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# A Critical Review of Optimization Strategies for Simultaneous Integration of Distributed Generation and Capacitor Banks in Power Distribution Networks

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**Abstract:** This paper reviews the optimization strategies for the optimal simultaneous allocation of distributed generation (DG) and shunts capacitor banks (SCBs) in electrical distribution networks. These optimization strategies aim to determine the optimal size, location, and combination of DGs and SCBs to constitute a techno-economic system while satisfying the constraints and energy demand of the load. The optimization strategies explicitly reviewed include the problem formulations, optimization techniques, restrictions posed for optimization problems, decision variables, and network operating modes typically assumed while allocating the DGs and SCBs. In addition, there is an attempt to highlight the limitations of the existing literature and future research directions. This study undertakes a comprehensive review of the literature that systematically considers the simultaneous application of DGs and SCBs to advance the existing literature, which lacks such a review. Expectedly, this review will serve as a principle platform for researchers intending to explore the subject area for further improvement.

**Keywords:** distributed generation; shunt capacitor banks; simultaneous allocation; distribution networks; optimization strategies

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## 1. Introduction

The distributed generation (DG) systems have recently attracted much interest as a long-term solution for expanding electric power systems and electrifying remote areas. Its rising demand is fueled by the diminution of traditional fossil fuels, fuel price instability, and increased awareness of the importance of reducing environmental emissions [1]. Members of the European Union (EU) have committed to sourcing at least 20% of their electrical and thermal energy needs from renewable sources [2]. Several European countries, including Germany, Denmark, Finland, and Sweden, aim to attain significant DG penetration levels in their existing electrical power systems using a range of policies and financial schemes [3]. The expansion of DG systems has also been noticed in emerging Asian countries, particularly Malaysia. Energy services were recommended to include greener power generation technology in power supply services and industrial sectors in the comprehensive low carbon society blueprint for Iskandar Malaysia 2025 [4]. However, effective energy planning is a challenging endeavor influenced by various technological, economic, market, entrepreneurial, and socio-political aspects [3]. As far as innovation and financial matters, efficient DG framework coordination is perplexing without sufficient asset allotment and framework scope organization, which should consider nearby renewable asset accessibility, dynamic variation and development of load demand, cost factors, mechanical productivity, and carbon intensities of different power creation advances [5]. A representative and complete energy planning optimization tool is essential for policymakers to decrease overall system costs without sacrificing DG system reliability or environmental quality.

### 1.1. Overview of Electrical Power System

An electric power system encompasses interconnected structures to produce, transmit, and dispense electricity to consumers. Its supply side is divided into generation, transmission, and distribution. A series of transformers connect these components and adjusts the electric voltage to acceptable operating levels. The power generation component is responsible for turning fossil fuel and renewable energy sources into electricity. It could be applied in two ways: centralized generation and distributed generation [6]. The former involves massive power facilities that produce vast amounts of electricity that are then transferred at high voltage to the grid. The latter includes customer-owned standalone on-site production systems as well as relatively small generators connected to the distribution system (at low and medium voltage levels), which are typically run by independent power producers (IPP). Table 1 compares these generation modes. It should be emphasized that the central power system includes DG as a subset.

**Table 1.** Comparison of centralized and distributed power generation systems [4].

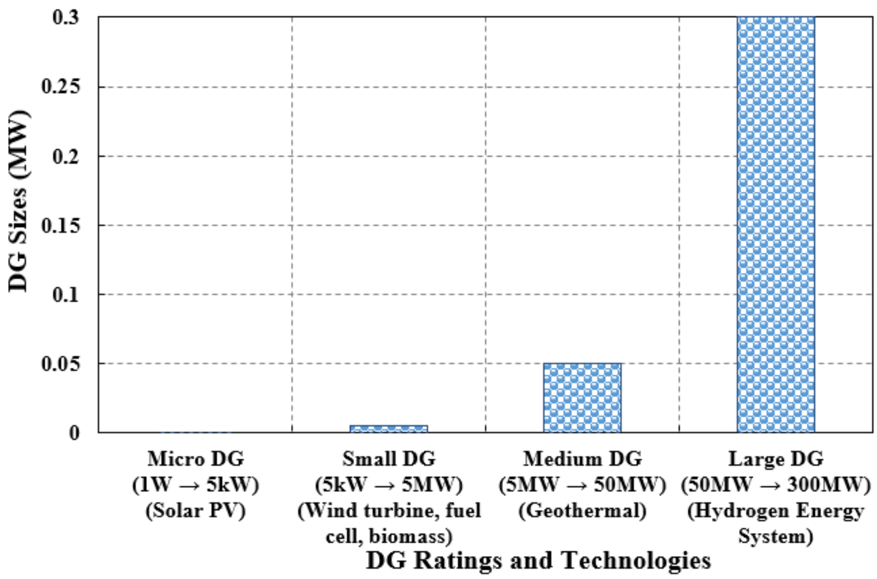
| Feature | Centralized Power Generation | Distributed Generation |
|---|---|---|
| Generation capacity | Large in order to achieve economies of scale; the reported range is 100–1000 MW | Below and up to 300 MW |
| Location | Located distant from the load centers, generally close to the resource extraction locations | Integrated with customer facilities and situated closer to the power consumption centers |
| Location of penetration to the electrical system | Connected to a high-voltage transmission system, which step-up electricity before transmission to substations (for further distribution) to reduce line losses | On-grid: Connected to a lower-voltage distribution system or customer facilities. Off-grid: DG that is not connected to the utility grid operates independently with customer facilities or in a microgrid system. |

Transmission and sub-transmission lines are often configured in a mesh network, with transmission switching stations serving as the interface between the two types of lines (for example, voltage down-stepping). Its principal responsibility in the central generating mode is to efficiently transport large amounts of electrical power at a high voltage level over a long distance from generators to the distribution system [7,8]. Additionally, it increases power supply dependability and decreases the chance of an electricity outage by offering backup transmission lines in case of line failure [9]. With this setup, the transmission company may synchronize the operation of several generators in response to changes in load-side demand and their level of performance for more stable operations overall [10]. This set up enables the transmission operator to coordinate the activities of several generators in response to their level of performance and variations in load-side demand for higher overall operational stability [10].

The distribution system also serves as a conduit for power between the end-user facilities and the transmission system. Substations connect the transmission and distribution systems, stepping down the transmitted electricity to the utility voltage level before it is delivered. It has a medium-to-low voltage radial network that is linked to the final users (i.e., medium and small consumers). Additionally, it might provide DGs (as reserves) with a suitable protective system.

### *1.2. Distributed Generation (DG)*

A decentralized power generation system, or DG, consists of power generators with lower capacity than traditional centralized power plants that are integrated directly into the distribution network or located close to energy consumption sites [11]. As a new option to replace the centralized energy generation system, it often involves small-scale technologies for harnessing renewable and non-renewable energy sources [12]. To attain utility self-sufficiency and to share excess utilities; it functions as an integrated network for residential, commercial, and industrial units with the ability to generate heat and electricity. So far, there is no global accepted size of DG. Figure 1 presents the categorization of DG systems based on their generating levels, technology, and real-reactive power injection and consumption abilities.

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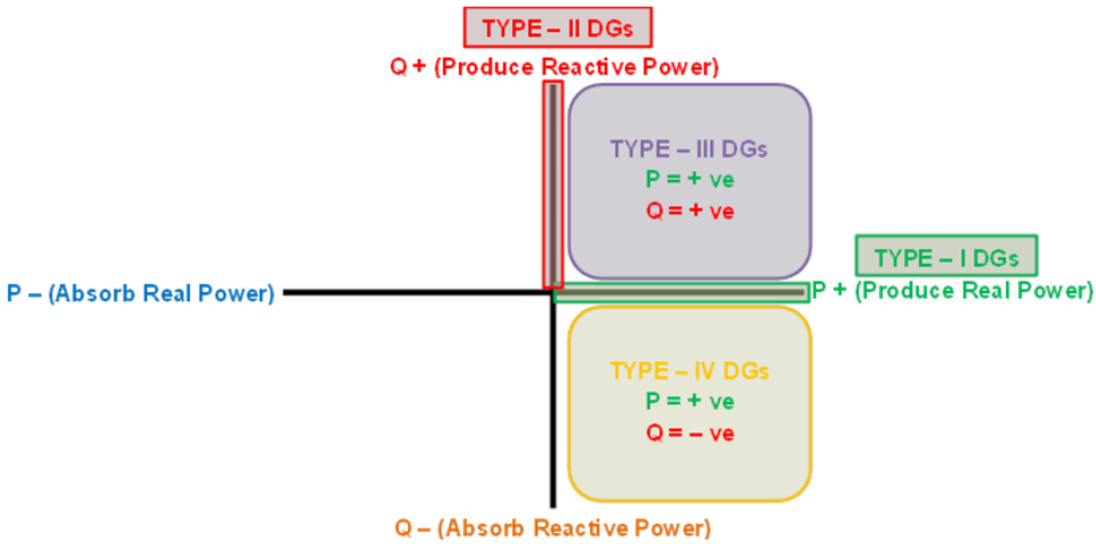



(**b**)

**Figure 1.** (**a**) DG power rating levels, technologies (**b**) DG types [12–15].

DG systems were mostly implemented at the transmission and distribution levels as backup measures during the initial stages of the development of the electrical sector, which was dominated by centralized station generation development [16]. However, due to a number of key driving forces, DG has lately become a viable alternative for producing electricity. Peak shaving by DG offers more effective energy management, allowing customers to meet their energy needs during peak demand hours with onsite electricity generating sources under the guidance of an energy storage schedule that is appropriate [17]. This makes a win-win situation with customer electricity bills [18] and the utility's technical burden reduction [19].

When DG is integrated into the electric power system, it provides the system with the complementary power sources it needs, boosts system dependability overall (by providing backup power in case the primary generators fail), and removes the need for extra spinning reserve plant investments [20]. Moreover, it improves electric power system efficiency, provides auxiliary grid support, and increases power supply quality. DGs reduce power loss by avoiding large transmission and distribution [21]. As a result, the voltage of the electric power grid gets elevated, making energy transmission to remote areas easier [22]. Furthermore, in the event of an unscheduled power plant shutdown or a sudden load surge, DGs can stabilize the falling frequency in the electric power system [23].

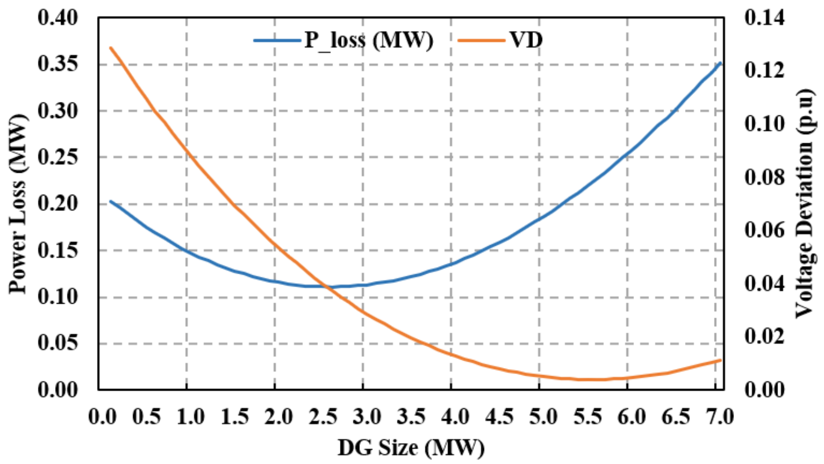
### 1.3. Shunt Capacitor Banks (SCB)

Shunt capacitors banks (SCBs) are commonly used in the distribution system for reactive power compensation. Capacitors are the first equipment to improve the power system voltage [24]. Prior to the 1950s, the main substation was closer to the SCBs due to capacitive reactive power compensation, which helps to increase power factor, decrease power losses, and enhance voltage profile. SCB reduces power losses up to the coupling point, but in order to reap the greatest benefits, it must be installed as close to the load as is practical. Due to the accessibility of pole-mounted equipment, particularly SCB, the tendency has shifted. Additionally, the SCBs are now installed on key distribution lines.

The capacitor unit is regarded as the fundamental SCB building block. Within a steel casing, capacitor units are connected in parallel and series to create a single-phase capacitor bank. While the parallel combination improves the overall capacitance of the SCB, the series combination lowers the cost of the dielectric. In general, the minimum number of units connected in parallel is chosen so that the isolation of a single capacitor unit in a group should not result in a voltage imbalance of more than 110% of the rated voltage on the group's remaining capacitors. A group must have a minimum of two series connections in order for its complete bypass to prevent a permanent overvoltage of more than 110% from affecting the other groups that are still in service. It is thought that the incorporation of SCBs can minimize power losses in highly loaded systems more effectively and proportionately reduce voltage drops as well.

### 1.4. Need to Optimize the DG and SCB Allocation

The power system's infrastructure, protection, and control architectures were originally designed without considering the DGs. Because power flow is believed to be from the grid to the substation, excessive DG penetration may therefore cause the flow of power to be disrupted and the system's operation limitations to be exceeded. In addition, DG is a power generation source that is usually connected to the distribution grid or usage points. It is a well-known fact that the distribution system is the most unreliable among the three components of the power system, generation, transmission, and distribution. The distribution system has the highest power losses due to the higher line resistance to reactance ratio, high current flows and radial configuration [25]. As per the data, the distribution system accounts for almost 70% of the total power system losses [26]. The reference [27] has shown this range from 33.7% to 64.9%. It is apparent that when the DG begins to inject power into a network bus, the system's losses decrease at first. However, at a certain point, the system's power losses begin to climb; hence, the DG's optimal size is obtained at the critical point. In other words, DG penetration in the power system minimizes system power losses to a certain extent [28,29]. This phenomenon can better be understood by Figure 2, which presents a U-shape trajectory between the power losses and DG/SCB penetration.

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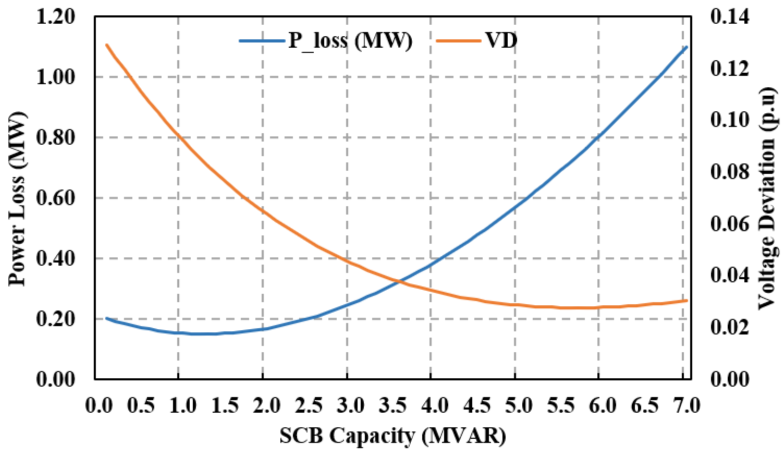


(**b**)

**Figure 2.** Impact of DG/SCB size on the power loss and voltage deviation in the distribution network; (**a**) for DG, (**b**) for SCB.

