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# A Survey on STATCOM Techniques

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## ABSTRACT

The Static Var Compensator (SVC) and the Static Synchronous Compensator (STATCOM), as two components of Flexible AC Transmission System (FACTS) devices, play an important role in controlling the reactive power flow to the power network. Because of economic considerations, identifying the best location for installing the SVC and STATCOM is also important. The FACTS devices placement problem is commonly solved using heuristic optimization techniques which are diverse and have been the subject of ongoing enhancements. This paper presents a survey of the literature from the last decade that has focused on the various heuristic optimization techniques applied to determine optimal placement and sizing of the SVC and STATCOM.

**Streszczenie.** W artykule analizuje się optymalne usytuaowanie elementów SVC I STATCOM w systemie FACTS. Przedstawiono stan wiedzy wykorzystania do tego celu różnych heurystycznych metod optymalizacji. (**Optymalne usytuowanie elementów SVC i STATCOM w systemie FACTS**)

**Keywords:** *Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Heuristic Optimization, Placement, Sizing.*
**Słowa Kluczowe :** SVC – statyczny kompensator mocy biernej, STATCOM – statyczny kompensator synchroniczny

## I. INTRODUCTION

Flexible AC Transmission Systems (FACTS) can provide benefits in increasing system transmission capacity and power flow control flexibility and speed [1]. FACTS devices are power electronic converters that have the capability to control various electrical parameters in transmission circuits and facilities, both in steady state power flow and dynamic stability control [2]. These devices include Thyristor Controlled Series Compensator (TCSC), Static Var Compensator (SVC), Unified Power Flow Controller (UPFC), Static Compensator (STATCOM), and others [3]. The SVC is the most widely used shunt FACTS device in power networks because of its low cost and good performance in system enhancement. It is a shunt- connected static Var generator or absorber with an adjustable output, which allows the exchange of the capacitive or inductive current so as to provide voltage support. When installed at a proper location, the SVC can also reduce power losses [4]. The STATCOM is also a shunt compensator and one of the important members of the FACTS family that are increasingly being used in long transmission lines in modern power systems. STATCOMs can have various applications in the operation and control of a power system, such as in power flow scheduling, reducing the number of unsymmetrical components that damp the power oscillations, and enhancing the transient stability [5].

The benefits of reactive power compensation greatly depend on the placement and size of the added compensators. The installation of shunt controllers in all buses is impossible and unnecessary because of economic considerations. Identifying the best location for Var compensators involves the calculation of steady-state conditions for the network. However, the problem becomes highly complex because of the nonlinearity of the load flow equations, and an extensive investigation has to be undertaken in order to solve it.

Several studies on the use of these controllers for voltage and angle stability applications have been conducted and reported in the literature. A variety of methods are used to optimize the allocation of these devices in power systems. These methods may be classified into the following categories [6]:

- Loss sensitivity analysis
- Voltage stability analysis using modal analysis and Continuation Power Flow (CPF)
- Cost analysis using Optimal Power Flow (OPF)
- Heuristic optimization techniques

From the categories, the heuristic optimization techniques have been widely applied in solving the optimal SVC and STATCOM placement problem. In this work, a comprehensive analysis of the heuristic optimization techniques for optimal placement and sizing of SVCs and STATCOMs that have been proposed recently by various researchers is presented. This analysis includes important heuristic optimization techniques such as Evolution Strategies (ESs), Genetic Algorithms (GAs), Simulated Annealing (SA), Particle Swarm Optimization (PSO), and Harmony Search (HS) algorithms used in solving power system optimization problems. In addition, applications of hybrid techniques in optimal shunt FACTS device placement problems are discussed.

## II. METHODS AND MATERIAL

### 1. *Characteristics of SVC and STATCOM*

Shunt compensation is used to influence the natural electrical characteristics of transmission lines to increase the steady-state transmittable power and control the voltage profile along the line [7]. Providing adequate reactive power support at the appropriate location not only leads to a reduction in the power loss and improvement in the voltage profile, but also solves voltage instability problems. Many reactive compensation devices are used by modern electric power utilities for this purpose, and each device has its own characteristics and limitations. At present, utilities aim to achieve this purpose using the most beneficial compensation device [8]. Among the reactive compensation devices the SVC and STATCOM play an important role in controlling the flow of reactive power to the power network, thereby affecting the voltage fluctuations and stability of the system. Descriptions of the characteristics of SVCs and STATCOMs are given in the next subsections.

