Distributed Generations and Capacitor Banks in Distribution Systems

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Integration of Distributed generations (DGs) and capacitor banks (CBs) in distribution systems (DS) have the potential to enhance the system's overall capabilities. This work demonstrates the application of a hybrid optimization technique the applies an available renewable energy potential (AREP)-based, hybrid-enhanced grey wolf optimizer–particle swarm optimization (AREP-EGWO-PSO) algorithm for the optimum location and sizing of DGs and CBs. EGWO is a metaheuristic optimization technique stimulated by grey wolves, and PSO is a swarm-based metaheuristic optimization algorithm. Hybridization of both algorithms finds the optimal solution to a problem through the movement of the particles. Using this hybrid method, multi-criterion solutions are obtained, such as technical, economic, and environmental, and these are enriched using multi-objective functions (MOF), namely minimizing active power losses, voltage deviation, the total cost of electrical energy, total emissions from generation sources and enhancing the voltage stability index (VSI).

available renewable energy potential (AREP) | capacitor banks (CBs) | distributed generations (DGs) | enhanced grey wolf optimizer and particle swarm optimization (EGWO-PSO) | power loss | voltage deviation index (VDI) | voltage stability index (VSI)

1. Introduction

Distributed generations (DGs) have become an attractive option for integrating power distribution systems due to their economic, technical, and environmental advantages [1][2]. Although DGs can offer several benefits to the system, their installation is subject to their primary energy source's availability and geographical location [3]. On the other hand, DGs can cause undesired effects in the system, such as fluctuations in the voltage profile, increased fault current, and inversion in the power flow direction, etc. [4][5]. These effects become more evident when DGs use renewable energy resources (RER). RER play an energetic role in resolving environmental and security issues. They have a probabilistic nature, such as wind speed and solar irradiation [6]. Therefore, technical studies should be conducted to properly install DGs in passive systems, avoiding the degradation of reliability, system operation, and supply quality [3].

In a radial distribution system (RDS), the reactive power flow is considered the main reason for power quality issues [6]. The compensation of reactive power plays the leading part in power system planning. The capacitor banks (CBs) are treated as the familiar reactive power resources that offer loss reduction, voltage regulation, stability improvement, and a financial return for distribution companies when optimally installed in distribution systems [3][7][8].

To reduce the overall production costs and improve system reliability, both the DGs and CBs are commissioned as real and reactive power injection sources [7]. The installation of DG and the capacitor in the distribution network has various technical and economic benefits [9]. These multiple benefits cannot be achieved without the appropriate allocation of the DGs and CBs in power system networks. Further, the optimal allocation of both DG and CB can be carried out using optimization techniques using several methodologies [10]. The complete analysis of the existing works relating to the optimization is described in the following section.

The techniques proposed for the placement of DG and CB in distribution networks can be divided into four types: numerical, analytical, metaheuristic, and hybrid optimization [10][11]. The analytical methods have fast convergence, but their computational time and complexity become high when the type and number of DGs and CBs increases [12]. This is particularly true for multi-objective formulations with a large number of equality and inequality constraints. Analytical approaches require more robust algorithms to solve differential and nonlinear equations. In this respect, metaheuristic techniques are helpful in solving the distribution system problems which do not involve differential equations. However, the algorithms need to be appropriately tuned to reach the global solution for DG sizing and placement [12][13].

Among various metaheuristic optimization techniques, particle swarm optimization (PSO) is the most widely used for the siting and sizing DGs. PSO has significantly better computation efficiency, i.e., its functional evaluation. A vital issue with PSO is the trapping of particles into local optima that could consume a large amount of time to converge to an optimal solution. Additionally, there is no guarantee that the optimal solution will be global optima. As a result, several research works highlighted the hybridization of the standard PSO with analytical approaches or other optimization techniques for achieving better results [14]. By using a hybrid optimization technique, better optimization results can be produced by merging two optimization algorithms [9]. Instead of searching in the whole area, the search space is limited by loss sensitivity factor (LSF), increasing the possibility of finding a good solution. After selecting the candidate buses by LSF, an optimizer finds the optimum size of DGs and CBs on the buses. Consequently, a fast convergence is achieved without compromising the siting and sizing aspects [10][14].

2. Optimal Installation of DGs and CBs

A complete survey of numerous literary works associated with the optimal installation of DGs and CBs is elaborated in **Table 1** [15][16].

Table 1. Survey of prevailing research works with respect to optimal installation of DGs and CBs.

Ref. No.	Year	Optimization Algorithm	Objectives	Constraints	Allocation		Inferences	Limitations
					DG	CB		
[17]	2018	Improved grey wolf optimizer	Minimizing generation	Equality, generator,		√	Improved rate of convergence	Voltage stability and

Ref. No.	Year	Optimization Algorithm	Objectives	Constraints	Allocation		Inferences	Limitations
					DG	CB		
		(IGWO)	cost, power loss, and voltage deviation	transformer, bus voltage, line loading, and installed reactive power resource constraints			with quality solution	power factor constraints are neglected
[10]	2018	Modified power loss index + Crow search (MPLI + CS)	Minimize active power loss and cost	Bus voltage, reactive power injected, complex power, capacitor size and power factor		√	Reduced search space, accurate and quick convergence	Voltage stability is not considered
[18]	2019	Voltage stability index + Genetic algorithm (VSI + GA)	Minimize feeder current, voltage deviation and power losses	Voltage and branch current carrying capacity	√	√	Hourly variation of load demand is modelled	Relaxed network constraints and single test system
[7]	2020	Enhance grey wolf algorithm (EGWA)	Minimize total investment costs, maximize voltage profile, loading capacity, and benefits from the reduction of losses and purchased power	Equality constraints, DG penetration level, power factor limit, CB size, node voltage, and branch current limits	√	√	Improved performance, highly stable and superior capabilities	Voltage stability and emission perspectives are ignored

