ISSN: 2096-3246
Volume 58, Issue 01, 2026

OPTIMAL INTEGRATION OF FACTS DEVICES USING HYBRID OPTIMIZATION

Kavya Prayaga[1], **Sanjeevakumar R A***[2]
Research Scholar [1] Associate Professor[2]
Department of Electrical and Electronics Engineering, PDACE Kalburagi, Karnataka, India
Corresponding Author: sanju.san999@gmail.com

ABSTRACT

New trends in power system includes the optimal placement of Flexible AC transmission System (FACTS) devices to improve the performance of the system by managing the power by managing the load. A meta heuristic method is proposed for the optimal placement and sizing of FACTS devices, namely the Thyristor-Controlled Series Compensators (TCSCs), Shunt VARs Compensators (SVCs), and Unified Power Flows Controllers (UPFCs). To find the optimal locations of these devices in a network, weak buses and lines are determined through the line sensitivity index, Then, Hybrid GA-PSO is employed not only to find an ideal rating for these devices but also the optimal coordination of SVC, TCSC, and UPFC with the reactive power sources already present in the network (tap settings of transformers and reactive power from generators). The Line sensitivity index (LSI) in which three scenarios are considered with line outage and also with different loading conditions, to calculate the power loss. The objective here is the minimization voltage deviation and reduction of power losses in the network to improve the system performance. The methods are applied to the IEEE 14 bus test system.

Keywords: Line sensitivity index (LSI), Shunt VARs Compensators, Thyristor-ControlledSeries Compensators, Unified Power Flows Controllers, Hybrid GA-PSO

1. INTRODUCTION

The integration of FACTS devices into power systems has become an essential strategy for enhancing voltage stability, reducing transmission losses, and increasing the overall reliability and efficiency of electrical networks. FACTS devices, such as Static Var Compensators (SVCs), Thyristor-Controlled Series Capacitors (TCSCs), and Unified Power Flow Controllers (UPFCs), offer dynamic control of power flows, voltage levels, and system impedance, making them indispensable tools in modern power system management. However, optimum placement and size of devices pose significant challenges because of complexity and nonlinearity of power systems. Traditional optimization methods often fall short in addressing these challenges, leading to the exploration of more advanced techniques. Among these advanced methods, PSO and GA have emerged as powerful tools to solve optimization with FACTS devices.

PSO is population-based meta-heuristic stimulated by social behavior of birds and fish. PSO simulates the movement and interaction of a swarm of particles in the search space, where each particle represents a potential solution. By adjusting their positions based neighboring particles behaviour, the swarm converges toward optimal solutions. PSO's simplicity, ease of implementation, and ability to find global optima make it a popular choice to solve compound efficacy issues in power systems. Genetic Algorithm (GA), conversely, is stimulated with principles of natural selection and genetics. GA employs populace of candidate solutions that evolve over generations through selection, crossover, and mutation. The fittest individuals are selected for reproduction, ensuring the propagation of advantageous traits. GA's robustness and ability to handle high-dimensional and multimodal search spaces make it suitable for optimizing integrating of FACTS devices

FACTS devices are power electronic-based systems that provide dynamic control of voltage, impedance, and phase angle of high-voltage AC lines. Power systems are made more stable and easier to regulate using these devices, which improve voltage profiles, decrease power losses, and make system more reliable. These advantages could just be realized by carefully considering size and location of FACTS devices; but, due to nonlinearity and complexity of power systems, it's no easy feat.

PSO is a population-based meta-heuristic stimulated with social conduct of birds and fish. It simulates the movement and interaction of a swarm of particles in the search space, where each particle represents a potential solution. By adjusting their positions based on personal experience & experience of neighboring particles, the swarm converges toward optimal solutions. PSO's simplicity, ease of implementation, and ability to find global optima make it a popular choice to solve compound optimizing issues in power systems.

GA is inspired by the principles of natural selection and genetics. It employs a population of candidate solutions that evolve over generations through selection, crossover, and mutation. The fittest individuals are selected for reproduction, ensuring the propagation of advantageous traits. GA's robustness and ability to handle high-dimensional and multimodal search spaces make it suitable for optimizing the integration of FACTS devices. Research proved that GA works well for improving size and location of FACTS devices to decrease system losses and increase voltage stability. New power generating and transmitting techniques have emerged as a result of authors' call for better management of electrical networks. In order to improve voltage stability,

Hybrid approaches that combine PSO and GA or integrate these algorithms with traditional optimization approaches were projected for enhancing robustness and efficacy of optimization process. These hybrid methods leverage the strengths of different algorithms to achieve better solutions and improve overall system performance. For instance, hybrid approaches can combine the exploration capabilities of GA with the exploitation capabilities of PSO, leading to more robust and efficient solutionsOne area of future research is the development of adaptive and self-tuning variants of PSO and GA. These variants can adjust their parameters dynamically based on the search space characteristics, leading to more efficient and effective optimization. Another area of focus is the integration of machine learning techniques, such as reinforcement learning, into PSO and GA to enhance their performance and adaptability.

