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8 2

Improving Multi-Objective Voltage Stability by FACTS Devices Placement Through Circular Optimization Algorithm

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ABSTRACT

Analyses of voltage stability in the presence of STATCOM has been premeditated, focusing on the relationship between voltage stability collapse and power system voltage stability. STATCOM and its allocation expected to improve the power system's voltage stability. To boost the voltage profile of the system, a circular optimization approach is employed to determine the best sizing of STATCOM. On IEEE 14 bus test bed, simulation results are confirmed using several STATCOMs in various circumstances.

Keywords: voltage stability, circular optimization, power loss, STATCOM, energy systems, simulation

NONMENCLATURE

N_S	Number of STATCOMs
λ	Loading Factor
P_{Di}	Real power demand at bus *i*
Q_{Di}	Reactive power demand at bus *i*
P_{Gi}	Real power generated at bus *i*
Q_{Gi}	Reactive power generated at bus *i*
F_d	Objective function for voltage deviation
N_b	Number of buses
V_j	Voltage at receiving end of the bus
P_{LL}	Total active power loss
P_S	Active power loss at sending end
P_R	Active power loss at receiving end
F_L	Objective function for total active power loss
Q_k	
F_{Stat}	Numerical value of STATCOM
F^{ML}	Objective function for optimal quantity of STATCOMs
	Objective function for maximum loadability
$\lambda_{crucial}$	Crucial value of loading factor

1. INTRODUCTION

Voltage stability is vital in the planning and operation phases of power systems because it helps to maintain system security. Due to rising demand, power systems have recently experienced higher power flow. Many power systems are approaching their stability limits, resulting in voltage instability. Flexible AC transmission system (FACTS) controllers are well suited to controlling power system parameters due to their rapid expansion. To restore the system to normal operating conditions, the system operator can use devices such as on load tap changers (OLTCs), generator excitations, static VAR compensators (SVC), and FACTS controllers like STATCOM, UPFC, and IPFC. These controlling devices have been tweaked to improve the system's voltage profile.

Omidi *et al.* [1] proposed a strategy for improving voltage stability margin (VSM) in outages based on reactive power production management through condensers. To improve voltage stability, Chang *et al.* developed a procedural strategy for coordinated operation of multiple FACTS devices. Kamarposhti *et al.* [2] looked at the effects of various FACTS devices on voltage stability in power systems. According to the data, UPFC and STATCOM have a little higher loading point and better voltage profiles than other FACTS devices. Furthermore, these devices significantly improve the voltage profile of weak buses. Wang *et al.* [3] looked at how effective STATCOM is at controlling the voltages of weak buses in a power system. Also included are summaries of various STATCOM-related publications. The FACTS site in a vertical integrated power system is often identified using a heuristic-based process. However, as the electrical system becomes more deregulated, more sophisticated methods for determining FACTS device allocation are required.

Park *et al.* [4] used a genetic algorithm (GA) to discover the best capacitor numbers and positions in a distribution system. However, one of the most difficult aspects of power system engineering is making the right choices and coordinating them to regulate the voltage profile. Particle Swarm Optimization (PSO) is another effective method for solving power system optimization issues [5]. The programme mimics the behaviour of individual swarms to increase the species' chances of survival. Individuals choose their own best, while some have global best [6]. The PSO changes the positions of rotating points in a multi-dimensional space to identify a space. Individual particles are dragged stochastically to their current velocity position depending on individual previous preeminent performance and similar patterns from their neighbors [7]. Kumarasamy *et al.* [8] anticipated the method for improving the particle swarm optimization to handle mixed-integer non-linear problems (MINLP). Rashed *et al.* [9] proposed GA and PSO-based methodologies for determining the best number, placements of various FACTS devices to provide extreme loadability with the lowest device cost of installation. Ratra *et al.* [10] proposed technique to increase voltage stability margin while considering load and wind uncertainties. Valle *et al.* [11] employed PSO to optimise STATCOM allocation to improve the system's voltage profile. Kunwar *et al.* [12] anticipated an approach to improve voltage profile, minimise power system total losses, and maximise system loadability in for doubly fed induction generator farm. STATCOM improves the loadability limit (λ). The optimal allocation of a multiple STATCOM utilising the circular optimization algorithm (COA) is proposed in this research to improve the voltage stability of the system. Different STATCOMs' outputs are tested under various loading circumstances.