In these circumstances, optimizing the DG and SCB outputs before integrating them into the distribution networks to maximize their benefits is essential. Optimizing the DG and SCB outputs might cause higher power loss and voltage deterioration in the distribution network than in the initial condition when no DG or SCB is connected. Hence, the optimal allocation of DG and SCB units close to the load centers can boost the performance of distribution networks by:

1. Reducing the total power loss;
2. Improving the voltage profile;
3. Increasing the overall efficiency and reliability of the power supply;
4. Deferring the development of new centrally operated generation and transmission systems;
5. Providing fast development and construction of new power supply units to cope with the growing load demand;
6. Reducing the power transmission and distribution costs;
7. Reducing the peak load shaving at the transmission side.

Therefore, an appropriate planning methodology must be carried out to incorporate DG and SCB units into the distribution network to get constructive benefits for the power system.

### 1.5. Benefits of Simultaneous DG and SCB Integration

In the prospect of power losses and voltage regularity, it has been proven in a number of studies that DGs alone offer better performance than SCBs. This is expected in the electrical power system; the active power losses exceed the reactive power losses. Thus, without active power support, the performance enhancement in the power system will not be up to mark. However, in comparison to SCBs, the investment cost of DGs is very high. The related control, protection, and interface components for the DGs add to the capital cost. DG that costs approximately 41% of the total investment produces a share of 47% in cost-benefit, whereas an SCB with only 0.1% share in the total investment generates a cost-benefit of 12% [30]. Although the percentage benefit produced by SCBs is much less than that acquired by the DGs, investment-to-benefit costs ratio is much higher than the DGs. Consequently, the high cost of DGs necessitates using an additional component in parallel with the low implementation cost [31].

Besides the economic benefit of combining SCBs with DGs, the SCBs' reactive power support significantly decreases losses and enhances the voltage profile [32]. In [33], the percentage loss reductions attained with SCBs, DGs, and their simultaneous integration are reported as 14.3%, 62%, and 74.85%, respectively. In addition, the average improvements in per phase bus voltage are depicted as 0.54%, 2.77%, and 3.07%, respectively. In another study [32], the simultaneous installation of DG-SCB units attained an improved outcome against their integrations when measuring their annual loss reduction, enhanced voltage profile, and cost saving. The yearly cost savings achieved with combined DG-SCB placement in a 33-bus distribution system was 14.65%, 13.2%, and 3.86% more than the individual SCB and DG cases. Some other studies [34,35] have also proved the techno-economic dominance of simultaneous DG-SCB integration over their individual installations. Thus, by simultaneously installing the DGs and SCBs, the distribution networks' much-improved performance can be obtained compared to the individual integrations, along with a significant reduction in the operating cost of the DGs. This highlights the need for their coordinated integration into the distribution networks.

### 1.6. Related Work

In the contemporary literature, several reviews have been published for the individual cases, i.e., optimized allocation of either DG or SCB. Viral and Kathod [13] presented potential benefits, issues, impacts, and limitations of DG integration and optimization techniques. Tan et al. [36] reviewed the optimization techniques used for optimal DG allocation. Priyanka et al. [37] studied different DG technologies and their integration issues. The authors also discussed the planning objectives and techniques in detail. The detailed reviews of objectives, constraints, techniques, variables, and methods employed for optimal DG planning were presented by Sultane et al. [38], Jordehi [39], Prakash and Khatod [20], and Pesaran et al. [40]. Zubo et al. [14], in their review, focused on the technical and economic parameters-based uncertainty modeling approaches and optimization techniques. Singh and Parida [41] studied various technical, financial, and environmental issues with DG integration and proposed future research avenues in these directions. Singh and Sharma [42] reviewed several technical factors hindering DG planning. Khatib et al. [43], in their review, explicitly focused on the photovoltaic (PV) based standalone system and discussed various technical, economic, social, and political criteria for sizing the standalone PV systems. Falahi and Enshaei [44] critically compared single and hybrid algorithms and software tools for sizing solar and wind-based standalone renewable systems. Theo et al. [4] conducted review from the viewpoint of numerical and mathematical modeling methods employed for DG optimal placing. Abdmouleh et al. [45] have also concentrated on the optimization techniques applied for locating the renewable DGs optimally. The review by Ehsan and Yang [46] was limited to the analytical optimization methods. In the area of optimal capacitor allocation, several studies based on the optimization methods were presented by Kishore and Ghosh [47], Sonwane and Kushare [48], Tarun and Neha [49], and Aman et al. [28]. The performance of six different optimization techniques employed for the optimum SCBs placement was analyzed by Aman in his review [28].

In the past few years, the combined DG and SCB allocation have exposed their performance dominance over the sole implication [50]. Therefore, the integrated approach of DGs and SCBs in the distribution system is receiving significant attention from researchers and engineers due to their collective effect on technical and financial benefits. For this reason, this review paper covers research studies explicitly conducted in the area of simultaneous DG and SCB allocation in the distribution system.

### 1.7. Review Methodology

This section presents the method used in selecting published literature on the performance optimization of distribution networks by simultaneous DGs and SCBs allocation. It is essential to segregate what has been done previously and highlight future research areas. For this comprehensive review, priority is given to peer-reviewed articles published in reputed journals and conference papers. The major online services, namely, Google Scholar (https://scholar.google.com/), Science Direct (http://www.sciencedirect.com/), IEEE Xplore digital library (https://ieeexplore.ieee.org/), and Web of Science (http://webofknowledge.com/) were used. The searched keywords were; "Optimal simultaneous DG and SCB allocation in distribution networks", "distributed generation and shunt capacitor allocation", "optimal combined placement of DGs and SCs", "optimal sizing and siting of DGs and SCBs", "concurrent distribution generation and capacitors allocation", and "simultaneous distributed generation and capacitor banks placement in distribution networks". This paper presents the critical review of ninety (90) research articles pertinent to the subject area and published from 2006–2022. The yearly frequency of research papers is presented in Figure 3, which has been published per the current literature review. More than 1000 articles are available in the literature on the optimal allocation of DG or SCB units in distribution networks. However, the key focus of studies selected for this review is on the combined DG and SCB allocation or the optimal allocation of one prior existence of other elements at some fixed point of the distribution network. Few studies have incorporated voltage regulator (VR), thyristor controlled series capacitor (TCSC), and network reconfiguration as an additional constituent of DG–SCB mix.

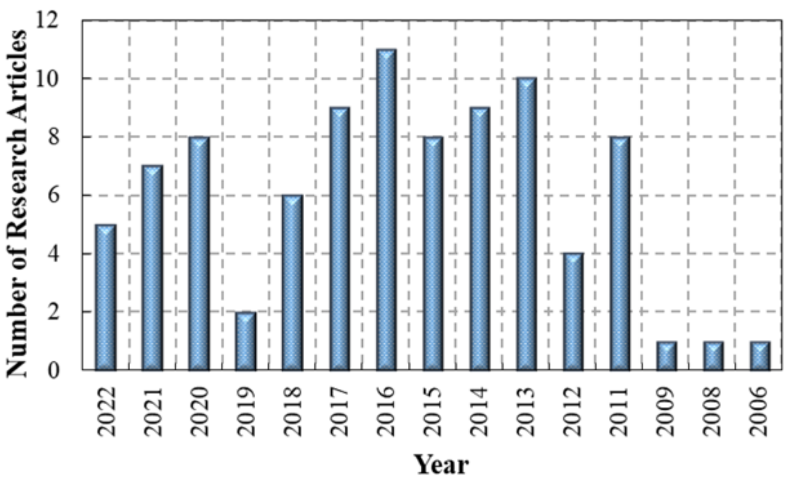


**Figure 3.** Publications frequency.

The top ten (10) countries with the most publications in the area of simultaneous DG-SCB allocation in distribution networks are shown in Figure 4. The number of publications during different time periods was calculated based on the country of affiliation of the first authors. Additionally, the top fifteen (15) organizations (universities/institutions) with most publishing articles are presented in Figure 5.

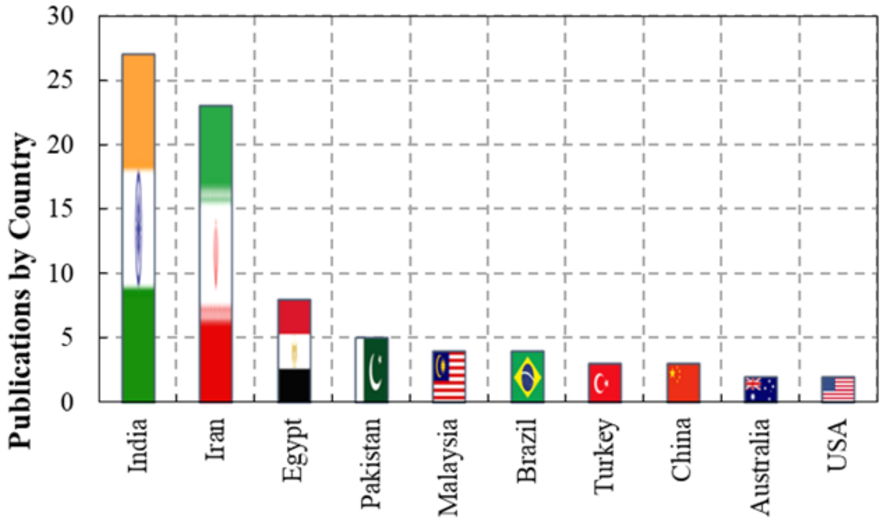


**Figure 4.** Countries with the most publications in the field of simultaneous DG-SCB allocation in distribution networks.

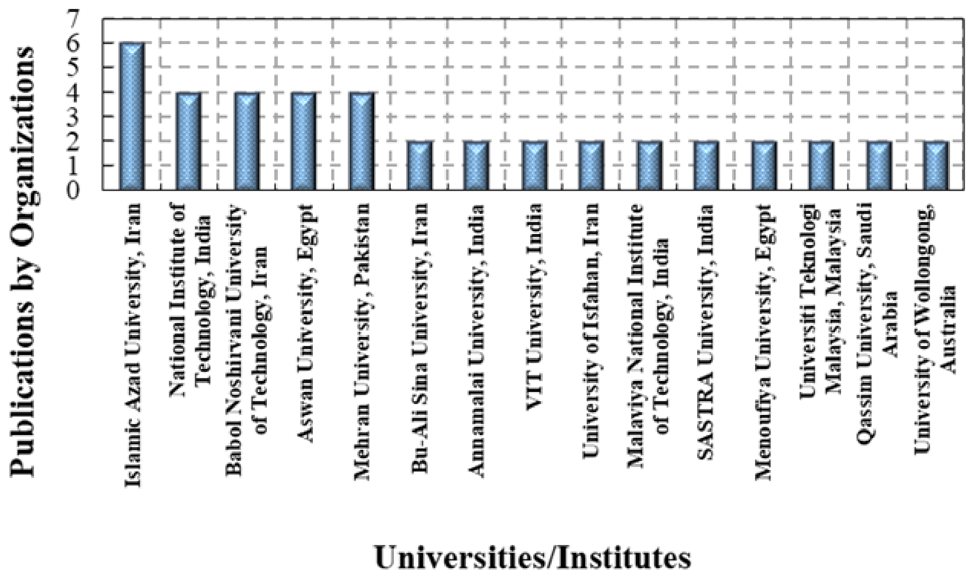


**Figure 5.** Organizations (universities/institutes) with the most publications in the field of simultaneous DG-SCB allocation in distribution networks.

This paper is organized as follows: after a detailed introduction in Section 1, Section 2 covers the optimization strategies that are further categorized into the objective functions, optimization techniques, constraints, decision variables, nature of load and operation modes. The limitations of the existing literature are attempted to highlight in Section 3. Finally, the conclusion and future research directions are presented in Section 4. Figure 6 displays the key contribution and aspects sought to be illustrated by this review.

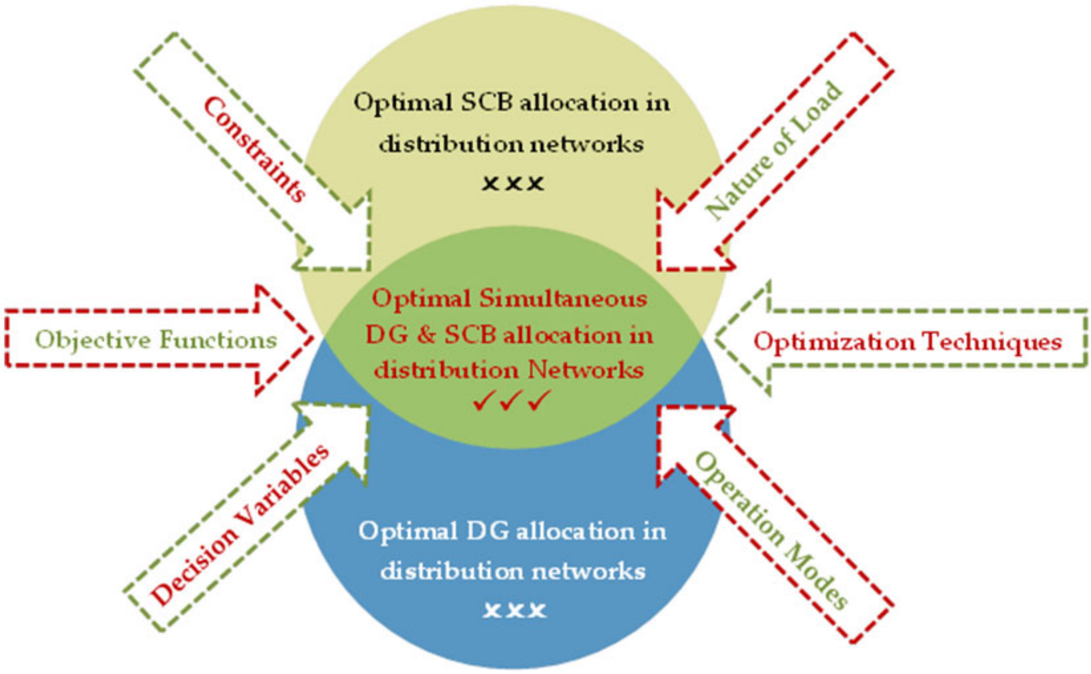


**Figure 6.** Key contribution and different aspects reviewed in this article.

## 2. Planning Framework for DG and SCB Optimal Allocation

The DG and SCB planning framework for the electrical power system involves the determination of necessary network reinforcement that ensures the efficient and secure operation of the system. It involves numerous contradictory technical, financial, social, and environmental objectives to simultaneously find the optimal trade-off. The criteria used to determine the optimum configuration, scheduling, or expansion in the existing system varies significantly according to the specific conditions and organization of the electrical industry.

The optimal DG and SCB allocation planning for any electrical network involves several key factors. These factors include research objectives (goals to achieve), optimization techniques (algorithms), constraints (physical limits of the power system), and decision variables (quantity to be controlled), as shown in Figure 7. Optimization is making the best or most effective use of a resource or situation. The key criterion for the optimal simultaneous DG and SCB allocation in the distribution networks is to ensure the efficient, environment-friendly, secure, and quality supply for the consumers with minimum use of resources. This can be accomplished by selecting the appropriate sizes, placements, types, and quantities of DGs and SCBs. The optimization problem is dealt with concerning certain technical constraints that imitate the security criteria of the system. In-depth reviews of above described four elements are presented in the coming sections.

