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Review

A Review on Optimization Objectives for Power System Operation Improvement Using FACTS Devices

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Abstract: In recent decades, the rapid rise in electricity demand has compelled transmission and distribution systems to operate at almost their maximum capacity. This can pose numerous technical challenges such as excessive power losses, voltage and transient instabilities, as well as reduced power quality and reliability. Employment of Flexible Alternating Current Transmission System (FACTS) devices can be an effective approach to obviate such challenges and reinforce the power system functionality. Nevertheless, FACTS devices require a high initial investment, and hence their optimal allocation in terms of various aspects such as type, size and location is of utmost importance. This cannot be achieved without the deployment of optimization techniques. The aim of this paper is to provide a comprehensive review of the existing proposals for the enhancement of power system performance adopting FACTS devices. Adhering to that, an in-depth analysis is carried out, in which the most pertinent options are classified into specific groups based on their optimization objectives. Finally, a comparative analysis is accomplished in which the main attributes and drawbacks of each optimization technique are presented.

Keywords: FACTS devices; optimization techniques; power system performance

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1. Introduction

Owing to the growing dependency on the power system, the economy and service sectors of the modern world are substantially swayed by its quality and reliability. The boost of technology has catalyzed the proliferation of businesses and industries in recent years, and, as a consequence, the energy demand is rapidly rising. This growth of energy consumption has triggered metastasis in the number of power companies, causing fierce competition in the market. Since various electric power companies compete with each other to supply cheaper electricity to the consumers, they exert intense pressure on the transmission lines to run near the operating limits. Apart from that, uneven distribution of loads is frequently encountered in the power systems which adversely affects the voltage profile and enhances the vulnerability of the networks to the short-circuit. Therefore, the power systems are recently faced with a plethora of technical issues encompassing transmission congestion, power losses, voltage drop, rise in transients, etc. In order to ameliorate these issues, Flexible Alternating Current Transmission System (FACTS) devices came into existence [1,2].

Since the initial development of FACTS devices, they have been found to be very effective in mitigating power system challenges. However, they are relatively expensive, and if they are not properly employed, their investment fees might surpass their saved energy cost. To obviate this challenge and to maximize the economical benefits provided by FACTS devices, deployment of optimization techniques is inevitable. The main purpose of utilizing these techniques is to improve various aspects of power system performance through optimal allotment of FACTS devices [3].

In recent years, several review articles have discussed the main merits and demerits of the available techniques addressing the challenge of optimal allocation of FACTS devices. Ref. [4] provides a comprehensive review of optimal placement and sizing of various types of FACTS via the deployment of multiple optimization techniques. In this study, details of several FACTS devices, numerous optimization techniques, and their working principles are included. Ref. [5] provides another review article in this field. In this study, retrospection of various generations of FACTS devices and several examples of optimal allocation of FACTS devices using optimization techniques are encompassed. Review of the operation and reliability impacts of FACTS technologies for the enhancement of power quality and security of modern cyber-physical power systems is conducted in [6]. In this study, FACTS devices based on different generation and connection types are discussed. In addition to that, the relevance of cyber-physical power systems and their integration with distributed FACTS technology is interpreted. In [7], a survey is carried out on optimal reactive power dispatch using FACTS devices. In this work, the reactive power dispatch design is discussed for line loss minimization, total voltage deviation, and cost minimization. In addition to that, modeling of FACTS devices such as TCSC and SVC for reactive power dispatch is included. Ref. [8] provides a review of congestion management deploying FACTS devices. Additionally, a case study encompassing detailed market analysis under N-1 contingency cases with optimally allocated TCSC is discussed employing the PSO technique while also taking voltage deviation and losses into the consideration. An extensive review of the distribution system with distributed generation and distributed FACTS allocation is performed in [9] for the improvement of voltage profiles, reduction in line losses, and amelioration of loadability. A reflection on various past research conducted for the optimal allocation of UPFC device in electric power systems is provided by [10]. In this study, various sensitivity analysis-based methods, conventional optimization-based methods as well as artificial intelligence-based methods used for allocation of UPFC are included. In [11], a retrospection of several research regarding the configuration method of FACTS devices is comprehended. Ref. [12] presents a review of the Social Group Optimization (SGO) technique focused on the enhancement of power capability encompassing combined TCSC-UPFC deployment. In the presented work, the impact of employing TCSC and UPFC is closely scrutinized for the reduction of power losses and sustaining voltage stability in the power system. Moreover, a study on several research regarding optimal reactive power dispatch encompassing FACTS devices and renewable energy sources is delineated in [13].

Despite numerous review articles covering the most recent research works in the field of optimal allocation of FACTS devices, the majority of them have only focused on individual or a few objectives such as improvement of transient stability, cost optimization, etc. In other words, such articles have failed to incorporate several other objectives behind the optimal allocation of FACTS devices using optimization techniques. To address this issue, the present paper aims to encompass various objectives behind the optimal allocation of FACTS devices in a single review article. Moreover, a taxonomy of the reviewed articles is presented where the information about deployed FACTS devices, adopted optimization techniques, and their additional benefits are illustrated. In addition to that, a large number of optimization techniques have been classified based on their origin, salient features, as well as limitations. This will provide valuable knowledge to the researchers while making selection of a particular FACTS device and optimization technique based on the research objectives and the nature of optimization problem.

The remainder of this paper is organized as follows: Section 2 explicates the significance of FACTS devices in the power systems and classifies various types of FACTS devices and optimization techniques; Section 3 elaborates various objectives of optimization in power systems, for which FACTS devices are optimally allocated; in Section 4, a comparative assessment for different optimization techniques is presented; and, finally, the conclusions are reported in Section 5.

2. Classification of FACTS Devices and Optimization Techniques

The rapid enhancement of demand, the essentialness of economic efficiency and optimal operation of power systems, as well as the huge investment required for construction of new power networks have provoked inevitable challenges such as excessive congestion of transmission lines, low energy efficiency, voltage instability, reduced power quality and reliability, and voltage profile problems. To remedy such challenges and to reinforce the power system performance, the recently developed FACTS devices are extensively utilized around the world.

FACTS devices can be classified into two generations. The first generation included thyristor switched capacitors, reactors and quadrature tap changing transformers which resulted in the development of Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC) and Thyristor Controlled Phase Shifter (TCPS) [2], whereas the second generation comprised Gate Turn Off thyristor (GTO) switched converters which provoked the development of Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), Interline Power Flow Controller (IPFC), etc. [3]. FACTS devices can also be grouped into the following four categories based on their connection type to the power system as shown in Figure 1:

- Series FACTS devices: The FACTS devices in this category are connected in series to the power system. Interphase Power Controller (IPC), Thyristor Controlled Phase Angle Regulator (TCPAR), Thyristor Switched Series Capacitor (TSSC), TCSC, Thyristor Switched Series Reactor (TSSR), SSSC, Thyristor Controlled Series Reactor (TCSR) are some examples of series FACTS devices;
- Shunt FACTS devices: Shunt FACTS devices include Dynamic Voltage Restorer (DVR), STATCOM, SVC, Mechanically Switched Capacitor (MSC), Thyristor Switched Reactor (TSR), etc., which are connected in parallel with the power system. These devices are advantageous for reactive power flow control, alleviation of grid losses, refinement in power quality, static and transient stability, etc;
- Series-Series FACTS devices: IPFC is the most commonly used type of series-series FACTS devices. The main purpose of deploying IPFC instead of other FACTS devices is that it can provide series compensation for a required transmission line in the power system. Moreover, IPFC can control power flow across different lines of the power systems simultaneously. Generalized Interline Power Flow Controller (GIPFC) is another type of series-series FACTS device;
- Series-Shunt FACTS devices: These FACTS controllers include both series and shunt-connected devices. FACTS devices based on this topology are UPFC, Generalized United Power Flow Controller (GUPFC), Unified Power Quality Conditioner (UPQC), Unified Dynamic Quality Conditioner (UDQC), Hybrid Power Flow Controller (HPFC), Thyristor Controlled Phase Shift Transformer (TCPST), etc;

Since FACTS devices require a high initial investment, their type, size, and location should be properly optimized based on each objective for the power system performance improvement [14,15]. In terms of the number of objectives, the optimization techniques might be single-objective or multi-objective. Multi-objective optimization techniques can be further categorized into dominated and non-dominated sorting algorithms, from the objective's priority perspective. In the non-dominated algorithms, the compromise between various objectives gives rise to a Pareto optimal front of solutions, whereas dominated techniques give more priority to one certain objective over other objectives.