Another promising direction is the exploration of multi-objective optimization techniques. In real-world power systems, multiple conflicting objectives, such as minimizing power losses and maximizing voltage stability, must be accounted simultaneously. Multi-objective optimizing methods can offer numerous solutions that balance these conflicting objectives.

2. METHOD

2.1.Modelling of TCSC

Depending on the firing angles of thyristors, TCSCs can provide both capacitive or inductive compensations. They are positioned in series with the line and can influence impedance of transmission line. Thus, a TCSC can modify transmission line power carrying capabilities. The mathematical model of TCSC is presented in Figure 1.

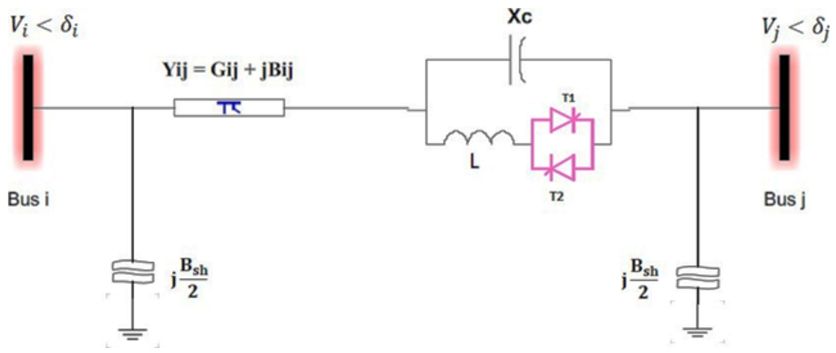


Figure 1. Static model of TCSC

In the presence of TCSCs, the true and reactive power flow equations from the respective buses can be given as

$$P_{ij} = V^2 G_{ij} - V_i V_j \; G_{ij} \cos \delta_{ij} + B_{ij} \sin \underset{i}{\delta}_{ij} \qquad (1)$$

$$Q_{ij} = -V^2 \; B_{ij} + B_{sh} - V_i V_j \; G_{ij} \sin \delta_{ij}{}^{i} - B_{ij} \cos \delta_{ij} \qquad (2)$$

$$P_{ji} = V^2 G_{ji} - V_j V_i \; G_{qi} \cos \delta_{ji} - B_{ji} \sin \overset{j}{\delta}_{ji}$$
(3)

$$Q_{ji} = -V^2 \;\; B_{ij} + B_{sh} \; + V_i V_j \; G_{ij} \sin \underset{j}{\delta}_{ij} + B_{ij} \cos \delta_{ij} \qquad (4)$$

Where, $V\,i$ and $V\,j$ are voltage of sent & received end buses, δij is bus angle differences amongst sent & received end, T1 and T2 are thyristors and Bsh is shunt admittance of line.

G_{ij} and B_{ij} are given as:

$$G_{ij} = \frac{R}{R^2 + X_{ij} - X_{Tcsc}^2} \qquad (5)$$

$$B_{ij} = \frac{-X_{ij} - X_{Tcsc}}{R^2 + X_{ij} - X_{Tcsc}^2} \qquad (6)$$

2.2.Modelling of SVC

Because of their parallel connection, SVCs are able to alter reactive power flows at coupling point. In their most basic form, SVCs are capacitors or variable inductors. Reactors & capacitors controlled by thyristors and linked by shunt to electrical power grid. Figure 2 displays static model of SVC.

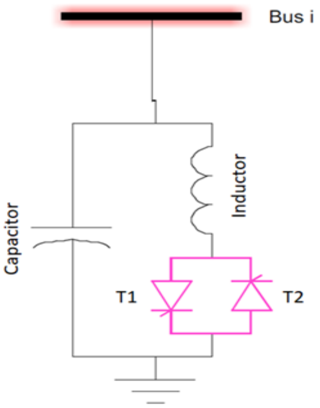


Figure 1 Static Model of SVC

The relationship between the injected or absorbed VAr at the bus by the SVC is given as follows:

$$Q\,svc = V\,2\,Bsvc \qquad (7)$$

where B_{svc} and 'V' are the susceptance and bus voltage.

2.3.Optimal Integration of FACT Devices

System architecture and intended results are major factors in determining which bus and line to use for FACTS device placement. To change the overall reactive power flow across buses, SVCs are set up in this project. This is where series compensators TCSCs come in utilize; by adjusting line's impedance, they can regulate the transmission lines' actual power flow. The voltage and the power flow capacity of transmission lines may both be enhanced with the use of UPFCs. Because of their ability to indirectly redistribute power flow and change overall flow of reactive power in weak & buses, FACTS are strategically located to prevent transmission line overloads

By building PV curves for every load bus while employing Lmn Index, we may identify weak lines and buses. A lot of methods exist for identifying power system weak lines and busses, but they're all either complicated or have their own set of problems. FVSI is one such tool; it produces reliable findings under base case reactive loading but becomes unreliable when reactive loading is varied. In a similar vein, reactive compensations are necessary for weak buses whose voltages decrease sharply with increasing load. This is why PV curves are often the most reliable signs for identifying underperforming buses in power grid networks. Whereas SVCs are situated on weak busses, TCSCs are positioned at weak lines. Amount of electricity that a line is actively carrying determines where UPFC is located

2.4.Optimal Placement of TCSC

Weak lines, as measured by Lmn index—a great predictor of the line's proximity to instability—are where TCSCs are located. When the Lmn index value is near to 1, it means line is crucial; for a line to be resilient, its value should be lower than 1. As indicated in Equation (12), Lmn index may be calculated using this formula.

$$Lmn = \frac{4XQ_r}{[V_S \sin(\theta - \delta)]^2} \tag{12}$$

as the line's reactance is represented by X. There are many variables in this equation: VAr demand at receiving bus (Qr), magnitude of transmitting end's bus voltage (Vs), difference between bus angles (θ), & impedance angle (δ). Refer to for more information on the Lmn index.