### 1.1. SVC

The SVC is a shunt-connected static Var generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control a specific power system variable [9,10]. Typically, the power system control variable is the terminal bus voltage. SVCs have two popular configurations. One configuration consists of a Fixed Capacitor (FC) and a Thyristor-Controlled Reactor (TCR) and the other consists of a Thyristor-Switched Capacitor (TSC) and TCR. In the limit of minimum or maximum susceptance, the SVC behaves like a fixed capacitor or an inductor. The choice of the appropriate size is one of the important issues in the application of SVCs in voltage stability enhancement [11].

### 1.2. STATCOM

The STATCOM is a voltage-source, converter-based device that converts a DC input voltage into an AC output voltage to compensate for the active and reactive needs of the system. STATCOMs have better characteristics than SVCs. When the system voltage drops sufficiently to force the STATCOM output to its ceiling, its maximum reactive power output is not affected by the voltage magnitude. Therefore, the STATCOM exhibits constant current characteristics when the voltage is below the limit [10]. A schematic diagram of an SVC and a STATCOM is shown in Fig. 1. Figure 2 shows the terminal characteristics of the SVC and STATCOM [11].

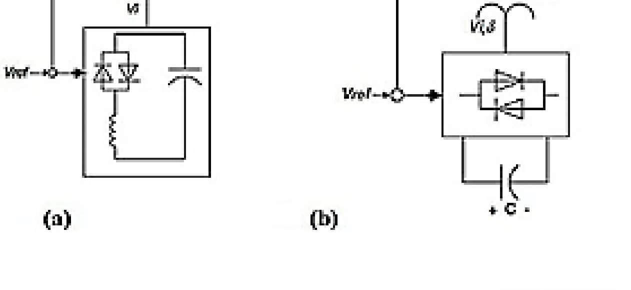

**Figure 1.** Basic structure of (a) a static Var compensator (SVC); and (b) a static synchronous compensator (STATCOM)

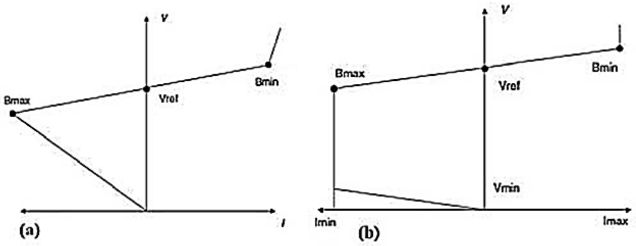

**Figure 2.** Terminal characteristics of (a) SVC; and (b) STATCOM

## 2. Application of Heuristic Optimization Techniques for Optimal Placement and Sizing of SVC and STATCOM

Recently, heuristic optimization techniques have become a popular choice for solving complex and intricate problems which are otherwise difficult to solve by traditional methods [12]. In the past few decades, several global optimization algorithms have been developed that are based on the nature inspired analogy. These are mostly population based heuristics, also called general purpose algorithms because of their applicability to a wide range of problems [12]. Some popular global optimization algorithms include ESs [13], GAs [14,15], SA [16], Artificial Immune Systems (AIS) [17], Ant Colony Optimization (ACO) [18], PSO [19] , HS algorithms [20], Bee Colony Optimization (BCO) [21], and others.

This section presents the basic knowledge of evolutionary computation and other heuristic optimization techniques as well as how they are combined with knowledge elements in computational intelligence systems. Applications to the optimal placement and sizing of SVCs and STATCOMs in power networks are emphasized, and recent research is presented and discussed.

Figure 3 shows the number of published research papers that have addressed the optimal shunt FACTS devices problem using heuristic optimization techniques during the last eight years. A review is also made on the use of heuristic optimization techniques in optimal placement and sizing of SVC and STATCOM.