2. CIRCULAR OPTIMIZATION

The circular optimization algorithm (COA) is employed in this study as an optimization strategy. This method is classified as an optimization method that considers specific limitations. The algorithm is run based upon quantities in the objective function. Typically, this method trades between two optimization quantities. Using the equations below, the boundary coordinates are determined for each iteration.

$$x = \bar{x}.r.\cos\emptyset \qquad (1)$$

$$y = \bar{y}.r.\sin\emptyset \qquad (2)$$

Where x, y are the boundary coordinates $\bar{x}$, $\bar{y}$ represents *the center coordinates r is the radius of the circle,∅ is angle between x and y coordinates taken anticlockwise with respect to x axis. The expected goal* function then executes these boundary coordinates, and a turning coordinate is assessed. The turning coordinate represents local minimum or maxima point. This turning coordinate, together with the objective function's optimum value, is saved for later use.

Following that, the next iteration generates new coordinate points and a corresponding goal function. This coordinate point will be saved in the following location. Finally, the global minima between them can be found by evaluating all the turning coordinates and their associated objective function values. The algorithm's flowchart diagram is presented in Fig. 1 to understand the processes in the method.

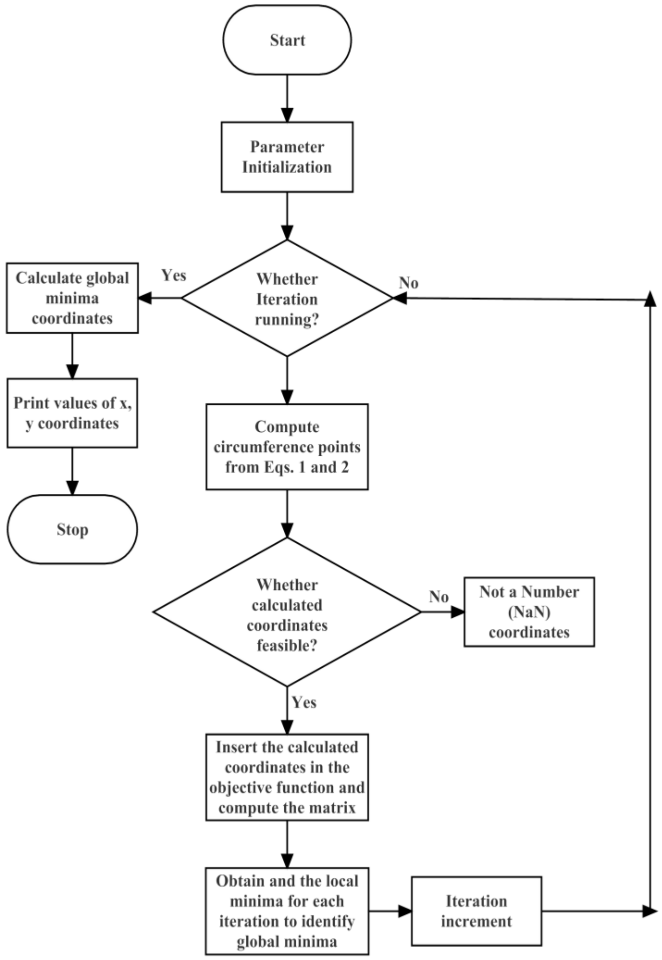

Fig. 1. COA algorithm flowchart

3. PROBLEM FORMULATION

3.1 Objectives

Node voltages in the power system are very susceptible to load and topological fluctuations. The major aim of the optimization is to identify the optimal voltage profile under various loading scenarios. STATCOMs (a FACTS family member) are in this regard [13], [14].