Optimization techniques can be also grouped into three types based upon the history of their development, i.e., Classical Analytical-Based Methods (CABMs), Classical Arithmetic Programming-Based Algorithms (CAPBAs), and Modern Metaheuristic-Based Algorithms (MMBAs), as indicated in Figure 2. The CABMs are optimization techniques that have the advantage of computing efficiency and provide useful information about the impact of different scenarios on the optimization objective. However, they are time-consuming and may not be used for large-scale power systems. The CAPBAs are another type of optimization techniques which have effective convergence characteristics, but they are often inefficient in dealing with constrained optimization problems. The MMBAs are the most commonly used optimization techniques that are suitable for solving multi-objective problems since they can find multiple optimal solutions in a single run.

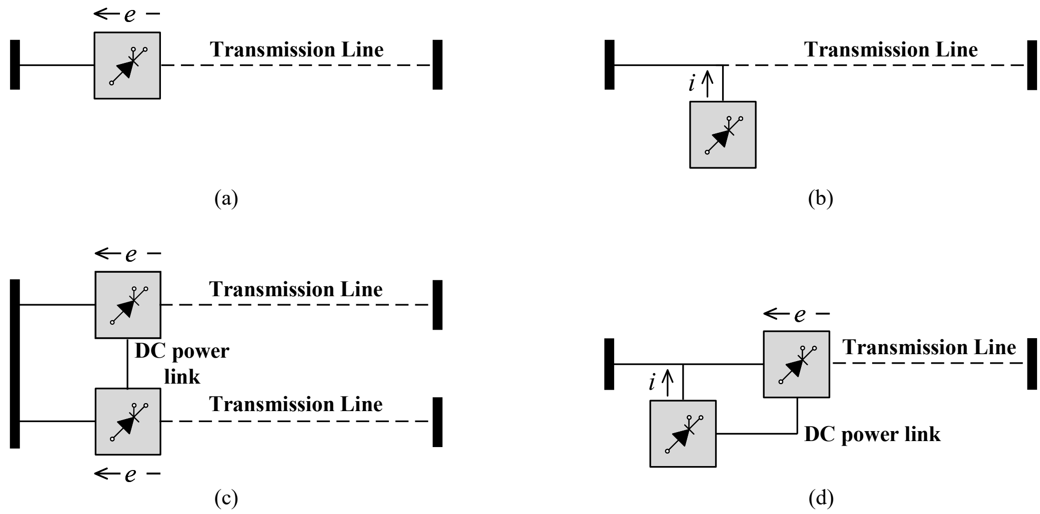

Figure 1. Different kinds of FACTS devices based on their connection type to the power system. (**a**) series; (**b**) shunt; (**c**) series-series; and (**d**) series-shunt.

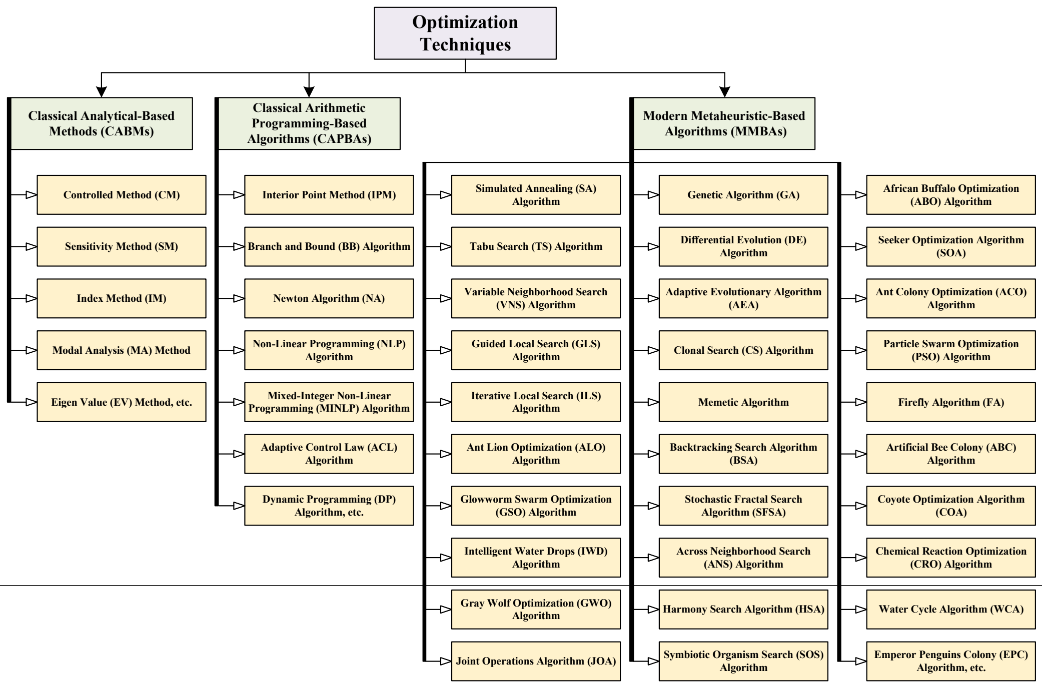

Figure 2. Classification of optimization techniques.

3. Optimization Objectives for Power System Performance Improvement

Figure 3 displays various objectives of optimization, for which FACTS devices are optimally allocated. These objectives include congestion relief, cost minimization, power loss reduction, reliability and security enhancement, voltage and transient stability improvement, frequency stability reinforcement, reactive power planning, as well as control of Green House Gases (GHG) emissions. These objectives are discussed in detail in the

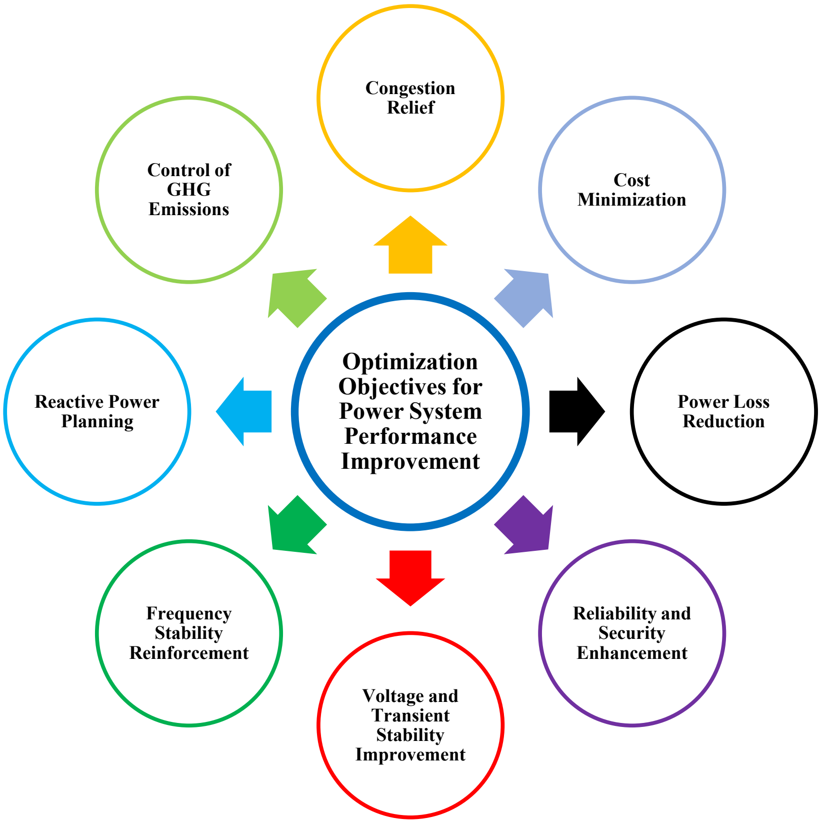

Figure 3. Various optimization objectives for power system performance improvement.