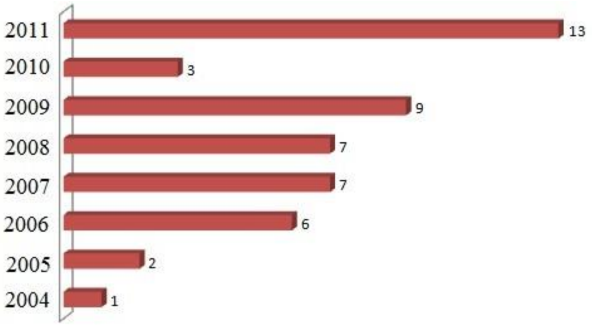

**Figure 3.** The number of papers published each year on the subject of optimal placement and sizing of SVC and STATCOM

### 2.1. Evolution Strategies (ES)

The ES optimization technique was introduced in the early 1960s and developed further in the 1970s by Rechenberg and Schwefel at the University of Berlin in Germany. It was originally created to solve technical optimization problems, and its first application was in the area of hydrodynamics [22]. Nowadays, the ES is recognized as a very strong optimization method capable of solving large scale, multimodal, highly constrained, nonlinear problems [23]. The main search procedure in the ES is the mutation operator that generates random samples around search points (solution candidates) selected from a population of different search points. The original strategy, denoted by 1+1, generates one offspring from a single parent by applying mutation. If the child performs better than its ancestor, it will be the parent of the next generation [24].

An ES was developed to obtain the best points of operation of FACTS devices [25]. The objective function was defined to adjust the control variables of the SVC, STATCOM, and UPFC in order to improve the power system operation by reducing losses that electric network suffers under a certain load condition, taking into account the voltage drop constraints and operation limits of the devices. The ES developed in this paper was applied to various power systems with satisfactory results and low computational effort. The ES was used as an optimization technique which allowed the correct adjustment of control variables associated with the FACTS controllers to be determined. ES was also used to find the optimal placement of FACTS devices such as SVC, TCSC, and

UPFC in power system with the objective of maximizing system loadability [22].

### 2.2. Genetic algorithm (GA)

GA is one of the most popular types of evolutionary algorithms. To be more precise, it constitutes a computing model for simulating natural and genetic selection that is related to the biological evolution described in Darwin's Theory [14,15]. In this computing model, a population of abstract representations called as chromosomes or the genome of candidate solutions called as individuals, to an optimization problem could result in better solutions, which are traditionally represented in binary form as strings comprised of 0s and 1s with fixed length. But other kinds of encoding are also possible which include real values and order chromosomes. The program then assigns proper number of bits and coding [12].

Being a member of the evolutionary computation family, the first step in GA is population initialization, which is usually done stochastically. GA usually uses three simple operators called as selection, recombination or crossover and mutation [12]. Selection is the step of a GA in which a certain number of individuals are chosen from the current population for later breeding (recombination or crossover); the rate of choosing is normally proportional to the individual's fitness value. There are several general selection techniques, namely, tournament selection and fitness proportionality selection which is also known as roulette-wheel selection. Other techniques only choose those individuals with a fitness value greater than a given arbitrary constant. Taken together, crossover and mutation are called reproduction which is analogous to biological crossover and mutation [12].

Talebi et al. [26] used GA for SVC placement with the objective of load balancing during a specific period of time. The unbalanced treatment of some real samples of the feeders was studied and the effect of SVC application was simulated. Simulation results demonstrated that optimal use of the SVC can balance load current and decrease unfavourable effects considerably. Financial analysis showed that this technique is optimal from the economic point of view.

A GA based optimization procedure has been implemented to find the best placement, type, and size of selected FACTS devices for reducing total financial losses in the network caused by voltage sags [27]. Three types of FACTS devices were considered, namely, SVC, STATCOM, and Dynamic Voltage Restorer (DVR). Farsangi et al. [28] used power system stability as an index for optimal allocation of the controllers. First, several SVCs were optimally placed in a power system on the basis of modal analysis and a GA. After placing the SVCs on the basis of their primary functions, the most appropriate input signal for the supplementary controller was selected. The frequency response characteristics of the system for all located SVCs were determined by selecting the best input signals.

Another GA based allocation of FACTS devices considered the cost function of FACTS devices and power system losses [29]. Simulation of the test system for different scenarios showed that the placement of multi-type FACTS devices leads to an improvement in the voltage stability margin of power system and reduction of losses. A messy GA-based optimization scheme for voltage stability enhancement of power systems under critical operation conditions was presented in [30]. The multi-objective optimization was transformed into a fuzzy decision problem with a single objective function, which was decomposed into two sub-problems. In the main sub-problem, the messy GA performs a search for the optimal SVC reinforcement that optimizes the SVC performance. At each step of GA searching, the Lagrange multiplier techniques are used to solve the second sub-problem, to calculate the system's worst-case Var margin, the power losses, and the voltage magnitudes for a given SVC placement. The proposed optimization scheme took into account all system constraints and nonlinear effects and focused upon system performance under most critical conditions.

