Electrical Engineering (2024) 106:3961–3982
https://doi.org/10.1007/s00202-023-02199-2

ORIGINAL PAPER

A mini review on optimal reactive power dispatch incorporating renewable energy sources and flexible alternating current transmission system

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Received: 4 September 2023 / Accepted: 4 December 2023 / Published online: 11 January 2024

Abstract

The electrical power system (EPS) has been heavily stressed due to high load demand. It operates close to the total capacity limits, resulting in voltage instability that can lead to voltage collapse. In this regard, incorporating flexible alternating current transmission system (FACTS) devices and renewable energy sources (RESs) to obtain the optimum values of the generator voltage, reactive compensation, and transformer tab in optimal reactive power dispatch (ORPD) is essential in increasing the reliability and safety of the system. ORPD involves discrete and continuous variables, which are nonlinear, noncontinuous, non-convex, and complex problems. The objective functions of ORPD are reduction in active power loss (Ploss), voltage deviation, and voltage profile enhancement. This paper presents a recent advancement of the ORPD problem, mathematical formulation of the objectives function, and a summary of various metaheuristic optimization methods (single and hybrid) used to solve the ORPD problems. The hybrid method combines two or more methods to improve the demerits of one method to obtain a quality solution to a problem. This review covered incorporating FACTS devices and RESs used in solving the ORPD problem to reduce the active Ploss and improve the voltage profile in the EPS. The benefits of FACTS devices and RESs are also discussed. Also, various metaheuristic algorithms (single, modified, and hybrid) employed to solve the ORPD problem were discussed. The future direction for researchers in this field was provided to give insight into the applicability and performance. Overall, this research explores different techniques used in solving ORPD problems from the optimization point of view to incorporating RESs and FACTS devices to obtain quality solutions. Some existing methods do not guarantee an optimum solution, but incorporating RESs and FACTS devices will help attain the best solution to the problem for better power system operation to improve system reliability and voltage profile. Based on the review journal, it can be concluded that hybrid techniques offer efficient quality solutions to the ORPD problem.

Keywords ORPD · FACTS · Renewable energy sources (RESs) · Metaheuristic algorithms

Abbreviations

A-CSO	Chaotic symbiotic organisms search algorithm
ALO	Ant lion optimizer
BOA	Butterfly optimization algorithm
ACO	Ant colony optimizer
A-CSOS	Adaptive chaotic symbiotic organism search
CABC-DE	Chaotic artificial bee colony differential evolution
CSO	Cat swarm optimization
CKHA	Chaos embedded krill herd algorithm
CSA	Cuckoo search algorithm
CTFWO	Chaotic turbulent flow of water base optimization algorithm
DE	Differential evolution
DBA	Directional bat algorithm
DG	Distributed generation
EMA	Exchange market algorithm

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ETLBO	Enhanced teaching learning-based optimization
FA and APT-FPSO	Firefly algorithm and adaptive particularly tunable fuzzy particle swarm optimization
FAHCLPSO	Fuzzy adaptive heterogeneous comprehensive learning PSO
FOPSO-CE	Fractional-order PSO entropy evolution
FACTS	Flexible alternating current transmission system
GSA	Gravitational search algorithm
GTLBO	Gaussian bare-bone teaching learning-based optimization
GA	Genetic algorithm
GBBWCA	Gaussian bare bone water cycle algorithm
GWO	Grey Wolf optimizer
HNMS-FA	Hybrid Nelder–Mead simplex-based firefly algorithm
HPFA	Hybrid pathfinder algorithm
HPSO-TS	Hybrid PSO and tabu search
HPSO-ICA	Hybrid PSO with an imperialistic competitive algorithm
HLGA	Hybrid loop genetic algorithm
HTVNLPSOGA	Hybrid time-varying nonlinear PSO and GA
IALO	Improved ant lion optimizer
ICBO	Improve colliding bodies optimization
IGSA-CSS	Improved GSA and conditional selection strategies
IPG-PSO	PSO with improved pseudo-gradient search
IPSO	Improve PSO
JA	Jaya algorithm
MFO	Moth flame optimizer
mPFA	Modified pathfinder algorithm
MSFS	Modified stochastic fractional search
MSCA	Modified sine cosine algorithm
NRM	Newton–Raphson method
OXDE	Orthogonal crossover-based differential evolution
PSO	Particle swarm optimization
PG-PSO	PSO with pseudo-gradient search
PSO-TVAC	PSO with time-varying acceleration coefficient
PSO-TVAC	PSO with time-varying inertia weight
PSO-CF	PSO with constriction factor
PGSWT-PSO	PSO with stochastic weight trade-off and pseudo-gradient search
QODE	Quasi-opposition differential evolution
RESs	Renewable energy sources
RSGA	Genetic algorithm with rank selection method
WOA	Whale optimization algorithm
SGA	Specialized genetic algorithm
SCA	Sine cosine algorithm
SWT-PSO	PSO with stochastic weight trade-off

1 Introduction

1.1 Motivation and incitement

The electrical power system consists of generation, transmission, and distribution systems, which are the key elements to ensure adequate electricity supply to the end users. However, these elements face a lot of disturbance (such as losses along the line, equipment age, failure of generators, etc.), which make electricity unstable and even lead to voltage collapse if adequate measures are not taken [1]. Due to a large amount of power drawn in the electrical power system, active power is utilized, but reactive power is circulated inside the system. However, reactive power plays a significant role in real power transfer inside the system and voltage stability. One of the most prominent ways of improving the bus voltage stability of the power system is optimal reactive power dispatch (ORPD). ORPD is a sub-problem of optimal power flow (OPF) that contains discrete and control variables (i.e., nonlinear problem) in an electrical power system (EPS) while maintaining the constraints. It is used to find the adequate reactive power the system needs to dispatch reactive power sources correctly.

Recent findings indicate a significant surge in interest within the Optimal Reactive Power Dispatch (ORPD) field. Between 2012 and 2022, a substantial total of 1737 journal articles were published, showcasing remarkable growth compared to the numbers observed in 2010. Figure 1 illustrates a clear upward trend in ORPD publications over the past decade, reflecting a heightened interest among researchers, academicians, and scientists. Analyzing the application domains obtained from Scopus search engine data (Fig. 2) reveals a predominant focus on engineering, energy, and computer science in ORPD research. These fields have the highest application percentages, with 35.4%, 22.8%, and 16.7%, respectively. Furthermore, the integration of metaheuristic algorithms in ORPD has experienced substantial growth, as depicted in Fig. 3. The figure underscores the ongoing progress in leveraging metaheuristic algorithms for ORPD in recent decades.

The objective function of the ORPD is to diminish the active power loss (Ploss), voltage deviation (VD), and voltage stability index (VSI) [2–4]. Some operating parameters

