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Different Techniques for Allocation of SVC: A Review

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Abstract- **One of the issues in today's power system, particularly in the transmission network which operates at maximum capacity is overloading. As a result of disturbances, the network of today's power systems is prone to instability and collapse. Towards this end, Flexible AC Transmission System (FACTS) offers a remedy to problems such as line overloading, voltage stability, losses, and power flow. FACTS have the potential to dramatically improve the power system's static and dynamic performance. However, FACTS devices demand a significant upfront investment. Therefore, these devices should be allocated in terms of position, size and rating to reap maximum benefit. Thus, this paper presents literature survey on different techniques for allocation of Static Var Compensator FACT device.**

Keywords– **FACTS, Static Var Compensator (SVC), Voltage Stability, Optimal Placement, Reactive Power Compensation**

1. INTRODUCTION

According to a rise in the prevalence of load demand and a dynamic load behavior that has a detrimental effect on transmission lines, the modern power system is becoming a more comprehensive, integral function. Operating in a manner like either they are under-loaded or they are functioning at capacity. System voltage security is susceptible to fault due to the uneven load distribution's impact on the voltage profile. It gets harder to keep the security and dependability of the electricity grid. Therefore, building new electricity generation facilities and expanding the system with additional transmission lines are traditionally constrained by technical and financial constraints. Utilizing the current generation and transmission network to its fullest potential is the smartest and maybe only remaining alternative. The best and most efficient alternative for developing complex new transmission corridors is to use FACTS controllers to enhance the entire state's capabilities in areas including fault detection, solutions require, and voltage regulation, among others. Series, shunt, series-series, and series-shunt arrangements can be used to connect these units. The type of FACTS device should be chosen following with the intended use or requirement. Series regulators can be used to regulate the line's energy transfer, while shunt controllers are preferable for controlling voltage at the point. [1]

The idea of FACTS was first suggested by Hingorani and Gyugyi in 1999. With the FACTS approach, it is possible to modify and control the flow of line power in an accurate, quick, and precise manner [2]. The basic power electronics components are the foundation basis of FACTS controllers. Applications for FACTS devices include increasing the ability of transmission lines to transport electricity and controlling various transmission network parameters like current, impedance, phase angle, and voltage. These gadgets provide the control or flexibility of power flow. FACTS devices lessen harmonic distortions and current flows in heavily loaded lines, and it help the network be more loadable [3]. System security and voltage collapse are issues that are successfully addressed by FACTS devices. These tools aid in the control of the congestion issue. Also, with help of FACTS devices, the system easily adapted to the developments [4].

The best placement and configuration of FACTS controllers are crucial for improving system performance and reaping financial rewards. Experts have already presented several solutions regarding the appropriate placement of FACTS devices. Therefore, the device placement approaches that are frequently used are subdivided into analytical, linear regression, heuristic and metaheuristic optimization techniques. Since they are dependable, rapid, and best suited for actual power system issues, heuristic search methods are the optimal tools for such issues. The challenge of optimal placement is considered to be a combinatorial analysis problem. The Genetic Algorithm (GA), Differential Evolution (DE), Particle Swarm Optimization (PSO), Harmony Search Algorithm (HSA), and Ant Colony Optimization (ACO) are common heuristic search techniques proposed for optimal placement in research [5-6].

The paper has summarized wide range of research work reported under the area of FACTS devices. Further it has summarized details of objectives, methodology, test systems and outcomes in a simple and comprehensible format. The review can be facilitated to understand outline of the research that has been reported till date along with different objectives and methodologies for allocation of SVC in power system.

2. LITERATURE REVIEW

In this part, we have presented a comprehensive review of the study publications on the ideal placement of fact devices in an ac transmission network. They are outlined as:

In 2020 [7], authors studied the dependability of the grid network, although is severely impacted by the voltage instability. This work aims to solve the voltage deviation (VD) issue of the system. To increase voltage at the load bus, voltage imbalance is minimized. Therefore, the system's voltage enhancement and its stability are the main topics of this study. The system's weakest bus is determined using the simplified voltage stability index (SVSI). PSCAD simulation software is being used to complete further analysis.