- Minimum variation in voltage

- Minimum power loss
- Optimal Allocation of FACTS devices
- Maximum loadability limit

The following procedure can be used to convert a multi-objective into a single-objective problem, subject to certain restrictions. The objective function is made up of four terms, each with its own set of requirements. The voltage profile is the initial part of the goal function. Node voltages should be proximate to 1 p.u. as possible. Deviation in voltage for each bus is given by Eq. (3).

$$F_D = \sqrt{\sum_{k=1}^{n_b} (V_k - 1)^2} \tag{3}$$

Where, k=1 ...n_b *is total buses in the system and* V_k *is node voltage at k. Next term is associated with total losses in the transmission lines and to reduce the line losses, the Eqs. (4-5) are used.*

$$P_L = \overline{P_S} - \overline{P_R} \tag{4}$$

$$F_L = P_T = \sum_{i=1}^{n_l} P_L \tag{5}$$

Where P_L *show line losses and* F_L *depicts total losses in the system. 1, 2,...,.*n_l *represent total transmission lines associated in the system.*

Another expression term is linked to optimal sizing of STATCOMs considering STATCOM control is given by Eq. (6).

$$F_{Statcom} = \sum_{s=1}^{N_{st}} Q_s \tag{6}$$

Where capacity of STATCOMs is N_{st} *and* Q_s *is the value of STATCOM. Considering voltage stability, the extreme loadability of the system is significant as it imparts important role in the system. Last term identifies the extreme loadability of the system, which is given in Eq. (7).*

$$F_{Lo} = \frac{1}{\overline{\lambda_{critical}}} \tag{7}$$

On the above discussion, the objective function can be outlined as shown in Eq. (8).

$$\min(F) = \overline{\lambda_1}\min(F_D) + \overline{\lambda_2}\min(F_L) + \overline{\lambda_3}\min(F_{St}) + \overline{\lambda_4}\max(F_{Lo}) \tag{8}$$

3.2 Search Space

A conventional IEEE 14-bus test setup with five PV buses is used in this research. These PV buses do not require STATCOMs and are therefore removed from the algorithm search process; the remaining 24 load buses are the STATCOM placement options. While considering algorithm, there is a different locus at each iteration that includes the PV bus as well; however, the location will be changed geographically to the nearest PQ bus. Furthermore, technological improvements in the system limit the number of buses in the range of 1 to 14, necessitating the resolution of the constraints described in Eq. (9).

$$1 \le \overline{\lambda_1} \le 14$$
$$1 \le \overline{\lambda_2} \le 14$$
$$1 \le \overline{\lambda_3} \le 14 \tag{9}$$

To solve this problem, if $\overline{\lambda_1}$, $\overline{\lambda_2}$, $\overline{\lambda_3}$ *are outside the acceptable limit, their values are random which means the particle is moved to a bus at random. Furthermore, if additional STATCOMs are linked to the same bus, it will be quite not useful, and they are constrained as described in Eq. (10). The problem is handled by moving the other STATCOM to the closest bus.*

$$\overline{\lambda_1} = \overline{\lambda_2} = \overline{\lambda_3} \tag{10}$$

Each solution that does not satisfy the above conditions is unachievable, and the value of its objective function is set to infinity. The limitation indicated in Eq. (11), which is applicable to all values derived from iterations, is used to limit the sizing of STATCOMs. If the size limit is surpassed, the solution's value is reformed using randomness.

$$1 \le \overline{\lambda_1} \le 30$$
$$1 \le \overline{\lambda_1} \le 30$$
$$1 \le \overline{\lambda_1} \le 30$$
$$\ldots$$
$$1 \le \overline{\lambda_n} \le Q_{St} \tag{11}$$

4. SIMULATION RESULTS & DISCUSSIONS

Under three different circumstances, the suggested COA methodology is investigated on IEEE 14 bus test system.

Case I: When the real and reactive power demands of the load are compounded.

Case II: When the real and reactive power of the load and generator are multiplied simultaneously.

4.1 IEEE -14 bus system

This system has 5 generator buses 9 load buses and 4 transformers with 100 MVA base and base voltage of

69 KV. The schematic system is depicted in Fig. 2. Now, different cases as mentioned above are thoroughly investigated.

Case I: is multiplied with load active power and reactive power demand. In this scenario, active and reactive power demand is enlarged by the factor of 1.6 times. The optimum allocation of STATCOM identified by the COA algorithm is shown in Table 1.