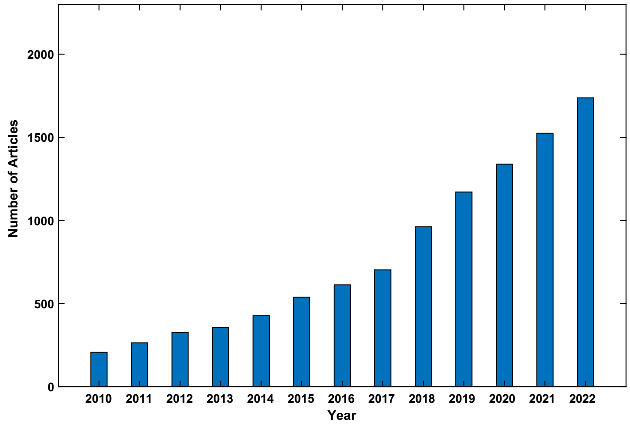

Fig. 1 Journal published on Optimal Reactive Power Dispatch *Source* Scopus

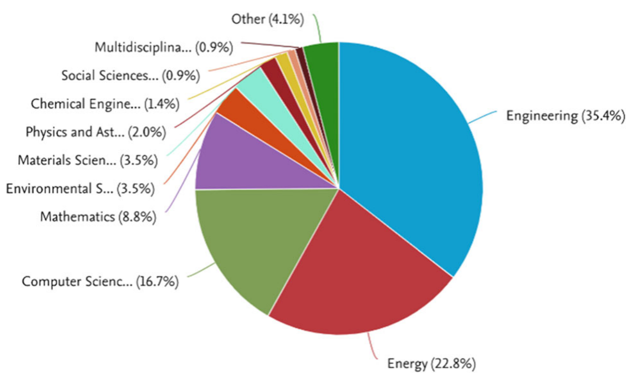

Fig. 2 Application of ORPD in different fields of studies *Source* Scopus

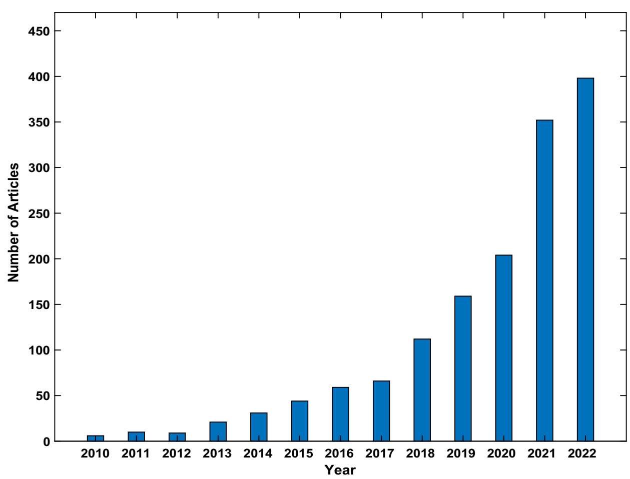

Fig. 3 Application of metaheuristic algorithms in ORPD *Source* Scopus

must be tuned to the optimal value to achieve the objectives mentioned above. Such operating parameters are generator voltages, reactive power compensation, and transformer tap settings while keeping/maintaining the constraints [5–7]. The conventional techniques for solving the ORPD problem in electrical networks are interior point techniques, Newton techniques, linear programming, gradient point, and quadratic programming [8–12]. These techniques lack some specific strength in handling the discrete and non-convex nature of the problem. As a result, they stocked into local optimal and did not give accurate results.

Recently, computational intelligence techniques have been used to solve ORPD problems and overcome difficulties with conventional methods. However, some of these metaheuristic methods have merits and demerits. For example, PSO has fast convergence advantages and fewer parameters to tune but still has the problem of local optimal [13]. PFA has a weakness of decrease in searchability when the problem dimensions become high [14, 15]. The Vortex search algorithm (VSA) has been reported as not escaping from the local minimum point due to adaptive step size adjustment in VSA [16]. Also, ABC has been reported to have a global solution to the ORPD problem [17]. CSO can dynamically explore the search area to balance the intensification and diversification. It has premature convergence, leading to local fall into optimal [18–20]. GSA has greater randomness to give better global exploration. It has poor capability in local search [21, 22]. ACO has greater strength to implement to any problem because of the parallel numerical calculation and has more reliability to solve ORPD problems. However, it encounters difficulties during simulation [23]. However, this review focuses on metaheuristic methods due to advancement and their ability to improve on their drawbacks to overcome their challenges and the conventional technique's drawbacks. However, hybrid metaheuristic methods give optimum solutions to problems.

1.2 Literature review

Several works have been presented in the literature on ORPD by incorporating renewable energy sources (RESs) and FACTS devices that have been used to overcome the challenges of power system voltage instability. FACTS is the application of semiconductor devices to control electrical variables and improve the power security system. It helps to reduce disruptions, leading to the reliability and stability of the power systems. A simulation on biography-based optimization (BBO) was reported for the placement of thyristor-controlled series compensator (TCSC) and static Var compensator (SVC) [24]. Mohammad et al. [5] reported the fractional evolutionary approach to obtain the objectives of reactive power planning using two FACTS devices, namely, SVC and TCSC. Also, Keerio et al. [25] have used RESs to solve the multi-objective ORPD incorporating wind and solar power integration to diminish the Ploss and VD. Decision theory based on OPF with high voltage direct current (HVDC) connected to wind farms was presented [26]. Optimum planning and integrating distributed generation (DG) in power system distribution networks were reported [27]. RESs give the advantages of reducing waste generation, reducing the transmission network burden, and creating employment opportunities. FACTS devices give advantages of voltage stabilization, minimizing the spinning reverse/operating margin, controlling the power dynamically, and reducing overloading and managing congestion. These benefits play an important role in the security, stability, reliability, and efficiency of the power system's operation to meet electricity demand cost-effectively [23, 28, 29].

For the past decay, metaheuristic algorithms have been applied to solve the ORPD problem and have gained researchers' attention due to the impact on EPS security and the economy of the country. It gives the optimum solution to a problem and has led to several works. Previous literature has reported a review based on RESs to solve the ORPD problem [2, 4, 30]. Li et al. [31] reviewed reactive power and voltage optimization of active distribution networks with time-varying load and RES. Muhammad et al. [8] reported a comprehensive literature survey on the ORPD problem incorporating FACTS devices. Ahmad and Sirjani [32] presented a review based on different types of FACTS and modeling. A review of different techniques used to allocate FACTS and various optimization methods has been reported [33, 34]. Mirsaeidi et al. [35] present a review of power system operation optimization objectives using FACTS devices. A review of ORPD has been given to discuss various works by researchers using conventional and metaheuristic techniques. Hamdi Abdi et al. present a comprehensive study on metaheuristic algorithms to investigate their capacity to study the ORPD problem [36]. In addition to that, a comparative study on Ploss and the optimum control variables were obtained using GA, PSO, Sine cosine algorithm (SCA), and orthogonal crossover-based differential evolution (OXDE) [37]. A review based on metaheuristic algorithms for power systems was reported [38]. Six problems regarding the power system and the basic concept of metaheuristic were also presented [38]. The transmission line AC estimation parameter was present under several bundle conductors using flux linkage methods [39]. A comprehensive review of optimization methods used to optimize FACTS devices for power system enhancement, application, and solving methods was reported [23]. The comprehensive review of recent literature used to solve the ORPD problems using metaheuristic algorithms and the objective functions is illustrated in Table 1. It contains the original algorithms, modified algorithms, and hybrid algorithms. Figure 4 summarizes the few techniques used to solve the ORPD problems.

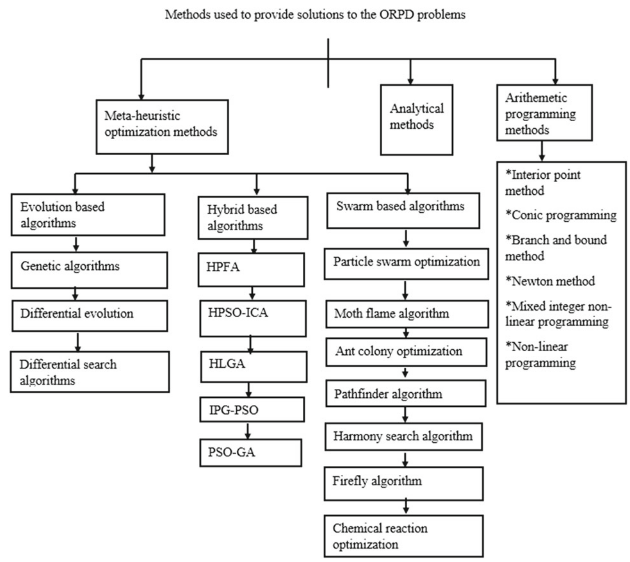

Fig. 4 Some of the methods used in solving the ORPD problem

1.3 Contribution and paper organization

The advancement in the state-of-the-art improvement, the accuracy obtained, and their ability to overcome the difficulties of conventional techniques and give the optimum solution to the problems make the present study to explore and discuss the importance of metaheuristic algorithms. This review presents the RESs and FACTS devices incorporated to solve the ORPD problem, which is currently lacking in the previous work. Therefore, alleviating these issues requires progress discussion in the area. Thus, this paper presents up-to-date literature between 2015 and 2023 on ORPD problems incorporating FACTS devices and RESs. The data were sources from Google Scholar, Scopus, web of Science, IEEE Explore, Elsevier, Springer, IET, Taylor & Francis, and Google database using the keywords ORPD, FACTS, RESs, minimization voltage deviation (VD), minimization voltage stability index (VSI), and minimization of Ploss. Only the articles written in the English language were considered.

The rest of the paper is organized as follows: Section 1 gives an introduction to the work; Sect. 2 presents the modeling of the ORPD problems (i.e., the objective functions along with their equations). Section 3 discusses the past works on the ORPD (single and multi-objective functions). The impact of RESs, the past work on ORPD incorporating RESs, and their benefits on the ORPD problem are discussed in Sect. 4. Section 5 presents the FACTS devices on the ORPD problem and its benefits. It also discussed the work done in ORPD incorporating FACTS devices, and Sect. 6 discusses various metaheuristic algorithms used to solve the ORPD problem. In addition, the conclusion and future prospects of this study were presented.