The literature shows that, while simultaneously optimally allocating the DG and SCB units in the radial distribution networks, the objectives of power loss minimization and voltage profile improvement have commonly been studied. This may be because utilities are usually interested in reducing power losses and improving the voltage profile of the distribution system because of the technological and economic benefits. Some studies have been presented with financial objectives that were established to examine the profit made by power systems after loss reduction and enhancement in voltage magnitudes. Additionally, very few studies have concurrently optimized the cost, environment, and technical objectives. Research on optimal simultaneous DG-SCB allocation is predominately conducted using metaheuristic optimization techniques. Different tables presented in the coming sections provide an overview of the studies conducted in the subject field.

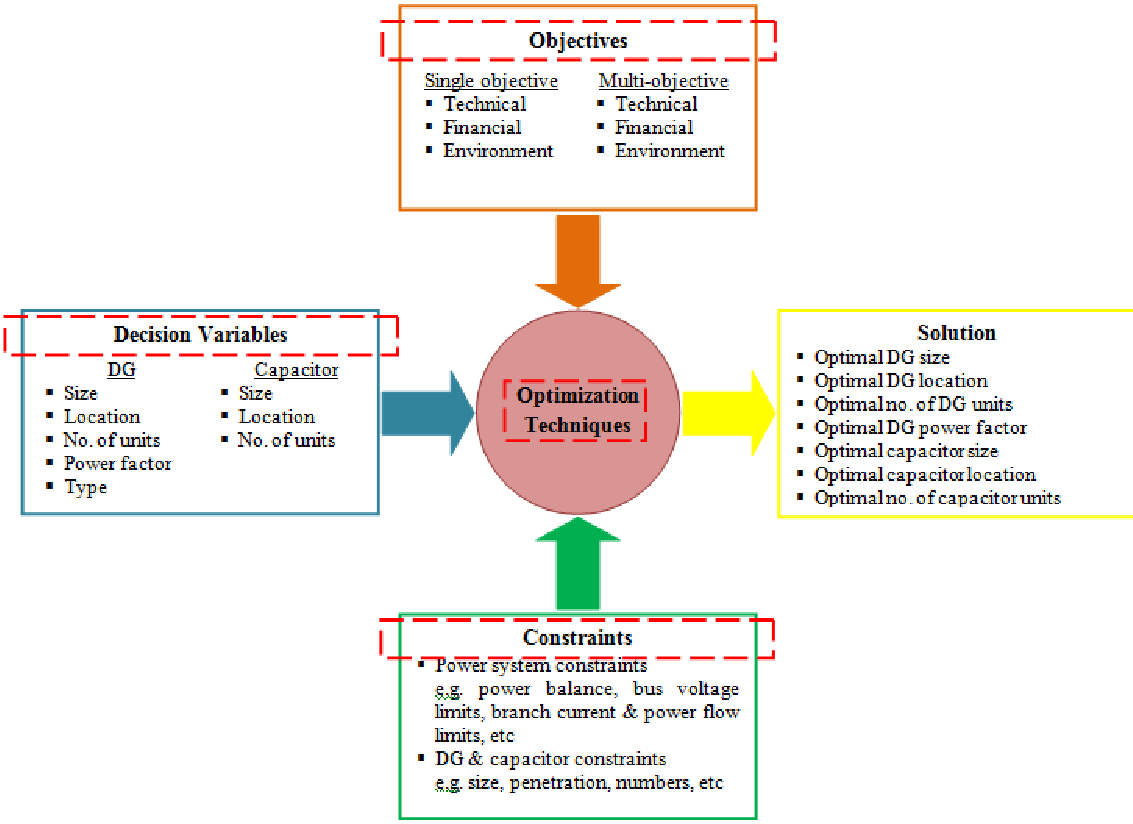


**Figure 7.** Components of the DG and SCB planning framework.

### 2.1. Objective Functions

The objective function (also known as the cost function) is the mathematical expression of a real-world problem that either needs to be minimized or maximized by optimizing certain decision variables, subject to some constraints that must be satisfied. Based on the functions, they have been categorized into technical, economic, and environmental objectives. Most research studies conducted for simultaneous DG-SCB allocation have worked on technical objectives, while the economic and ecological objectives follow the sequence.

The widely considered technical objectives in the literature are the power loss/energy loss minimization, maximization of power loss reduction, depreciation of the voltage deviation, voltage drop, voltage profile improvement, and maximization of the lowest bus voltage. In studies [31–33,35,50–67], the problem of power loss minimization has been solved as the main function. To minimize power losses, the literature presents two different mathematical expressions: branch loss and current loss formulas. The formulation of power loss functions is usually made under the constraint of power balance in the electrical network; the difference between generated and consumed powers at all nodes must be equal to the power loss in that part of the network. Authors in [32,51–53,59,63,65–67] computed the minimum values of total real loss in the distribution networks using the branch power loss formula, Equation (1),

$$P_{lossT} = \sum_{i=0}^{n-1} R_{i,i+1} \frac{P_i^2 + Q_i^2}{|V_i|^2} \tag{1}$$

where $P_{lossT}$ : system's cumulative real power loss across the distribution network branches, $R_{i,i+1}$ : resistance of the branch between buses $i$ and $i$+1, $P_i$, $Q_i$ : load's active and reactive power demands at bus $i$, and $V_i$: voltage magnitude at bus $i$. By attaining the minimum value of the active power loss function, Dixit el al. [32] determined that the simultaneous optimal allocation of three units of each DG and SCB produces better techno-economic results than other combinations. Imran and Kowsalya [51] used the method of Loss Sensitivity Factor (LSF) to determine the suitable location for DG and SCB placement to minimize the power losses. Using the branch loss formula, the authors expressed the total power loss as the maximization function equal to the summation of power loss reductions produced by the DGs and SCBs. Saonerker et al. [52] and Rugthaicharoencheep et al. [65] minimized the total branch loss function by altering the position of network switches pre-allocated with DGs and SCBs. The switch positions were allowed to change under the constraints of un-interruption of the load bus and the radial nature of the distribution network. Authors of [53,59] investigated how individual and simultaneous DG and SCB installations affected the functioning distribution networks. According to the studies, simultaneously allocating DG-SCBs is a more practical approach to obtaining techno-economic benefits. In reference [63], the authors used a multiobjective approach to minimize the real power loss and reactive power flows through the distribution system. For active power loss minimization, Salkuti [66] proposed a method to determine the optimal sizing and location of SCBs for reactive power compensation in the distribution networks with DGs.

The application of active power loss as the product of branch currents and branch resistances, Equation (2), is presented in [31,35,54–57].

$$P_{lossT} = \sum_{i=1}^{N_{br}} I_{bi}^2 R_{bi} \tag{2}$$

where $I_{bi}$ and $R_{bi}$ are the branch current and branch resistance, respectively. Using the branch current expression, individual and simultaneous placement of single and multiple DG-SCB units were studied by Syed and Injeti [31]. The findings led the authors to conclude that while the percentage of power loss reduction improves as the number of units increases, the rate of improvement in percentage loss reduction continues to decline. According to [35], compared to the optimal allocation of multiple SCB units, the optimal allocation of single DG or simultaneous allocation of single DG-SCB units is more effective in improving the distribution system's functioning. The findings reported in [54] revealed that combining Type-III DGs with active and reactive power generating capabilities to SCBs can significantly reduce active power loss compared to Type-I DGs. Furthermore, Naik et al. [55] found that the improvement will be even more significant if Type-III DGs operate at the load power factor.

Apart from the power loss reduction, various studies in the literature also focused on improving the voltage profile of distribution networks. To ensure that a network's minimum node voltage is higher than the lower voltage bound in grid-connected and islanded operations, Wang and Zhong [68] introduced a maximizing function determined by network bus voltage levels. As per the findings of this study, incorporating SCBs in a DG integrated system has a favorable impact on the lowest bus voltage. Khan et al. [69,70] optimized the allocation of DG and SCB units to increase the distribution network's performance by minimizing total line loss (*TLL*) and total voltage deviation (*TVD*) functions. The study's [69] results reveal that decreasing the *TLL* function is more promising in lowering distribution network power losses; nevertheless, it lags behind the *TVD* minimization method in boosting the lowest bus voltage. To tackle the problem of simultaneous minimization of power loss and voltage deviation, authors in [71,72] presented the power/energy loss functions in the form of a voltage deviation penalty factor to maintain the voltage deviation at different nodes within limits. Lalitha et al. [73] modelled the optimization problem as summating two minimization functions: real power loss and voltage deviation. The optimization problem formulated by Uchendu et al. [74] adds two functions: total power loss minimization and maximization of voltage stability index. On the other hand, Sadighmanesh et al. [75] presented cost function as the sum of two minimization functions; real power loss and voltage deviation, and one maximization function; available transfer capability (*ATC*) of distribution networks. In [76,77], the authors used the weighted-sum-based multi-objective approach to simultaneously handle the minimization objectives of real power loss, reactive power loss, and voltage deviation/stability index. Malik et al. [78] and Mahesh et al. [79] used a non-dominated sorting Pareto-front approach to obtain the best trade-off solution among the real power loss, voltage deviation, and voltage stability.

In addition to the power loss and voltage profile, the literature suggests several other technical objectives solved using the simultaneous optimal allocation of DG-SCB units' methodology. The research goals include improved power quality, reliability, loading capacity, and the distribution network's line security. Problem formulation proposed by Yousefzadeh et al. [80] comprised the real power loss and reliability index of energy not supplied (ENS) in a weighted-sum model. Heydari et al. [81] proposed a multi-criterion function consisting of the indices of active power loss, reactive power loss, voltage deviation, total harmonic distortion (*THD*), and resonance to improve the quality of power supply and to prevent the distribution system from experiencing resonance. A priori weighted-sum method was used to handle the proposed objectives concurrently. Weighting factors based multi-criterion minimization function presented in [82] include the technical factors of real power loss reduction index, voltage deviation index and maximum branch current capacity limit index. Based on the simulation results, it was inferred that an integrated network reconfiguration approach with the simultaneous installation of DG and SCB units is an effective method for improving network performance. In [83,84], the proposed weighting coefficients were based on the multi-criterion function incorporate power loss reduction, improving voltage profile and increasing the voltage stability index and the load balancing of the lines. To solve the problem of SCB's optimal reactive power scheduling in a DG integrated distribution network, Ghanegaonkar and Pande [85] proposed single- and multi-objective problems. Total energy loss over a day was minimized as an objective function for a single objective optimization problem. Total energy loss reductions and SCBs switching operations over a day were minimized for multi-objective problems using the weighted-sum approach. In [86], Doostan et al. utilized the weighted-sum method to develop two indices functions: one for DG and one for SCB. The proposed index functions, in turn, were composed of six indices, which include: a real power loss index for DG, real power loss index for SCB, reactive power loss index for DG, reactive power loss index for SCB, voltage profile index for DG and SCB, and power factor index for DG and SCB. The authors used the proposed indices functions to determine the best locations for DG and SCB placements.

Furthermore, in some studies [87–89], non-dominated sorting Pareto-front and fuzzy approaches have been employed to handle the proposed multi-criterion functions. In [87], the formulated multi-criterion function problem combines the active power and voltage stability functions with the index of balancing the current of sections. In contrast, Gallano and Nerves [88] modeled the real power loss and voltage deviation functions with the problem of line loading reduction. To observe the impact of SCBs integration on the functioning of DG embedded distribution network, Jannat and Savić [89] modeled the optimization problem in the form of voltage deviation, and the total installed reactive power capacity of SCBs was required to keep the bus voltages within the limit.

A summary of the research objectives that have been studied in the literature is presented in Table 2. The table clearly shows that the minimization of active power loss has been widely considered a cost function in these studies, followed by the objective function of voltage profile improvement, whereas the benefits of reactive power loss minimization have been ignored in most of the articles. Some studies have established economic objective functions to examine the profit made by the power system. The usually considered cost objective functions include: the installation and running costs of DG and SCB units, cost of energy loss, and the economic benefits that can be attained by cutting down the purchasing of electrical power from the grid. The objectives of minimization of THD, reliability improvement of the distribution networks, and reduction in greenhouse gas emissions are also getting attention in research studies. Furthermore, it was observed that approximately 70% of the existing studies had been conducted using the multi-objective functions, which is a practical approach to optimize the functioning of a distribution network while simultaneously integrating the DG and SCB units.

*2.2. Optimization Techniques*

Optimization techniques employed to solve the mixed-integer non-linear optimization problem of simultaneous DG-SCB allocation can be divided into conventional and metaheuristic techniques. However, most studies have employed metaheuristic techniques to solve this complex optimization problem. In this context, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) were two of the most often employed metaheuristic methods. A detailed classification of the optimization techniques used in the domain of simultaneous DG-SCB allocation is presented in Figure 8.

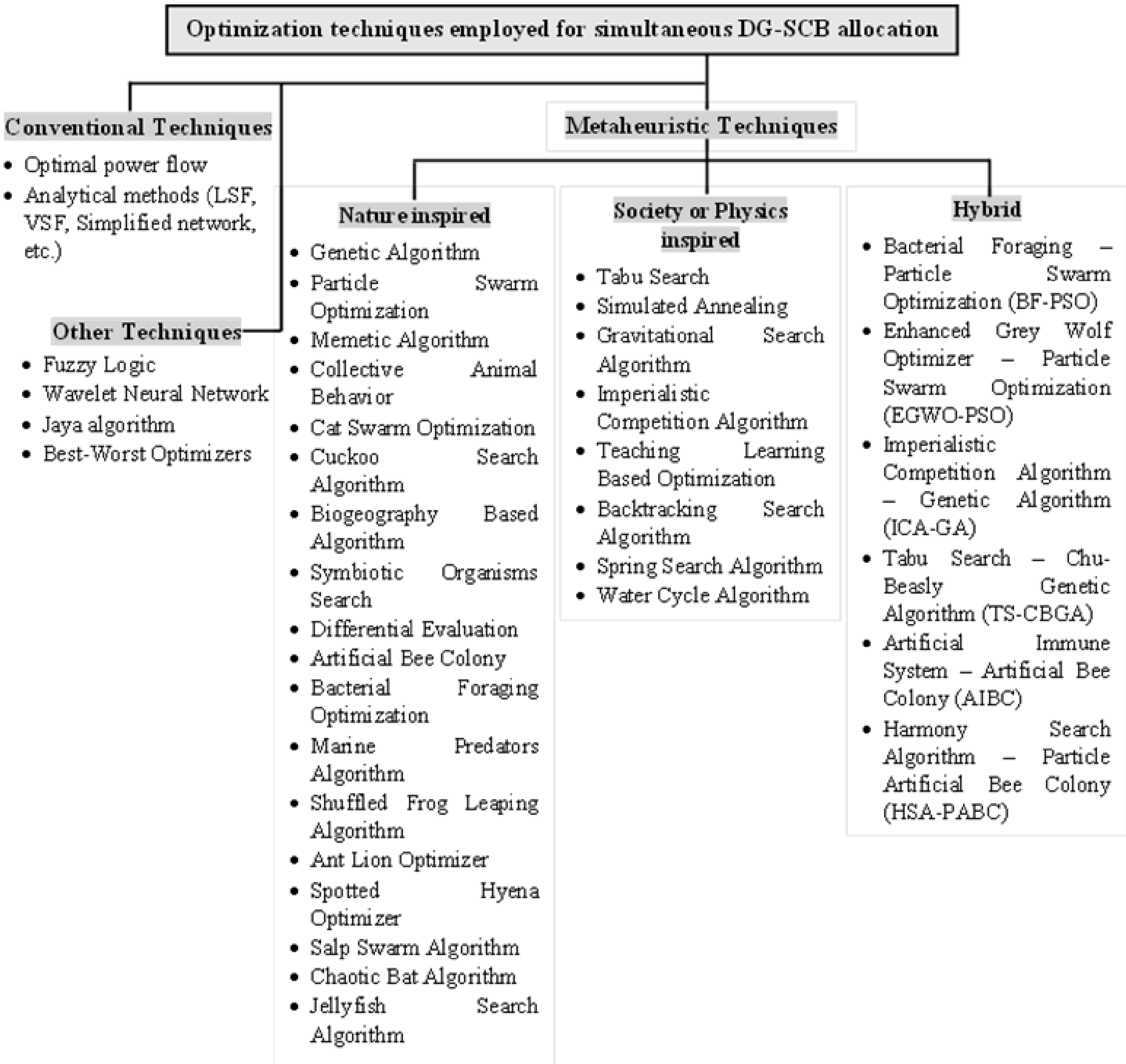


**Figure 8.** Classification of the optimization techniques employed for simultaneous DG-SCB allocation.

2.2.1. Conventional Techniques

The application of conventional optimization techniques is based on the mathematical models of the research problem, which are generally solved using an iterative numerical approach. For simultaneous DG-SCB allocation, conventional optimization techniques reported in the literature mainly depend on sensitivity-based analytical methods and the optimum power flow (OPF). Sensitivity analysis is based on the concept that the variation in any one parameter will bring a change in the targeted parameter [20]. This approach helps to reduce the search space significantly and, in turn, reduces the computation time of the simulation.