In [8-9] authors suggest using the Voltage Power Sensitivity Index (VPSI) to identify power system nodes that are voltage sensitive. The power system's voltage-sensitive nodes are identified by the proposed index. A bus's voltage sensitivity is indicated by the suggested index's value, which is higher for a bus. The FACTS Controller (series or shunt) is then mounted on the bus with minimal voltage. To maximize the voltage stability margin and voltage distribution in the configuration for reduction of line congestion, the Taguchi Method (TM) is considered for determining the size of TCSCs. To demonstrate the suggested methodology's applicability on an IEEE 14-bus test.

In [10-12], through the use of Genetic Algorithm (GA) and the well-known Newton Raphson power flow method, this work introduces a novel way of determining the best rating of FACTS controllers. In this paper, the Static VAR Compensator (SVC), one of many FACTs controllers, is taken into consideration. The objective is to decrease the reactive power loss in the system by operating the SVC at its highest performance. Voltage regulation loss reduction was used as the goal parameter to get the optimal SVC grading. The suggested algorithm is a useful and efficient approach in this direction. Studies on IEEE 9 bus and IEEE 30 bus systems are conducted under various loading circumstances to confirm the efficacy of the suggested algorithm. The various loading situations taken into consideration are average loading, 80% loading, 90% loading, 110% loading, and 120% loading. Also, every test system is assessed under identical loading conditions.

In [13] to order enhance the loadability of the network and lower generating costs, the Improved Moth Flame Optimization (IMFO) algorithm is used in this study to allocate FACTS optimally. This study uses Static Synchronous Compensator (STATCOM) and Static VAR Compensator shunt FACTS devices (SVC). To solve the Optimum Power Flow (OPF) problem, which is presented by a multi-objective function, the IMFO method is merged with Continuation Power Flow (CPF) in order to calculate the Maximum Loadability Point (MLP). This function is designed for enhancing the electrical overall network transfer capability, generally lower transmission line failures, reduced operating costs, and minimize the transient stability of IEEE 30-bus system. Comparisons are made between the MFO and the suggested approach's findings. The comparison proves the strength and effectiveness of suggested methodology.

In [14-17], the authors conduct a performance analysis where the Fast Voltage Stability Index (FVSI) is considered to identify the weak bus position in the network, which helps to minimize the estimated hour needed for the effective placement of SVC. The VPSI indicates improvements to the reactive power compensation and margin for voltage stability. The cost savings associated with electricity generation are enhanced by the loss reduction offered by an SVC. The device's capital costs, and related principal payments can be repaid using the monthly generation cost reductions achieved through the use of SVC.

In [18-23] FACTS controller, such as the SVC, is taken into consideration in this article to improve stability and reduce loss in a nine-bus system. The Thyristor Switched Capacitor (TSC), Thyristor Controlled Reactor (TCR) and a capacitor linked in parallel to the line, and filter components make up the SVC. In this instance, the voltage amplitude and phase variability and total real and reactive power losses at each bus in regard to the location of the SVC implementation are reviewed to increase voltage regulation and eliminate the expense. The very first power flow study for an impedance system has been conducted and the second was performed for a system with SVC compensation by moving the deployment of the SVC from every bus. Additionally, by evaluating the power scale fluctuation and total losses in the demand peak flow, it is possible to select the ideal site for SVC whereas, MATLAB/SIMULINK has been used for all performance analysis.

Authors studied [24] about sequential quadratic programming considering hybrid genetic approach as an algorithm and to examine how the Total Transfer Capability (TTC) of electrical operations across supply as well as sink’s locations are impacted by the SVC regulator (GASQP). An innovative algorithm for power systems is GASQP. The suggested approach is utilized to simultaneously solve for OPF to enrich the TTC and discover the best location for the SVC controller. Utilizing a viable TTC level, the recommended OPF is utilized in conjunction with actual and reactive power production limitations, line heat conditions, amplitude thresholds, and SVC operating confines. A five-bus test setup is implemented to showcase the GASQP application's capacity to enhance the TTC of the network. The findings unmistakably show that the inclusion of SVC with the right settings and placement could improve TTC.