Table 1 Metaheuristic algorithms used to solve the ORPD problem

Algorithms	Objective (s) function	Method compared with	IEEE test system (s)	References
RSGA	Ploss	NRM	30 bus	[40]
HLGA	Ploss	GA	14 bus	[41]
CABC-DE	Ploss	DE	14 and 30 bus	[42]
PSO	Ploss	–	14 bus	[43, 44]
PSO-TVAC	Ploss	–	14 and 118 bus	[45]
GBTLBO	Ploss	BBDE and BBPSO	14 and 30 bus	[46]
CSA	Ploss	MFO, GWO, FA, FPA, and GSA	30 bus	[47]
ICBO	Ploss	CSA, PSO, and GSA	57 bus	[48]
ACO	Ploss	LPM	Indian 24 bus	[49]
WOA	Ploss	PSO and PSO-TVAC	14, 30, and Algerian 118 bus	[50]
DBA	Ploss	–	14 and 30 bus	[51]
mPFA	Ploss	DE, SOA, GA, GSA, PSO, GWO, ALO, and IALO	57 and 118 bus	[14]
HPFA	Ploss	BA, CBA-III, CBA-IV, and SGA	118 and 300 bus	[52]
SGA	Ploss and VD	–	30 and 57 bus	[53]
ETLBO	Ploss and VD	–	57 and 118 bus	[54]
MFO	Ploss and VD	–	30, 57, and 118 bus	[55]
CTFWO	Ploss and VD	TFWO, GBO, EO, and AEO	30 and 57 bus	[56]
HPSO-ICA	Ploss and VD	PSO and ICA	57 and 118 bus	[57]
FAHCLPSO	Ploss and VD	–	30, 35, and 118 bus	[58]
HPSO-TS	Ploss and VD	TS and PSO	30 bus	[59]
HNMS-FA	Ploss and VD	GSA, BFO, FA, ABC, and PSO	30 and 118 bus	[60]
GWO	Ploss and VD	SGA, PSO, and HAS	30 and 118 bus	[61]
A-CSOS	Ploss and VD	HFA, PSOGSA, and BBA	30 bus	[62]
GBBWCA	Ploss and VD	WCA	30, 57, and 118 bus	[63]
ALO	Ploss and VSI	BA, GWO, and ABC	30 and 118 bus	[64]
GSA	Ploss, VD, and VSI	–	30 and 57 bus	[65]
CKHA	Ploss, VD, and VSI	KHA	30 and 57 bus	[66]
EMA	Ploss, VD, and VSI	–	30 and 118 bus	[67]
IGSA-CSS	Ploss, VD, and VSI	PSO, GSA, and GSA-CSS	14, 30, and 57 bus	[68]
IALO	Ploss, VD, and VSI	ALO	30, 57, and 118 bus	[69]
MSFS	Ploss, VD, and VSI	SSFS	30 and 118	[70]
MSCA	Ploss, VD, and VSI	SCA	30 bus	[71]
FA and APT-FPSO	Ploss, VD, and VSI	PSO, FA, HS, HFAPSO, GA, JA, CA, IWO, ABC, BBO, and ACO	30, 57, and 118 bus	[9]
JA	Ploss and capacitor installation cost	–	30 bus	[72]
FOPSO-EE	Ploss, VD, and cost minimization	–	30 and 57 bus	[73]

2 Modeling of ORPD problems

ORPD is a nonlinear, non-convex, and complex function and must satisfy the operational constraints (equality and inequality) when solving a problem. When solving the ORPD problem, there are dependent and independent variables. Dependent variables are the load bus voltage and apparent power flow [74]. Independent variables are the generator's voltage, reactive power compensation, and transformer taps. Some of the objective functions mostly considered in the ORPD problems are explained in this section, along with their constraints.

2.1 Active ploss

Because of the effect of active Ploss in power systems generators to maintain a stable voltage profile, most researchers considered it the first objective function to deal with. Active Ploss influences the final cost of energy dispatched. The formulae is given in Eq. (1) [74].

$$\min(f_1) = P_{\text{loss}} \sum_{K=1}^{N_L} G_k\left(v_i^2 + v_j^2 - 2V_iV_j\cos\theta_{ij}\right) \quad (1)$$

where P_{loss} is the real total losses, G_k is the conductance of the branch kth, N_L is the overall number of transmission losses, k is the branch between bus i and j, V_i is the voltage at the ith bus, V_j is the voltage at the jth bus, and θ_{ij} is the voltage angle between bus i and j.

2.2 Voltage deviation (VD)

Another important objective considered by researchers to solve ORPD is the VD. The design of electrical equipment is to deliver optimal operation at normal voltage, but deviation occurs from normal operating voltage, resulting in the performance of reduction of electrical apparatus. The VD must be minimized to the lowest value at the load bus to enhance the voltage profile. In other words, VD is the total sum of the absolute difference between the nominal and actual voltage at the system nodes [75, 76]. The VD equation is given in Eq. (2) [66].

$$f_2 = VD = \sum_{j=1}^{N}\left|V_j - V_j^{\text{ref}}\right| \quad (2)$$

where V_j is the voltage at the jth nodes and V_j^{ref} is the voltage magnitude at the jth nodes equals one p.u.

2.3 Voltage stability index (VSI)

In the ORPD problem, various techniques have been employed to improve static voltage stability, including modal analysis based on the static voltage stability index (SVSI) to determine the voltage stability margin [77]. Based on power voltage curves, SVSI modeling was used. The index used to determine the systems' voltage stability includes the singular value of the load flow (LF) Jacobian matrix [77]. The L-index is primarily employed in ORPD issues to improve voltage stability. It foretells how far the voltage collapse point is to the system's stability. When the value is closer to zero, the system is stable; however, it becomes unstable when closer to unity. The formula used for the L-index is as follows [78]:

$$f_3 = L_j = \left|1 - \sum_{i=1}^{T} F_{ik}V_i/V_K\right|,\ k = 1, 2, 3 \ldots, N_L \quad (3)$$

$$F_{ik} = -[\Upsilon_1]^{-1}[\Upsilon_2] \quad (4)$$

where T is the total number of PV nodes, N_L is the total number of PQ nodes, $\Upsilon_1$andΥ_2 are the sub-matrices of the system.

2.4 Constraints

2.4.1 Equality constraints (ECs)

ECs are considered the most rigorous and challenging to satisfy when compared to inequality constraints [79]. When optimization contains many ECs to satisfy, the rate at which the solution succeeds becomes low. Most researchers used the small threshold value to convert the ECs to inequality. ECs and variable reduction strategy (ECVRS) is a recent efficient handling constraint that has been presented to effectively reduce the number of ECs and variables when solving the constraints optimization problems (COPs) [79]. The LF solution obtains the power system parameters from Newton–Raphson's (NR) method used in practice [67]. The power balance equations are real and reactive power and are used in the ORPD problem as given in Eqs. (5)–(6).

$$P_{gi} - P_{di} - V_i \sum_{K=1}^{N_B} V_j(G_k\cos\theta_{ij} + B_K\sin\theta_{ij}) = 0 \quad (5)$$

$$Q_{gi} - Q_{di} - V_i \sum_{K=1}^{N_B} V_j(G_k\sin\theta_{ij} + B_K\cos\theta_{ij}) = 0 \quad (6)$$

where N_B is the overall number of nodes, P_{gi} is the active power generation, Q_{gi} is the reactive power generation, P_{di} and Q_{di} are the active and reactive load power demand at the ith bus, and B_K is the mutual susceptance.

2.4.2 Inequality constraints (ICs)

ICs are the operating limits of the power systems network components. ICs are divided into two parts in ORPD problems: the dependent variable of ICs and the independent variable of ICs.

Independent variable of ICs The control variables used in ICs are independent variables created randomly inside the given bounds. To run the NR LF program and determine the results of unknown quantities of load bus voltage, transmission line, the output of slack bus, and reactive power of the generators, the independent variables are transferred into it [67]. Equations (7)–(9) list the independent variables.

Generator voltage constraints The voltage generated by the generator must be within the operational boundary. Equation (7) represents the generator voltage constraints.

$$V_{gi}^{\min} \leq V_{gi} \leq V_{gi}^{\max} i = 1, \ldots, N_g \tag{7}$$

where N_g is the number of generator buses.