A variety of sensitivity factor based analytical methods are reported in the studies [32,51,52,55,86,90]. Dixit et al. [32] introduced the Index Vector Method (IVM) and Power Loss Index (PLI) to determine the optimal position of DGs and SCBs in the distribution networks. Buses with IVM values below 1.01 were considered the best for the DG placement, whereas for the SCB placement buses with higher PLI values and voltage below 0.95p.u were considered suitable. The mathematical expressions for computing IVM and PLI at any bus $i$ are given in Equations (3) and (4), respectively.

$$IVM(i) = \frac{1}{V_i^2} + \frac{I_q(m)}{I_p(m)} + \frac{Q(i)}{total\ Q} \tag{3}$$

$$PLI(i) = \frac{LR(i) - LR_{min}}{LR_{max} - LR_{min}} \tag{4}$$

To select the candidate buses for DGs' and SCBs' placements, the studies [51,52,55,90] used the Loss Sensitivity Factor (LSF) based sensitivity analysis method. The proposed LSF method was based on the idea that the bus with the highest real power loss sensitivity concerning the real power injection, Equation (5), was chosen as the DG candidate bus, while the bus with the highest real power loss sensitivity concerning the reactive power injection, Equation (6), was selected as the SCB candidate bus. The LSF on each bus was then ranked in descending order; the top most vulnerable buses were chosen as potential locations. Consider a distribution network's line section between buses $i$ and $i$+1 with an impedance of $R_{i,i+1} + jX_{i,i+1}$ and supplying a load of $P_{i+1,eff} + jQ_{i+1,eff}$. The LSFs then can be computed using the following equations

$$\frac{\partial P_{Loss\ i,i+1}}{\partial P_{i+1,eff}} = \frac{2 \times P_{i+1,eff} \times R_{i,i+1}}{|V_{i+1}|^2} \tag{5}$$

$$\frac{\partial P_{Loss\ i,i+1}}{\partial Q_{i+1,eff}} = \frac{2 \times Q_{i+1,eff} \times R_{i,i+1}}{|V_{i+1}|^2} \tag{6}$$

To select the optimal location and size of DGs and SCBs, Doostan et al. [86] proposed the overall DG and capacitor indices method. Mathematical expressions of the proposed indices were composed of: real and reactive power loss indices of DGs and SCBs, voltage index for DG and SCB, and power factor index of DG and SCB. The study concludes that, in comparison with the SCB installation, DG installation in the distribution network is an effective way to improve the distribution networks' performance. In [91], Mahmood proposed a loss reduction (*LR*) based OPF method that finds the optimal sizing of DG and SCB units when the loss reduction reaches its maximum value. At this point, the rate of change in *LR* becomes zero (i.e., $\partial LR/\partial P_g = 0$).

#### 2.2.2. Metaheuristic Optimization Techniques

The research on optimal DG-SCB allocation is predominately conducted with metaheuristic techniques. These methods are very promising in solving complex optimization problems in diversified fields. The most interesting characteristic of a metaheuristic is that it does not require a deep understanding of the optimization problem to be solved [92]. Metaheuristic algorithms are approximation methods as they cannot always obtain the optimal global solution. Moreover, the metaheuristic techniques can be categorized into nature-inspired, physics or society-inspired, and hybrid algorithms.

##### Nature-Inspired Metaheuristic Optimization Techniques

Among nature-inspired metaheuristic techniques, GA and PSO are the widely used methods applied in almost 50% of the studies conducted in simultaneous DG and SCB allocation. From these studies, GA was employed in [29,34,52,57,65,75,76,90,93–97]. Using

GA, Andebili [29] investigated the planning problem of simultaneous DG-SCB installation in the distribution network from a distribution company's (DISCO) perspective. By optimally allocating the DGs and SCBs using GA, the author noticed an evident increase in bus voltages, decreased energy loss, and reduced feeder failure rate (FFR) over the planning period. In [34], GA was used to find the best combination of different types of DGs and SCBs to tackle the multi-objective problem of reducing power losses, improving voltage stability, and lowering the cost of DG-SCB units. Results show that GA achieved loss reductions of 74.97% and 59.94% when Type-IV DG was incorporated into the distribution system with and without SCBs, respectively. In [65], 76.32% and 64.68% loss reductions were achieved using GA when DGs and SCBs were allocated concurrently in conjunction with and without network reconfiguration. Saonerkar et al. [52] used GA optimization MATLAB toolbox to optimize the sizes of DGs, SCBs, and reconfiguration of the network switches. Prior, the authors applied the sensitivity analysis method to opt for suitable buses for DG and SCB locations. The GA findings were compared to those obtained using the Heuristic Search Algorithm (HAS) technique and found superior. In [75], the GA attains the best values of loss reduction, voltage deviation, and *ATC* when the allocation of one DG and four SCB units was concurrently optimized along with the tap setting of the transformer. In [76], GA produces minimum values of power losses and voltage deviation when SCBs were optimally allocated distributedly in a DG-embedded distribution network. In [93], the GA decreased the active power loss of a 33-bus distribution system by 47.8% when a single unit of each DG and SCB were placed simultaneously. In comparison, the combined allocation of two units reduced the line losses by 68.9%. In [94], Taher et al. employed GA to minimize energy loss costs and used network capacity and SCBs by optimally allocating the SCBs in the distribution networks with non-linear loads and DG that impose voltage-current harmonics. Using GA in [95], the authors achieved a cost saving of \$83.605 k from energy loss reduction by initiating the SCBs in 69-bus DG embedded distribution system. In [96], Mahaei et al. solved the optimization problem of simultaneous DG and SCB allocation in a practical 20 kV distribution network to minimize the energy losses and investment costs of DGs and SCBs and to improve the reliability of the distribution system in terms of the System Average Interruption Duration Index (*SAIDI*) and System Average Interruption Frequency Index (*SAIFI*). In [97], for the proposed various DG combinations with and without SCBs, the GA attains superior results against the Biogeography Based Optimization (BBO), PSO, Artificial Bee Colony (ABC), and Differential Evolution (DE) techniques. However, in the results presented by Lotfi et al. [57], it has been observed that the power loss reduction achieved with GA was slightly inferior to that of PSO. Furthermore, a comparative GA analysis against other optimization techniques is missing in the above-presented studies [65,75,76,90,93,94,96].

The GA proposed by Gholami et al. [98] comprised of five types of crossover and mutation operators: row, column, array, row-array and column-array operators. Using the proposed GA, the authors demonstrated a countable improvement in loss reduction and minimum bus voltage under grid-connected and islanded operations. They omitted its comparative investigation against the conventional GA. Later, Naderipour et al. [99] extended this study, solved the same optimization problem using the Spotted Hyena Optimizer (SHO) algorithm, and demonstrated its superiority against GA. In [100], Fuzzy GA (FGA) was proposed to integrate a fuzzy system with GA to locate the DGs optimally, whereas for the optimal capacitor placement, LSF based analytical approach was adopted. To conduct the load flow analysis, the authors used Distributed Load Flow (DLF) method, whose execution involves the development of Bus Injection to Branch Current (BIBC) and Branches Current to Bus Voltage (BCBV) matrices. The proposed methodology produces a loss reduction of 72.32% from the projected three cases when DG and SCB units were simultaneously allocated. The incurred loss reductions in the case of individual SCB and DG placements were reported as 32.84% and 42.84%, respectively. In [88,89], a multi-objective variant of GA, named non-dominated sorting based GA (NSGA–II), was proposed. Besides NSGA–II, in [88], the authors deployed a fuzzy decision-making process to identify the best solution from the Pareto-front solutions. The presented results show that the maximum decrements of 195.214 kW in power loss, 0.1568 in *VSI*, and 0.1311 in line loading index (*LLI*) were obtained with NSGA–II when positions of network switches of a 69-bus distribution network were reconfigured in the presence of DG and SCB units. In [89], the NSGA–II produced an annual energy saving of 0.41 GWh alongside an annual cost saving of more than €14,000 when the SCB units were optimally placed in a 28-bus DG embedded distribution network in Serbia. An improved variant of GA (IGA) with brute force crossover and acquiescent mutation parameters was proposed by Kanwar et al. [71]. Using the proposed parameters, the authors observed an enormous improvement in exploration and exploitation capabilities against the conventional GA. In addition, the proposed IGA performed superior against the PSO and other heuristic techniques. The Elitist Speciation-based GA (ESGA) proposed by Mehmood et al. [101] accomplishes the crossover between two parents if both belong to the same species. The similarity between the parents was checked based on the value of the distance metric. If it was found to be less than the threshold value, the parents were allowed to mate. Else, if the unsuitable solution was found in the premises of the first solution, then the second solution was allowed to generate randomly.

PSO is the second most commonly employed algorithm for solving the simultaneous DG-SCB allocation optimization problem. PSO is a population-based stochastic optimization technique inspired by the social behavior of birds flocking together or fish schooling. To optimally locate the DGs and SCBs in the distribution network, Zou et al. [102] used PSO that improved the lowest system voltage by 3.53% and dropped the feeder's loading from 70% to 40%. In addition, the authors also claimed a significant reduction in the system's total cost. In another study [103], the same authors employed the PSO to minimize the purchasing and installation costs of DGs and SCBs. The optimization results revealed that below 60% of the feeder's loading, one SCB unit is sufficient for the requisite voltage support and the lowest cost of the system as well. Whereas, the feeder's loading above 60% enforces the simultaneous integration of the SCB and DG units, raising the system's capital cost. By applying PSO, Ghanegaonkar and Pande [85] solved the optimization problem of hourly scheduling of SCB units in coordination with a photovoltaic DG (PVDG). The presented results show that the PSO achieved maximum power loss reduction when one PVDG and three SCB units were placed optimally in the 33- and 69-bus distribution networks. In the latter part of the study, PSO attained a considerable decrease in energy losses and capacitor switching events by optimizing the allocation of SCBs along with PVDG. In [56], Aman et al. achieved a substantial decrease in power loss by optimizing the loss function with PSO. The effectivity of the PSO algorithm against other optimization techniques is not presented in the several studies mentioned above [56,85,102,103].

With time, various changes in conventional PSO have also been suggested in the literature. Chen et al. [67] introduced PSO with the Orientation and Shrinking factor (PSO-OS) to balance the search capabilities, which guides the search space based on network loss sensitivity outcomes. In [87], a proposed multi-objective variant of PSO (MOPSO) produces several non-dominated sorting solutions. To select the best solution from the Pareto-front set, the authors used a tool of fuzzy logic decision-making. The provided comparative analyses of MOPSO against the NSGA, Multi-Objective Differential Evolution (MODE), Strength Pareto Evolutionary Algorithm (SPEA), and hybrid Imperialist Competitive Algorithm-Genetic Algorithm (ICA-GA) discloses its dominated efficiency in finding the optimal solution. Kayal et al. [104] also employed the non–dominated sorting MOPSO technique with a fuzzy decision tool to optimize the allocation of SCBs and renewable DGs. To deal with the intermittent behavior of PVDG and wind-based renewable DGs (WDGs), the authors employed the beta and Weibull probability distribution functions (PDFs), respectively. In another study [77], Abul'Wafa used the Ant-Lion Optimizer (ALO) to optimize the allocation of renewable DGs concurrent with synchronous condensers. In [79], Mahesh et al. introduced a mutation factor for non–dominated sorting MOPSO to enhance its exploration capability. Using the proposed MOPSO, the installation of renewable DGs and discrete SCBs were concurrently optimized, bringing a countable reduction in power losses and bus voltage deviations. To minimize the active power loss in the distribution network, Srinivasan et al. [50] proposed the Autonomous Group PSO (AGPSO) that distributes the swarm particles into predefined groups. Each independent group is comprised of individual particles with diverse abilities. The independence of these groups to search the space locally and globally improves the efficiency of conventional PSO. The binary version of PSO (BPSO) employed in [105] optimizes the problem in discrete search spaces, i.e., the velocity of each particle was defined with the probability of either 0 or 1. The proposed BPSO improved the PLI by 69.94% and 53.97% in 10- and 33-bus test systems, respectively. Heydari et al. [81] introduced Discrete PSO (DPSO) to optimize the DG and SCB integrations in the distribution networks having non-linear loads. The proposed DPSO reduced power losses by 39.61% and THD by 72.74%. To raise the global solution search capability of the conventional PSO, Arulraj et al. [106] suggested the use of improved weight, cognitive and social parameters whose values will change with succeeding iterations. The proposed improved PSO technique was termed as Weight-Improved PSO (WIPSO). The WIPSO produced the lowest value of the system's operation cost when DGs and SCBs were installed simultaneously but at distinct locations. The studies [81,105,106] did not discuss the performance analysis of proposed modified variants of PSO against the standard PSO or other techniques. To optimize the DG-SCB allocations simultaneously, Kanwar et al. [71] proposed three improved optimization algorithms, namely: Improved PSO (IPSO), IGA, and Improved Cat Swarm Optimization (ICSO). For IPSO, the authors introduced the modified time-dependent models of velocity and position of particles. Furthermore, instead of the change in power loss or node voltage, the population was initiated using the probability-based intelligent search approach that allows to detect sensitivity of the nodes in terms of the change in objective function value. The proposed approach allows for keeping all nodes in search space and selecting only the best nodes based on the cost function value. Hence, the search space was not squeezed instead scanned intelligently without the loss of diversity. The presented findings proved escalated performance of the proposed IPSO over the IGA, ICSO and standard PSO. However, in terms of the convergence, accuracy, and solution quality, IPSO lags behind the ICSO.