An application of GAs has been presented for finding the best location of SVC within a power network with the objective of reducing power losses and reducing voltage deviations and costs [31]. For simplicity, the placement of only one SVC device was addressed and the improvements were assessed with respect to voltage deviation and power loss reduction in the network.

An optimization method termed "the Queen Bee assisted GA" has been explored to obtain optimal placement of FACTS devices for voltage profile enhancement [32]. The proposed algorithm is a modification of the standard GA incorporating the evolutionof a queen bee in a hive. This algorithm converges much faster than the standard

GA with smaller number of parameters and reduced computational burden. A performance criterion using a voltage stability index was defined to quantify voltage stability at any given bus. The effectiveness of the approach was confirmed through simulation results.

The Non-Dominated Sorting Genetic Algorithm (NSGA) has been used for continuous, discrete, and multiple placement of five MVars of compensator devices in the IEEE 57-bus test system [33]. The problem was planned as a multi-objectives problem, while taking into account the active power losses, using compensation devices such as the SVC and TCSC. The results illustrated that the non- dominated solutions obtained were well distributed and had satisfactory range characteristics.

GA was also applied for solving both the inter-area congestion and oscillation issues in a high voltage transmission system by installing FACTS devices [34]. The algorithm considered a multi-objective approach and two FACTS devices, namely SVC and TCSC. The multi- objective optimization was studied for a wide range of weights on the objective functions. The results showed the potential of the algorithm in providing system operator with useful information for making the correct decision according to its criteria.

Tavakoli et al. [35] examined the average model of STATCOM in the time domain and then adapted its power flow analysis. A combinatorial optimization was arranged which focused on voltage stability, reactive power, and losses of transmission lines as three main objectives for the power system. GA was employed to seek the optimal solution for sizing and placing STATCOMs across the IEEE 14-bus network, while a correcting power ratio was defined for adapting the optimized values with those obtained by the average model.

An approach based on sensitivity analysis and GA was applied to optimally locate STATCOM in a distribution network [36]. A step-by-step sensitivity analysis approach is utilized to find optimal placement of compensators. In this process, a compound voltage-loss sensitivity index is used to meet various optimization requirements. In the next step, reactive power injection of the STATCOM is defined by the GA. The objective function takes into account voltage stability, reduction of active losses and reduction of reactive power in a power network.

### 2.3. Simulated Annealing (SA)

Based on the analogy between statistical mechanics and optimization, SA is one of the most flexible techniques available for solving difficult optimization problems. The main advantage of SA is that it can be applied to large- scale systems regardless of the conditions of differentiability, continuity, and convexity, which are usually required for conventional optimization techniques [12]. SA was originally proposed by Metropolis in the early 1950s as a model of the crystallization process. The SA procedure consists of first melting the system being optimized at a high temperature, and then slowly lowering the temperature until the system freezes and no further change occurs. At each temperature instant, annealing must proceed for long enough for the system to reach a steady state [16].

A method based on the SA and Lagrange multiplier techniques for optimal placement of SVCs was presented in [37]. A four-step procedure was proposed for synthesizing the optimal reactive reinforcement for a selected design configuration. The procedure maximized the reactive margin of a design configuration as the criterion. The optimal SVC placement was realized by solving two sub-problems. The SA performed a search for the optimal SVC reinforcement which maximized the reactive margin of the power system.

Gitizadeh and Kalantar proposed an approach based on SA and Sequential Quadratic Programming (SQP) in the optimization process for optimally locating TCSC and SVC [38]. The problem was formulated according to the SQP problem in the first stage to accurately evaluate the static security margin with the congestion alleviation constraint in the presence of FACTS devices, and in the next stage an SA based optimization technique was used to find an optimal solution. The simulation results showed that this placement approach reduced congestion in the transmission lines and enhanced distance of the voltage collapse point without the use of procedures with a high computational burden such as the CPF method.