3.1. Congestion Relief

In any deregulated market paradigm, multiple suppliers and consumers have access to resources. In case of the energy market, such deregulation implies that the opportunity to use energy must be availed equally among the stakeholders. Thus, each party in the market tries its best to obtain the greatest benefits from inexpensive sources of energy to ensure maximum profit. After the industrial revolution, growth in industries and businesses has increased energy demand from the power grid. Meanwhile, the gradual addition of new loads and sources is subjecting the grid to more network contingencies. Since there is pressure from both the supplier and consumer sides for reliable power at a competitive price, the rise in energy demand is pushing power systems towards their stability limits [16]. As a consequence, the transmission lines are becoming overloaded and often cross their thermal and voltage stability limits, enfeebling the security and reliability of power systems [17,18]. Violation of operating limits begets congestion and creates difficulty to fulfill the surety of dispatching obligated power from the desired corridors. In case it is not tackled timely, transmission congestion leads to unnecessary outages, augmentation of losses and price of energy, and might endanger the entire grid [19]. Deployment of proper FACTS devices and optimal allotment of them results in the increased loadability of the network, as well as better system stability. This preserves the surety of contracted power dispatch by avoiding excessive congestion. Over the past several decades, FACTS devices have been proved to be very efficient in controlling the power flow due to their lower switching losses and eminent performance. The main purpose behind the application of FACTS devices for congestion relief is to mitigate overloading while maximizing profit to all entities via lower investment costs and higher energy savings.

In [20], an approach for congestion relief is proposed by optimal allotment of SVC and TCSC through the Eigenvalue (EV) method. In [21], TCSC devices are optimally placed for congestion management in the deregulated environment along with minimization of fuel and emission penalty costs. In this research, the Bacterial Foraging Algorithm (BFA) and Nelder–Mead Simplex (NMS) method are employed to solve the Optimal Power Flow (OPF) problem. Ref. [16] canvasses allocation of FACTS devices for the relief of congestion, as well as the stability of voltage. In this study, Particle Swarm Optimization (PSO) is used for the placement of TCSC and SVC, and OPF analysis is conducted via the Sequential Quadratic Programming (SQP) technique. In [22], congestion relief is attained by employing the UPFC via Index Method (IM). The results demonstrate that enhancement of voltage profile and control of power flow from less stressed lines to more stressed lines is achievable by harnessing the UPFC. Ref. [23] evaluates the impact of FACTS devices on the power system performance for congestion relief. In this study, the concept of ideal FACTS has been used to evaluate the security constraints and loss reduction; and the comparison has been made with UPFC and IPC. However, the practicality of ideal FACTS considered in the study requires further discussion. Ref. [24] improves congestion management using STATCOM and SSSC. In the presented work, Genetic Algorithm (GA) and SQP techniques are adopted for optimal allocation of FACTS. The authors of [25] attempt to optimally allocate the FACTS devices including HPFC and UPFC to reduce the power losses and improve system loadability. In this research, the Mixed-Integer Non-Linear Programming (MINLP) algorithm is adopted to solve the optimization problem. In addition, a mathematical model of the GUPFC is proposed for optimal power flow study in [26]. In this study, the Interior Point Method (IPM) is used and the results demonstrate a satisfactory congestion relief. The authors of [27] suggest the deployment of FACTS devices such as TCSC, TCPST, Thyristor Controlled Voltage Regulator (TCVR), and SVC for loadability enhancement of the power system. In the conducted research, the concept of Genetic Algorithm (GA) is utilized for allotment of the FACTS devices. In addition, the selection of FACTS devices is well reasoned by the authors. Ref. [28] discusses maximum power transfer and loadability improvement in the power systems and adopts TCSC and UPFC allocation using the Sensitivity Method (SM). An approach based on the PSO algorithm is presented in [1] to discern the optimal location of TCSC and SVC for congestion relief. In this study, the problem is formulated for minimizing power loss and voltage variations in the power system. Ref. [19] suggests a method to scrutinize the optimal location of TCSCs based on performance index and reduction of active and reactive power losses. In this study, IPM is used for determining the optimal location of TCSCs. Pertaining to the control coordination, the authors of [16] assay the allocation of multiple FACTS devices for congestion relief and voltage stability. To achieve this, they utilize a hybrid of PSO and SQP algorithms. A multi-objective configuration for assuaging congestion is proposed in [29]. The overall framework encompasses congestion management cost as the main objective function, and voltage transient stability margins as ensuing objective functions. In this study, TCSC is used as the FACTS device and Non-Linear Programming (NLP) is used for the optimization of FACTS. Finally, Pareto solutions are yielded with the modified augmented Epsilon-constraint method and the most effective Pareto solution is singled out by a fuzzy decision-maker. For alleviation of congestion and amelioration of loadability, a method based on the coupling of EV method and Min-Cut (MC) algorithm is proposed in [30]. The desired purpose is accomplished via injecting the reactive power and alteration of the line reactance by deploying optimally located SVC and TCSC. The work presented in [31] also attempts to increase the loadability through optimal location of series FACTS devices by using GA. Ref. [32] implements the improved Moth-Flame Optimization (MFO) algorithm and contributes to congestion relief by deploying SVC and STATCOM. In order to relieve congestion of the power system and increase the flow of power, the authors of [33] contemplate optimal allocation of TCSC using the Evolutionary Particle Swarm Optimization (EPSO) technique.

3.2. Cost Minimization

Keeping the cost and quality of electricity within prescribed confinement is an arduous task. For any similar quality products, the majority of people prefer inexpensive options. Therefore, various aspects entangled with the cost optimization of electricity are closely assayed by investors and consumers[14,34,35]. Since fluctuation in energy price immediately alters the price of goods in the global market, cost optimization is a key point of focus to researchers as well. When energy price is lower, more people can afford it and social discrepancy becomes minimized via equal access to energy. In addition, energy consumption is directly proportional to productivity, implying that cheaper energy will also avail better social welfare and economic security of the country.

Ref. [36] proposes SM to allocate series FACTS devices for downsizing the energy generation cost and refining transfer capability. With the aspiration to attain economic generation and consignment of power in a deregulated market setting, the study carried out by [37] adopts GA for making the optimal choice and allotting of FACTS devices. In this study, FACTS devices such as UPFC, TCSC, TCPST, and SVC are deployed. In Ref. [38], a hybrid of classical and modern optimization techniques is employed for the analysis of FACTS devices from the economic point of view. More precisely, in this research, a combination of biogeography-based optimization and NLP algorithms is applied on two types of FACTS devices, i.e., TCSC and SVC. The research conducted in [39] discusses the economic feasibility of FACTS devices. In this study, GA is applied to optimally locate various types of FACTS devices for cost reduction. Meanwhile, the working methodology of GA in the proposed scheme is briefly explained. The authors of [40] demonstrate the adoption of immune GA and immune PSO algorithm to place UPFC devices for minimizing the overall cost function. In [41], the optimal allocation of SVC and TCSC devices is carried out by employing a Greedy Randomized Adaptive Search Procedure (GRASP) metaheuristic algorithm to shrink the figures of generation cost while ameliorating the reliability. Ref. [42] also contemplates minimization of fuel cost and strengthening the loadability for optimal allocation of series FACTS devices, i.e., TCSC and SSSC, through harnessing an improved Moth Flame Optimization (MFO). Reduction of the total generation cost and real power loss is discussed in [43]. In this study, the optimal allocation of three FACTS devices, i.e., TCSC, TCPS, and SVC, is facilitated by deploying Success History-Based Adaptive Differential Evolution (SHADE), as a powerful evolutionary algorithm. Ref. [44] proposes a method for optimal placement, coordination, and sizing of TCSCs, SVCs, and UPFCs so as to reduce the operating costs and power losses by employing the Whale Optimization Algorithm (WOA). In this research, the effectiveness of the proposed method is tested in the standard IEEE 14 and 30 bus systems, and the results are compared with GA and PSO. Minimization of operating costs in large-scale systems by optimal allocation of series FACTS devices using a two-phase decomposition algorithm is discussed in [45]. With the aim of reducing the installation cost of FACTS devices, line loadings, and load voltage deviations while enhancing the system security, optimal allocation of TCSC, SVC, and UPFC is presented in [46]. In this study, Biogeography Based Optimization (BBO), PSO, and Weight Improved PSO (WIPSO) algorithms are deployed, and the results of using various FACTS devices are compared with each other. With the objective to reduce the investment cost, the optimal allocation of series FACTS devices is discussed in [47] under high penetration of wind power within a market environment by deploying a customized reformulation and decomposition algorithm.