Reactive shunt compensator This involves the output of the reactive shunt compensator, which should be in a specific range of operation. Equation (8) represents it.

$$Q_{ci}^{\min} \leq Q_{ci} \leq Q_{ci}^{\max} i = 1, \ldots, N_C \tag{8}$$

where N_C is the number of reactive power compensation.

Transformer tabs setting The tap setting of transformers must be within specific limits, as given in Eq. (9)

$$T_k^{\min} \leq T_k \leq T_k^{\max} i = 1 \ldots, N_T \tag{9}$$

where N_T is the number of transformer taps.

The dependent variable of ICs Another important point for researchers is the dependent variables. The dependent variables are represented in Eqs. (10)–(13). Different techniques like penalty factor, self-adaptive penalty, epsilon constraint, the superiority of feasible solution, etc., are used in ORPD problems to handle the dependent variable of ICs to avoid unrealistic solutions [67].

Generator's power constraints The reactive power generation of the generator must be kept within the specified operating limits. In the ORPD problem, the actual power generation of PV generators is kept constant. The output of slack power generator real power must be at a specific limit. Equations (10) and (11) represent the power constraints of the generators.

$$Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max} i = 1, \ldots, N_g \tag{10}$$

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} i = 1, \ldots, N_g \tag{11}$$

Security constraints The constraints are transmission line and load voltage limitations. Therefore, they must be within specified boundaries. Equations (12) and (13) are used to represent security constraints.

$$V_{ki}^{\min} \leq V_{ki} \leq V_{ki}^{\max} i = 1, \ldots, N_B \tag{12}$$

$$S_k \leq S_k^{\max} i = 1, \ldots, N_K \tag{13}$$

where N_B and N_K are the number of load buses and transmission lines, respectively.

3 Survey of ORPD problem

This section discussed the previous works on the ORPD problem. It is divided into single and multi-objective functions. A single-objective function is when only one function is considered, while a multi-objective is when two or more objective functions are considered.

3.1 The single-objective function

Real Ploss is the single-objective function considered by different authors on the ORPD problem. For example, Yapici [14] proposed a modified pathfinder algorithm (mPFA) to solve the ORPD problem by considering the Ploss reduction as the objective function. The mPFA was tested on IEEE 57 and 118 test systems. The results obtained outperform some well-known algorithms in the literature. Also, mPFA was used for statistical tests for ranking and consistency. The simulation result showed that the method effectively ranked with the statistical test analysis [14]. Suresh and Senthil Kumar proposed a hybrid PFA (HPFA) to obtain the optimum control variables, such as the transformer tabs setting, voltage magnitude of generators, and capacitor banks, to minimize Ploss while obeying the constraints. HPFA was tested on a large-scale system, i.e., IEEE 118 and 300 test systems. The results proved the quality solution by obtaining the satisfying optimum solution over existing methods, which confirms its ability to solve the ORPD problem [52]. Adegoke and Sun proposed improved PFA (IPFA) based inertia weight to diminish Ploss in EPS. It was reported that using IPFA effectively improved the voltage profile when Ploss was reduced in the systems than other methods reported in the literature [80]. Hybrid PSO and PFA (HPSO-PFA) were proposed to diminish Ploss and find the optimum value of the control variables. HPSO-PFA was tested on IEEE 30 and 118 test systems. The results obtained were superior to other methods in the literature [15]. JAYA was used to minimize Ploss as the objective function [81]. The method was tested on benchmark function and IEEE 14, 30, 57, and 118 bus systems. The results obtained from JAYA are compared with other PSO variants and methods. JAYA algorithms outperform them in efficiency, robustness, and high convergence rate [81]. A unique improved DE (IDE) was put forth by Xie et al. [82] to reduce Ploss while still meeting the ECs and ICs. On IEEE 30 and 33 bus systems, the approach was tested. When the results from several methods were examined, IDE provided a satisfying optimum solution [82].

Additionally, Chi et al. [83] reported the ORPD problem using IDE and evaluated it using the benchmark function. Transformer tabs, generator voltage, shunt reactors, and other reactive power sources are considered the control variables. The approach was tested using the benchmark function and the IEEE 14 and 30 bus systems. The outcomes demonstrate that IDE satisfactorily addresses the ORPD problem. A backtracking search optimizer (BSO) was described and is utilized to reduce Ploss on the Egyptian network's West Delta region and the IEEE 14, 30, and 57 bus systems [84]. The acquired results were contrasted with those of other algorithms. BSO provides more precise results than other methods [84]. Bat algorithm (BA) was reported to minimize Ploss in IEEE 39 and 57 test systems. The results were reported to be superior to other algorithms in the literature [85]. The transformer tab, the output of the VAR compensators, and the generator's voltage are the decision variables that can be changed to reduce Ploss in the ORPD problem using the directional BA (DBA) [51]. DBA gave the lowest result when the Ploss result was compared with other algorithms like PSO, GSA, GA, etc. [51]. Bhattacharyya and Karmakar [86] used GA to reduce operating costs, and the ideal value for the generator voltage, transformer tap setting, shunt capacitor, and reactive power generation was determined using GA. In IEEE 30 and 57 bus systems, the weak node was identified using the power flow solution. Other algorithms were used to test the method's effectiveness, and GA proved the most effective method [86]. The AC-DC (direct current) ORPD using the ABC algorithm was reported to minimize transmission Ploss along the line, keeping the ECs and ICs. The effectiveness of the result was compared to others, and ABC gave a satisfactory solution [17]. Mousassa and Bouktir [87] used ABC to obtain the control variables (transformer tap position, voltage of generator, and shunt capacitor) to minimize Ploss. Water wave optimization (WWO) was reported to solve the ORPD problem by minimizing Ploss while keeping the constraints [88]. DE based on new VSI to identify weak buses in the system. DE was used to minimize Ploss [89]. Semidefinite programming (SDP) was reported for lower Ploss. SDP was tested on 30 and 118 bus systems. The result revealed that SDP outperformed others [90]. Tight-and-cheap conic relaxation was used to solve the ORPD problem by lowering Ploss [91].

3.2 Multi-objective function (MOF)

The researcher's focus has recently turned to the multi-objective (MO) ORPD problem. The ORPD considers the Ploss, VD, and L-index (voltage stability enhancement) the most objective functions. Some metaheuristic methods used to solve the ORPD are: A weighted elitism base modified ALO (MALO) was developed to tackle the ORPD problem [92]. The suggested approach enhanced ALO for improved exploration and exploitation search. MALO and ALO were utilized to discover the best control variables within the limitations. The three objective functions considered are the voltage stability index (VSI), Ploss, and VD. MALO and ALO were tested on benchmark function, IEEE 30, and 57 test systems after being simulated in MATLAB software. Compared to ALO and other algorithms in the literature, the results showed that MALO provides a more pleasing solution [92].

Ploss and VD were minimized using a hybrid artificial bee colony (ABC-FFA) that combines an ABC and a firefly algorithm [93]. The ABC-FFA is validated using the IEEE 14 and 39 bus systems, and the outcomes are contrasted with those of alternative methods. The best optimal solution to the ORPD problem is provided by ABC-FFA [93]. To lower the VD and Ploss on IEEE 30 and 57 bus systems, CTFWO was reported [56]. The desired function can be accomplished by obtaining the optimum values of the generator bus voltage, reactive compensation, and transformer tap position. The suggested CTFWO's output was compared to that of the other algorithms. In terms of stability, precision, and convergence rate, CTFWO provides the best solutions [56]. The chaotic BA (CBA) has been created to address the BA drawback. It is utilized to reduce the Ploss, VD, and VSI. The superiority of the suggested technique was verified using the IEEE 14, 39, 57, 118, and 300 test systems [94]. The CBA approach has been compared to other algorithms, and CBA produces more accurate results [94]. The best control variables were obtained using a two-archive MOF grey wolf optimizer (2ArchMGWO) to tackle the Ploss and VD problems. The outcomes of 2ArchMGWO were contrasted with other algorithms in the literature, and 2ArchMGWO gave a good solution [95]. An improved GSA (IGSA) with condition selection strategies (CSS) (IGSA-CSS) was proposed by Chen et al. [68] to reduce Ploss and VD. The IEEE 14, 30, and 57 bus systems were used to test IGSA-CSS. The suggested method's findings were compared to other methods in the literature; IGSA-CSS outperformed the others [68]. According to Ettappan et al. [10], the ABC can solve the ORPD problem considering the objective functions of the L-index, Ploss, and VD. The output of reactive power compensation, the generator's voltage, and the setting of the transformer tab are all controlled variables that were set using the ABC algorithms. The approach was tested on the IEEE 30 and 57 bus systems, and the outcomes were contrasted with other algorithms. The findings from ABC converge more quickly than the others [10]. The reactive power of the generator, the size of the shunt capacitors to reduce Ploss, the cost of the line charging components, and the cost of installing shunt capacitors at vulnerable nodes were all determined using GA. When GA's output was compared to other algorithms, GA produced the best results [86]. To reduce Ploss, boost voltage stability, and improve voltage profile, QODE was introduced [78]. The results were compared to those from other methodologies to demonstrate the superiority of the QODE, and the QODE provided the best solution [78].

