insufficiency of the reactive power in the system will impact to the voltage profile performance in the system. Therefore, the SVC compensation or other compensation devices are crucially needed to compensate the deficiency of reactive power.

Fig. 5. Voltage profile without- and with- SVC compensation

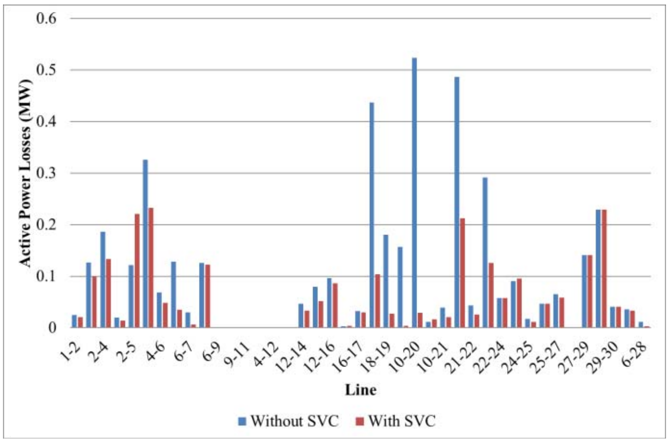

Fig. 6. Active power losses profile with and without SVC optimization

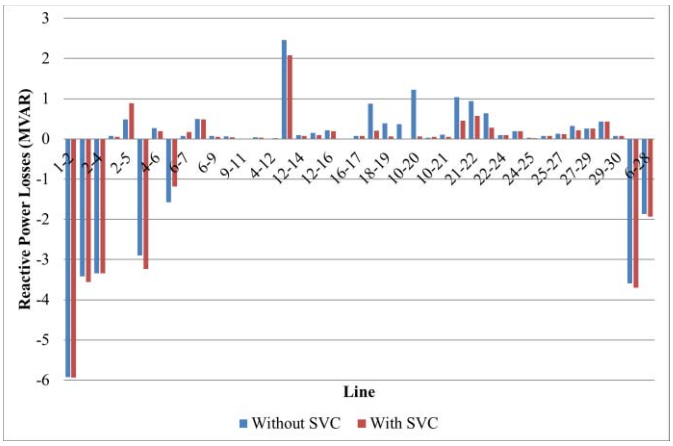

Fig. 7. Reactive power losses profile with and without SVC optimization

The comparisons of active and reactive power losses for both with- and without-SVC compensations are given in Figure 6 and 7 respectively. It shows the impact of SVC in term of active and reactive power losses reduction. The blue chart indicates the power losses performance without SVC compensation, while the red chart represents the performance using SVC compensation. The power losses conditions are improved with the amount of 35.36% and 40.90% subsequently for the active and reactive power improvements, with respect to the condition without the SVC compensation in the system.

V. CONCLUSION

The Artificial Bee Colony (ABC) algorithm has been implemented to determine the optimum size and location of the Static VAR Compensator (SVC) to improve the steady-state performance of the power system under consideration. Using the 30-bus IEEE standard system, it shows a good performance with minimum iteration required (normally 5-8 iteration). For the considered system, the two optimum locations of SVC implementation have been obtained on the Bus#5 and Bus#19 with SVC capacity of about 36.996 MVAR and 36.971 MVAR respectively. It has also been proven that the SVCs could overcome the under voltage problem in the system and maintain the voltage level within the allowable range ($0.95 \leq V_{bus} \leq$ 1,05 p.u.). In addition, the SVC installation could also reduce the power losses in the transmission line, with about 35.36% and 40.90% of reduction for both active and reactive power losses, respectively, being compared to without the SVC compensation.

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