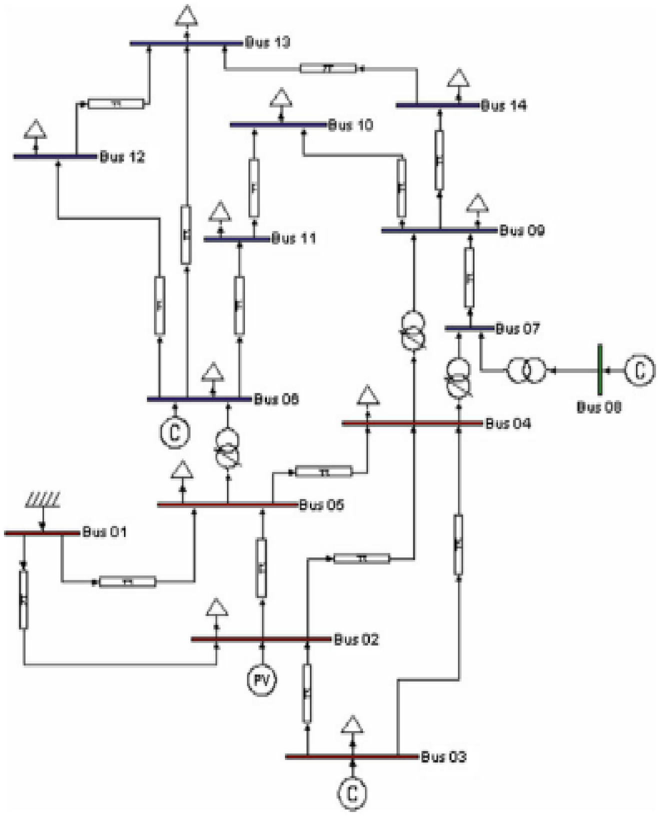

Fig. 2 IEEE 14- test bed

Table 1 Optimal allocation of STATCOMs for case I

Location (Bus No.)	14	9	13
Size (MVAr)	30.02	47.14	76.37

When STATCOMs are placed optimally, active, and reactive power losses are decreased in comparison to the base case. Table 2 compares active power loss in the system with and without STATCOM.

Table 2 MVA reduction for case II

Particular	Without STATCOM	With STATCOM	% Diff
Active power loss (MW)	36.5	34.5	5.47

Figure 3 and 4 show comparison of voltage profiles with and without STATCOMs. The buses 14, 9, and 13 have low voltage profiles and are particularly sensitive to voltage collapse, as seen in Fig. 3. However, by strategically placing STATCOMs, the voltage profile of these critical buses is enhanced, as is the overall voltage profile, boosting the system's stability. Fig. 4 shows that after installing STATCOMs on the sensitive buses, shortage in reactive power can be reduced, and therefore voltage stability margin of the system will increase.