The literature also proposes applications of several other nature-inspired metaheuristic techniques to solve the optimization problem of simultaneous DG-SCB allocation. These techniques include: Memetic Algorithm (MA), Collective Animal Behavior (CAB) algorithm, Cat Swarm Optimization (CSO), BBO algorithm, DE, Symbiotic Organisms Search (SOS) algorithm, Cuckoo Search Algorithm (CSA), ABC algorithm, Bacterial Foraging Optimization Algorithm (BFOA), Marine Predators Algorithm (MPA), Shuffled Frog Leaping Algorithm (SFLA), SHO, and Multi-objective Evolutionary Algorithm based Decomposition (MOEA/D). The MA, initially introduced by Moscato [107], is an extension of the conventional GA that uses the local search technique to reduce the likelihood of falling into premature convergence. With local search capability, MA examines the vicinity of found responses from genetics, leading to a diverse performance. Sajjadi et al. [108] employed the MA technique to optimize DG and SCB placements to minimize power loss, energy loss, and voltage profile improvement. Besides significant improvement in each of these objectives, the collective installation of DGs and SCBs resulted in a total cost benefit of $4,653,500. In [70], Khan et al. proposed the binary version of CAB (BCAB) that replaced the real coded variables with the binary variables (0 and 1) and expressed them in the form of binary strings. The CAB is a metaheuristic method based on the collective behavior of animals, such as fish schools, bird flocks, locust swarms, and wildebeest herds. Using BCAB, the authors minimized the *TLL* and *TVD* by optimally allocating the DGs and SCBs collectively and produced superior results against the BPSO and Normal Power Flow (NPF) methods.

Inspired by the hunting pattern of cats, Chu and Tsai [109] developed the CSO algorithm, whose improved variant ICSO was proposed by Kanwar et al. [71]. In addition, the authors introduced two more improved versions of swarm-based optimization techniques: IGA and ICSO. Based on the findings, the ICSO showed better functioning over IPSO and IGA in terms of accuracy, solution quality, and convergence characteristics. To overcome the problem of local minima stagnation for the standard MPA, Eid et al. [110] proposed an improved MPA (IMPA) whose execution is divided into four phases. In terms of minimized power losses and convergence speed, the suggested IMPA surpassed the original MPA and the PSO and Artificial Ecosystem-based Optimization (AEO) algorithms. In [111], Ghaffarzadeh and Sadeghi employed the BBO algorithm to optimize the allocation of inverter-based DGs and SCBs to minimize the harmonic pollution in the distribution system. The study reveals that neglecting the THD shows an increased amount of generated profit; however, its avoidance will affect the smooth functioning of the distribution network if the THD level exceeds the acceptable range. Furthermore, from the findings, it was observed that BBO produces more cost-benefit than GA and PSO, which was calculated in terms of the power loss reduction and the reduced purchasing power from the power transmission network. In one recent study [66], Salkuti proposed the application of DE to optimize the placement and capacity of SCB units in DG integrated distribution networks and demonstrated the DE's efficient performance against the PSO and GA. To optimally allocate the DGs and SCBs simultaneously, Khodabakhshian and Andishgar [112] proposed the Intersect Mutation based DE algorithm (IMDE) variant that proved to have a better performance against the analytical PSO, BPSO, FGA, and BFOA methods. In [73], Lalitha et al. adopted the SOS algorithm to simultaneously allocate the Type-I DGs and SCBs. With the increment in the number of DG and SCB units, the authors have observed a significant decrease in power losses and improved bus voltage.

In studies [33,74,113], the CSA technique has been employed to optimize the simultaneous allocation of SCB and DG units in the distribution systems. Authors of [33,113] did not verify the effectiveness of CSA against any optimization method; however, Biswal et al. [74] proved the CSA's dominance over some metaheuristic and analytical techniques. To determine the optimal capacity and locations of DGs and SCBs for a 33-bus unbalanced distribution network of Neyriz County, Yousefzadeh et al. [80] proposed the ABC algorithm. To validate the findings, the ABC's results were compared against those produced using the GA and PSO algorithms and proved more efficient. In addition, Dixit et al. [32] proposed a $G_{best}$ guided variant of the ABC algorithm (GABC) that overcomes the ABC's lacking poor exploitation. Imran and Kowsalya [51] proposed BFOA to optimize the DG and SCB allocation to minimize the distribution network's power losses. The BFOA proved its performance supremacy over the PSO and analytical techniques by producing better results. Using a modified SFLA (MSFLA) based strategy, Lotfi [114] improved the techno-economical performance of multiple distribution systems considering the uncertain power generation-consumption patterns and time-of-use (ToU) tariff mechanism. The author evidenced the dominate performance of MSFLA over the GA, GSA, ICA, NSGA-II, and original SFLA. Biswas et al. [63] introduced the application of MOEA/D for the optimization problem of simultaneous DG-SCB placement. MOEA/D decomposes a multi-criterion optimization problem into several sub-problems and concurrently optimizes them. To optimize each of the sub-problems, the information obtained from the numerous neighboring problems was used. Authors utilized the MOEA/D to minimize the distribution networks' real and reactive power losses when reinforced with DGs and SCBs. The authors used the idea of Pareto-front to avoid any conflict between the objectives. As a result, the proposed MOEA/D demonstrated its performance edge over the IMDE, Backtracking Search Algorithm (BSA), and analytical techniques.

Society or Physics-Inspired Metaheuristic Optimization Techniques

Different physics or society-inspired algorithms have been employed to solve the optimization problem of simultaneous DG-SCB allocation. This category of optimization techniques includes: Tabu Search (TS), Simulated Annealing (SA), Gravitational Search Algorithm (GSA), Imperialistic Competition Algorithm (ICA), Teaching Learning Based Optimization (TLBO), and BSA. TS is a metaheuristic search technique that solves optimization problems by tracking and guiding the search toward the best solution. The term tabu portrays its ability to prohibit or avoid revisiting previously considered solutions in the search space. This feature makes it more efficient to search the solution space economically. Golshan and Arefifar [115] employed TS and obtained the maximum power loss reductions in 33- and 69-bus distribution networks when DG-SCB units were simultaneously allocated in conjunction with tap settings of the voltage regulator (VR) and network restructuring. However, the authors did not illustrate the performance efficiency of TS against any other optimization algorithm of a similar class.

SA is a probabilistic approach introduced by Kirkpatrick et al. [116]. It imitates the physics process where a metal gradually cools until its structure settles at a state of minimum energy configuration. Elmitwally and Eldesouky [117] proposed the modified variant of SA (MSA) in which the parameter B acts similar to a variable. To compute its value, a linear algebraic expression is proposed by the authors. In comparing the conventional SA, improved cost savings and bus voltages have been reported with the MSA technique. The conventional GSA presented by Rashedi et al. [118] is based on Newton's theory's law of gravity and mass interactions. The same authors in [119] proposed the binary form of GSA (BGSA) where every dimension can either take the value of 0 or 1 only. Khan et al. [69] employed BGSA to obtain the optimal simultaneous DG-SCB allocation and equated its performance against the BPSO. By attaining more loss reduction and less deviation in voltages, the presented results have declared BGSA a superior technique to the BPSO.

ICA, proposed by Gargari and Lucas [120], depicts the imperialistic competition between the colonizers and their colonies. To optimize the discrete variables of DG size, location, power factor, capacitor size, and location, Mahari and Mahari [35] introduced the discrete ICA (DICA) to minimize losses in the distribution network. With the proposed DICA method, the authors achieved 92.5% and 93% reductions in active power loss for 69-bus RDS operating at normal and peak loads, respectively. The reactive power loss reductions at normal and peak loads were 88% and 89%, respectively. The comparative analysis of the DICA algorithm versus the traditional ICA or any other metaheuristic technique was neglected in the research study. TLBO is a population-based evolutionary algorithm invented by Rao et al. [121] in 2012, miming a class's teaching-learning process. Similar to SOS, this algorithm does not require the algorithm-specific parameters that allow it to converge faster than other population-based techniques. To cope with the flaws of TLBO, Kanwar et al. [72] proposed several modifications in the teaching-learning process of the algorithm. The phases in the conventional TLBO include self-adaptive, self-learning, diversified, and teacher's learning. Moreover, the proposed intelligent search phase causes an implicit squeeze in search space, thus, overall improving the accuracy and convergence of TLBO. While optimally placing the DGs and SCBs in distribution networks under the multi-level load scenario, this improved TLBO (ITLBO) variant showed significant performance dominance over the PSO and other heuristic techniques in terms of the suitable solution and the convergence rate. Rahiminejad et al. [122] also proposed a modified TLBO (MTLBO) for the optimal simultaneous allocation of DGs–SCBs and the network reconfiguration. The MTLBO differs from the TLBO in that it does not restrict learners from sharing their knowledge with one student at a time. Instead, it allows them to share their knowledge in a group of two or more students. This mechanism enables the MTLBO to attain the highest loss reduction in the comparison of TLBO, GA, PSO, and a direct search algorithm (DSA).

The BSA is an optimization technique that systematically solves the problem when sufficient information about the best choice is unavailable. It will obtain the correct sequence from the various available arrangements of decisions that will satisfy the criterion function. Fadel et al. [61] presented the BSA based optimal sitting and sizing of DGs, SCBs, and TCSC in a 33-bus distribution network and compared the results with GA, PSO, improved analytical, DE, analytical approach, sensitivity analysis technique, BFOA, FGA, and hybrid harmony search and partial artificial bee colony (HAS-PABC) algorithms. The

BSA outclassed each technique by obtaining the lowest power losses in the power system and enhancing the distribution network's voltage profile.

Hybrid Metaheuristic Optimization Techniques

These algorithms combine two techniques and are considered more accurate and efficient than individual algorithms. Various studies have proposed hybrid methods for the simultaneous allocation of DGs and SCBs. Hooshmand and Mohkami [123] hybridized the Bacterial Foraging (BF) algorithm with the PSO to orient the direction of movement of each bacterium. The study's findings showed that the proposed hybrid BF-PSO method performs better against the PSO, GA, and DE by producing the highest annual cost saving. To acquire mutual benefits of the exploration ability of the Enhanced Grey Wolf Optimizer (EGWO) and the exploitation ability of the PSO, Venkatesan et al. [124] hybridize the EGWO with PSO (EGWO-PSO) to achieve the optimal DG-SCB allocation in 33- and 69-bus distribution networks. Moradi et al. [83] suggested the hybridization of ICA and GA algorithms to combine both algorithms' searching ability and convergence characteristics. In the algorithm's first part, the ICA finds the values of decision variables for the imperialist and colonies in each empire. In the next step, using the crossover and mutation operators, the GA generates a new set of colonies in all search spaces that may have better values than the imperialist ones. The proposed ICA/GA method produces better results when compared with the GA, PSO, and hybrid GA/PSO methods. In [125], a hybrid combination of TS and Chu–Beasly GA (TS-CBGA) algorithms has been proposed, where TS was held responsible for finding the locations of SCB, DG, and DG types. In contrast, CBGA finds the DG power dispatch, type of SCB, and the operational scheme of SCB. The proposed technique produced the optimized value of the investment and operating costs of DGs and SCBs when they were allocated simultaneously in the 69-bus distribution system. As the previously carried majority of the studies, the authors neglected its comparative analysis against sole TS, GA, or any other heuristic technique. Mohamed et al. [59] proposed the hybrid combination of GA and the Moth Swarm Algorithm (GMSA) to minimize the active power loss in 33- and 69-bus test systems. The study's findings showed that the GMSA achieved a reduction in power losses up to 20% more than the contending algorithms.

To improve the performance of ABC, Nabil et al. [64] combined the Artificial Immune System (AIS) with ABC and named the resulting technique as the Artificial Immune Bee Colony (AIBC) algorithm. In AIBC, AIS imitates the behavior of the human immune mechanism and involves the processes of initialization, duplication, mutation, sorting, and selection. This proposed combination allows all the variables to mutate at the same time. The proposed AIBC algorithm manages to reduce the power losses in the 33-bus test system by 74.42% with the concurrent addition of a single unit of each DG and SCB. The main drawbacks of the Harmony Search Algorithm (HAS) are its premature and slow convergence which were overcome by Muthukumar and Jayalalitha in [54] and [82] by hybridizing it with the Particle Artificial Bee Colony (PABC) method. The standard HAS was inefficient in identifying the local search spaces for numerical optimization applications. In the proposed hybrid HAS-PABC method, the PABC was used for the local search, whereas the HAS looked for global solutions. In a study [54], authors used the HS-PABC to optimally site and size the DGs and SCBs in distribution networks to reduce power losses and improve bus voltages. To optimize the same objectives, the authors of [82] opted for network reconfiguration along with the simultaneous DG-SCB allocation. The presented results in both studies have proven the apparent edge of HS-PABC over HAS in terms of convergence rate and accuracy.

The optimization techniques employed to solve the optimization problem of simultaneous DG-SCB allocation are listed in Table 2. The table demonstrates that past studies have usually used metaheuristic optimization techniques. In addition, compared to the GA and PSO, the researchers have not paid much attention to the other promising optimization algorithms. So far, several optimization techniques have not been employed for combined DG-SCB allocation. Some of these techniques are: Ant Colony optimization, Firefly optimization algorithm, Bat algorithm, Plant Growth optimization algorithm, Honey Bee optimization algorithm, Big Bang-Big Crunch, Shark Smell optimization algorithm, Whale optimization algorithm, Grey Wolf optimization algorithm, Arithmetic optimization algorithm, etc. Furthermore, the implementation of most of the reported metaheuristic optimization techniques in the literature either involves two or more phases or requires tuning of algorithm-specific control parameters. For instance, GA employs parameters of mutation probability, crossover probability, and selection operator and involves three stages. PSO utilizes three inertia weight, social, and cognitive parameters and involves two phases. ABC uses the parameters of onlooker bees, employed bees, scout bees, and limit, and it involves three steps. HS algorithm employs harmony memory consideration rate, pitch adjusting rate, and the number of improvisations. SSA uses a balancer operator and involves two stages. SOS involves three phases Mutualism, Commensalism, and Parasitism, and the TLBO involves the two phases (teaching and learning), etc.

Other algorithms, such as DE, BFO, SFLA, and ICA, also require tuning algorithm-specific parameters. Therefore, the optimization problem of simultaneous DG-SCB allocation requires further investigation of the application of new and parameter-free metaheuristic algorithms. Furthermore, several studies have been reported in the literature that used a sequential strategy rather than concurrently optimizing the sizing and positioning of DG and SCB units. First, they employed a method based on power sensitivity or voltage sensitivity factor to determine the best bus locations for DGs and SCBs. The size of DG-SCB units was then optimized using any metaheuristic technique. Although the search-space of the optimization problem can be squeezed by utilizing a sequential approach, the results obtained by this method will not be as effective as those obtained by simultaneously optimizing both sizing and placement using a metaheuristic algorithm. Therefore, future research should use a simultaneous optimization approach to implement combined DG-SCB allocation in distribution networks.