IPG-PSO is based on a chaotic inertia weight factor that is linearly decreasing and is driven by the pseudo-gradient search [12]. To reduce VD, VSI, and Ploss, the ORPD problem was solved using IPG-PSO. IPG-PSO provides a better solution and takes less time to compute than other strategies, according to testing of the method on the IEEE 30 and 118 bus systems [12]. Because of its uniqueness in the transition from the exploration to the exploitation phase, EMA was employed to tackle the ORPD problem [67]. The EMA was validated on IEEE 30 and 118 bus systems using MATLAB software. EMA outcomes were superior since they produced reliable and effective results compared to other techniques [67]. A differential search algorithm (DSA) was used to obtain the control variables (voltage of generator, transformer tap position, and shunt capacitor), lower the Ploss, and enhance the voltage profile and VSI. DSA was reported to give a satisfactory solution for the result obtained compared to other methods [96, 97].

4 Impact of RESs on the ORPD Problem

The dependability, security, and cost-effectiveness of the electrical power system have been significantly increased with the incorporation of RES-based distributed generation (DG). However, inappropriate positioning results in subpar system performance. Controlling reactive power is becoming more difficult as RES penetration increases since the electrical system operates dangerously near an unstable state. Volatility collapse is high due to resource uncertainty and its fluctuating nature. Numerous uncertainty impacts on ORPD have recently been documented [2, 4, 30]. Some impacts offered by RESs on the ORPD problems objectives function are discussed below.

4.1 Reactive power support

To handle the ORPD problem, RESs has offered reactive power support to the power system network for quality supply to the end users. PSO and pattern search optimization were used to find the appropriate location of RESs to offer reactive power support (RPS) and reduce Ploss [98]. Along with other distributed renewable generators, a time-varying load that participates in reactive power and voltage optimization, wind power, photovoltaic (PV), and active distribution networks is introduced [31, 99]. An enhanced firefly algorithm (EFA) was reported; active and reactive multi-objectives were considered with the load uncertainties and wind [100]. PV is a term used to describe a centralized, coordinated voltage and reactive power control (CCVRPC) dominated by RES [101]. The active distribution network and a wind power system monitor the medium voltage. Reactive power from inverter base RESs and the ideal setup of the on-load tap changer (OLTC) are the objective functions considered [101].

4.2 Ploss, VD, and L-index

For quality delivery of power supply to end users, RESs have been incorporated to solve the ORPD problem. For example, Ploss and L-index were reduced when wind and load uncertainties were considered by a stochastic multi-objective (SMO) known as Monte Carlo simulation [2, 25, 102–104]. By deploying wind and solar PV, the ORPD problem has been solved using lighting attachment procedure optimization (LAPO) [105]. LAPO was employed to reduce the Ploss when considering the load demand and RES uncertainties. The outcome demonstrates that the LAPO approach successfully resolved ORPD issues at uncertainty and normal states [105]. By adding RES, Ahmed et al. [106] reported the ORPD issue to address the single- and multi-objective functions to reduce the Ploss and improve the voltage profile. The ideal location for RES was determined using the modified PSO (MPSO) [106]. To lower the Ploss and VD, Mohamed et al. employ marine predators algorithms (MPA), which consider the output power of solar and wind generation systems and load demand uncertainties [107, 108]. Multi-objective DG allocation was solved using hybrid EHA and PSO to reduce Ploss and VD and increase VSI [109]. Adding the RESs (wind energy and reactive power resource) to solve the ORPD problem using an improved coyote optimization algorithm (ECOA). The sensitivity analysis was used to locate the best place to put wind energy. According to tests conducted on the IEEE 30, 118, and 300 test systems, the ECOA was reliable in both single- and multi-objective instances for Ploss reduction [110]. According to Ntombela et al. [111], HGAIPSO reduces Ploss while maintaining a voltage magnitude of one p.u. Based on the limit of active Ploss and reactive power, the node at which the DG was installed was located. According to a report, HGAIPSO decreases the search space and boosts its convergence rate, resulting in a smaller total Ploss when compared to GA, IPSO, and PSO [111]. GWO was reported to reduce Ploss, thereby strengthening the power system's reliability [112].

4.3 Operational costs

It is necessary to reduce the operational costs to desire limits for adequate operation and economic efficiency of the system. The author Ederer [113] evaluated the overall operating costs and relative capital of offshore wind farms (OWFs), which have been calculated using a data envelopment analysis (DEA). To overcome the ORPD problem, Ali et al. [114] introduced the Africa Vultures Optimization Algorithm (AVOA), which penetrates RESs to reduce system operating costs, Ploss, and VD. The single-objective function becomes a multi-objective function when using the weighted sum method. On standard IEEE 30, 57, and 118 test systems, AVOA was validated. The collected results show that AVOA provides more accurate results than all methods examined and enhances the system's overall performance in all situations [114]. The elephant herding optimization (EHO) for DG's proper location and sizing in the electrical distribution system was reported by Vijay and Muppalla. EHO was sufficient for lowering system overloading, real and reactive power, voltage swell and sag, and electricity production costs [115]. Due to their advantages, such as reactive absorption capabilities and the nature of variable speed, doubly-fed induction generators (DIG) and permanent magnet synchronous generators (PMSG) are the standard technologies utilized in wind farms around the world [26, 116]. Slime mold algorithm (SMA) was reported to minimize operating costs with RES. The result was compared with and without RES and with other methods. Evidence shows that the operating cost was effectively reduced by incorporating RES using SMA [117].

4.4 Benefit of RESs

RESs have several benefits to humankind due to their availability and pollution free. Such benefits include environmental, technical, and economic benefits [28, 118, 119].

4.4.1 Environmental benefits

a. It reduces emissions (air pollutants).
b. It reduces waste generation.
c. It encourages a RES-based generating unit.

4.4.2 Technical benefits

a. It increases the voltage profile.
b. It reduces transmission line losses.
c. It aids congestion in distribution and transmission.
d. It enhanced the power quality.
e. It reduces the transmission network burden when it is placed near the consumer.
f. It increases the overall efficiency of the system
g. It improves system security and reliability.

4.4.3 Economic benefits

a. It diminishes the maintenance and operating costs of wind and PV, which are technologies of DG.
b. It reduces operating costs.
c. It can be installed in smaller increments to meet the load growth.
d. It creates employment opportunities.

5 Incorporation of FACTS to solve ORPD problem

The use of FACTS devices in power systems has gained attention due to their dependability, security, and cost-effectiveness. When FACTS devices are introduced into the network, several solutions for the power system are satisfied, including enhancing reliability, stability, voltage management, and impedance. Without affecting generation rescheduling, it also regulates voltage, system damping, and power factor correction [120]. The objective function of the ORPD was achieved by adjusting the operational parameters factor like the best position and size for FACTS using a metaheuristic algorithm [11]. When FACTS devices are used, the performance of power system networks is enhanced. For example, fuel costs and Plosses are reduced, and the system's load-ability, voltage profile, and voltage stability are improved utilizing computational methods [120]. The ORPD problem has been solved using the chaotic krill herd algorithm (CKHA) to reduce Ploss. Thyristor-controlled series capacitors (TCSC) and thyristor-controlled phase shifters (TCPS) are two FACTS devices implemented into the power system. The outcomes were superior to every strategy that was evaluated [120]. To install SVC and TCSC properly and increase voltage stability, hybrid PSO and VCS were presented. The goal functions considered are Ploss, cost function, and VD. According to the results, the convergence time, VSI, and VD are decreased [121]. The ORPD problem of declining line stability index (Lmn) and investment cost was reportedly solved using PSO [122]. Algeria 114 power system was utilized to test the approach, and the result was stated as resilient in overcoming the ORPD problem [98]. TCSC was put at the transmission system's most stressed line [122].