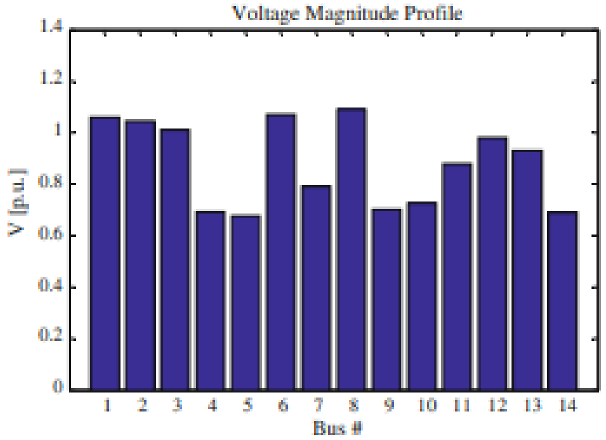

Fig. 3 Voltage magnitudes of IEEE 14- bus test system without STATCOM for Case I

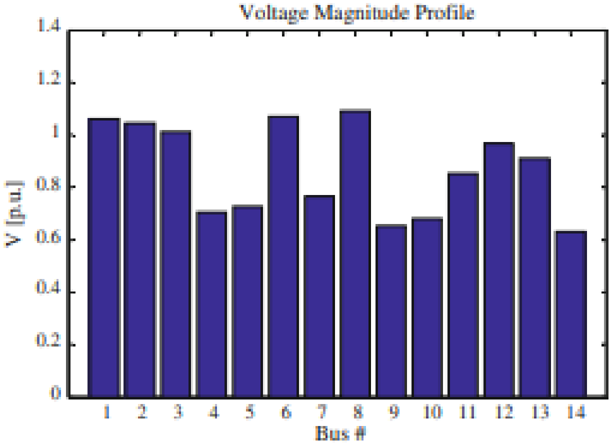

Fig. 4 Voltage magnitudes of IEEE 14- bus test system with STATCOM for Case I

Case II: When λ is multiplied with load and generation active and reactive power simultaneously.

Generating capacity and load demand are both increased to λ=1.6 in this scenario. Reactive power restrictions are calculated as Q_{min}=0 and Q_{max}=75 percent of the generator's real power, respectively. Because generators are not permissible to have a higher power factor, this is done to prevent consumption of reactive power in the generator bus. Table 3 shows ideal STATCOM allocation produced by the optimization technique in this circumstance. As shown in Table 4, the algorithm effect on minimizing active power losses is compared to the basic case. In instance II, the voltage profiles of each bus are examined with and without STATCOMs. Figure 5 depicts the results.

Figure 6 depicts the evaluation of the voltage profile with and without STATCOMs for Case II. The important buses 14, 9, and 13 have significantly low voltage profiles, as seen in Fig. 5. The implementation of STATCOMs, on the other hand, has resulted in a significant improvement in the voltage profiles of the important buses as seen in Fig. 6. The voltage stability margin of the two most crucial buses has improved following STATCOM deployment, indicating that the system's voltage stability has been maintained.