**Table 2.** Research objectives and optimization techniques presented in the existing studies for the simultaneous allocations of DGs and SCBs.

| Ref #/Year | Optimization Technique(s) | Research Objectives | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Real Power/Energy Loss or Real Power Injection | Reactive Power/Energy Loss or Reactive Power Injection | Voltage Profile/Deviation/Sag | Voltage Stability | Power Quality (THD, Resonance, etc.) | Reliability (SAIDI, SAIFI, CAIDI, ENS, etc.) | Line Loading–Network Security/Capacity Installed *P-Q* Capacity/Switching Operations | Load Balancing/Transfer Capability/Power Factor | Cost of Power/Energy Loss | Capital/Running Costs of DGs/SCBs | Other Economic Objectives (Costs of: Power Purchase, Transmission, Reliability, Risk, etc.) | Gas Emissions & Other Environmental Objectives |
| [115] 2006 | TS | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |
| [102] 2008 | PSO | × | × | × | × | × | × | × | × | ✓ | ✓ | ✓ | × |
| [103] 2009 | PSO | × | × | × | × | × | × | × | × | × | ✓ | × | × |
| [76] 2011 | GA | ✓ | ✓ | ✓ | × | × | × | × | × | × | × | × | × |
| [65] 2011 | GA | ✓ | × | × | × | × | × | × | × | × | × | × | × |

**Table 2.** *Cont.*

| Ref #/Year | Optimization Technique(s) | Research Objectives | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Real Power/Energy Loss or Real Power Injection | Reactive Power/Energy Loss or Reactive Power Injection | Voltage Profile/Deviation/Sag | Voltage Stability | Power Quality (THD, Resonance, etc.) | Reliability (SAIDI, SAIFI, CAIDI, ENS, etc.) | Line Loading–Network Security/Capacity Installed *P-Q* Capacity/Switching Operations | Load Balancing/Transfer Capability/Power Factor | Cost of Power/Energy Loss | Capital/Running Costs of DGs/SCBs | Other Economic Objectives (Costs of: Power Purchase, Transmission, Reliability, Risk, etc.) | Gas Emissions & Other Environmental Objectives |
| [93] 2011 | GA | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [94] 2011 | GA | ✓ | × | ✓ | × | ✓ | × | × | × | ✓ | ✓ | ✓ | × |
| [53] 2011 | DE | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [68] 2011 | OPF | × | × | ✓ | × | × | × | × | × | × | × | × | × |
| [123] 2011 | BF-PSO | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |
| [126] 2011 | Fuzzy | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |
| [127] 2012 | GA | ✓ | × | × | ✓ | × | × | × | × | × | ✓ | × | × |
| [117] 2012 | MSA | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |
| [75] 2012 | GA | ✓ | × | ✓ | × | × | × | × | ✓ | × | × | × | × |
| [96] 2012 | GA | ✓ | × | × | × | × | ✓ | × | × | × | ✓ | ✓ | × |
| [55] 2013 | Analytical | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [100] 2013 | FGA | × | × | ✓ | × | × | × | × | ✓ | ✓ | × | × | × |
| [60] 2013 | PSO | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [56] 2013 | PSO | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [81] 2013 | DPSO | ✓ | ✓ | ✓ | × | ✓ | × | × | × | × | × | × | × |
| [105] 2013 | BPSO | ✓ | × | ✓ | × | × | ✓ | × | × | × | ✓ | × | × |
| [128] 2013 | BPSO | × | × | × | × | × | × | × | × | ✓ | ✓ | ✓ | × |
| [69] 2013 | BGSA | ✓ | × | ✓ | × | × | × | × | × | × | × | × | × |
| [108] 2013 | MA | × | × | × | × | × | × | × | × | ✓ | ✓ | ✓ | × |
| [106] 2013 | WIPSO | × | × | ✓ | × | × | × | × | × | ✓ | ✓ | ✓ | × |
| [129] 2014 | MPSO | ✓ | ✓ | ✓ | × | × | × | × | × | × | × | × | ✓ |
| [64] 2014 | ABC-AIS | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [35] 2014 | DICA | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [52] 2014 | GA | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [97] 2014 | GA | ✓ | × | ✓ | × | × | × | × | × | ✓ | ✓ | ✓ | × |
| [83] 2014 | ICA-GA | ✓ | × | ✓ | ✓ | × | × | × | ✓ | × | × | × | × |
| [31] 2014 | BSA | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [51] 2014 | BFOA | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [30] 2014 | TLBO | × | × | × | × | × | × | × | × | ✓ | ✓ | ✓ | × |
| [70] 2015 | BCAB | ✓ | × | ✓ | × | × | × | × | × | × | × | × | × |
| [71] 2015 | IGA, IPSO, ICSO | ✓ | × | ✓ | × | × | × | × | × | × | × | × | × |
| [72] 2015 | ITLBO | ✓ | × | ✓ | × | × | × | × | × | × | × | × | × |
| [88] 2015 | NSGA-II | ✓ | × | × | ✓ | × | × | ✓ | × | × | × | × | × |
| [87] 2015 | MOPSO | ✓ | × | × | ✓ | × | × | × | ✓ | × | × | × | × |
| [98] 2015 | GA | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |

**Table 2.** *Cont.*

| Ref #/Year | Optimization Technique(s) | Research Objectives | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Real Power/Energy Loss or Real Power Injection | Reactive Power/Energy Loss or Reactive Power Injection | Voltage Profile/Deviation/Sag | Voltage Stability | Power Quality (THD, Resonance, etc.) | Reliability (SAIDI, SAIFI, CAIDI, ENS, etc.) | Line Loading–Network Security/Capacity Installed *P-Q* Capacity/Switching Operations | Load Balancing/Transfer Capability/Power Factor | Cost of Power/Energy Loss | Capital/Running Costs of DGs/SCBs | Other Economic Objectives (Costs of: Power Purchase, Transmission, Reliability, Risk, etc.) | Gas Emissions & Other Environmental Objectives |
| [34] 2015 | GA | ✓ | × | × | ✓ | × | × | × | × | × | ✓ | × | × |
| [95] 2015 | GA | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |
| [84] 2015 | WNN | ✓ | × | ✓ | ✓ | × | × | × | ✓ | × | × | × | × |
| [89] 2016 | NSGA-II | × | × | ✓ | × | × | × | ✓ | × | × | × | × | × |
| [111] 2016 | BBO | × | × | × | × | × | × | × | × | ✓ | ✓ | ✓ | × |
| [112] 2016 | IMDE | × | × | × | × | × | × | × | × | ✓ | × | × | × |
| [73] 2016 | SOS | ✓ | × | ✓ | × | × | × | × | × | × | × | × | × |
| [54] 2016 | HAS-PABC | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [122] 2016 | MTLBO | × | × | × | × | × | × | × | × | ✓ | ✓ | ✓ | × |
| [104] 2016 | MOPSO | ✓ | × | × | ✓ | × | × | ✓ | × | × | ✓ | ✓ | ✓ |
| [125] 2016 | TS-CBGA | × | × | × | × | × | × | × | × | × | ✓ | ✓ | × |
| [29] 2016 | GA | × | × | × | × | × | × | × | × | ✓ | ✓ | ✓ | × |
| [86] 2016 | Analytical | ✓ | ✓ | ✓ | × | × | × | × | ✓ | × | × | × | × |
| [82] 2017 | HAS-PABC | ✓ | × | ✓ | × | × | × | ✓ | × | × | × | × | × |
| [32] 2017 | GABC | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [85] 2017 | PSO | ✓ | × | × | × | × | × | ✓ | × | × | × | × | × |
| [50] 2017 | AGPSO | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [61] 2017 | BSA | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [33] 2017 | CSA | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [79] 2017 | MOPSO | ✓ | ✓ | ✓ | × | × | × | × | × | × | × | × | × |
| [63] 2017 | MOEA/D | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [91] 2017 | Analytical | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [59] 2018 | GMSA | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [57] 2018 | GA, PSO | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [113] 2018 | CSA | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |
| [130] 2018 | WCA | ✓ | × | ✓ | ✓ | × | × | × | × | × | ✓ | × | ✓ |
| [62] 2018 | WIPSO-GSA | ✓ | ✓ | × | × | × | × | × | × | × | × | × | × |
| [101] 2018 | ESGA | ✓ | × | ✓ | × | × | × | × | × | × | ✓ | × | × |
| [77] 2019 | ALO | ✓ | ✓ | × | ✓ | × | × | × | × | × | × | × | × |
| [131] 2019 | SSA | ✓ | × | ✓ | ✓ | × | × | × | × | × | ✓ | ✓ | ✓ |
| [132] 2020 | SSA | ✓ | × | ✓ | × | × | × | × | × | × | ✓ | ✓ | ✓ |
| [133] 2020 | TPA | ✓ | × | × | ✓ | × | × | × | × | ✓ | ✓ | ✓ | × |

**Table 2.** *Cont.*

| Ref #/Year | Optimization Technique(s) | Research Objectives | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Real Power/Energy Loss or Real Power Injection | Reactive Power/Energy Loss or Reactive Power Injection | Voltage Profile/Deviation/Sag | Voltage Stability | Power Quality (THD, Resonance, etc.) | Reliability (SAIDI, SAIFI, CAIDI, ENS, etc.) | Line Loading–Network Security/Capacity Installed *P-Q* Capacity/Switching Operations | Load Balancing/Transfer Capability/Power Factor | Cost of Power/Energy Loss | Capital/Running Costs of DGs/SCBs | Other Economic Objectives (Costs of: Power Purchase, Transmission, Reliability, Risk, etc.) | Gas Emissions & Other Environmental Objectives |
| [134] 2020 | OCSO | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |
| [58] 2020 | EGA | ✓ | × | ✓ | × | × | × | × | × | × | × | × | × |
| [78] 2020 | MOPSO | ✓ | × | ✓ | ✓ | × | × | × | × | × | × | × | × |
| [74] 2020 | CSA | ✓ | ✓ | × | ✓ | × | × | × | × | × | × | × | × |
| [80] 2020 | ABC | ✓ | × | × | × | × | ✓ | × | × | × | × | × | × |
| [135] 2020 | Analytical | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |
| [66] 2021 | DE | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [110] 2021 | IMPA | × | ✓ | × | × | × | × | × | × | × | × | × | × |
| [114] 2021 | MSFLA | ✓ | × | × | × | × | ✓ | × | × | × | ✓ | × | × |
| [99] 2021 | SHO | × | × | × | × | × | × | × | × | ✓ | ✓ | × | × |
| [67] 2021 | PSO-OS | ✓ | × | × | × | × | × | × | × | × | × | × | × |
| [124] 2021 | EGWO-PSO | ✓ | × | ✓ | ✓ | × | × | × | × | × | ✓ | ✓ | ✓ |
| [136] 2021 | IJaya | ✓ | × | ✓ | × | × | × | × | × | × | × | × | × |
| [137] 2022 | BWOs | ✓ | × | ✓ | × | × | × | × | × | × | × | × | × |
| [138] 2022 | CBA | ✓ | × | ✓ | ✓ | × | × | × | × | × | × | × | × |
| [139] 2022 | GA | ✓ | × | × | × | × | × | × | × | × | ✓ | × | × |
| [140] 2022 | GA | ✓ | ✓ | × | × | × | × | × | × | × | × | × | × |
| [141] 2022 | JSA | ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × | × | × |

### 2.2.3. Constraints

Constraints are the posed restrictions on the optimization study or the additional conditions that must be met for a successful solution. These are the set boundaries for an optimizer, which it cannot cross. For the optimal simultaneous DG-SCB allocation, posed limitations on the optimization problem can be divided into three categories: power system constraints, DG constraints, and SCB constraints.

#### Power System Constraints

Power system constraints include the limitations that are imposed on the studied test distribution systems. Power balance, voltage limits at buses, current and power flow limit of lines equal to or below the thermal limits, and the total harmonic distortion due to non–linear loads are the usual limitations observed in the simultaneous allocation studies. In most studies, active and reactive power balance at nodes has been set as a key constraint that should not be overcome while minimizing or maximizing the cost function. The generated amount of active and reactive powers must equal the load's consumption plus the losses. This generated power is supplied through the substation and/or DG but must be consumed fully. Violation of this constraint will result in a backward power flow from the passive to the active part of the network, which must be avoided. Except for a few studies, the minimum and maximum bus voltage limits are the most exerted bounds for the proposed optimization problems. Violation of these limits will affect the stability of the power system. No particular standard for the subject limit is observed from the reviewed articles; hence different ranges of voltage bounds have been exercised. With $\pm 5\%$ variation in the system's rated voltage, the normally set boundary values for the bus voltages are 0.95 p.u–1.05 p.u. Whereas other noted range of minimum and maximum bound for voltage limit are: 0.90 p.u and 1.10 p.u [68,79,82,123], 0.90 p.u–1.05 p.u [63], 0.94 p.u–1.06 p.u [85], 0.9038 p.u–1.00 p.u [31], 0.90 p.u–1.00 p.u [70] and 0.985 p.u–1.00 p.u [53]. The ref. [104] has only set the maximum voltage limit of 1.05 p.u at the buses. Besides the voltage limits, the line's current and power flow limits are considered stability margins for power system operation. Allowable current and power flows are bound by the thermal capacity of the lines in references [30,69,122,127]. Similar to voltage limits, no particular standard is followed for selecting the current limits. Hence, they are set by the authors on their own. For example, ref. [61] applied 400 A, 300 A, and 200 A as conductors' maximum allowable current capacities, while in references [52,65] used values are only 400 A and 200 A. Total harmonic distortion (THD) is the factor that impacts the system's power quality and is considered by references [81,90,94,97,111,117] for their proposed works. THD is caused by the non–linear loads in the power system, and this distortion must be limited to a maximum ($THD_{max}$) of 5% as per IEEE–519 standard [111]. Other set restrictions for the optimization studies include radial network topology [52,65,71,82,88,115] that the system will remain in radial configuration; load bus interruption [52,65] that the load will not interrupt or shade during the optimization process; as well as the number of tie-switches [122], substation power generation [68–70], power factor [125] limits, reactive power generation of the slack bus during islanded operation mode [98], power loss limit of lines [100], the network's voltage drop [51] and the slack bus voltage remains constant [129]. Limitations on unit sizes of DGs, capacitors, their numbers, power factors and percentage shares in total active-reactive power generations also have an impact on the power system operation. These constraints are covered separately in the coming DG and capacitor constraints sections.