In [25-27] researchers analyzed this study presents a different framework merging the Chemical Reaction Optimization & Cuckoo Search Algorithm (CSA) and to overcome the challenge of giving suitable SVC for the typical IEEE 14-bus, 30-bus, and 57-bus auxiliary equipment under strongly loaded situations (CRO). The best SVC allocation takes into account both commercial and technical factors, including investments on the yearly price of electricity production and the duration of the returns on investment (ROI) for the prices charged for the SVC as well as technical factors like voltage stability, power generation minimization, and line loss reduction. An innovative component of the challenge conceptualization is the ROI computation that gives the viability of investment a practical perspective. As a result, a comprehensive technique is used to determine the SVC's ideal location within the power network, and the outcomes confirm the suggested algorithm's higher performance.

In [28-29] order to minimize transmission losses while considering cost function, this work provides the ideal position and size of SVC employing PSO. One such method like resolving this issue is PSO, a heuristic search technique with an inhabitant. SVC is selected as the compensating component for this study. PSO's viability to complete the assignment was validated through implementation on the IEEE 30-bus system. The computational findings are compared to those from the EP approach in an attempt to highlight its advantages.

In this research [30], the ideal A SVC's location and dimensions inside distribution networks are found using a meta-heuristic optimization method called Harmony Search Algorithm. Voltage instability issues are being caused by the rising daily demand for electricity. A strained power system's voltage stability status could be enhanced with efficient reactive power compensation, which is possible with high SVC utilization. To reduce L-index, enhance a multi-objective approach to reduce harmonic distortion and the power quality problem is established. Here, the system's essential buses are located using the L-index to determine where the Static Var Compensator, a shunt-connected FACTS controller, should be placed (SVC). The HSA is used to figure out the multi-objective approach and their drawbacks by determining the best SVC sizes on the IEEE 30-bus and IEEE 14-bus test systems. The results show that the combination and proportions of the SVC optimize actual power costs, improve voltage regulation, and reduce L-index under base case and 125% overloading conditions.

In 2014 [31] authors examined to identify the best position and size for Static Var Compensators (SVC), which are used to compensate for voltage variation, real power losses, this research suggests the responsive congestion length of the non-dominated sorting GA (NSGA-II). Single-line interruptions are considered a contingency, while voltage restrictions for the routes are considered a hazardous restriction when determining the best location and size for SVC. The proposed method's efficacy has been demonstrated by using NSGA-II to locate and size the SVC in the best possible place on an IEEE 30 system. The obtained findings show that the NSGA-capacity II's may generate an equitably spread, quasi-Pareto front, and they are extremely encouraging. A comparison table has been summarized where the optimal placement of SVC and the related objective with the objective functions is presented.