2.5.Optimal Placement of SVC

By studying PV curves, we can find the best spots for SVCs. One method for constructing PV curves is CPF construction. At the bifurcation or maximum load-ability points, traditional approaches to power flow analysis encounter a singularity in Jacobian matrix, rendering them ineffective. Ajjarapu and Christy modified power flow equations significantly and produced CPF in 1992 to detect power flows at all loading points. To solve the power flow problem at all loading locations, CPF employs the predictors and correctors system, displayed in Figure 4.

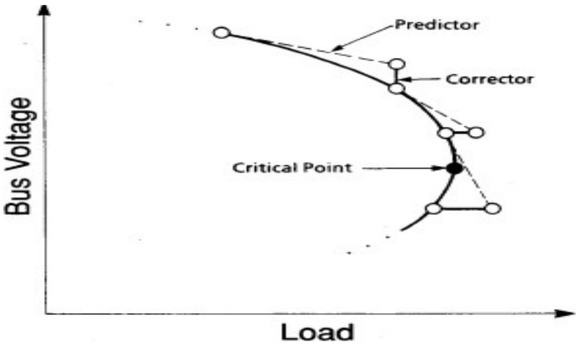


Figure.2 - Predictor and corrector scheme used in CPF

2.6.Optimal Placement of UPFC

To optimally place the UPFCs, lines carrying higher active power are identified, and UPFCs are installed at the starting buses of these lines. This placement allows for the control of their voltage magnitude and corresponding phase angle.

3. PROBLEM FORMULATION

In order to enhance efficiency of system in electrical networks, FACTS devices are put in this job. Providing these devices optimally utilizing Genetic algorithm and Particle Swarm optimization may increase power quality. By incorporating certain FACTS devices in the right manner, we may improve system's performance by providing a more accurate voltage profile and decreasing system losses.

A scientific formula of transmission system's efficiency is possible with usage of line sensitivity index $f_1(x)$, line stability analysis index $f_2(x)$, & voltage stability index $f_3(x)$.

the objective function can be:

$$\text{Min } F(x) = [\ f_1(x)\ , f_2(x),\ f_3(x)] \tag{13}$$

In both the objective functions, *x* denotes the vector of dependent variables which includes slack bus power *PG1,* generator reactive power outputs *QG*, load bus voltages *VL* and apparent power flows in transmission lines *SL*. Therefore, x can be defined as:

$$x^T = [\ P_{G1},\ Q_{G1},\ \ldots Q_{NGB},\ V_{L1}, \ldots V_{NLB},\ S_{L1}\ , \ldots . S_{NL}] \tag{14}$$

where NGB is the number of generator buses.

Similarly, *u* denotes the vector of control variables such as generator bus voltages V_G, location of FACTS devices *L*, and real and reactive power injections P_{inj} & Q_{inj} at FACTS device incident buses *i, j* respectively.

Therefore, *u* can be expressed as:

$$u^T = [\ V_{G1}, \ldots V_{NGB}, L_1,\ \ldots L_{NL},\ P_{inj}\ , I, Q_{inj.i,}\ ,\ P_{inj,j,},\ Q_{inj,j}\ \ ] \tag{15}$$

As per the type of FACTS device, the power injections again controlled with their respective controlling parameters.

3.1.Line Sensitivity Index (LSI)

Prior to delving into the idea of a congestion management issue, the sensitivity index is computed for each line of test system that is being studied. Utilizing loading conditions and base case power production, LSI is computed. To start, we generate a line outage in order to calculate value of line severity index. Then, depending on severity of the line, we simulate a few test scenarios to make the system experience transmission congestion

$$LSI = \sum_{ij=1}^{NL} \left(\mathrm{P_{ij}} / \mathrm{P_{ij} Max} \right]^2) \tag{16}$$

3.2.Constant Power Model

It is a static load model in which the power will not change or vary with change in voltage and it expresses the Real and Reactive powers at any instant of time as a function of bus voltage magnitude and frequency at the same instant represented by the following equations,

$$\mathrm{P} = \mathrm{KV^{np}} \tag{20}$$

$$Q = K_0 + K_n V^{np} \tag{21}$$

$$np = (\partial p/P_0)/(\partial v/V_0) \tag{22}$$

$$nq = (\partial Q/Q_0)/(\partial v/V_0) \tag{23}$$

np= Voltage Slope Active Power
nq= Voltage Slope of Reactive Power
K_0= Initial Power Value
K_n= Volt Dependent Gain

The set of equality and inequality constraints need to be satisfied are:

1. Bus voltages should be in their appropriate limits as $0.95 \leq V_j \leq 1.05$.
2. Thermal Limits of the transmission lines $S_{min} \leq S_L \leq S_{max}$ where S_L is the apparent power flowing through the line in Mega Volt Ampere (MVA).
3. Generator's reactive power supply limits $Qg, min \leq Qg \leq Qg,max$
4. Limit on the arrangements of the transformer tap setting $Ti, min \leq Ti \leq Ti, max$
5. SVC size Constraints $-0.9 \leq Z_{SVC} \leq 0.9$ (pu) where Z_{SVC} is the size of the SVC in pu.
6. TCSC size constraints $-0.8X_L \leq X_{TCSC} \leq 0.2X_L$ pu where X_{TCSC} is the size of the TCSC in pu

3.3.Flowchart

The Positive effect of both methods GA and PSO are used to develop a hybrid algorithm which gives better results in finding optimal size and location for FACTs devices. Kind of FACT device is selected initially, then the allocation is done for development of voltage stability and reducing power losses. Projected technique flowchart is as portrayed into Figure 5.This technique provides the allocation of the FACTS's devices by obtaining the minimum value of objective function. Therefore, each member of the GA- PSO consists of kind of FACTs device, reactive power and location in the considered system. Simulation is done using MATLAB and iteratively executed. The solution after the last iteration will be the optimal output.

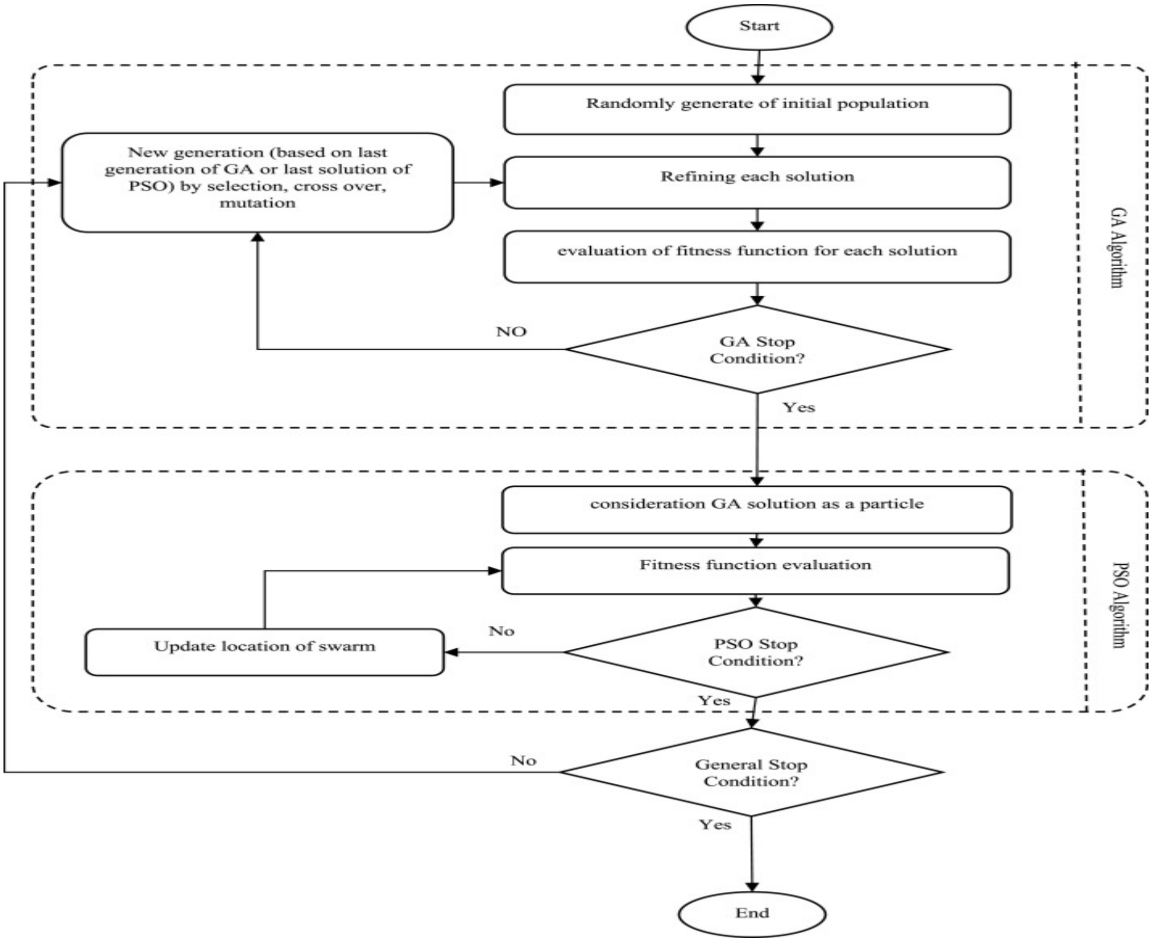


Figure *5* Flow chart for the optimal allocation of FACTs devices in the network by hybrid GA- PSO algorithm