DG Constraints

The integration of DG units has a positive impact on the power system if it does not breach any of the set boundaries of the distribution system, such as reduced power loss, voltage regulation, and load sharing. Some constraints are also imposed on DGs in terms of the unit size limit, power share limit in the system, limit of the number of units, power factor limit, and so on. A minimum and maximum power generation bound of a DG unit is the most commonly used constraint in the literature. When connected to a bus in the distribution system, that limit prevents a DG unit from generating power less than the minimum and more than the maximum limit. Most authors have not specified limits, while some have assumed these independently, as there is no rule of thumb for selection. The references [54,85] assumed these limits in terms of the percentage of load demand, whereas studies [71,83,87,111] specified the specific values for these limits. The authors of reference [108] have set the maximum power generation of DGs only and allowed the algorithm to adopt any value equal to or below that limit. DG penetration, cumulative power generation capacity of all DGs as a percentage of total load demand or total load plus losses, is set as a limit in [31,32,35,50,55,63,64,71,72,82,97,100,104,111,115,127]. Few of these set percentages of the total load demand are 10–80% [35], 35% [115], 40% [100], 50% [55,63,82,97,111], 65% [32], and 100% [31,64,71,72]. This limit has been set to 100% of the total load plus losses by ref. [50] to and ref. [127] set it to 100% of the maximum power generation limit of DGs. The combined reactive power generation limit of both DGs and capacitors is 85% and 100% of total reactive power demand in references [98] and [54], respectively. In contrast, [98] has bound the DGs' reactive power generation to 25% of their apparent power. The minimum and maximum power factor limits as constraints are considered in [35,82,83,87]. The values of this range was specified by reference [35] as 0.8, lagging to 0.8 leading. Fix values of power factor was chosen by [32,54,63,73,76,86,89,102,111,129] for their studies. The rest of the DG constraints, number of units [33,51,68,75,86,88,89,91,102,125], unit size [29,35,129] and bus position of DG's [79,104] are also acquired by the authors. For the position of the DG, the authors have bound the algorithm not to select the first bus, i.e., slack bus, as an optimal choice for the DG location.

SCB Constraints

SCB is also a type of DG that generates only reactive power. Therefore, a similar constraint as observed for the DGs has been employed for SCBs. These include minimum and maximum power generation limit of capacitor, cumulative power generation capacity as percentage of total loads reactive power demand, number of capacitor units, discrete value of smallest unit size, total reactive power capacity of capacitors as the multiple of smallest unit size, position of capacitors, capacitive reactive power generation limit per bus, and the cost of capacitors equal to or below the allocated budget. The references [60,93] have specified the range in terms of numerical values for the minimum and maximum generation limit of capacitors. In contrast, [55] has associated this range with being equal to or less than the reactive power production of the slack bus. For the collective capacity of all capacitors, it has kept not more than 100% of the load demand [31,32,55,63,71,72,82,83,87,111], while study [51] set this to 80% of the load's reactive power. The capacitors availability in discrete size is assumed in several optimizing studies, thus, the commonly applied size of a single capacitor unit are 25 kVAR [35,115], 50 kVAR [54], 100 kVAR [55], 125 kVAR [79], 150 kVAR [32,81,83,85,87,98,104,111,122], 250 kVAR [97], 300 kVAR [71,72], and 1 MVAR [29]. Similar to DGs, [104] has only restricted capacitors' positioning at the slack bus.

Table 3 details the range of constraints used in the research, demonstrating that the DGs' operating power factor ($pf_{DG}$) constraint has not been frequently posed in the literature. The reason is that most of the existing research considered $pf_{DG}$ being equal to unity, ignoring the DG units' reactive power generation.

**Table 3.** Constraints employed in the existing studies for optimizing the simultaneous allocation of DG and SCB units.

| Ref. # | Power System Constraints | | | | | | | DG Constraints | | | | | SCB Constraints | | | | VR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Power Balance** | **Bus Voltage** | **Current Flow Limits** | **Power Flow Limits** | **THD** | **Radial Topology** | **No-Load Point Interruption** | **Size** | **Site** | **Number of Units** | **Penetration** | **Power Factor** | **Size** | **Site** | **Number of Units** | **Penetration** | **Tap Positions** |
| [115] | ✓ | ✓ | | | | ✓ | | ✓ | | | | | ✓ | | | | ✓ |
| [102] | | ✓ | ✓ | | | | | | | | | | | | | | |
| [103] | | ✓ | ✓ | | | | | | | | | | | | | | |
| [76] | ✓ | ✓ | | ✓ | | | | | | | | | | | | | |
| [65] | ✓ | ✓ | ✓ | | | ✓ | ✓ | | | | | | | | | | |
| [93] | ✓ | ✓ | | ✓ | | | | | | | | | ✓ | | | | |
| [94] | | ✓ | | | ✓ | | | | | | | | | | ✓ | | |
| [53] | | ✓ | | | | | | ✓ | | | | | ✓ | | | | |
| [68] | ✓ | ✓ | | | | | | ✓ | | ✓ | ✓ | | ✓ | | ✓ | ✓ | |
| [123] | ✓ | ✓ | | | | | | ✓ | | | | | ✓ | | | | |

**Table 3.** *Cont.*

| Ref. # | Power System Constraints | | | | | | | DG Constraints | | | | | SCB Constraints | | | | VR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Power Balance | Bus Voltage | Current Flow Limits | Power Flow Limits | THD | Radial Topology | No-Load Point Interruption | Size | Site | Number of Units | Penetration | Power Factor | Size | Site | Number of Units | Penetration | Tap Positions |
| [126] | ✓ | ✓ | | | | | | ✓ | | | | | | | | ✓ | |
| [127] | | | | | | | | | | ✓ | ✓ | | | | | ✓ | |
| [117] | | ✓ | | | ✓ | | | ✓ | | | | | | | ✓ | ✓ | |
| [75] | | ✓ | | ✓ | | | | | | ✓ | | | | | ✓ | | |
| [96] | | | | | | | | | | | | | | | | | |
| [55] | ✓ | ✓ | ✓ | | | | | | | | ✓ | | | | | ✓ | |
| [100] | | ✓ | | ✓ | | | | | | | ✓ | | | | | | |
| [60] | ✓ | | ✓ | | | | | | | | | | ✓ | | | | |
| [56] | | ✓ | | | | | | ✓ | | | | | ✓ | | | | |
| [81] | | ✓ | | | ✓ | | | | | | | | | | | | |
| [105] | | ✓ | ✓ | | | | | | | | | | | | | | |
| [128] | | ✓ | ✓ | | | | | | | | | | | | | | |
| [69] | ✓ | | | | | | | | | | | | | | | | |
| [108] | | ✓ | | ✓ | | | | | | | ✓ | | | | | | |
| [106] | ✓ | ✓ | | ✓ | | | | ✓ | | | | | ✓ | | | | |
| [129] | ✓ | ✓ | | | | | | ✓ | | | | | ✓ | | | | |
| [64] | ✓ | | | | | | | ✓ | | | ✓ | | ✓ | | | | |
| [35] | ✓ | ✓ | ✓ | | | | | ✓ | | | | ✓ | ✓ | | | | |
| [52] | ✓ | ✓ | ✓ | | | ✓ | ✓ | | | | | | | | | | |
| [97] | ✓ | ✓ | | ✓ | ✓ | | | ✓ | | | | | | | | | |
| [83] | ✓ | ✓ | | ✓ | | | | ✓ | | | | ✓ | | | ✓ | ✓ | |
| [31] | | ✓ | | | | | | | | | ✓ | | | | ✓ | | |
| [51] | ✓ | ✓ | ✓ | | | | | ✓ | | ✓ | | | ✓ | | ✓ | ✓ | |
| [30] | ✓ | | | | | | | ✓ | | | | | ✓ | | | | |
| [70] | ✓ | ✓ | | ✓ | | | | | | | | | | | | | |
| [71] | | ✓ | ✓ | | | ✓ | | ✓ | | | ✓ | | ✓ | | ✓ | | |
| [72] | | ✓ | ✓ | | | | | ✓ | | | ✓ | | ✓ | | | ✓ | |
| [88] | | | ✓ | | | ✓ | | | | ✓ | | | | | | ✓ | |
| [87] | ✓ | | | ✓ | | | | ✓ | | | | | | | ✓ | | |
| [98] | | ✓ | ✓ | | | | | | | | | | ✓ | | | ✓ | |
| [34] | | | | | | | | ✓ | ✓ | | | | ✓ | ✓ | | | |
| [95] | ✓ | ✓ | | | | | | | | | | | | | | | |
| [89] | | ✓ | | | | | | | | ✓ | | | | | | | |
| [84] | | | | | | | | | | | | | | | | | |
| [111] | | ✓ | | | ✓ | | | ✓ | | | ✓ | | | | ✓ | | |
| [112] | | | ✓ | | | | | ✓ | | | | | ✓ | | | | |
| [73] | ✓ | | | | | | | ✓ | | | | | ✓ | | | | |
| [54] | ✓ | | | | | | | ✓ | | | | | | | ✓ | | |
| [122] | | ✓ | | ✓ | | ✓ | | ✓ | | | | | | | ✓ | | |
| [104] | ✓ | ✓ | ✓ | | | | | | | | ✓ | | | | ✓ | | |
| [125] | ✓ | ✓ | ✓ | | | | | ✓ | | ✓ | | | ✓ | | | | |
| [29] | | ✓ | | ✓ | | | | | | | | | | | | | |
| [86] | | ✓ | | | | | | | | ✓ | ✓ | | | | ✓ | ✓ | |
| [82] | | ✓ | ✓ | | | ✓ | | ✓ | | | ✓ | | | | ✓ | | |
| [32] | ✓ | | ✓ | | | | | | | | ✓ | | | | ✓ | | |
| [85] | ✓ | ✓ | | | | | | ✓ | | | | | ✓ | | | | |
| [50] | ✓ | ✓ | | | | | | ✓ | | | ✓ | | ✓ | | ✓ | | |
| [61] | ✓ | | ✓ | | | | | ✓ | | | | | ✓ | | | | |

**Table 3.** *Cont.*

| **Ref. #** | **Power System Constraints** | | | | | | | **DG Constraints** | | | | | **SCB Constraints** | | | | **VR** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Power Balance** | **Bus Voltage** | **Current Flow Limits** | **Power Flow Limits** | **THD** | **Radial Topology** | **No-Load Point Interruption** | **Size** | **Site** | **Number of Units** | **Penetration** | **Power Factor** | **Size** | **Site** | **Number of Units** | **Penetration** | **Tap Positions** |
| [33] | | | ✓ | | | | | ✓ | | ✓ | | | ✓ | | | ✓ | |
| [79] | ✓ | ✓ | ✓ | | | | | ✓ | | | | | ✓ | | | | |
| [63] | | ✓ | ✓ | | | | | ✓ | | | ✓ | | ✓ | | ✓ | | |
| [91] | | | | | | | | | | ✓ | | | | | ✓ | | |
| [59] | ✓ | ✓ | | | | | | ✓ | | | | | ✓ | | | ✓ | |
| [57] | ✓ | ✓ | ✓ | | | | | | | | ✓ | | | | | ✓ | |
| [113] | ✓ | ✓ | | | | | | ✓ | | | | | ✓ | | | | |
| [130] | | ✓ | | | | | | ✓ | | | | ✓ | ✓ | | | ✓ | |
| [62] | | ✓ | ✓ | | | | | ✓ | | | ✓ | ✓ | ✓ | | | ✓ | |
| [101] | | | ✓ | | | | | | | | | | | | | | |
| [77] | ✓ | ✓ | | | | | | ✓ | ✓ | | | | ✓ | | | | |
| [131] | ✓ | ✓ | | | | | | ✓ | | | | ✓ | ✓ | | | ✓ | |
| [132] | ✓ | ✓ | | | | | | ✓ | | | | ✓ | ✓ | | | ✓ | |
| [133] | ✓ | ✓ | ✓ | | | ✓ | | | | | | | | | | | |
| [134] | ✓ | ✓ | | ✓ | | | | ✓ | | | | | ✓ | | ✓ | ✓ | |
| [58] | | ✓ | ✓ | | | | | | | | ✓ | | | | | ✓ | |
| [78] | ✓ | ✓ | | ✓ | | | | ✓ | ✓ | | | | ✓ | ✓ | | | |
| [74] | ✓ | ✓ | | | | | | ✓ | | | | | | | | | |
| [80] | ✓ | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | |
| [135] | ✓ | ✓ | | | | | | ✓ | | | ✓ | | ✓ | | | ✓ | |
| [66] | | ✓ | | | | | | | | | | | ✓ | | | | |
| [110] | ✓ | ✓ | | | | | | | | | ✓ | ✓ | | | | ✓ | |
| [114] | ✓ | ✓ | ✓ | | | | | ✓ | | | | | ✓ | | | | |
| [99] | | ✓ | ✓ | | | | | | | | | | ✓ | | | | |
| [67] | ✓ | ✓ | | | | | | | | | ✓ | | | | | ✓ | |
| [124] | ✓ | ✓ | | | | | | ✓ | | | ✓ | ✓ | | | | | |
| [136] | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | |
| [137] | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | |
| [138] | ✓ | ✓ | | ✓ | | | | ✓ | | ✓ | | | ✓ | | ✓ | | |
| [139] | ✓ | ✓ | ✓ | | | | | | | ✓ | ✓ | | | | ✓ | ✓ | |
| [140] | | ✓ | ✓ | | | | | ✓ | | | ✓ | | ✓ | | | | |
| [141] | | ✓ | | | | | | ✓ | | | ✓ | | ✓ | | | ✓ | |

### 2.2.4. Decision Variables

The decision or design variables are the quantities that can be controlled or varied by the decision-makers. These unknown values need to be optimized to get the desired values of objective functions. While allocating the DGs and SCBs, the commonly used decision variables are size, location, quantity, type, and power factor for DG and for SCB: size, location, and quantity. Any variation in these quantities will directly affect the distribution system's performance, such as feeder voltage, power flow, voltage drop, current flow through conductors, reliability, and power quality of the supply. Thus, the design variables promptly strike the techno-economic operation of any power system. Table 4 summarizes the decision/design/control variables optimized in the literature while simultaneously allocating the DGs and SCBs. Remember that optimizing the allocation of DG and SCB units entails optimizing decision variables, such as unit siting, sizing, number, and type, as well as $pf_{DG}$ of DG units. However, DG quantity, type, $pf_{DG}$, and SCB quantity are some of the critical variables that have not often been considered in the literature to optimize the operation of distribution networks. In contrast, the existing studies have primarily focused on optimizing the location and sizing of DG and SCB units. Hence, it is required that future studies must pay attention to other design variables as well.