Table 3 Optimal allocation of STATCOMs for case II

Location (Bus No.)	14	9	13
Size (MVAr)	13.54	22.67	34.45

Table 4 MVA reduction for case II

Particular	Without STATCOM	With STATCOM	% Diff
Active power loss	53.2	49.95	6.10

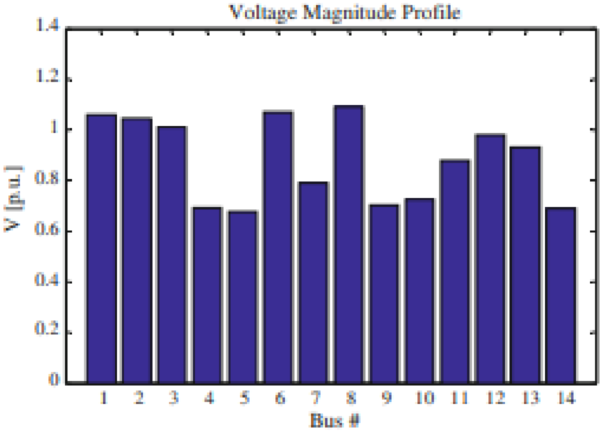

Fig. 5 Voltage profile for IEEE 14 bus test system without STATCOM for Case II

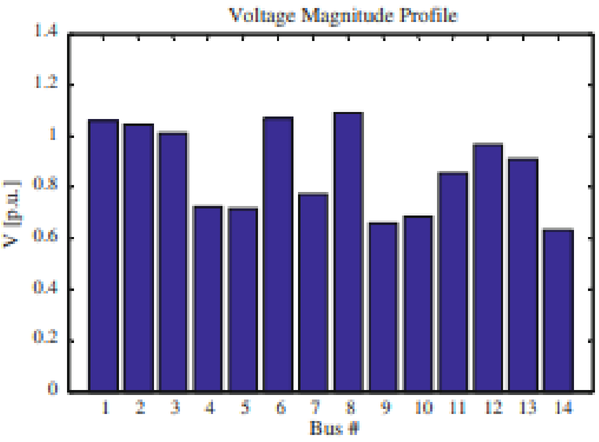

Fig. 6 Voltage magnitude of IEEE 14- bus system with STATCOM for Case II

5. CONCLUSIONS

This research investigates the strategic STATCOMs allocation in the power system considering circular optimization approach. The findings in this research show that the system's performance has improved significantly in terms of minimal voltage variation, reduced power losses, and higher loadability limit. The methodology is simple to implement, and the problem is multi-objective. According to the findings, when both the real and reactive power demand are increased, the STATCOM location is significantly more beneficial in improving the loadability limit and maintaining a decent voltage profile than in the other circumstances. When the generation's actual and reactive powers are increased, the loadability limit improves slightly. Furthermore, as generation real and reactive powers are increased, the voltage profile of the system improves significantly, as does the loadability of the critical buses. As a result, the predicted algorithm performs well in a variety of settings. Additionally, in the future, the predicted algorithm might be examined in conjunction with renewable energy integration in the power system.

REFERENCES

[1] Omidi, H., Mozafari, B., Parastar, A., & Khaburi, M. A. Voltage stability margin improvement using shunt capacitors and active and reactive power management. In IEEE Electrical Power & Energy Conference (EPEC), pp. 1-5, 2009.

[2] Kamarposhti, M. A., & Lesani, H. Effects of STATCOM, TCSC, SSSC and UPFC on static voltage stability. Electrical Engineering, 2011, vol. 93 No. 1, pp. 33-42.

[3] Wang, H., Li, H., & Chen, H. Application of cell immune response modelling to power system voltage control by STATCOM. IEE Proceedings-Generation, Transmission and Distribution, 2002, Vol. 149, No.1, pp. 102-107.

[4] Park, J. Y., Sohn, J. M., & Park, J. K.. Optimal capacitor allocation in a distribution system considering operation costs. IEEE Transactions on Power Systems, 2009, Vol. 24, No. 1, 462-468.

[5] Kennedy J., Eberhart R.. Particle swarm optimization. Proceedings of IEEE International Conference on Neural Networks (lCNN'95), vol. IV, 1995, pp. 1942-1948, Perth. Australia.

[6] Li, X & Clerc, M.. Smarm Intelligence. In handbook of Metaheuristics, Springer, 2019, pp. 353-384.

[7] Zhang, D., & Shao, Z.. Modified particle swarm optimization algorithm based on particle classification. in recent developments in intelligent computing, Communication and Devices, 2019, pp. 407-415, Springer, Singapore.

[8] Kumarasamy, K., Raghavan R. Particle swarm optimization algorithm for voltage stability improvement using multiple STATCOM. International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICETEEEM), 2012.

[9] Rashed G.I., Shaheen H.I., Cheng S.J. Optimal Location and Parameter Settings of Multiple TCSCs for Increasing Power System Loadability Based on GA and PSO Techniques. Third IEEE International Conference on Natural Computation (ICNC 2007), Vol. 4, pp. 335-344.

[10] Ratra S., Bansal, R. C., and Naidoo, R. Stochastic estimation and enhancement of voltage stability margin considering load and wind power uncertainties. 6th IEEE IAS International Conference on Computing, Communication and Automation (ICCCA), December 17-19, 2021.

[11] Del Valle, Y., Hernandez, J. C. Venayagamoorthy, G. K., & Harley, R. G. Optimal STATCOM sizing and placement using particle swarn optimization. In IEEE/PES Transmission & Distribution Conference and Exposition: Latin America, 2006, pp. 1-6.

[12] Kunwar, A., Bansal, R. C., Krause, O. Steady state and transient voltage stability analysis of a weak distribution system with a remote doubly fed induction generator based wind farm. Energy Science and Engineering, vol. 2, no. 4, pp. 188-195, 2014.

[13] Bansal, R.C., and Bhatti, T.S. Small signal analysis of isolated hybrid power systems: reactive power and frequency control analysis. Alpha Science International, Oxford, U.K. 2008.

[14] Shah, R., Mithulananthan, N., Bansal, R. C., Lee, K.Y., and Lomi, A. Influence of large-scale PV on the static voltage stability of sub-transmission system. International Journal of Electrical Engineering and Informatics, vol. 4, no. 1, pp. 148-161, March 2012.