3.3. Power Loss Reduction

Regarding the cost associated with each unit of energy, power loss can be contemplated as a financial loss to the power companies. Since polluting fossil fuels such as coal and petroleum are still the major sources of global energy, loss of electricity also means an increase in pollution and wastage of natural resources. The research indicates that nearly 10% to 13% of the entire generated power is wasted in radial distribution systems [48]. Pertaining to the lower efficiency and higher per-unit cost of electricity, rural communities often have a lower interest in pursuing renewable energy sources as compared to other polluting sources such as coal and firewood. On the one hand, many people still have no access to electricity, but on the other hand, electricity consumption in the urban areas is ascending higher. Compared to the previous decades, connectivity of the world has bloomed very well in terms of transportation and communication. In such conditions, the provision of electricity cannot be possible to the rural marginalized communities, unless we pay attention to conservation of the energy. Consequently, to reduce economic loss and ecological impacts, as well as to promote the better social welfare of the general public, escalation of energy efficiency through power loss reduction is indispensable.

In [49], TCPSs are deployed to reduce the power system losses in steady-state conditions, and Modal Analysis (MA) is carried out for the optimization. In addition, the work presented in [48] optimally allocates a Distributed Static Synchronous Compensator (DSTATCOM) to minimize energy losses using a Cuckoo Search Algorithm (CSA). Ref. [50] reviews the application of metaheuristic methods for energy efficiency augmentation. It narrates the significance of power loss reduction in modern power systems and elaborates on some commonly applied optimization techniques. In [51], the optimal placement of FACTS devices is discussed to reduce the power system losses using evolutionary algorithms. In [52], the power losses and voltage deviation are effectively reduced via the application of FACTS devices such as TCSC, SVC, and UPFC, and their allocation is conducted via adoption of the hybrid Artificial Bee Colony-Differential Evolution (ABC-DE) optimization algorithm. In [53], the optimal placement and sizing of wind power as well as three FACTS devices, i.e., TCSC, TCPS, and SVC is discussed for the optimal power flow analysis considering reduction of costs alongside mitigation of power losses by deploying the Moth–Flame Optimization (MFO) algorithm. In [54], the optimal allocation of UPFC, SVC, and TCSC is discussed using the improved GWO algorithm to mitigate the real power losses, bus voltage deviations, and system operating costs. In [55], seven different metaheuristic algorithms, namely, Barnacles Mating Optimizer (BMO), Moth–Flame Optimization (MFO), Particle Swarm Optimization (PSO), Marine Predators Algorithm (MPA), Gravitational Search Algorithm (GSA), Heap Based Optimizer (HBO) and Teaching–Learning-Based Optimization (TLBO), are employed for the reduction of power loss and generation costs. In the presented research, shunt compensation is provided by SVC, whereas TCSC and TCPS are used for series compensation. With the objective of minimizing the real power losses and voltage deviations, optimal allocation and sizing of TCSC and SVC is analyzed in [56] by using the sensitivity index and PSO algorithm. With due attention to reducing the active power losses, improving the voltage profile and maximizing the return on investment of FACTS devices, a novel algorithm is proposed in [57] to optimally allocate the SVCs. In [58], the minimization of power system losses are investigated for the cases without using any FACTS device and with optimal allocation of SVCs in the electric power systems. For optimization purposes, the GAMS modeling tool is employed alongside PSO, GSA, ABC, and DE algorithms, and the results depict the robustness of the GAMS based optimization. For the purpose of mitigating the total active power losses in a transmission line, optimal placement and sizing of SVCs are presented in [59]. In this study, Autonomous Groups Particle Swarm Optimization (AGPSO) is proposed, and the results are compared with several other variations of PSO and Moth Flame Optimization (MFO) algorithms. For the minimization of power losses and voltage deviation, optimal allocation of SVC and TCSC is accomplished via deployment of a Modified Lightning Attachment Procedure Optimization (MLAPO) technique in [60]. In the presented study, the effectiveness of the MLAPO technique is established by analyzing the outcomes of several other metaheuristic optimization algorithms with and without using FACTS devices. In [61], the optimal allocation of FACTS devices is performed by using a multi-objective Teaching Learning Based Optimization (TLBO) algorithm, and the fuzzy decision-making approach is deployed to extract one of the Pareto optimal solutions as the best compromise. In the presented study, TCSC and SVC are deployed to accomplish the objectives of maximizing system loadability while minimizing power losses in the network and installation cost of the FACTS devices.

3.4. Reliability and Security Enhancement

Whether it would be critical facilities such as emergency health care or economic activities such as online banking, all sectors of modern society depend on the power system to function properly. As a result, power system reliability and security are of paramount importance. Power companies constantly endeavor to design and operate reliable power systems with minimum cost and maximum profits. Electrical networks are planned according to the security obligations such that they remain secure and operational under presaged contingencies. Nonetheless, maintaining the security margin within the limited budget resources is not an easy task. In order to facilitate this, FACTS devices are widely used. However, for making a proper assessment about their type, size and location, adoption of optimization techniques is inevitable.

The authors of [62] consider the optimal placement of TCSC to retrofit static and dynamic voltage security of the network using SM. Ref. [63] develops an alternative approach for static security enhancement using the concept of Single Contingency Sensitivity (SCS) index. In the undertaken study, TCSCs are applied to minimize line overloads and undesirable loop flows under single contingencies using SM. In [64], Gravitational Search Algorithm (GSA) is employed to improve the power system security via optimal allocation of the FACTS devices. In this study, FACTS devices including TCSC, SVC, and UPFC are used; in addition, bus voltage deviation and line power flow factor are contemplated as security indices. For better reliability of the power system, Ref. [65] presents a hybrid approach of Quasi-Newton and NMS methods along with GA for the trade-off between accuracy, reliability and time elapsed to find the global optimum. In [66], optimal placement of two types of FACTS devices, i.e., SVC and TCSC, is achieved by employing the PSO algorithm to improve the reliability of the power system. In [67], security enhancement in the power system is discussed using various FACTS devices. In this study, the Atom Search algorithm is deployed for determining the precise optimal placement of FACTS devices and the performances are evaluated using several indexes such as severity index, line overload sensitivity index, etc. including other aspects like voltage deviation, power loss, fitness function, and the fuel cost in case of the IEEE 30, 118, and 300 bus systems. In order to validate the proposed methodology, it has been tallied with various other methods such as the Dragonfly Algorithm (DA), Whale Optimization Algorithm (WOA), Jaya, Flower Pollination Algorithm (FPA), Grey Wolf Optimization (GWO) algorithm, and the Jaya Flower Pollination (JA-FP) systems, making it one of the extensive research studies in the domain. Ref. [68] discusses a nonlinear programming approach for assessing remedial steps to improve the dynamic security of power systems upon encountering any transient instability. In this study, the rapid response of UPFCs is utilized to carry out the remedial operations.

3.5. Voltage and Transient Stability Improvement

Due to practical limitations of predicting the future energy trends, grid infrastructures of the power utilities had been developed with limited capabilities in the past. Those structures are already aging while emerging new technologies are promoting continuous rise of energy demand. As this trend grows higher, transmission networks are subjected to bear more pressure from rising power flow, pushing it towards the operating limit. Under such circumstances, the consecutive voltage drop and line losses increase sharply and undermine voltage stability of the system. In order to reduce the network losses and to improve the voltage and transient stability of the power systems, FACTS devices offer promising alternatives, deferring the necessity of constructing new transmission lines to a large extent.