## 2.4. Particle swarm optimization (PSO)

PSO algorithm belongs to the category of evolutionary computation for solving global optimization problems. The the PSO algorithm was first introduced for solving optimization problem in 1995 by Eberhart and Kennedy [19]. PSO is a well-known and popular search strategy that has gained widespread appeal amongst researchers and has been shown to offer good performance in a variety of application domains, with potential for hybridization and specialization. It is a simple and robust strategy based on the social and cooperative behaviour shown by various species like flocks of bird, schools of fish, and so on. PSO and its variants have been effectively applied to a wide range of real life optimization problems [12].

A modified PSO approach has been developed for determination of the global or near global optimum solution for optimal location of TCSCs and SVCs considering economic saving in the objective function [39]. The non- dominated sorting PSO has been used to solve a mixed continuous discreet multi-objective optimization problem which consists of optimizing the location and size of SVCs and TCSCs in order to maximize the static voltage stability margin, reduce power losses, and minimize the load voltage deviations [40]. While finding the optimal location, thermal limits for the lines and voltage limits for the buses were taken as security constraints.

Optimization of the location of FACTS devices has been found to minimize the cost of installation of FACTS devices and to improve system loadability for single- and multi-type FACTS devices using the PSO technique [1]. Simulations were performed on the IEEE 6, 30, 69 and 118 bus systems and Tamil Nadu Electricity Board 69 bus system. The multi- objective PSO has been used to solve a mixed continuous- discrete multi-objective optimization problem in order to find optimal location of SVC [41]. A contingency analysis to determine the critical outages with respect to voltage security was also examined in order to evaluate their effect on the SVC location analysis.

The applicability and effectiveness of modern heuristic optimization techniques using GA, PSO and evolutionary PSO (EPSO) for solving the SVC placement problem was investigated in [42]. The main objective of the problem was to find the optimal number and sizes of the SVC devices to be installed in order to minimize the load margin deviation and SVC installation cost. The results showed that the number of iterations required to obtain the optimal solution through PSO or EPSO is less than that required with GA. Moreover, a comparison of the results obtained by GA, PSO, and EPSO techniques showed that PSO based techniques outperform others in terms of calculation time and avoidance of trapping in local minima. The GA, PSO and EPSO techniques have also been applied successfully to a large scale mixed-integer nonlinear programming reactive power planning problem [42].

An approach for transmission loss reduction by using SVC installation via PSO as the optimization technique was also presented [43]. The source code of the PSO optimizations technique was developed to determine the optimal sizing of the SVC in order to minimize the transmission loss in the system. Besides that, the voltage profiles and cost of SVC installation were also considered.

A method for determining minimum voltage deviations obtained from using FACTS devices was presented in [44]. A PSO technique was used to obtain the minimum voltage deviation and active power loss by optimally locating the SVC. The technique was able to find the optimal solution with regards to the global best position and size of the SVC. The PSO technique has also been used to solve a multi- objective optimization problem for minimizing total power loss and maximizing the total transfer capability simultaneously through optimal placement and rating of SVC [45]. The problem was divided into two parts in which the first part considered optimal placement of SVC using a line loss sensitivity index and the second part considered solving the multi-objective optimization for minimizing power loss and maximizing total transfer capability with system constraints like power balance, voltage limits, and line thermal limits using PSO to calculate the optimal SVC parameters.

Another PSO method has been proposed for attaining the maximum instantaneous wind penetration by optimal placement and setting of FACTS controllers [46]. Multiple SVCs were used to achieve the maximum wind penetration and the PSO technique was developed to obtain the maximum instantaneous penetration by adjusting the grid parameters and FACTS controller settings. Del Valle et al. [47] demonstrated the application of PSO for optimal sizing and location of STATCOM in a power system, considering voltage deviation constraints at each bus. Results from the illustrative example showed that the PSO is able to find the solution with the best size and location with a high degree of convergence and with statistical significance when the minimum, maximum, average and standard deviation values of the voltage deviation metric are evaluated.

Hernandez et al. [48] demonstrated the feasibility of applying the PSO technique in solving optimal allocation of a STATCOM in a 45-bus section of the Brazilian power system. The technique was able to find the best location for the STATCOM in order to optimize the system voltage profile with a low degree of uncertainty. Another approach for optimal placement of STATCOMs in power systems was proposed using simultaneous application of PSO and CPF in order to improve the voltage profile, minimize the power system's total losses, and maximize the system loadability with respect to the size of the STATCOM [5].