**Table 4.** Decision variables employed for optimal DG and SCB allocations.

| Ref. # | DG Variables | | | | | SCB Variables | | | Position of Network Switches | Voltage Regulator | | TCSC Firing Angle & Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Size | Location | Quantity | Type | $pf_{DG}$ | Size | Location | Quantity | | Tap Position | Location | |
| [115] | ✓ | ✓ | | | | ✓ | ✓ | | ✓ | ✓ | | |
| [102] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [103] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [76] | | ✓ | | | | | ✓ | | | | | |
| [65] | | | | | | | | | ✓ | | | |
| [93] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [94] | | | | | | ✓ | ✓ | | | | | |
| [53] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [68] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [123] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [126] | | | | | | ✓ | ✓ | | | | | |
| [127] | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | |
| [117] | | | | | | ✓ | ✓ | | | | | |
| [75] | | | | | | | | | | | | |
| [96] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [55] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [100] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [60] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [56] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [81] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [105] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [128] | | | | | | | | | | | | |
| [69] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [108] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [106] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [129] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [64] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [35] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [52] | | | | | | | | | ✓ | | | |
| [97] | ✓ | ✓ | | | | | | | | | | |
| [83] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [31] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [51] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [30] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [70] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [71] | ✓ | ✓ | | | | ✓ | ✓ | | ✓ | | | |
| [72] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [88] | | ✓ | | | | | ✓ | | ✓ | | | |
| [87] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [98] | | | | | | ✓ | ✓ | | | | | |
| [34] | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | | | | | |

**Table 4.** *Cont.*

| Ref. # | DG Variables | | | | | SCB Variables | | | Position of Network Switches | Voltage Regulator | | TCSC Firing Angle & Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Size | Location | Quantity | Type | $pf_{DG}$ | Size | Location | Quantity | | Tap Position | Location | |
| [95] | | | | | | ✓ | ✓ | | | | | |
| [89] | | | | | | ✓ | ✓ | | | | | |
| [84] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [111] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [112] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [73] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [54] | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | |
| [122] | ✓ | ✓ | | | | ✓ | ✓ | | ✓ | | | |
| [104] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [125] | ✓ | ✓ | | ✓ | | ✓ | ✓ | | | | | |
| [29] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [86] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [82] | ✓ | ✓ | | | | ✓ | ✓ | | ✓ | | | |
| [32] | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | |
| [85] | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | |
| [50] | ✓ | ✓ | | | | ✓ | ✓ | | ✓ | | | |
| [61] | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | ✓ |
| [33] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [79] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [63] | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | |
| [91] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [59] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [57] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [113] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [130] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [62] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [101] | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | | | |
| [77] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [131] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [132] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [133] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [134] | | | | | | ✓ | ✓ | | | | | |
| [58] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [78] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [74] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [80] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [135] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [66] | | | | | | ✓ | ✓ | | | | | |
| [110] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [114] | ✓ | | | | ✓ | | | | | | | |
| [99] | | | | | | ✓ | ✓ | | | | | |
| [67] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [124] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [136] | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | | | |
| [137] | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | | | |
| [138] | ✓ | ✓ | | | ✓ | ✓ | ✓ | | | | | |
| [139] | ✓ | ✓ | ✓ | | | ✓ | ✓ | | | | | |
| [140] | ✓ | ✓ | | | | ✓ | ✓ | | | | | |
| [141] | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | | | | |

#### 2.2.5. Nature of Load

Because of the load's highly scattered and intermittent nature, detailed load modelling in the optimal planning of DG in the distribution system is complex [142]. In the literature, authors have considered three ways for load modeling: fixed, multi-level, and time-varying loads. In addition, the authors solved the optimal simultaneous DG-SCB planning problem by considering residential, commercial, and industrial loads.

#### 2.2.6. Operation Modes

One of the most prominent benefits of integrating DGs into the distribution network is that it reduces the distribution network's reliance on a single power source (i.e., an electric substation) to meet the load demand. The DGs' inclusion into a distribution system allows a microgrid (MG) system to be established by disconnecting the network from the primary grid and splitting it into several zones [143]. The installed DGs can meet the distribution network's energy requirement without the grid's supply. The SCBs mounted in the distribution networks can assist DGs in bearing the load's reactive power demand. Most studies have been conducted in the literature considering the grid-connected operation of distribution networks in the presence of DGs and SCBs. Only three studies [68,98,99] have extracted this vital feature of MG formation in the distribution networks. Wang and Zhong [68] optimized DG and SCB units' placement under grid-connected and islanded operation modes to improve the distribution network's voltage profiles. However, authors have used DG and SCB units of different sizes for both operation modes, whose positions also change with the change in operation mode, which is an impractical approach to simultaneously dealing with both modes of operation. Gholami et al. [98] and Naderipour et al. [99] optimized the SCB's allocation for a DG-embedded distribution network's grid-connected and islanded operations. Instead of optimizing the DG units' allocation, the authors have assumed their fixed size and location, supplying energy to a particular part of the distribution network under the islanded operation. However, the authors of both studies neither provide any basis for selecting the DG sizes nor give a mechanism to operate the mounted devices to their full potential under the islanded operation.

## 3. Limitations of the Existing Studies

In view of the objectives highlighted in this review, the following limitations can be found in the existing studies:

i. Most of the approaches consider only the active power injection of the DG, i.e., DGs' operation at the unity power factor;
ii. DGs' operations at optimal power factor and network constraint of $pf_{DG}$ were unnoticed in the majority of the studies;
iii. The location or sizes of DGs and/or SCBs were considered fixed in some studies;
iv. Variations in loading conditions are avoided;
v. SCBs are assumed as a continuous source of reactive power, whereas they are commonly available in discrete sizes (constant type) in the market;
vi. Islanded operation of the distribution networks as MG and efficient utilization of the installed DG and SCB units during the islanded operation has not been addressed;
vii. The proposed optimization techniques' function usually involves more steps or depends on the proper selection of algorithm-specific parameters. Therefore, their implementation is problematic, raising the need to implement new established and improved optimization algorithms.

A summary of the limitations of the existing optimization studies explicitly conducted in the area of simultaneous DG-SCB allocation is presented in Table 5.

**Table 5.** Limitations of the existing optimization studies.

| Ref. # | Ignored Active Power Loss Minimization | Ignored Reactive Power Loss Minimization | Ignored Voltage Profile Improvement | Assumed Fixed Size and/or Location for Dg Units | Assumed Fixed Size and/or Location for Scb Units | Ignored Reactive Power Injection from Dgs | Ignored the $pf_{DG}$ Constraint | Assumed Fixed $pf_{DG}$ Value for Dgs | Assumed Scb as a Continuous Power Source | Proposed Technique Involve More Steps or Tunable Parameters | Worked Only on the Grid-Connected Operation | Evaluated the Network Performance at Fixed Load |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [115] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | |
| [102] | | ✓ | | | | ✓ | | | ✓ | ✓ | ✓ | |
| [103] | ✓ | ✓ | | | | ✓ | | | ✓ | ✓ | ✓ | |
| [76] | | | | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ |
| [65] | | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ |
| [93] | | ✓ | ✓ | | | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| [94] | | ✓ | | ✓ | | | | | | ✓ | ✓ | ✓ |
| [53] | | ✓ | ✓ | | | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| [68] | ✓ | ✓ | | | | | ✓ | | | | | ✓ |
| [123] | ✓ | ✓ | | | | ✓ | | | | ✓ | ✓ | |
| [126] | | ✓ | ✓ | ✓ | | | | | | | ✓ | |
| [127] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [117] | | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | |
| [75] | | ✓ | | ✓ | ✓ | | ✓ | | | ✓ | ✓ | ✓ |
| [96] | | ✓ | ✓ | ✓ | ✓ | | | | | ✓ | ✓ | |
| [55] | | ✓ | ✓ | | | | | ✓ | | | ✓ | ✓ |
| [100] | ✓ | ✓ | | | | ✓ | | | | ✓ | ✓ | ✓ |
| [60] | | ✓ | ✓ | | | | | | | ✓ | ✓ | ✓ |
| [56] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [81] | | | | | | ✓ | | | | ✓ | ✓ | ✓ |
| [105] | | ✓ | | | | ✓ | | | | ✓ | ✓ | ✓ |
| [128] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [69] | | ✓ | | | | ✓ | | | | ✓ | ✓ | ✓ |
| [108] | | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | |
| [106] | | | | | | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| [129] | | | | | | | | | ✓ | ✓ | ✓ | |
| [64] | | ✓ | ✓ | | | | | | | ✓ | ✓ | ✓ |
| [35] | | ✓ | ✓ | | | | | | | ✓ | ✓ | ✓ |
| [52] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [97] | | ✓ | | | ✓ | ✓ | | | | ✓ | ✓ | |
| [83] | | ✓ | | | | | | | | ✓ | ✓ | ✓ |
| [31] | | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ | ✓ |
| [51] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [30] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | |
| [70] | | ✓ | | | | ✓ | | | | ✓ | ✓ | ✓ |

**Table 5.** *Cont.*

| **Ref. #** | **Ignored Active Power Loss Minimization** | **Ignored Reactive Power Loss Minimization** | **Ignored Voltage Profile Improvement** | **Assumed Fixed Size and/or Location for Dg Units** | **Assumed Fixed Size and/or Location for Scb Units** | **Ignored Reactive Power Injection from Dgs** | **Ignored the $pf_{DG}$ Constraint** | **Assumed Fixed $pf_{DG}$ Value for Dgs** | **Assumed Scb as a Continuous Power Source** | **Proposed Technique Involve More Steps or Tunable Parameters** | **Worked Only on the Grid-Connected Operation** | **Evaluated the Network Performance at Fixed Load** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [71] | | ✓ | | | | ✓ | | | | ✓ | ✓ | |
| [72] | | ✓ | | | | ✓ | | | | ✓ | ✓ | |
| [88] | | ✓ | ✓ | ✓ | ✓ | | | ✓ | | ✓ | ✓ | ✓ |
| [87] | | ✓ | ✓ | | | | | | | ✓ | ✓ | |
| [98] | | ✓ | ✓ | | | | | | | ✓ | | |
| [34] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [95] | | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | |
| [89] | ✓ | ✓ | | ✓ | | | | | | | ✓ | |
| [84] | | ✓ | | | | ✓ | | | | | ✓ | ✓ |
| [111] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | |
| [112] | | ✓ | ✓ | | | ✓ | | | ✓ | ✓ | ✓ | |
| [73] | | ✓ | | | | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| [54] | | ✓ | ✓ | | | | ✓ | ✓ | | ✓ | ✓ | |
| [122] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | |
| [104] | | ✓ | ✓ | | | ✓ | | | | | ✓ | |
| [125] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | |
| [29] | | ✓ | ✓ | | | | | | | ✓ | ✓ | |
| [86] | | | | | | ✓ | | | | ✓ | ✓ | ✓ |
| [82] | | ✓ | | | | | | | | ✓ | ✓ | |
| [32] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | |
| [85] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | |
| [50] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [61] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [33] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [79] | | ✓ | | | | ✓ | | | | ✓ | ✓ | |
| [63] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [91] | | ✓ | ✓ | | | ✓ | | | ✓ | | ✓ | ✓ |
| [59] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [57] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [113] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [130] | | ✓ | | | | | | | | ✓ | ✓ | ✓ |
| [62] | | | ✓ | | | | | | | ✓ | ✓ | ✓ |
| [101] | | ✓ | | | | | | | | ✓ | ✓ | |
| [77] | | | | | | ✓ | | | | ✓ | ✓ | ✓ |
| [131] | | ✓ | | | | | | | | ✓ | ✓ | ✓ |

**Table 5.** *Cont.*

| **Ref. #** | **Ignored Active Power Loss Minimization** | **Ignored Reactive Power Loss Minimization** | **Ignored Voltage Profile Improvement** | **Assumed Fixed Size and/or Location for Dg Units** | **Assumed Fixed Size and/or Location for Scb Units** | **Ignored Reactive Power Injection from Dgs** | **Ignored the $pf_{DG}$ Constraint** | **Assumed Fixed $pf_{DG}$ Value for Dgs** | **Assumed Scb as a Continuous Power Source** | **Proposed Technique Involve More Steps or Tunable Parameters** | **Worked Only on the Grid-Connected Operation** | **Evaluated the Network Performance at Fixed Load** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [132] | | ✓ | | | | ✓ | | | | ✓ | ✓ | ✓ |
| [133] | | ✓ | ✓ | | | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| [134] | | ✓ | ✓ | | | | | | | ✓ | ✓ | |
| [58] | | ✓ | | | | ✓ | | | ✓ | ✓ | ✓ | |
| [78] | | ✓ | | | | ✓ | | | | ✓ | ✓ | |
| [74] | | | ✓ | | | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| [80] | | ✓ | ✓ | | | ✓ | | | | ✓ | ✓ | ✓ |
| [135] | | ✓ | ✓ | | | | | | | | ✓ | ✓ |
| [66] | | ✓ | ✓ | ✓ | | | | | | ✓ | ✓ | ✓ |
| [110] | ✓ | | ✓ | | | | | | | ✓ | ✓ | ✓ |
| [114] | | ✓ | | | | | | | | ✓ | ✓ | |
| [99] | | ✓ | ✓ | | | | | | | ✓ | | |
| [67] | | ✓ | ✓ | | | | | | | ✓ | ✓ | ✓ |
| [124] | | ✓ | | | | | | | | ✓ | ✓ | ✓ |
| [136] | | ✓ | | | | ✓ | ✓ | | ✓ | | | ✓ |
| [137] | | ✓ | | | | ✓ | ✓ | | ✓ | | ✓ | ✓ |
| [138] | | ✓ | | | ✓ | | | | | ✓ | ✓ | ✓ |
| [139] | | ✓ | | | | ✓ | ✓ | | | ✓ | ✓ | |
| [140] | | | | ✓ | ✓ | ✓ | | | | ✓ | ✓ | |
| [141] | | | | | | | | | | ✓ | ✓ | |

## 4. Conclusions and Future Directions

This review concludes that the concurrent penetration of DGs and SCBs into the distribution network is the techno-economic method, enhancing the utilization limit of the present in-hand power system to its extreme extent. Thus, it diverts the extension of centrally operated power generation and transmission systems. Alone, SCB placement is the most cost-effective means; however, its technical impact on the system performance is not as practical as that of DG integration. Moreover, the functioning of the distribution network with DG addition is a successful option to reduce power losses, voltage deviation, loading of the lines, and annual expenses of the power system. However, the implementation cost of DG is relatively high, which deviates from the utilities' intention toward the combined installation of DGs and SCBs. The review reveals that the research objectives of active power loss minimization and voltage profile improvement of the distribution system are the key focus in the literature on simultaneous DG-SCB allocation. In addition, the literature presents numerous optimization techniques and recent developments in these techniques to simultaneously allocate the DGs and SCBs. Metaheuristic optimization techniques have widely been used in the literature to solve this complex optimization problem due to their efficient performance against other heuristic and analytical methods.

Moreover, compared to GA and PSO, the researchers have not paid much attention to other promising optimization algorithms. Therefore, which technique is more appropriate to solve the simultaneous DG-SCB allocation problem still requires comprehensive research. Many studies have been conducted with deterministic DG output and fixed load, which is not a practical approach for planning studies. Instead, the author's adoption of hourly daily load curves is a sensible way to be adopted for optimization studies. Implementing the proposed approach for the intermittent renewable sources and load demands may require the forecasting and day-ahead scheduling of the stochastic components. Researchers can also develop such schemes in the future. Additionally, simultaneous DG and SCB allocation has been observed in the distribution network's performance, usually when operating in the grid-connected mode. To what extent their integration will benefit the utilities and customers when that part of the distribution system works in islanded mode needs focus in future studies. In addition, the existing studies are limited to balanced networks and can be extended to unbalanced power distribution systems.

Hence, in the future, the proposed review can be extended to renewable energy-based DGs and various load types, evaluating the uncertainties related to power generation and loads. Furthermore, researchers may also review different optimal allocation methodologies adopted for balanced and unbalanced power distribution networks.

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