In order to ameliorate voltage stability improvement of the Korean power system around Seoul, Ref. [69] adopts the Controlled Method (CM) algorithm and shunt-type FACTS devices, i.e., STATCOM and SVC. In [70], the coordinated design of power system stabilizers and supplementary control of FACTS devices are considered aiming at the robustness of the power system stability. In this study, SVC and TCSC are selected as FACTS devices and the Eigenvalue (EV) method is used for the optimization. Ref. [71] performs a transient stability assessment by taking advantage of the Controlled Method (CM). In the undertaken study, optimal control strategies are used and SSSC is deployed to achieve higher stability. In [72], Modal Analysis (MA) is adopted to scrutinize the influence of large-scale wind power on the angle and voltage stability of the power systems, and FACTS devices like STATCOM, SVC and TCSC are deployed. Ref. [73] investigates the employment of SVC to obviate the transient voltage instability caused by large induction loads using the EV analysis technique. However, the performance of SVC is not compared with other FACTS devices. In [74], another strategy for the improvement of voltage stability by SVC is put forward using MA. Ref. [75] discusses analytical approaches, particularly SM and IM, for the optimal placement of STATCOM so that the power losses and voltage instability are reduced. Ref. [76] propounds an approach based on Mixed-Integer Dynamic Optimization (MIDO) to ensure acceptable transient voltage performance and short-term stability against severe contingency by optimal allocation of dynamic var support. In this study, SVC is used for var support, and the overall problem formulation is converted into a mixed integer nonlinear problem, which is solved by using the Branch and Bound (BB) method. In [77], optimal allocation of FACTS devices to preclude the voltage collapse is discussed. In the established study, SVC is optimally allocated and the problem is formulated as a Mixed-Integer Non-Linear Programming (MINLP) problem which is solved by using GA and sequential linear programming methods. The authors of [78] suggest Adaptive Control Law (ACL) technique based on the use of SVC and Static Phase Shifter (SPS) device to enrich transient stability of the power system. In [79], to regulate voltage and amend the transmission capability, the influence of UPFC is discussed using concepts of the MA method. Ref. [80] illustrates the nonlinear analysis of power flow and voltage profile improvement. In the research carried out, to obtain comprehensive data about the angle and magnitude of voltage from each bus, the performance of SVC is evaluated under various specified real power and voltage conditions. In [81], based on reactive power loss sensitivity, optimal allocation and sizing techniques of FACTS devices are discussed. In this study, SM is adopted and FACTS devices like UPFC, SVC, TCSC, STATCOM, and SSSC are implemented. Meanwhile, under both normal and contingency conditions, performance measures like PV curves, voltage profile and power losses are compared for studying static voltage stability. With the motivation of enhancing voltage profile and minimizing power losses, Ref. [48] develops a new approach based on the Loss Sensitivity Factor (LSF) and a newly developed CSA, in which DSTATCOM is optimally allocated. In [16], the cost-effective allocation of FACTS devices is considered while voltage stability and congestion relief are taken into the account. Ref. [29] also concentrates on the improvement of voltage and transient stability in addition to congestion management. The devised method in this study contemplates optimal allocation of TCSC to minimize the total operating cost and enhance the voltage and transient stability margins. In [82], voltage profile improvement and frequency stability reinforcement are discussed by employing the PSO algorithm and Salp Swarm Algorithm (SSA) alongside the deployment of the FACTS device. In [83], the reduction of voltage deviation is discussed alongside various other aspects of improving the power system performance. In this study, four different optimization algorithms, i.e., Slime Mould Algorithm (SMA), Artificial Ecosystem-based Optimization (AEO), Marine Predators Algorithm (MPA), and Jellyfish Search (JS) are deployed to solve the optimal power flow problems for a power network encompassing FACTS devices and stochastic renewable energy sources. In [84], alongside various other objectives, enhancement of the voltage profile through minimizing the buses voltage deviations is discussed by incorporating Adaptive Parallel Seeker Optimization Algorithm for deploying TCSC devices in the power system. In [85], Teaching Learning Based Optimization (TLBO) algorithm is employed to explore the optimal capacity of the SVCs considering voltage stability and reduction of real power losses. In this study, the Index Method (IM) is utilized to identify the weak buses for the placement of the FACTs device. With the aim of facilitating transient stability, optimal allocation of TCSCs is studied in [86]. In this research, the proposed optimization algorithm is structured through a combination of the catastrophe theory (CT), multi-objective PSO algorithm, and clustering technique. In [87], the viability of real-time control during transients is investigated for series compensation by deploying TCSC. For establishing the practicality and efficacy of the proposed method, both voltage and transient stability are tested on a realistic sized network. The allocation of Distributed FACTS (DFACTS) is studied for dynamic security, transient stability, and control of the power system in [88]. In this study, a dynamic optimization based controlled strategy is proposed and tested on a realistic-sized transmission system.

3.6. Frequency Stability Reinforcement

Escalation in power demand and rising awareness among the public about ecological hazards such as global warming has drawn the attention of the stakeholders and led them to invest in cleaner means of energy. As a result, power generation from renewable sources is increasing each year. This quest for clean energy has acted as a stimulus for restraining climate change to a great extent. However, due to the random nature of the load pattern and low system inertia of the comparatively smaller renewable sources, they are often incapable of handling large digressions in frequency. If such oscillations in a power system are not dampened timely, the performance of the system is drastically degraded and may lead to total system blackouts. Grid blackouts of Brazil on 11 March 1999, North American areas on 14 August 2003, Switzerland and Italy on 28 September 2003, Bangladesh on 1 November 2014, etc. can be taken as some examples [89]. Therefore, load frequency control is an indispensable aspect in power system operation, and it is given due attention by the grid operators. In order to achieve better control in this aspect, advanced control methodologies such as optimal, suboptimal, adaptive, self-tuning, robust, variable structure, and intelligent control techniques are being focused nowadays [90]. Ref. [91] presents an SVC-based CM technique to alleviate damping of the power system. Future research on this technique might include performance comparison of different FACTS devices. In [92], sub-synchronous resonance characteristics are analyzed using the EV method and damping torque analysis techniques. Moreover, a comparative study on the influence of Voltage Source Converter (VSC) based FACTS devices is carried out to remediate the oscillations.

In [93], a UPFC-based model is designed and simulated for the elimination of harmonics and enhancement of the power quality. In this study, the Modal Analysis (MA) of the UPFC device is conducted for different control schemes. Future works based on this scheme might include performance comparison of UPFC with other FACTS devices. In [90], various deregulated power system structures, market models, contracts, agreements, as well as control techniques, are reviewed for alleviating load frequency control issues. In this study, the use of optimization techniques like GA, PSO, etc. is explained and the use of FACTS devices like TCSC, TCPS, STATCOM, UPFC, SSSC, etc. is retrospected. Furthermore, an overview of fast-acting energy storage appliances like Battery Energy Storage System (BESS), Superconducting Magnetic Energy Storage (SMES), and Redox Flow Batteries (RFB) is incorporated. The authors of [89] contemplate traditional and renewable energy domains for frequency management using classical, fractional order, cascaded, sliding mode, tilt-integral-derivative, and H-infinity controllers. Additionally, the use of FACTS devices like TCSC, TCPS, SSSC, etc. is reviewed alongside optimization algorithms like GA, FA, etc. In [94], optimal allocation of SSSC is conducted for improving the frequency stability of the power system using the ant colony algorithm. In this study, the reduction of operating costs has also been achieved. In [95], in order to reinforce the frequency stability of power system, employment of UPFC and Grasshopper Optimization Algorithm (GOA) is depicted. In [96], various objective functions are scrutinized so as to acquire optimum results in frequency stabilization and tie-line power control. In this study, GOA is deployed in a power system connected with FACTS devices.

3.7. Reactive Power Planning

Due to the segregated nature of natural resources, generating sites and load centers of a power system are often separated from each other. When the bulk power is carried for a long distance by transmission lines, it is common to experience voltage drop because of the line losses. Owing to the capacitive and inductive effects posed by various system components and loads, voltage changes become further pronounced, which adversely affects the voltage profile and system stability. If the components are not properly envisaged, the system parameters might sway beyond control, triggering critical system failures like blackouts. In order to tackle such issues in the power grid, reactive power planning is performed through the optimal allocation of various series and shunt compensators. However, optimal reactive power dispatching is a sophisticated task and requires accurate planning. To facilitate such planning, myriads of strategies and optimization techniques are developed.