The PSO technique has also been applied to determine the optimal location and controller parameters of STATCOM [49]. Here, a systematic procedure to determine the optimal location of the STATCOM for transient stability improvement following a severe disturbance was presented. The application of PSO for sizing and locating a STATCOM in a power system while considering voltage deviation constraints was demonstrated in [50]. Results from the illustrative example showed that the PSO techniques is able to find the best size and location with statistical significance and a high degree of convergence when evaluating the minimum, maximum, average, and standard deviation values of the voltage deviation metric.

To find the optimal location and sizing of a STATCOM in a power system for voltage profile improvemen, different variations of the PSO techniques have been applied [51]. From among the various PSO techniques, namely, the classical PSO, PSO time varying inertia weight, PSO random inertia weight and PSO time varying acceleration coefficients (PSO-TVAC), the PSO-TVAC model was found to be superior in terms of computational speed and accuracy of solution [51]. The effect of population size and initial and final values of acceleration coefficients was also investigated in this paper.

## 2.5. Harmony Search (HS) Algorithm

The HS algorithm is an optimization technique that is inspired by musicians improvising their instrument pitches to find better harmony [20]. In the same way as musical instruments can be played with discrete musical notes based on player experience or based on random processes in improvisation, optimal design variables can be obtained with certain discrete values based on computational intelligence and random processes [52]. Music players improve their experience based on aesthetic standards while design variables in computer memory can be improved based on an objective function. Among the advantages of the HS algorithm are that it can consider both discontinuous and continuous functions because it does not require differential gradients, it does not require initial value setting for the variables, it is free from divergence, and it may escape local optima [52].

The HS algorithm has been applied to determine the optimal location of FACTS devices such as UPFC, TCSC, and SVC in a power system to improve power system security [53]. Line overload and bus under-voltage were solved by controlling the active and reactive power of the series and shunt compensator, respectively. Another method for placement of multi-type FACTS devices such as SVC, Thyristor Controlled Phase Angle Regulators (TCPARs), and UPFC using HS algorithm was presented in [54]. The optimization criteria considered were the voltage stability index and minimization of losses. To investigate these objectives, different scenarios were considered. In the first scenario, the TCPAR, UPFC, and SVC were placed exclusively in transmission lines and indices were calculated. Then, two types of the above controllers were tested to improve the parameters randomly. Next, three types of controllers were implemented simultaneously to improve the voltage stability index and losses.

The application of the Improved Harmony Search (IHS) algorithm for determining optimal location and sizing of SVC in a transmission network was presented in [4]. The proposed multi-objective IHS algorithm was validated on a 57-bus transmission network and the obtained results showed that the IHS algorithm gave greater reduction in power loss, voltage deviation, and total costs compared to using the PSO technique.

### 2.6. Hybrid Artificial Intelligence Techniques

To create a hybrid intelligent system, two or more artificial intelligence techniques are applied. During the last decade, hybrid systems have been applied in engineering applications. A combination of the micro-GA and fuzzy logic has been used to optimize the various process parameters of four different FACTS devices such as the TCSC, TCPAR, UPFC, and SVC in a power system [55]. In the first stage, fuzzy logic was applied to reduce the search space. The second stage followed a micro-GA which worked only with previously known buses. The various parameters take into consideration the location of the FACTS devices, their types and rated values to ensure the quality of power supply to the consumer without overloading lines and with an acceptable voltage level.

A hybrid PSO-GA was proposed in [56] to obviate the drawbacks of both PSO and GA. This algorithm was applied to solve the optimal locating of the SVC devices in an IEEE 68-bus test system. The results showed that the new hybrid algorithm was more effective and efficient than using PSO and GA separately. A combination of Modified Simulated Annealing (MSA) and PSO techniques has been proposed to minimize total losses in a power system with FACTS devices [57]. The problem was decomposed into two sub- problems in which the first sub-problem considered optimal placement of FACTS devices using a line loss sensitivity index and the second sub-problem considered load flow with FACTS parameters using the MSA/PSO techniques.