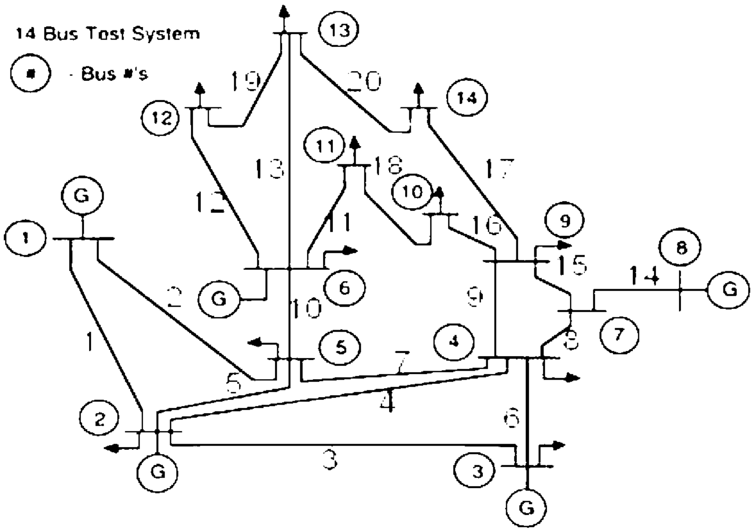
4. RESULTS AND DISCUSSION

For this case study, the IEEE-14 bus test system is being utilized is as shown in figure 6. It is made up of 9 load buses and 5 generator buses, with this one bus serving as the slack bus in arrangement. The combined active and reactive power loads are 259 MW and 69.5 MVAR, respectively. Detailed bus information is provided below. The following are the results obtained by performing the combination of Genetic algorithm and Particle swarm optimization technique. The power losses for different load conditions with the help of the GA-PSO Algorithm can be shown in Table 1 Voltage profiles can be shown with the help of different load conditions in Table 3 with graphically shown in Figure 8 &9 respectively.

Table1. Real and Reactive Power losses before and after applying GA-PSO

Particulars	**Before Placing**	**After placing FACTS**	**Loss Reduction**
Normal case	13.5766 (MW)	13.3636(MW)	0.213(MW)
125% load	23.088(MW)	22.0721(MW)	1.0159(MW)
Normal case	28.553 (Mvaar)	27.889 (Mvaar)	0.664 (Mvaar)

130% load	67.64 (Mvaar)	64.329 (Mvaar)	3.311 (Mvaar)



Slack bus: 1st bus

Generator bus: 2nd, 3rd, 6th, 8th

Load buses: 4th, 5th, 7th, 9-14th

It consists of 20 Transmission lines

Base MVA = 100MVA

Maximum number of iterations 100.

Figure.6 Test Configuration for the IEEE-14 Bus System

4.1.Line Sensitivity Index

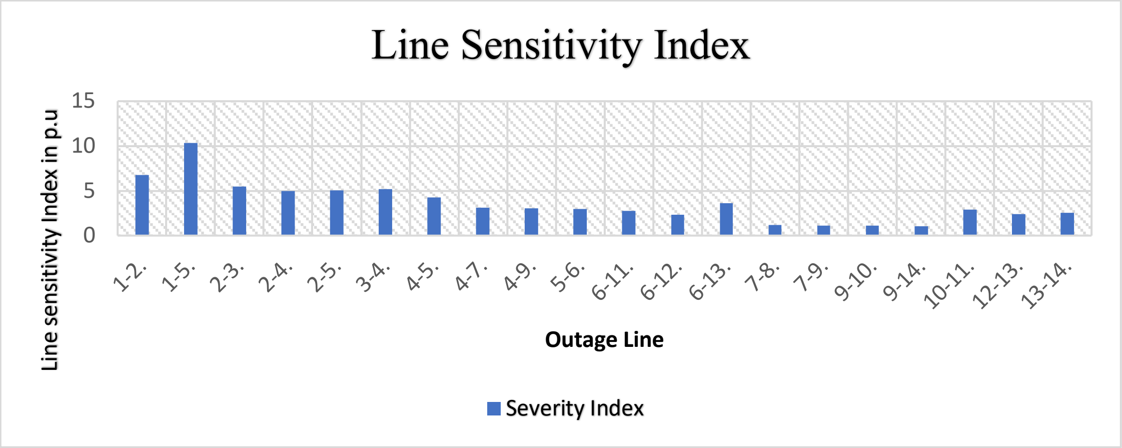


Figure 7 : Line Sensitivity Index of all Line Outages in IEEE-14 Bus System

For each line outage that corresponds to load state and base case power generation, LSI is first derived utilizing aforementioned equation, taking into consideration outages one line at a time. It is with these considerations that IEEE 14 bus system is based. For limit values larger than 3.0, line sensitivity index values have been portrayed into table 2, sorted by decreasing order. Among the lines in test system, one at outage line 1-5 has the greatest line sensitivity rating of 10.5 according to table 2. After previous outages (e.g., 2-3, 3-4, etc.), outage upon line 1-2 is 2nd-highest value

Table 2. Most severe line outages

L Voltage	**1-2**	**1-5**	**2-3**	**2-4**	**2-5**	**3-4**	**4-5**	**4-7**	**4-9**	**6-13**
LSI	**6.73**	**10.35**	**5.45**	**5.01**	**5.011**	**5.21**	**4.23**	**3.15**	**3.07**	**3.6**

Most severe line pretended to defect is determined using values supplied by line sensitivity index. Following three scenarios, each tested under its own exceptional set of circumstances, are used to illustrate congestion management system:

- Scenario-1 is for outage line 1-5
- Scenario-2 is for outage line 1-2
- Scenario-3 is for outage line 2-3 , At each step, transmission lines are loaded with 130% of active power load at all the busses.