Gravitational search algorithms (GSA) were used to determine the adequate control variable values to reduce Ploss and bus voltage [123]. Bus voltage was within the permitted range, and Ploss was decreased using the FACTS devices (i.e., SVC and TCSC) [123]. Quasi-oppositional chemical reaction optimization (QOCRO) was employed to reduce Ploss, VD, and L-index. The correct positioning of the TCSC and SVC was accomplished using QOCRO, which was utilized to solve single- and multi-objective functions [124]. The cost function was used as the objective function in PSO-CSA to rank many FACTS, including TCSC, SVC, and UPFC [125]. A novel partitioned ant lion optimizer was implemented to increase OPF accuracy while considering SVC and TCSC. The optimized fuel cost, VD, and Ploss considered the load growth. The findings demonstrate that, in comparison to previous methods, the suggested method is accurate [126]. The fractional-order Darwinian PSO (FO-PSO) method was introduced using FACTS devices like SVC and TCSC to achieve goals. The location of SVC was located using the voltage collapse proximity indication (VCPI), and the location of TCSC was located using LF analysis [5]. According to reports, BBO was reported to study the effect of active and reactive loading of TCSC and SVC should be placed. The outcomes of BBO and KHA were contrasted. This demonstrates that BBO is efficient in providing reliable findings [24]. According to reports, FOPSO-EE reduces line loss, VD, and cost function. The FACTS devices considered are the UPFC, SVC, and TCSC. In comparison to other methods in the literature, the FOPSO-EE method performs better [73]. For the ideal positioning of the FACTS devices and Var sources, Simple PSO (SPSO), Adaptive PSO (APSO), and Evolutionary PSO (EPSO) were used. Considerations include the operational cost, Ploss, and investment cost. According to reports, employing FACTS devices to acquire the planning variable produces superior outcomes for the target objective [127].

The WOA determined the reactive power supply and the best synchronization of the UPFC, SVC, and TCSC. The vulnerable nodes for installing FACTS devices are identified using the PV curve load buses/nodes and Lmn. The objectives are Ploss and total operating cost, and it has been claimed that WOA produced better results than PSO and GA [128]. To ascertain the line's outage in the transmission system, compensation strategies for OPF congestion management were developed. Although the line was reportedly overloaded, the overloading active power was decreased by adopting distributed FACTS (D-FACTS), series, shunt, and series-shunt compensation [129]. To investigate the effect on LF, computational allocation of D-FACTS was reported [106]. D-FACTS is used to reduce operational costs and renewable energy use. According to a report, D-FACTS findings are more accurate than regular FACTS results in accommodating future unpredictability and cutting costs [130].

To locate the best location for SVC on the power system to reduce losses and enhance the voltage profile, Edmarcio et al. [131] reported a branch and bound method based on OPF. Considering various load levels across various times improved the power system level when allocating the SVCs [131]. The fuzzy-based improved comprehensive-learning PSO (FBICLPSO) was used to solve the OPF problem with TCSC. The outcome contrasted with other methods, with fuel cost being the goal function. The outcome demonstrates that FBICLPSO produces more useful findings than others [132]. ABC was used to determine the ideal SVC size and placement to reduce active Ploss, reactive Ploss, and installation costs. It was reported that ABC outperformed PSO and TLBO [133].

Furthermore, while adding the SVC device, a Newton–Raphson LF reduces active Ploss [134]. The SVC performance was validated on the IEEE 9 and 30 bus systems. The results have revealed that it successfully improves the voltage profile [134]. The loss sensitivity factor technique and hybrid ABC-PSO were utilized to locate a capacitor placement in radial distribution networks [135]. The fuzzy inference system (FIS) was for capacitor position. The ORPD problem was solved using a sine cosine algorithm (SCA) to determine how to configure the control variables in conjunction with UPFC to reduce Ploss and enhance the voltage profile. As a result, SCA was demonstrated to be more reliable and effective than other literature [136]. Different algorithms and load models were used to minimize Ploss by placing SVC and TCSC [137]. Chemical reaction optimization (CRO) was present for installing STACOM to lower Ploss and improve the voltage profile and VSI [138]. Table 2 illustrates the summary article on the ORPD problem incorporated FACTS devices.

5.1 Benefit of FACTS devices

Several benefits of the FACTS device have been reported in the literature [29].

a. It helps diminish the length of the electrical transmission line, voltage violation, system losses, and LF loops.
b. It prevents blackouts, cascading outages, and giant swings in a power system.
c. It minimizes the spinning reverse/operating margin and controls the power dynamically.
d. It prevents voltage collapse caused by the load and withstands contingencies.
e. It minimizes the short circuit levels and faulty instant switches in the line.
f. It reduces overloading and manages congestion.
g. It increases the load-ability and improves the thermal limits of the lines to their capacity.

6 Metaheuristic techniques

The metaheuristic techniques are effective for finding a solution to optimization problems. It requires some parameters to tune to give the optimum solution to a problem. Different algorithms and the work done in solving the ORPD problem to improve the voltage profile are discussed.

6.1 JAYA algorithm

An easy-to-use and successful algorithm is JAYA [146]. It only has one phase that moves toward the perfect resolution while avoiding undesirable ones. Roy et al. [74] claimed that JAYA had reduced the Ploss on the transmission line system. The method was validated by bus systems IEEE 14, 30, 57, and 118. The authors expanded the investigation to include DG and compared the outcomes with and without DG [66].

Table 2 Summary of FACTS devices on ORPD problem

Method	Objective (s) function	FACTS devices	References
CKHA	Minimize Ploss and VD	TCSC and TCPS	[120]
GSA	Minimize Ploss and enhance bus voltage	SVC and TCSC	[123]
GSA	Minimize Ploss	SVC and TCSC	[139]
WOA, DE, QODE, GWO, and QOGWO	Minimize Ploss, VD, and operating cost	SVC and TCSC	[140]
FO-DPSO	Minimize Ploss	SVC and TCSC	[5]
BBO	Minimize active and reactive Ploss reduction	SVC and TCSC	[24]
QOCRO	Minimize Ploss, VD, and L-index	SVC and TCSC	[124]
SPSO, APSO, and EPSO	Minimize Ploss and operating cost	SVC and TCSC	[127]
Partitioned (PALO)	Minimize Ploss, overall fuel cost, and VD	SVC and TCSC	[126]
NR	Minimize operating cost	SVC and TCSC	[137]
GA	Minimize Ploss, VAR cost, and enhancement of voltage profile	SVC and TCSC	[141]
DE	Minimize Ploss and enhanced voltage profile	SVC, TCSC, and UPFC	[142]
WOA	Operating cost	SVC, TCSC, and UPFC	[143]
Kinetic Gas Molecule Optimization (KGMO)	Minimize Ploss, VD, cost of FACTS, and L-index	SVC, TCSC, and UPFC	[144]
PSO and CSA	Minimize total cost	SVC, TCSC, and UPFC	[125]
TS	Minimize cost functions	HVDC, TCSC, SSSC, STATCOM, SVC and UPFC	[145]
MILP	Minimize operating cost	D-FACTS	[130]
PSO	Minimize investment cost and voltage stability	TCSC	[122]
FBICLPSO	Minimize overall fuel cost	TCSC	[132]
NR	Enhance voltage profile	SVC	[134]
SCA	Minimize Ploss and enhance voltage profile	UPFC	[136]
CRO	Minimize Ploss and enhance voltage profile	STACOM	[138]

The comparison reveals that the technique was more successful [81]. The algorithm was used to decrease the actual Ploss reported by Asmaa et al. [147], the Egyptian grid West Delta Real Network (WDRN), and the IEEE 14, 30, and 118 bus systems were used for testing the efficacy of the method [147].

6.2 Turbulent flow of water-based optimization (TFWO) algorithm

The TFWO mimics the nature search phenomenon and was proposed [148]. TFWO was applied to multi- and single-objectives functions to diminish Ploss, fuel costs, VD, and enhance VSI. The method was investigated on the IEEE 30, 57 bus systems, and 17 cases were considered [149]. TFWO was used along with other algorithms to find the best size for TCPS and TCSC devices. The objective functions include diminishing the total fuel cost, VD, and transmission loss [150]. A modified version of TFWO was reported by Wahab et al. [56] called the chaotic (CTFWO) algorithm to solve the ORPD problem to diminish the VD and active Ploss. It was reported that the CTFWO gives the best value of optimized control variables.