The effect of SVC controller on the total transfer capability (TTC) of power transactions between source and sink areas using hybrid Genetic Algorithm–Sequential Quadratic Programming (GASQP) was presented in [58]. By using this hybrid method, the SQP speeds up the solving procedure while the GA enables the algorithm to escape from local optima. The proposed algorithm was used to determine the optimal placement of the SVC controller and to solve the OPF to enhance the TTC simultaneously. The proposed OPF was used to evaluate the feasible TTC value within real and reactive power generation limits, line thermal limits, voltage limits, and SVC operation limits.

In [59], to increase the accuracy of the new generated solutions, the BCO and HS algorithms were integrated to form a hybrid algorithm for finding optimal placement and sizing of SVCs in transmission systems. Here, optimal placement of five SVC devices has been addressed for voltage profile improvement and power loss reduction in the 57-bus test system. The obtained results were compared with the PSO, IHS algorithm, and BCO for validation.

### 2.7. Other Optimization Techniques

An AIS technique was used to determine the location of the SVC in order to minimize losses in the system [60]. An optimization technique based on the Low Discrepancy Sequences (LDS) has been employed to solve the optimal placement of FACTS devices in a power network to minimize the costs of both active and reactive power generation [61]. The LDS is, in principle, a uniform scattering of points in a space bounded originally between 0 and 1. In this study, four types of FACTS devices, namely, the SVC, thyristor-controlled voltage regulator, thyristor- controlled phase shifting transformer, and thyristor- controlled series capacitor were considered. The optimization procedure selected the number, size, type and location of these FACTS devices while at the same time considering the costs of individual FACTS devices.

A Group Search Optimizer with Multiple Producers (GSOMP) has been applied for solving reactive power dispatch problem incorporating FACTS devices [62]. The location of multi-type FACTS devices and their control parameters were optimized by GSOMP to minimize real power loss and improve the voltage profile. The group search optimizer is inspired by group-living which is a phenomenon of the animal kingdom. A multi-start Benders decomposition technique to maximize the loading margin of a transmission network through the placement of SVCs was presented in [64]. The proposed algorithm was proven to be efficacious in identifying optimal or near-optimal solutions and robust with regard to computational behaviour.

## III. RESULTS AND DISCUSSION

### Comparison of Various Heuristic Optimization Techniques

The number of publications and the heuristic optimization techniques applied to solve the optimal SVC and STATCOM placement problem in the specified period are shown in Fig. 4. The PSO, GA, and hybrid methods have been the most popular optimization techniques for solving the optimal SVC and STATCOM placement problem in the last decade.

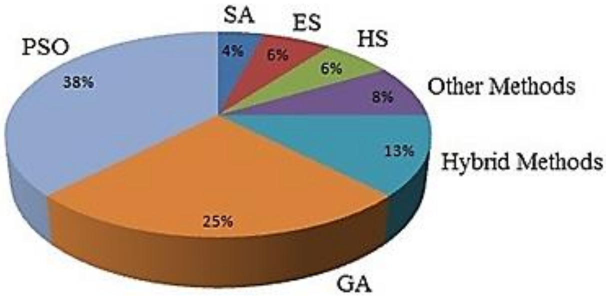

**Figure 4.** Number of papers published on different heuristic optimization techniques for optimal placement and sizing of SVCs and STATCOMs

From the figure, PSO is the most popular technique applied because of its advantages, which include simple implementation, small computational load, and fast convergence. PSO is efficient for solving many problems for which it is difficult to find accurate mathematical models. However, the PSO algorithm is prone to relapsing into local minima and premature convergence when solving complex optimization problems. The GA, which is considered one of the first global optimization techniques for solving the optimal FACTS placement problem, has some drawbacks such as divergence and local optima problems. Many recent publications use hybrid techniques or multi-stage methodologies to find the optimal locations and sizes of SVCs and STATCOMs. In most of these hybrid techniques, approaches are proposed to find the critical buses, while other optimization techniques such as PSO and GA are used to find the optimal sizes of the SVC and STATCOM.

## IV. CONCLUSION

This paper presents a bibliographical survey of the published work on the application of different heuristic optimization techniques to solve the problem of optimal placement and sizing of SVCs and STATCOMs in power systems. Various heuristic optimization techniques that have been used to address the problem are summarized and classified, including their advantages and limitations. The paper also provides a general literature survey and a list of published references as essential guidelines for the research on optimal placement and sizing of SVCs and STATCOMs.

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