Ref. [97] provides a review of disparate metaheuristic algorithms for assisting reactive power planning problems. The algorithms are classified into analytical, arithmetic programming, and metaheuristic optimization techniques; moreover, their applications are separately discussed. Ref. [7] retrospects optimal reactive power dispatch alongside minimization of line losses and voltage deviation to reinforce the power system performance. In this study, the use of FACTS devices like SVC and TCSC is explained. Alongside that, optimization algorithms like PSO and Non-dominated Sorting Genetic Algorithm II (NSGA-II) are reviewed for the overall cost reduction, and power system stability and reliability. In [98], a reactive power planning strategy is established by computing margin from the point of voltage collapse in the steady-state operation of the power system. In order to quantify the adequacy of the proposed approach, SVCs are applied and IPM is adopted for the purpose of optimization. However, the reason for the selection of SVC among other FACTS devices remains unexplained. Ref. [99] proposes the use of IPFC for equalization of real and reactive power flow between the line, power transfer from overloaded to underloaded lines and compensation against voltage drops. In addition, the corresponding reactive power of the line and the techniques to increase the effectiveness of the compensating system against dynamic disturbances are thoroughly discussed.

3.8. Control of GHG Emissions

Attributing to the proliferation in industrialization and the expansion of transportation services, energy consumption has significantly increased in recent decades. This energy is largely produced from burning of the fossil fuels and imposes negative impacts such as carbon emissions on the environment [15,100,101]. Numerous investigations have been conducted to comprehend global warming, and many contributing factors have been identified to date. The Kyoto Protocol, which operationalizes the United Nations framework convention on climate change, has specified CO_2, CH_4, and N_2O as the most contributing gases in the global warming phenomenon. These gases can be reduced only by replacing coal and petroleum with cleaner sources of energy. Taking this fact into the consideration, Ref. [102] reviews the role of FACTS devices like SVC and STATCOM in mitigating GHG emissions via enhancement of energy efficiency and energy storage. Future researchers on this topic might include a comparison based on the quantification of contribution made by different FACTS devices in terms of carbon reduction. Ref. [15] renders a broad-gauge retrospection on the contribution of power electronics devices such as DSTATCOM in reducing GHG emissions. In this study, a large number of optimization techniques, numerous power electronic devices, control difficulties associated with them, and their benefits and drawbacks are thoroughly reviewed regarding the control of GHG emissions.

4. Comparative Assessment of the Existing Optimization Techniques

Based on the analysis of the wide range of technical publications presented in the previous section, it can be concluded that the application of FACTS devices can generally improve the power system performance from various aspects. However, each aspect is particularly influenced by the application of specific types of FACTS devices and optimization techniques. Table 1 provides a taxonomy of the optimization techniques applied for power system performance improvement according to each specific objective. It also embodies the information about the types of FACTS devices deployed in each reference, alongside the additional benefits provided. Table 2 briefly compares the prevailing optimization techniques in terms of their features and limitations.

Comparing the features of three types of optimization techniques, CABMs offer a better efficiency in terms of computation. Nevertheless, failure to account for the nonlinearity of the power flow model might compromise their accuracy. Therefore, their use is limited when it comes to application in large-scale complex optimization problems. The CAPBAs have effective convergence characteristics but are often inefficient in handling constrained optimization problems. In the recent decade, MMBAs are the most commonly used optimization techniques for solving complex multi-objective problems as they can find multiple optimal solutions in a single run. Owing to their stochastic population-based nature, MMBAs are highly efficient. These algorithms are flexible and they can deal with complex problems with multiple constraints easily. However, there is no guarantee of the global optimal solution, and the solution discovered is reliant on the initial condition.

As can be seen from the comparison presented in Table 2, some optimization methods are well-suited for small problems, whereas others are more precise while dealing with large problems. Some algorithms have higher speed, whereas some algorithms have higher accuracy. Some optimization schemes work better for solving multi-objective problems, whereas others are faster at solving single-objective problems. Hence, it is essential to evaluate the nature of the optimization problem before applying a particular optimization technique. The use of a hybrid approach tries to overcome the limitations of two optimization techniques, and in most cases produces better results than either of them. For instance, in [85], first, to reduce search space and computational burden, the Index Method (IM) is used to identify the weak buses for the placement of the FACTs device, and then the Teaching Learning Based Optimization (TLBO) algorithm is deployed to determine the optimal size of the FACTS device for reducing power loss. Similarly, in [56], the location of weak lines and weak buses for connection of FACTS devices are determined by using sensitivity method, and subsequently, the optimal size of the FACTS devices is determined using the PSO algorithm. The results of these studies indicate that hybrid approaches are much more effective than individual application of each algorithm. Because of this reason, the number of research studies entirely based on classical techniques seems to be decreasing, and hybrid schemes of optimization employing classical techniques and metaheuristic algorithms are gaining more popularity. From the presented literature, it is also evident that only a handful of researchers use more than three FACTS devices in their research. Only some of the studies have compared their results with more than two alternative optimization methods in terms of speed, accuracy, and probability of getting trapped in the local optima. In order to have a fair comparison of results regarding the performance of any FACTS device and the optimization technique, such comparisons are essential so as to determine the most effective device and algorithm for solving a particular type of optimization problem. Future researchers in this domain might consider these factors for evaluation.

Table 1. Taxonomy of the optimization techniques applied for power system performance improvement.

Main Objective	Type of Algorithm	Reference	Optimization Technique Used	Deployed FACTS Device	Other Benefits Provided
Congestion Relief	CABMs	[20]	EV method	SVC, TCSC	-Loadability enhancement -Transient stability improvement
		[22]	IM	UPFC	-Voltage profile improvement
		[28]	SM	TCSC, UPFC	-Cost minimization, -Power loss reduction
		[30]	EV method	SVC, TCSC	-Power loss mitigation
	CAPBAs	[29]	NLP algorithm	TCSC	-Cost reduction -Transient stability improvement
		[25]	MINLP algorithm	HPFC, UPFC	-Loadability enhancement -Power loss alleviation
		[26]	IPM	GUPFC	-Voltage stability improvement
		[19]	IPM	TCSC	-Voltage stability improvement -Power loss reduction
	MMBAs	[1]	PSO algorithm	TCSC, SVC	-Power loss mitigation
		[21]	BFA	TCSC	-Cost minimization
		[16]	PSO algorithm	TCSC, SVC	-Voltage stability improvement
		[24]	GA	STATCOM, SSSC	-Voltage stability reinforcement -Power loss reduction
		[27]	GA	TCSC, TCPST, TCVR, SVC	-Loadability enhancement
		[31]	GA	Series FACTS devices	-Cost reduction
		[32]	MFO	SVC, STATCOM	-Power loss reduction
		[33]	PSO	TCSC	-Increase power flow
Cost Minimization	CABMs	[36]	SM	Series FACTS devices	-Better generation dispatch
	CAPBAs	[38]	NLP algorithm	TCSC, SVC	-Load shedding alleviation
	MMBAs	[39]	GA	SVC, TCSC, TCVR, TCPST	-Optimal power flow
		[37]	GA	UPFC, TCSC, TCPST, SVC	-Optimal power flow
		[40]	GA, PSO algorithm	UPFC	-Congestion management
		[41]	GRASP algorithm	SVC, TCSC	-Reliability enhancement
		[42]	MFO algorithm	TCSC, SSSC	-Loadability augmentation
		[43]	SHADE	TCSC, TCPS, SVC	-Reduction of power loss
		[45]	Decomposition algorithm	Series FACTS	-Power loss mitigation
		[44]	WOA	TCSC, SVC, UPFC	-Minimize power loss
		[46]	BBO, PSO	TCSC, SVC, UPFC	-Reduction of voltage deviations -Enhancement of system security
		[47]	Decomposition algorithm	Series FACTS	-Mitigation of losses