Table 1.1 Comparison of different techniques for the placement of SVC

S.No.	**Reference**	**Year**	**Objective**	**Test System**	**Objective Function**	**Solution Methodology**
1	[6]	2020	Reduce the voltage fluctuations and enhance stability	IEEE-14 Bus	$VD = min\left(\sum_1^n \mid V_n\mid \ - \ V_{refn}\right)$	Simplified Voltage Stability Index
2	[7]	2015	Optimal allocation of SVC	IEEE-14 Bus	$VP_i = \frac{(V_i - V_{\mathrm{max}})(V_{max} - V_i)}{(V_{nom} - V_{min})(V_{max} - V_i)}$	Fast Voltage Stability Index
3	[8]	2016	Reduction in line congestion	IEEE-14 Bus	$\Delta V_i = V_i^{Base} - \frac{1}{N_L}\sum_{l=1}^{N_L} V_i^l$ $\forall\ i \ = \ TN_B$	Voltage Power Sensitivity Index (VPSI), Taguchi Method (TM)
4	[9]	2011	Profit in cost of fuel	IEEE-14 Bus	$B_{TL} = C_B(\lambda \sum_{i\epsilon\pi_L} \Delta P_{li})$	PSO, CPF
5	[10]	2015	Optimal allocation of SVC	IEEE-30 Bus & IEEE-9 Bus	$I = jBV_k$ $Q = V_k^2 B$	Conventional NR power flow method, GA
6	[11]	2010	Enhance transfer capability of power	IEEE-9 Bus & IEEE-30 Bus	$minf(x) = \frac{1}{2}x^T Qx + c^T x$ $x_{min} \leq x \leq x_{max}$ $b_{min} \leq Ax \leq b_{max}$	MILP
7	[12]	2013	Load demand voltage stability improvement	IEEE-30 Bus	$P_{loss} = \sum_{i,j=1,2,..n} Y\ [u_i^2 + u_j^2 + 2u_i u_j \cos(\delta_i - \delta_j)] Y_{ij} cos\emptyset_{ij}$	GA, Lagrange multiplier method
8	[13]	2021	Reduction of energy losses, price and VSI	IEEE-30 Bus	$Min\ F = Min(w_1 * F_1 + w_2 * F_2 + w_3 * F_3 + w_4 * F_4)$ $S(M_i, F_j) = D_i . e^{bt} . \cos(2\pi t) + F_j$	MLP, IMFO, CPF
9	[14]	2020	Reduction of transmission dissipation and losses	IEEE-9 Bus & IEEE-30 Bus	$OF = \sum_{i=1}^{NG} (a_i P_{Gi}^2 + b_i P_{Gi} + C_{i)}$ $OF = \sum_{i=1}^{NG} (\gamma_i P_{Gi}^2 + \beta_i P_{Gi} + \alpha_i + \mathcal{E}ie^{\gamma_i} P_{Gi}^2)$	CONOPT Solver Embedded in GAMS
10	[15]	2015	Optimal design of a controller	IEEE-12 Bus	$V_{OUT} = (\frac{D}{1+n} + \frac{1-D}{1-n})V_{IN}$ $D = K_0 + K_2 \sin\ (2wt + \varphi)$	PSO
11	[16]	2018	Minimization of power loss	IEEE-30 Bus	$Cost_{SVC} = 0.0003Q_j^2 - 0.305Q_j + 127.38$ $Q_{gi} - Q_{di} = V_i \sum_{j=1}^{Nb} V_j\ (G_{ij} sin\delta_{ij} - B_{ij} cos\delta_{ij}$	CSA, Pareto-optimal
12	[17]	2017	Enhancement of transient stability	IEEE-30 Bus	$P_L = \sum_{k=1}^{nl} g_k [V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)]$ $TVD = \sum_{i=1}^{LB} \lvert V_i - V^{ref} \rvert$	KGMO
13	[18]	2018	Stability enhancement and loss minimization	IEEE-9 Bus	$P_{T,i} = \sum_{j=1}^{N} V_i V_j Y_{ij} \cos\ (\delta_i - \delta_j - \gamma_{ij})$ $Q_{T,i} = \sum_{j=1}^{N} V_i V_j Y_{ij} \sin\ (\delta_i - \delta_j - \gamma_{ij})$	Power Flow Solution by Newton Raphson Method
14	[19]	2012	Enhance Loading Margin	IEEE-24 Bus	$Risk(E_i) = P_r(E_i) * \Delta\lambda_{\mathrm{E}_i}$ $\Delta V = \xi \Lambda^{-1} N \Delta Q$	MOP, MOPSO