Table 3 Scenario wise Line Flow Violation in IEEE 14 Bus System

Scenario	Overloaded Lines	Line Limit MW	Actual Power Flow in MW	Amount of power Flow Violation in MW	Total power Flow Violation in MW	Total power Loss in MW	LSI
1	1-2	55	150.8397	95.8397	131.208	20.812	10.76
	2-3	45	52.074	8.074			
	2-4	45	60.8355	16.8355			
	2-5	45	54.4588	10.4588			
2	1-5	65	156.0669	90.0669	101.2275	21.23	7.03
	4-5	88	99.1606	11.1606			
3	1-2	55	126.8894	71.8894	141.0343	25.08	12.06
	1-5	65	83.435	17.435			
	2-3	45	67.98	23.98			
	2-4	45	71.7299	27.7299			

Table 3 examines three different scenarios for an IEEE 14 Bus System and shows how the power lines react to overloads at each step and Line Stability Index, indicating how stable the line is under the given conditions.

Scenario 1: Outage in line 1-5, Overloaded lines: 1-2, 2-3, 2-4, 2-5, here The most significant violation is on line 1-2 with an excess of 95.8397 MW, leading to a total power flow violation of 131.208 MW and a total power loss of 20.812 MW

Scenario 2: Outage in line 1-2, Overloaded lines: 1-5, 4-5, here The line 1-5 has the highest violation at 90.0669 MW, with a total power flow violation of 101.2275 MW and a total power loss of 21.23 MW.

Scenario 3: Outage in line 2-3, Overloaded lines: 1-2, 1-5, 2-3, 2-4, here the most notable violation occurs in line 1-2 with 71.8894 MW, amounting to a total power flow violation of 141.0343 MW and a total power loss of 25.08 MW.

Table 4 Voltage profile of GA-PSO for Different load conditions

Normal case			**130% load condition**	
Line no	**Before placing Facts devices**	**After placing Facts devices**	**Before placing Facts devices**	**After placing Facts devices**
1	1.06	1.06	1.06	1.06
2	1.045	1.045	1.025	1.043
3	1.01	1.01	0.98	1.132
4	1.0141	1.0231	0.984	1.0923
5	1.0173	1.0251	0.9897	1.0608
6	1.07	1.07	1.04	1.121
7	1.0461	1.0786	1.015	1.1136
8	1.08	1.099	1.06	1.141
9	1.0309	1.0834	0.9935	1.1152
10	1.0303	1.0686	0.9919	1.107
11	1.0463	1.0656	1.011	1.1096
12	1.0533	1.0611	1.0186	1.1033
13	1.0467	1.0687	1.0103	1.098
14	1.0195	1.0532	0.9769	1.0852

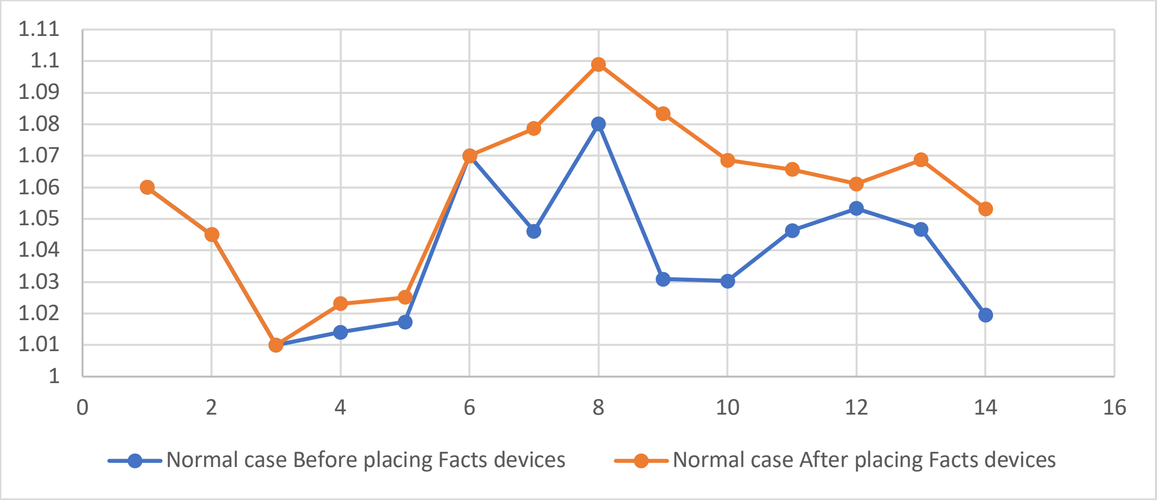


Figure 8 Voltage profile before and after placing FACTs devices for normal Load after applying GA-PSO