Table 1. *Cont.*

Main Objective	Type of Algorithm	Reference	Optimization Technique Used	Deployed FACTS Device	Other Benefits Provided
Power Loss Mitigation	CABMs	[49]	MA method	TCPS	-Transient stability improvement -Harmonics reduction
	MMBAs	[48]	CSA	DSTATCOM	-Cost minimization -Voltage profile enhancement
		[52]	ABC-DE algorithm	TCSC, SVC, UPFC	-Reduce voltage deviation
		[53]	MFO algorithm	TCSC, TCPS, SVC	-Reduction of costs
		[54]	GWO	UPFC, SVC, TCSC	-Minimize voltage deviation -Mitigate operating costs
		[55]	PSO, MPA, BMO, MFO, GSA, HBO, TLBO.	SVC, TCSC, TCPS	-Reduction of generation costs
		[56]	PSO	TCSC, SVC	-Improve voltage profile
		[59]	PSO	SVC	-Cost reduction
		[58]	GAMS, PSO, GSA, etc.	SVC	-Cost reduction
		[60]	MLAPO	SVC, TCSC	-Enhancement of voltage profile
		[61]	TLBO	TCSC, SVC	-Maximize system loadability -Minimize installation costs
Reliability and Security Enhancement	CABMs	[62]	SM	TCSC	-Loadability enhancement
		[63]	SM	TCSC	-Fault tolerance improvement -Optimal power flow
	CAPBAs	[68]	NLP algorithm	UPFC	-Voltage profile improvement
	MMBAs	[64]	GSA	TCSC, SVC, UPFC	-Voltage stability enhancement -Optimal power flow
		[66]	PSO	SVC, TCSC	-Voltage profile improvement
Voltage and Transient Stability Improvement	CABMs	[69]	CM	STATCOM, SVC	-Security enhancement
		[70]	EV method	SVC, TCSC	-Power loss reduction
		[71]	CM	SSSC	-Optimal power flow
		[72]	MA method	STATCOM, TCSC, SVC	-Power loss reduction
		[74]	MA method	SVC	-Optimal power flow
		[73]	EV method	SVC	-Power loss mitigation
		[75]	SM, IM	STATCOM	-Power loss mitigation -Security enhancement
		[79]	MA method	UPFC	-Power loss mitigation
		[81]	SM	UPFC, SVC, TCSC, STATCOM, SSSC	-Power loss reduction
	CAPBAs	[76]	BB algorithm	SVC	-Reactive power planning
		[78]	ACL algorithm	SVC	-Reactive power control
	MMBAs	[77]	GA	SVC	-Preventive and corrective control of faults
		[84]	APSO	TCSC	-Reduction of losses
		[85]	TLBO	SVC	-Reduction of power loss
		[86]	PSO	TCSC	-Power loss mitigation

Table 1. *Cont.*

Main Objective	Type of Algorithm	Reference	Optimization Technique Used	Deployed FACTS Device	Other Benefits Provided
Frequency Stability Reinforcement	CABMs	[91]	CM	SVC	-Transient stability enhancement
		[92]	EV method	IPFC, GUPFC, SSSC	-Transient stability improvement
		[93]	MA method	UPFC	-Transient stability improvement
		[94]	ACO	SSSC	-Voltage profile improvement
		[95]	GOA	UPFC	-Voltage profile improvement
Reactive Power Planning	CAPBAs	[98]	IPM	SVC	-Transient stability improvement -Harmonics mitigation
Control of GHG Emissions	MMBAs	[15]	GA, PSO, etc.	DSTATCOM	-Power loss reduction -Harmonics mitigation -Cost minimization

Table 2. Comparative analysis of the prevailing optimization techniques.

Type of Algorithm	Optimization Technique	Features	Limitations
CABMs	MA method	-Ability to predict key characteristics of the alternative designs	-Reduced accuracy because of applying constraints to the marginal parameters -Limited predictive capability
	IM	-Swift access to required parameters -Adequate performance	-Low flexibility -Difficulties in prediction and computation of non-indexed parameters
	CM	-Simple operating principle -Ease of implementation	-Decreased accuracy
	EV method	-Ability to split a complex problem into separate simple problems	-Requirement of a large number of computations
	SM	-High reliability -Capable of predicting outcomes	-Dependency on former solutions
CAPBAs	NA	-Quick rate of convergence -Non-complex implementation	-Necessity for modification before applying to large-scale problems
	IPM	-Quick and uncomplicated for constrained problems	-Risk of getting trapped in local optima
	BB algorithm	-Unchallenging to reduce the number of nodes -Low complexity and number of iterations	-Challenge of execution in large networks
	NLP algorithm	-Superior performance compared to Linear Programming (LP) algorithm -Feasibility of application to nonlinear parameters and large systems	-Risk of getting trapped in local optima
	MINLP algorithm	-Ability to cope with continuous and discrete variables	-Unable to guarantee finding the global optimum
	ACL algorithm	-Enhanced flexibility -Improved performance and robustness	-Unexpected instabilities -Intricate process -Relatively slow convergence
	DP algorithm	-Can use solutions of subproblems to solve the original complex problem -Suitable for finding local and global optimal solutions -Capable of optimizing on a step-by-step basis	-Lack of general algorithm -Requirement of expertise -Time-consuming due to dimensionality and multiple-state problems
MMBAs	SA algorithm	-Can handle highly nonlinear models, chaotic and noisy data and constraints -Guarantee of reaching the optimal solution -Non-sophisticated coding	-Time-consuming iterations -Inability to confirm attainment of the optimal solution
	TS algorithm	-Ability to intensify or diversify the search -Capable of escaping local optima -Avoidance of reverting to former solutions -Applicability to both discrete and continuous solutions	-Need for a large number of iterations -Presence of numerous tunable parameters
	VNS algorithm	-Ability to enhance the quality of solution via systematic neighborhood changes -Better coherence and precision	-Excessive exploration -Lack of adequate exploitation -Relatively slow convergence
	GLS algorithm	-Deployment of penalties to aid algorithm to escape the local minima -Better exploration -Improved robustness -Can examine an enormous number of possible solutions in a short time -High flexibility	-Lack of well-defined stopping criteria -Excessive exploration
	GSA	-Augmented randomness of individual moves -Better global exploration	-Poor local search capability
	GA	-Uncomplicated implementation -High degree of randomness due to stochastic nature -Increased diversity of solutions to avoid trapping in local optima	-High dependency on crossover and mutation rate -Slow convergence -No guarantee to find global optimum
	DE algorithm	-Ability to solve the problem by having a few parameters -Gradual improvement of solution -High exploration capability	-High contingency of performance on trial vector generation and choice of control parameters

Table 2. *Cont.*

Type of Algorithm	Optimization Technique	Features	Limitations
	CSA	-Ability to provide diverse solutions -High adaptability	-Risk of premature convergence -Decreased accuracy -Complexity of trade-off between convergence and diversity
	Memetic algorithm	-Avoidance of premature convergence -Rapid global optimization	-Low diversity of solutions
	BSA	-Elimination of incompetent solutions -Well-suited for time-bound problems with multiple solutions	-Inapplicable to problems without partial candidate solutions
	SOS algorithm	-No need for tuning parameters other than population size -Robust and fast convergence	-Difficulty in the trade-off between exploration and exploitation of the search space
	SOA	-Adequate global search capability -Expeditious convergence	-Chance of getting trapped in local optima
	ACO algorithm	-Inherent parallelism -Augmented adaptability -Provision of positive feedback -High probability of convergence	-Sophistication of mathematical analysis -Low-speed convergence
	PSO algorithm	-Simple implementation -High chance of convergence -Small number of adjusting parameters -Less dependent on initial points	-Reduced speed of convergence -Risk of being trapped in local optima
	ABC algorithm	-Increased robustness, flexibility, and convergence speed	-Challenges associated with low accuracy -Risk of premature convergence
	CSO algorithm	-Ability to modify tracing and seeking modes to trade off between exploration and exploitation -Swift convergence	-Probability of falling into local optima -Risk of premature convergence
	CRO algorithm	-Possession of variable population size -Increased adaptability -Ease of modification to run in parallel	-Slow convergence rate
	WCA	-Suitable for solving large-scale problems -Small number of insensitive user parameters	-Problem of premature convergence
	EPC algorithm	-Effective handling of multi-modal and nonlinear optimization problems -Significantly immune to premature convergence	-Gradual decrease of convergence rate
	GWO algorithm	-Provision of alternative second best and third best solutions	-Low precision -Slow convergence -Inadequate local search capability
	GSO algorithm	-Capable of splitting the main problem into subproblems -Simultaneous convergence into multiple local optima	-Reduced precision -Drawback of low-speed convergence
	IWD algorithm	-Selection of best solution based on average values -Rapid convergence	-Difficulties in the determination of stop criterion
	JOA	-Appropriate for large-scale global optimization problems	-Low flexibility
	ALO algorithm	-Support of global exploration and local exploitation -Small number of required parameters	-Risk of premature convergence -Chance of being trapped in local optima particularly while solving complicated problems