					$f_{si} = f_i . \sum_{k=1}^{NP} sh_i^k$ $d_i^k = \sum_j \left(\frac{x_{ij} - x_{kj}}{x_j^{max} - x_j^{min}} \right)^2$	
15	[20]	2015	Optimal allocation of SVC	IEEE-6 Bus	$F = \sum_{j=1}^{M} \Delta Q_{SVC_j}$	Linear Programming Technique
16	[21]	2018	Enhancing system reliability	IEEE-14 Bus & IEEE-30 Bus	$F_1 = \sum_{i=1}^{NPQ} (V_i - 1)$ $L_j = \|1 - \sum_{i=1}^{NPQ} F_{ij} \frac{v_i}{v_j}\|$ $F_3 = P_{loss} = \sum_{i=1}^{NPQ} G_{ij} (V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_{ij})$	Teaching-learning-based optimization (TLBO)
17	[22]	2010	Maximizing economic security while reducing the overall price sum of power flow	IEEE-39 Bus	$C(Q_{FACTS}) = c_{F2} Q_{FACTS}^2 - c_{F1} Q_{FACTS} + c_{OF}$ $F = \sum_{i=1}^{Ng} (c_{2i} . Q_{gi}^2 + c_{1i} Q_{gi} + c_{0i}) + \sum_{F=1}^{Kf} (c_{F2} Q_{FACTS}^2 - c_{F1} Q_{FACTS} + c_{OF})$	OPF
18	[23]	2018	Reduction of expense, terminal power fluctuations, and active and reactive power losses	IEEE-30 Bus	$L_k = \|1 - \sum i \in G \, (\frac{F_{ki} V_i}{V_k})$ $\min f_i = \sum_{i=1}^{N} \sum_{k=1}^{N} R[Y_{ik}^* \{\|V_i\|^2 - \|V_k\|^2 - V_i V_j\} + Y_{io}^* \, \|V_k\|^2]$	GWO & Sine-Cosine Algorithm (SCA)
19	[24]	2011	Optimal allocation of SVC	IEEE-5 Bus	$F = \sum_{i=1}^{ND\_SNK} P_{Di}$	Hybrid GASQP
20	[25]	2017	Optimal installation of SVC	IEEE 57-Bus	$Q_P^{SVC} = -V_p^2 B_p^{SVC}$ $C_{SVC} = (0.0003S^2 - 0.3051S + 127.4 * MVAr * 1000\$$	Cuckoo Search & CRO
21	[26]	2017	Reduction in power dissipation and voltage variation and SVC.	IEEE-30 Bus	$Minimise\ F = \left(I_{SVC} + Pf^* \|\|R - 1\|\| \right)$ $S_j = - \sum_{i=1}^{N} Y - Yi$ $A_j = \frac{\sum_{i=1}^{N} V_i}{N}$	Dragonfly Algorithm, Eigenvalue Decomposition
22	[27]	2015	Optimal sizing and siting of SVC	IEEE-14 Bus	$\min f_1 = P_{loss} = \sum_{k=1, j \neq 1}^{nline} G_{kj} [V_k^2 V_j^2 - 2V_k V_j \cos(\delta_k - \delta_j)]$ $min\ f_2 = IC = C_{SVC} \times S \times 1000$	Teaching Learning Based Optimization (TLBO) Technique
23	[28]	2011	Improvement of voltage profile.	IEEE-30 Bus	$\triangle Q_{is} = Q_{svc}$ $V_i^{t+1} = W . V_i^t + c_1 U_1^t (P_{b1}^t - P_i^t) + c_2 U_2^t (g_b^t - P_i^t)$	PSO, EP
24	[29]	2017	Optimal allocation of STATCOM	IEEE-30 Bus	$\Delta V = \sum_i \frac{\xi_i \eta_i}{\lambda_i} \Delta Q$ $L_v = \left(\sqrt{\sum_{i=1}^{n} \left(\frac{v_{iref} - v_i}{v_{iref}} \right)} \right)^2$	GSHA

25	[30]	2015	Optimal installation of SVC for reduction in losses, L-index and improvement in power quality.	IEEE-14 Bus, IEEE 30-Bus	$L_j = \left\|1 + \frac{V_{oj}}{V_j}\right\| = \frac{S_j^+}{Y_{jj} V_j^2}$ $V_{oj} = -\sum_{i \in \alpha_G} F_{ji} V_i$	HAS, MOP
26	[31]	2014	Minimize voltage deviation	IEEE-30 Bus	$VD = \sum_{k=1}^{NL} \|(V_k - V_k^{ref})\|$	NSGA-II

CONCLUSIONS

Modern power system is prone to voltage collapse and instability due to overloaded transmission lines. One of the solutions to this problem is installation of FACTS devices. Integrating FACT devices in power system mitigates line overloading, voltage stability, improves power flow and reduces losses. However, these devices need to be allocated optimally in terms of position, size and rating to extract maximum benefit. Optimal allocation of FACT devices thus becomes an optimization problem. This paper presents literature survey on different techniques for allocation of Static Var Compensator FACT device in power system. A wide range of research work reported under the area of FACTS devices, especially SVC is summarized. Comparative of different works is presented in term of objectives, methodology, test systems and outcomes in a simple and comprehensible format. The literature review presented in this paper can be useful in understanding summary of the research that has been reported till date for allocation of SVC in power system.

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