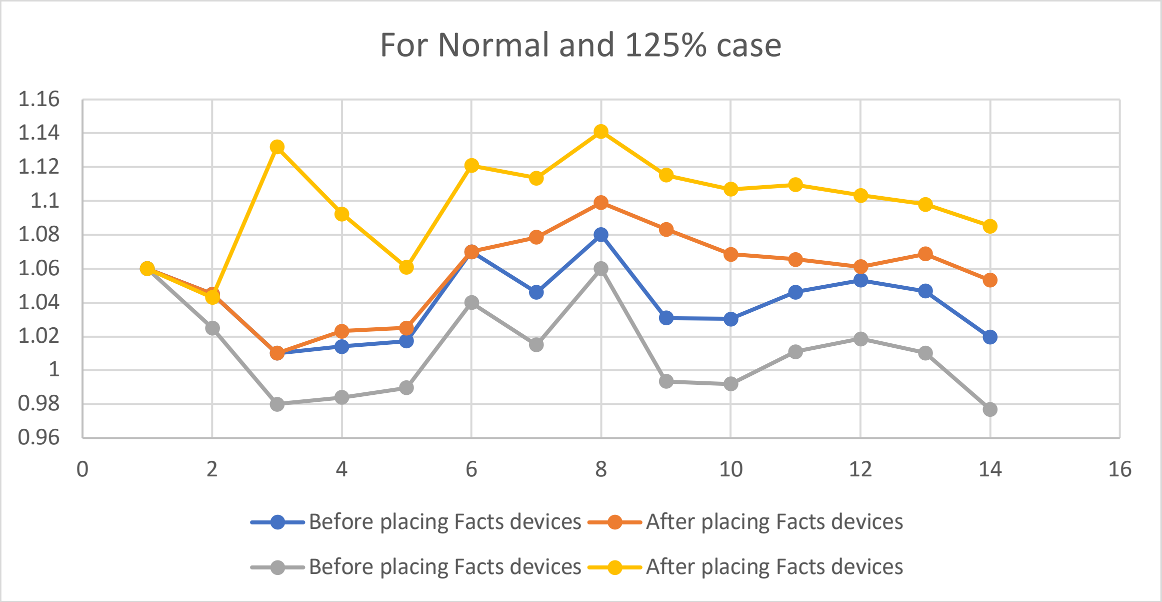


Figure 9 Voltage profile before and after placing FACTs devices for 125% Load after applying GA-PSO

TCSC (Thyristor-Controlled Series Capacitor) ratings as a percentage of line reactance (XL) under different load conditions. The table compares the performance of three optimization methods: Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and a hybrid GA-PSO approach.

Table *5* TCSC ratings in % of XL for different load conditions for different methods

	Normal	**125% load**	**140% load**	**150% load**
GA	4.5665	6.1543	11.2598	21.7865
PSO	3.2125	5.8786	9.0987	15.9876
GA-PSO	3.2009	5.8569	8.8765	14.9898

Hybrid GA-PSO: This approach combines the strengths of both GA and PSO, resulting in the lowest TCSC ratings across all load conditions. At normal load, the hybrid approach suggests a rating of 3.2009%, increasing to 14.9898% at 150% load. This approach outperforms both GA and PSO individually, suggesting the lowest TCSC ratings across all load conditions. This indicates that the hybrid method can achieve better performance and efficiency in optimizing FACTS device allocation.

SVC (Static VAR Compensator) ratings as a percentage of the reactive power load (QL) under different load conditions. The table compares the performance of three optimization methods: Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and a hybrid GA-PSO approach. This table 6 helps illustrate how different optimization methods can impact the suggested SVC ratings for maintaining voltage stability across varying load conditions.

Table 6 SVC ratings in % QL for different load conditions for different methods

	Normal	**125% load**	**140% load**	**150% load**
GA	25.3010	31.2341	43.4768	45.5989
PSO	29.2987	32.9578	43.5989	49.9999.
GA-PSO	27.6573	32.2143	43.4987	47.8671

Hybrid GA-PSO: This approach combines the strengths of both GA and PSO, resulting in intermediate SVC ratings across all load conditions. Under normal load conditions, the hybrid approach suggests a rating of 27.6573%, which increases to 47.8671% at 150% load. This approach typically provides balanced SVC ratings, blending the conservative nature of GA and the aggressive optimization of PSO, offering a middle-ground solution.

The Table 7 compares the performance of three optimization methods: Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and a hybrid GA-PSO approach. The ratings are provided in millifarads (mF), which indicate the capacitance value of the TCSC.

Table 7 TCSC ratings

	Normal	**125% load**	**140% load**	**150% load**
GA (mF)	0.7289	0.5343	0.3002	0.1499
PSO **(mF)**	0.9686	0.5586	0.3601	0.1899
GA-PSO(mF)	0.8661	0.53.24	0.3431	0.1781

Hybrid GA-PSO: This approach combines the strengths of both GA and PSO, resulting in intermediate TCSC ratings across all load conditions. Under normal load conditions, the hybrid approach suggests a rating of 0.8661 mF, decreasing to 0.1781 mF at 150% load. This provides balanced TCSC ratings, offering a middle-ground solution that combines the conservative nature of GA and the aggressive optimization of PSO. This table helps illustrate how different optimization methods impact the suggested TCSC ratings for maintaining voltage stability across various load conditions.