6.3 Pathfinder algorithm (PFA)

The PFA, which was proposed [151], imitates the behavior of animals. The modified PFA developed by Yapici [151] to reduce Ploss on the IEEE 57 and 118 bus systems was more accurate than existing methods. For the best allocation and concurrent intergeneration of solar PV, also known as interline PV (I-PV), the PFA was used by Janamala [152]. The performance of PFA to reduce Ploss in the system was investigated using the IEEE 33 and 69 bus systems. It was reported that the VD was decreased, and the VSI and voltage profile were enhanced. The Ploss fell to 77.87% and 98.33% for the two systems under consideration, respectively [152].

6.4 PSO

The behavior of the bird flocks and schooling of fish inspires PSO. A single and multi-objective function was used to diminish the Ploss and enhance the voltage profile in the ORPD problem by incorporating the RESs into the existing traditional grid [106]. PSO was used to find the sizing of different types of DG used. The VSI used to determine the best place for DG placement, the cost of DG, and the optimum power factor are also considered. The method effectively reduced the Ploss and yearly energy loss and improved the voltage profile [153]. Yongan distribution network (YDN) was used to solve the ORPD problem to reduce active and reactive Ploss. It was reported that PSO was better in reducing the Ploss in YDN [154]. PSO was used to solve the ORPD problem on the IEEE 14 bus system incorporating the RESs. The objective function considered is Ploss reduction. PSO was used to find the optimum place for Gust drive, solar PV, and microturbine [155].

6.5 Genetic algorithm

GA is based on the fitness function, crossover, and mutation. Multi-objective GA was reported for reactive power planning, considering diminishing Ploss, reactive compensation, maximizing the VSI, and improving overall transfer capacity (TC). Switchable VAR source allocation was not determined but treated as a control variable to enhance the techno-economic operation of the network (TEON). The IEEE 30 bus system and the South Egyptian electricity grid were used to study the method's effectiveness, and the result proved robust [141].

6.6 Harmony search algorithm (HSA)

The HSA uses rules and randomness that mimic natural phenomena and inspire the musician's improvisation process [156]**.** HAS and improved HSA were used to solve the ORPD problem by incorporating FACTS devices (TCPST and SVC) to diminish the Ploss while keeping operational constraints. The method was compared with other techniques; HAS and IHSA results proved more accurate than others, which validated the superiority of the proposed method [157].

6.7 Crow search algorithm (CSA)

The Crow search algorithm (CSA) is among the recent algorithms related to crow intelligent behavior that keeps the excess food and retrieves it back when needed [158]. Asma Meddeb et al. present CSA to minimize active Ploss on the IEEE 14, 30, and Tunisian 86 bus systems. The control variables are determined to obtain the lowest Ploss while keeping the operational constraints. Also, the sensitivity analysis was performed to validate the method's superiority. The result of CSA was compared with other algorithms, and the proposed method accurately achieved the lowest Ploss [159]. CSA was used to solve MOF considering the L-index and Ploss. IEEE 30 and 57 bus systems were used to validate performance [160]. Lakshmi and Kumar [161] applied CSA to solve the ORPD problem considering three objectives: diminishing VD, Ploss, and improving voltage stability. Kumar et al. reported CSA to optimize the power system stabilizer and SVC using MATLAB/Simulink to improve the power system's transmission capacity and voltage profile. The result was compared with other methods like TLBO and PSO, and CSA performed better than others [20]. CSA-PSO was used for best allocating, sizing, and number of RESs to install in the IEEE 30 bus system. A new percent reduction formulation (PRF) was introduced to estimate the overall cost and Ploss. The Wind power and solar PV were installed at nodes 19 and 30 bus of the system. The results of CSA-PSO proved effective in solving OPF by incorporating RESs [162].

6.8 Other algorithms

The marine predator's algorithm has been used to solve VD, active and reactive Ploss, fuel cost, and L-index as a single-objective function. The method was validated using the IEEE 30 bus system, and according to the study, the result is accurate compared to other methods in the literature [163]. The optimal control variables, including reactive compensation setting, generator bus voltage, and transformer tap setting, have been investigated using moth-flame optimization (MFO) [164]. With the IEEE 30, 57, and 118 bus systems as the test case, the VD and Plosses are the objective functions considered. The approach successfully lowered the objective function taken into account [164]. The active Ploss was decreased using the cuckoo search algorithm (CSA) by determining the transformer tap setting, generator bus voltage, and reactive compensation [47].

An improved social spider optimization algorithm (ISSOA) has been shown to successfully solve the ORPD problem by lowering VD and Ploss and enhancing the L-index [165]. The benchmark function and the IEEE 30 and 118 bus systems were used to test ISSOA. The outcomes outperformed the methods mentioned in the literature [165]. The ORPD problem was solved using the exchange market algorithm (EMA), which has two stages: oscillation and balanced market [67]. EMA was employed on the IEEE 30 and 118 bus systems to reduce the VD and Ploss while increasing the L-index. According to the result, the approach produces an accurate solution [67]. An improved SMA (ISMA) was reported to solve the ORPD problem to diminish Ploss [166]. The 23 benchmark functions from the IEEE CEC 2017 were used to assess the method's superiority, and it was shown that ISMA performs well at producing reliable results [166]. For the system's stability, the transmission Ploss was reduced using sine–cosine algorithms (SCA). The method was validated on IEEE 14, 30, and 57 bus systems, and the results were more accurate in Ploss reduction than other methods in the literature [167]. Alghamdi reported enhanced TLBO to obtain the optimal control variables by minimizing the VD and Ploss. A novel self-adaptive TLBO (θ-SATLBO) was used to strengthen the TLBO. The potential of the result reveals a high-quality solution compared with the TLBO [168]. An equilibrium optimizer (EO) was reported to minimize Ploss, VD, and enhancement of VSI. The results demonstrate that EO efficiently handles the ORPD [169].

6.9 Hybrid algorithm

A hybrid algorithm is a hybridization/combination of two or more algorithms. The combination is based on improving the performance of a single algorithm. Hybrid algorithms give better accurate solutions to reach the optimal global solution to a problem. Several techniques have been combined to solve ORPD problems. Such as Adaptive A-CSOS is a combination of a symbiotic organism's search algorithm (SOS) and adaptive chaos (AC). A-CSOS was used to solve the ORPD problem by solving two objective functions, Ploss and VD, on the IEEE 30 bus system. The method was improved over other algorithms by 30.39% in solving the ORPD problems [62]. Suresh and Senthil Kumar proposed a hybrid PFA to minimize the transmission loss on the IEEE large-scale 118 and 300 bus systems. The result was more accurate than other algorithms reported in the literature [52]. HPSO-TS is implemented for ORPD to diminish the active Ploss. The method was used to find the control variables and tested on the IEEE 30 bus system. The location of shunt capacitors was identified based on sensitivities bus. HPSO-TS gives more effective results than PSO, TS, and other methods reported in the literature [59]. PSO and pattern search (PS) algorithms (PSOPSA) diminish the active Ploss, VD, and VSI, incorporating reactive support from RESs. The simulation was conducted in the DigSilent power factory and MATLAB software, and the IEEE 39 test system was used to test the method's performance [170].

TS and GA were used to select the best place for the capacitor bank (CB) and DG, considering the operating and investment costs as the objective function. The validation of the method was done on IEEE 69 [171]. HGWO-PSO was proposed to solve the ORPD problem. Two objective functions were considered: diminishing VD and active Ploss. The method was tested on three IEEE 14, 30, and 118 bus systems. The method was more accurate than other reported methods and improved the system grid [172]. A hybrid approach based on the integration of the firefly algorithm (FA) and the adaptive particularly tunable fuzzy PSO (APT-FPSO) method has been presented to solve the ORPD problem [9]. The method was used to determine the optimal control variables and the objective function considered (i.e., Ploss, VD, and VSI). The method was tested on IEEE 30, 57, and 118 test systems while the solution was also compared with other techniques, and the APT-PSO outperformed them [9]. Augmented PSO and improved CSA were combined to form a hybrid method called (HAPSICS). HAPSICS was used to minimize Ploss on the IEEE 30 bus [173]. Enhanced Dwarf Mongoose Optimization and symbiotic organism search (EDMOSO) were proposed to reduce the L-index, VD, and Ploss using the IEEE 30 bus system. The proposed method was superior to the original DMOA and other algorithms [174]. Rajan and Malakar used a combination of FFA and Nelder–Mead simplex (NMS) method called hybrid (HFA) to solve ORPD considering minimization of VD and Ploss. The result was robust and gave good convergence compared to other methods [60]. A hybrid PSO-logarithmic barrier-interior point method (PSO-LB-ITM) was reported to adjust controlling parameters by reducing the Ploss in the electrical power system [175]. Hybrid chaotic PSO was reported for solving ORPD by minimizing Ploss. The CPSO was reported to overcome the drawback of PSO, thereby giving a quality solution [176]. HPSOBA was reported to minimize VD and Ploss in ORPD. Combining the two methods strengthened their weakness, and the result was compared with BBO and PSO. The proposed HPSOBA outperforms them [177]. Laouafi et al. [178] reported the DE and SA methods to give the proposed method to transit between exploitation and exploration. HDESA was used to reduce Ploss, and the result was reported to be effective [178]. A hybrid GA and JAYA algorithm called (HA) was reported to incorporate DG to lower VD, and Ploss. Result obtain reveal that HA offers superior result than other method like PSO, GA, SLFA, and JAYA [179]. Adegoke and Sun reported hybridization of PSO and PFA to lower Ploss. The efficacy of the result reveal that HPSO-PFA give satisfactory solution than other methods reported in the literature [15]. The best control variables were found using a hybrid grey wolf optimizer and PSO (GWO-PSO) to tackle the Ploss and VD problems at the load bus [172]. GWO-PSO outcomes were contrasted with other algorithms in the literature; GWO-PSO produces good results [172]. Summary of article used hybrid techniques for the ORPD problem is presented in Table 3.