5. Conclusions

As predicted by several reports of various notable organizations like the Institute of Electrical and Electronics Engineers (IEEE), and the International Energy Agency (IEA), energy demand is projected to further increase in the future. Since science and technology is continuously evolving, it is likely that new kinds of machinery and equipment will be added to the power grids. It means that the power grids will be subjected to grow into a more intricate network. In such a scenario, the deployment of FACTS devices and optimization of various aspects related to the power system will be indispensable. In terms of cutting-edge FACTS devices, the adoption of UPFC and GUPFC is likely to increase in the next decades, owing to their ability to automatically and selectively regulate multiple power system characteristics. However, one of the significant practical issues which must be considered while installing a certain type of FACTS device is its cost. As portrayed by the research in [46], despite providing much better performance in reduction of the line loadings and load voltage deviations, UPFC is less likely to be installed in the power system due to having higher installation costs than that of the TCSC and SVC put together. Therefore, in the future, more studies need to be conducted regarding their price optimization so as to make their use economically pragmatic. Observing the current trends in optimization, growth in variants of multi-objective optimization algorithms like Multi-Objective Genetic Algorithm (MOGA), Multi-Objective Particle Swarm Optimization (MOPSO) algorithm, and NSGA is likely in the near future. Moreover, it should be highlighted that some metaheuristic approaches are well-suited to tackle certain optimization issues, while being inappropriate for other sorts of problems. Hence, it is fruitful to test and evaluate several metaheuristic approaches for a certain problem. It is expected that hybrid techniques encompassing the amalgamation of non-dominated sorting multi-objective optimization algorithms and classical approaches will gain more popularity in the coming years because of their enhanced efficacy, flexibility, and speedy action on complex multi-objective problems.

The swift growth of electricity demand, the necessity of higher economic efficiency, and the significant investment required for the construction of new power networks have exacerbated power system performance in terms of transmission congestion, energy efficiency, voltage and transient stability, as well as power quality and reliability. FACTS devices have been proved to be efficient in the enhancement of power system performance from various aspects. In recent years, a plethora of studies have been performed for determining the optimal location, type, and capacity of FACTS devices through disparate optimization techniques. The target of this paper was to provide a retrospective review of the prevailing optimization techniques, addressing the challenge of optimal allocation of FACTS devices. In addition, an endeavor was made to categorize these techniques in terms of their specific optimization objective. Lastly, the available optimization techniques were comparatively assessed, and their merits and limitations were rendered.

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Abbreviations

The following abbreviations are used in this manuscript:

ABC	Artificial Bee Colony
ABO	African Buffalo Optimization
ACL	Adaptive Control Law
ACO	Ant Colony Optimization
AEA	Adaptive Evolutionary Algorithm
AEO	Artificial Ecosystem-based Algorithm
AGPSO	Autonomous Groups Particle Swarm Optimization
ALO	Ant Lion Optimization
ANS	Across Neighborhood Search
BB	Branch and Bound
BBO	Biogeography Based Optimization
BESS	Battery Energy Storage System
BFA	Bacterial Foraging Algorithm
BMO	Barnacles Mating Optimizer
BSA	Backtracking Search Algorithm
CABM	Classical Analytical-Based Method
CAPBA	Classical Arithmetic Programming-Based Algorithm
CM	Controlled Method
COA	Coyote Optimization Algorithm
CRO	Chemical Reaction Optimization
CS	Clonal Search
CSA	Cuckoo Search Algorithm
CSO	Cat Swarm Optimization
DA	Dragonfly Algorithm
DE	Differential Evolution

DP	Dynamic Programming
DSTATCOM	Distributed Static Synchronous Compensator
DVR	Dynamic Voltage Restorer
EPC	Emperor Penguins Colony
EPSO	Evolutionary Particle Swarm Optimization
EV	Eigen Value
FA	Firefly Algorithm
FACTS	Flexible Alternating Current Transmission System
FPA	Flower Pollination Algorithm
GA	Genetic Algorithm
GHG	Green House Gases
GIPFC	Generalized Interline Power Flow Controller
GLS	Guided Local Search
GOA	Grasshopper Optimization Algorithm
GRASP	Greedy Randomized Adaptive Search Procedure
GSA	Gravitational Search Algorithm
GSO	Glowworm Swarm Optimization
GTO	Gate Turn Off thyristor
GUPFC	Generalized Unified Power Flow Controller
GWO	Gray Wolf Optimization
HBO	Heap Based Optimizer
HPFC	Hybrid Power Flow Controller
HSA	Harmony Search Algorithm
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
ILS	Iterative Local Search
IM	Index Method
IPC	Interphase Power Controller
IPFC	Interline Power Flow Controller
IPM	Interior Point Method
IWD	Intelligent Water Drops
JOA	Joint Operations Algorithm
JS	Jellyfish Search
LP	Linear Programming
LSF	Loss Sensitivity Factor
MA	Modal Analysis
MC	Min-Cut
MFO	Moth–Flame Optimization
MIDO	Mixed-Integer Dynamic Optimization
MINLP	Mixed-Integer Non-Linear Programming
MLAPO	Modified Lightning Attachment Procedure Optimization
MMBA	Modern Metaheuristic-Based Algorithm
MOGA	Multi-Objective Genetic Algorithm
MOPSO	Multi-Objective Particle Swarm Optimization
MPA	Marine Predators Algorithm
MSC	Mechanically Switched Capacitor
NA	Newton Algorithm
NLP	Non-Linear Programming
NMS	Nelder–Mead Simplex
NSGA-II	Non-dominated Sorting Genetic Algorithm II
OPF	Optimal Power Flow
PSO	Particle Swarm Optimization
RFB	Redox Flow Batteries

SA	Simulated Annealing
SCS	Single Contingency Sensitivity
SGO	Social Group Optimization
SFSA	Stochastic Fractal Search Algorithm
SHADE	Success History-Based Adaptive Differential Evolution
SM	Sensitivity Method
SMA	Slime Mould Algorithm
SMES	Superconducting Magnetic Energy Storage
SOA	Seeker Optimization Algorithm
SOS	Symbiotic Organism Search
SPS	Static Phase Shifter
SQP	Sequential Quadratic Programming
SSA	Salp Swarm Algorithm
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator
TCPAR	Thyristor Controlled Phase Angle Regulator
TCPS	Thyristor Controlled Phase Shifter
TCPST	Thyristor Controlled Phase Shift Transformer
TCSC	Thyristor Controlled Series Capacitor
TCSR	Thyristor Controlled Series Reactor
TCVR	Thyristor Controlled Voltage Regulator
TLBO	Teaching Learning Based Optimization
TS	Tabu Search
TSR	Thyristor Switched Reactor
TSSC	Thyristor Switched Series Capacitor
TSSR	Thyristor Switched Series Reactor
UDQC	Unified Dynamic Quality Conditioner
UPFC	Unified Power Flow Controller
UPQC	Unified Power Quality Conditioner
VNS	Variable Neighborhood Search
VSC	Voltage Source Converter
WCA	Water Cycle Algorithm
WIPSO	Weighted Improved Particle Swarm Optimization
WOA	Whale Optimization Algorithm

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