The table 8 shows the optimal ratings for the UPFC device in terms of real power (MW) for various loading conditions using three methods: Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and a hybrid GA-PSO approach.

Table 8 UPFC ratings in terms of MW

	Normal	**125% load**	**140% load**	**150% load**
GA (MW)	50.3213	40.9764	35.5376	30.9863
PSO (MW)	48.2453	39.5472	34.8987	29.7649
GA-PSO (MW)	49.9981	39.5986	34.5564	29.5864

5. CONCLUSION

To address the voltage deviation challenge faced by many utilities, an algorithm is developed for the optimal placement of various FACTS devices, including SVC, TCSC, and UPFC. The primary goal is to simultaneously reduce power loss and the voltage deviation index (VDI) in the considered system. The optimal allocation for these devices is performed on the IEEE 14 bus test system using a Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and a hybrid algorithm that combines the strengths of both methods. This algorithm operates in multiple steps, placing SVC, TCSC, and UPFC devices at the most effective locations and sizes within the test system to enhance overall performance. The optimization strategies (GA, PSO, and their hybrid) are applied independently, and their results are analyzed for average load, 125% load, 140% load, and 150% load conditions. By examining the outcomes across all load scenarios, the analysis of GA, PSO, and the hybrid approach aims to identify the best solution.

REFERENCES

[1] Cai, L. J., Istvan Erlich, and Georgios Stamtsis. "Optimal choice and allocation of FACTS devices in deregulated electricity market using genetic algorithms." *Power Systems Conference and Exposition, 2024. IEEE PES*. IEEE, 2024.

[2] Sai Ram Inkollu and Venkata Reddy Kota, “Optimal setting of FACTS devices for voltage stability improvement using PSO adaptive GSA hybrid algorithm,” Engineering Science and Technology, an International Journal, Available online 17 March 2016.

[3] Jamnani, J.G.; Pandya, M. Coordination of SVC and TCSC for management of power flow by particle swarm optimization. *Energy Procedia 2019, 156, 321–326i*

[4] Singh, B.; Agrawal, G. Enhancement of voltage profile by incorporation of SVC in power system networks by using optimal load flow method in MATLAB/Simulink environments. *Energy Rep. 2018, 4, 418–434..*

[5] S. Ranganathan, V. Velmurugan and C. C. A. Rajan, "Optimal Placement of SVC with Single Objectives using Self-Adaptive Firefly Algorithm," *2019 Fifth International Conference on Science Technology Engineering and Mathematics (ICONSTEM), Chennai, India, 2019, pp. 311-315, doi: 10.1109/ICONSTEM.2019.8918749.*

[6] P. F. Le Roux, M. K. Ngwenyama and T. C. Aphane, "14-Bus IEEE Electrical Network Compensated for Optimum Voltage Enhancement using FACTS Technologies," *2022 3rd International Conference for Emerging Technology (INCET), Belgaum, India, 2022, pp. 1-7, doi: 10.1109/INCET54531.2022.9824172.*

[7]C. Roy, D. Chatterjee and T. Bhattacharya, "Control of a Hybrid Shunt FACTS Compensator for Voltage Collapse Prevention in Interconnected EHV Power Transmission Systems," in *IEEE Journal of Emerging and Selected Topics in Industrial Electronics, vol. 4, no. 2, pp. 538-548, April 2023, doi: 0.1109/JESTIE.2023.3244739.*

[8] D. Xiao, Y. Dong, Y. Wu, D. Meng and S. Tang, "Method of Judgment and Control Decision of

Voltage Instability in Electromechanical Transient of Power System," *2021 IEEE Sustainable Power and Energy Con- ference (iSPEC), Nanjing, China, 2021, pp. 3015-3019, doi: 10.1109/iSPEC53008.2021.9735926*

[9] R. Bekhradian, M. Sanaye-Pasand and A. Mahari, "Adaptive Wide-Area Load Shedding Scheme Based on the Sink and Source Concept to Preserve Power System Stability*," in IEEE Systems Journal, vol. 17, no. 1, pp. 503-512, March 2023, doi: 10.1109/JSYST.2022.3168541*

[10] M.A. Chitsazan, M.S. Fadali, A.M. Trzynadlowski, State estimation of IEEE 14 bus with unified interphase power controller (UIPC) using WLS method, *in 2017 IEEE Energy Conversion Congress and Exposition, ECCE, IEEE, 2017, pp. 2903–2908.*

[11] Mohamed, Khalid H., KS Rama Rao, and Khairul Nisak Bt Md Hasan. "Optimal parameters of interline power flow controller using particle swarm optimization." *Information Technology (ITSim), 2010 International Symposium in*. Vol. 2. IEEE, 2010.

[12] Gerbex, Stéphane, Rachid Cherkaoui, and Alain J. Germond. "Optimal location of multi-type FACTS devices in a power system by means of genetic algorithms." *Power Systems, IEEE Transactions on* 16.3 (2001): 537-544..