Table 3 Summary of publication used hybrid techniques for the ORPD problem

Objective (s) function	Method	Test system (s)	References
Minimize Ploss	HAPSICS	30 bus	[173]
Minimize Ploss	PSO-ITM	57 bus	[175]
Minimize Ploss	HPFA	118 and 300 bus	[52]
Minimize Ploss	CPSO	14 and 30 bus	[176]
Minimize Ploss	HDESA	30 bus systems	[178]
Minimize Ploss	HPSO-PFA	30 and 118 bus	[15]
Minimize Ploss	BOA–GWO–PSO	39 bus	[180]
Minimize Ploss	HTVNLPSOGA	14 bus	[181]
Minimize Ploss	GSAPSO	14, 30, and 57 bus	[182]
Minimize Ploss	HLGBA	14 bus	[41]
Minimize Ploss	PSOGA	30 and 118	[183]
Minimize Ploss	OXDE, SCA, HPSO-GA, and HGWO-PSO	30 and 57 bus	[37]
Minimize Ploss and VD	HPSO-TS	30 bus	[59]
Minimize Ploss and VD	A-CSOS	30 bus	[62]
Minimize Ploss and VD	HGWO-PSO	14, 30, and 118 bus	[172]
Minimize Ploss and VD	HFA	30 and 118 bus	[60]
Minimize Ploss and VD	HPSOBA	30 and 57 bus	[177]
Minimize Ploss and VD	HA	33 and 69 bus	[179]
Minimize Ploss and VD	GWO-PSO	14, 30, and 118 bus	[172]
Minimize Ploss and VD	IGSA-CSS	14, 30, and 57 bus	[68]

7 Discussion

This review has presented the detailed modeling of the objectives function and the benefits of RESs and FACTS devices in the ORPD problem. The improvement provided by FACTS devices in the ORPD problem was emphasized in the previous section. Based on the published research, several electrical issues can be reduced by solving ORPD problems, such as minimizing VD, Ploss, and voltage profile enhancement. Based on the past literature, the most efficient optimal value of generator voltage, shunt compensator, and transformer tap have been obtained in the ORPD problem. The technical benefits of metaheuristic methods are the fast convergence speed and enhanced computational time compared to traditional methods. Metaheuristic methods are mainly used to incorporate RESs and FACTS devices in the ORPD problems, which can minimize costs, VD, Ploss, and enhanced voltage profile. The metaheuristic methods face early convergence problems and result in inaccurate solutions. Also, the multi-objective function is easy to utilize and defined in metaheuristic. Several benefits of FACTS devices, applications, and controlled parameters are reported [23, 185]. However, a combination of two or more approaches called the hybrid method has been the focus of studies to elevate/improve the disadvantage of one algorithm in large-scale problems to obtain an accurate, robust, faster, and efficient solution to the problem. Based on the published articles, SSSC provided active power support. UPFC and IPFC are used for active and reactive control. TCSC was reported to control the impedance of the transmission line and installed at the most transmission-stressed line [23, 122]. Solar and wind have been employed to enhance the voltage profile in ORPD while reducing the Ploss when considering the load demand and RES uncertainties [105].

Furthermore, several studies focused on minimizing VD, Ploss, without considering the minimization of total harmonic distortion and consumer costs. This limits the benefit/potential of RESs and FACTS devices in ORPD problems in real-world applications. Therefore, power system practitioners and researchers must consider the total harmonic

Table 3 (continued)

Objective (s) function	Method	Test system (s)	References
Minimize Ploss, VD, and VSI improvement	APT-FPSO	30, 57, and 118 bus	[9]
Minimize Ploss, VD, and VSI improvement	HPSOPSA	39 bus	[170]
Minimize Ploss, VD, and L-index	EDMOSO	30 bus	[174]
Minimize Ploss, VD, and L-index	HAP-PSO	30, 57, and 118 bus	[184]

distortion and cost reduction to explore the potential of RESs and FACTS devices in the ORPD problem. Addressing that problem improves the economic efficiency of the power system. From the computation time point of view, modified DE has been reported to have an increase in CPU time when the size of the problem becomes complex. For example, the CPU time in the 39 bus system is 69.73 s compared to the Algeria114 bus AC system, which gives 664.98 s of computational time [11]. It is seen that there is a huge difference in computation time to obtain the solution to the ORPD problem. Therefore, more focus should be given to the computation time of any metaheuristic to reduce the computation burden to obtain faster solutions. However, metaheuristic techniques are mostly used to obtain the optimal control variables in ORPD. It offers good convergence to enhance the optimization benefit of the ORPD problem and computational time. Metaheuristic techniques efficiently optimize the multi-constraints, multimodal, discrete system, and multi-objective. Also, it offers optimal solution compared to other techniques [185, 186].

8 Conclusion

This paper presents recent literature works on ORPD problems using metaheuristic algorithms. Various studies reported the ORPD problem as a nonlinear, noncontinuous, and complex problem consisting of continuous and discrete variables. The major objective functions of the ORPD problem are reduction in Ploss, VD, and VSI. The various strategies to improve the voltage profile, such as RESs and FACTS devices, were discussed in the paper with their benefits (it helps in diminishing the length of the electrical transmission line, violation in voltage, losses in the system, and LF loops. It reduces overloading and manages congestion. It reduces emissions (air pollutants). It increases the voltage profile. It reduces transmission line losses). Incorporating RESs and FACTS devices improved the power system stability. Also, various metaheuristic algorithms used to solve the ORPD problems and the work done on each were discussed. From this article, some of the unrepresented or lack in the previous work to solve the ORPD problem are listed below as the future recommendation.

a. Reducing total harmonic distortion (THD) and carbon emission is essential in improving power quality. However, this should be considered for future research since previous works fail to consider it the objective function.
b. From this research, the hybrid approach is more efficient and robust in giving an optimum solution to a particular problem. Therefore, more work should be done on the current optimization methods to form the hybrid technique and combine three or more algorithms to find a robust solution to problems.
c. From the presented literature, several authors have worked on FACTS devices or RESs to solve the ORPD problem. However, no one has combined the two to check the one that is more effective in solving the ORPD problem and improving the voltage profile; this calls for further research.
d. From the literature considered in this work, most authors considered the multi-objective function separately (i.e., one after the others) except for Ali et al. [114] that uses the weighted sum approach to transform the single-objective function into a multi-objective function. Therefore, more work should focus on the weighted sum approach to transform the single-objective function into a multi-objective function instead of considering them separately.
e. Due to the advancement of clean energy, energy generation from RESs has increased daily. Therefore, there should be more focus on incorporating RESs to solve ORPD problems for a better solution to the fitness function intended to solve.
f. More attention should be given to FACTS devices in smart grid utility using hybrid methods to obtain efficient solutions.

Acknowledgements This research work was supported by Global Excellence Stature, Fourth Industrial Revolution (GES 4.0) at University of Johannesburg, South Africa.

Author contributions SAA contributed to conceptualization, data curation, formal analysis and investigation, methodology, validation, visualization, writing—original draft preparation, and writing—review, and editing. YS and ZW were involved in conceptualization, validation, visualization, review, editing, and supervision. OS was involved in validation, review, editing, and visualization. All authors read and approved the manuscript.

Funding Open access funding provided by University of Johannesburg.

Declarations

Conflict of interest The authors declare no competing interests.

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