Ref. No.	Year	Optimization Algorithm	Objectives	Constraints	Allocation		Inferences	Limitations
					DG	CB		
[3]	2016	Tabu search + Chu–Beasley genetic algorithm (TS + CBGA)	Minimize investment and operation costs	Technical and operational constraints	√	√	Very efficient and used for planning the system	Single test system and stability constraint is ignored
[19]	2017	Grasshopper optimization algorithm + Cuckoo search algorithm (GOA + CSA)	Minimize voltage deviation, line losses, and cost	Equality, load bus voltage and DG capacity	√		Less complexity with reduced computational time	Limited type of DGs, voltage stability, and emission analysis are ignored
[11]	2017	Hybrid grey wolf optimizer (HGWO)	Minimizing total real power losses	Equality, Bus voltage, DG unit size, and power factor	√		Algorithm performance is enhanced without tuning	Demand uncertainties and reliability are not considered
[20]	2017	Harmony search algorithm + Particle artificial bee colony (HSA + PABC)	Minimize real power loss, line loading, and voltage deviation	Bus voltage, thermal limit of the lines, maximum power injection from DGs and CBs	√	√	Enhanced performance with fast convergence	Economic and voltage stability constraints are ignored
[21]	2018	HGWO-PSO	Minimizing power losses	Equality, bus voltage, line current, total generated power, and DG size	√		Optimal solution with less iteration.	Power factor and voltage stability constraints are ignored
[13]	2019	Multi-objective hybrid teaching learning-based optimization-grey wolf optimizer (MOHTLBOGWO)	Minimizing power losses and improving reliability	Equilibrium, bus voltage, DG size, and line capacity	√		Improved speed of convergence and no local trapping	Solar PV and wind resources are only considered
[12]	2019	Hybrid teaching-learning based	Minimize power	Equality, active and	√		Avoidance of local	Tuning of algorithm

Ref. No.	Year	Optimization Algorithm	Objectives	Constraints	Allocation		Inferences	Limitations
					DG	CB		
		optimization	losses, voltage deviation and maximize voltage stability index	reactive power balance, voltage and thermal limits, and DG penetration			minima/maxima trappings and improved convergence	parameters are required; limited type of DGs
[22]	2019	Hybrid Whale optimization algorithm—Salp swarm algorithm (WOA-SSA)	Minimize power losses and voltage deviation	Bus voltage magnitude, DG number, and capacity	√		More effective and better execution time	Convergence is ignored, and limited types of DGs
[23]	2019	Hybrid weight improved particle swarm optimization + gravitational search algorithm (WIPSO + GSA)	Maximize total cost benefit	DG and capacitor power limits, voltage limits of bus	√	√	Feeder’s failure rate is evaluated through compensation coefficients, greater convergence speed	DGs with reactive power capabilities and stability are ignored
[1]	2020	Hybrid GA + PSO	Minimize active, reactive power losses and voltage deviation	Active and reactive power balance, voltage, line, and DG power limits	√		More realistic, accurate, improved performance, and easy to apply	Cost analysis, stability, and environmental factors are ignored
[14]	2020	Analytical hybrid PSO (AHPSO)	Minimize total cost	Real power of DG, angle deviation limit, and line current flow	√		Modified 2/3rd rule is used, faster convergence	No power factor and voltage stability assessment
[24]	2020	Hybrid Parameter improved PSO—Sequential quadratic programming (PIPSO-SQP)	Minimize real power loss	Net power flow, DG limit and node voltage	√		Highly stable, rapid convergence and less computation time	No power factor, cost analysis, and voltage stability assessment

Ref. No.	Year	Optimization Algorithm	Objectives	Constraints	Allocation		Inferences	Limitations
					DG	CB		
[25]	2020	Hybrid Phasor PSO and GSA (PPSOGSA)	Minimize active power losses	Equality, bus voltage, THD of voltage, branch flow, DG and capacitor capacity, and positions	√	√	Different constraints are used, solutions are effective, robust with high-quality and less no. of iterations	Limited type of DGs, power factor constraint, stability, and economic issues are ignored
[26]	2020	Hybrid CBGA—Vortex search algorithm (CBGA-VSA)	Minimize power loss	Complex power and network voltage	√		Successive approximation power flow is used. More efficient and better solution with low computational times	Limited type of DGs, emission, and stability investigations are ignored
[27]	2021	Hybrid empirical discrete metaheuristic—Steepest descent method (EDM-SDM)	Minimize power losses	Active and reactive power balance, DG status and limits, and voltage	√		High-quality and straightforward solutions with low tuning parameters	Stability and economic evaluations are ignored

enewable y sources systems. nd 69-bus [28] ork for the WO-PSO oss of the ely, using excellent observed he AREP- technical, e EGWO- of optimal power system operation. This research work can be extended to include reliability metrices with a reconfiguration of the distribution system. Moreover, a real-time potential assessment of an existing power system can be performed along with the reallocation of DGs based on AREP to validate the effectiveness of the proposed EGWO-PSO algorithm.

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