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Review of Metaheuristic Optimization Methods for Optimal Location and Sizing of Distributed Generation

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ABSTRACT
This paper presents a review of metaheuristic optimization methods for optimal location and sizing of distributed generation. Thirty-three research papers that are published between 2017 and 2019 are chosen for the review based on their significant contributions to the optimal location and sizing of distributed generation. The papers highlight single and multi-objective functions of their studies with aim at determining the optimal location and capacity of distributed generation, minimizing power losses and voltage profile improvements. Different IEEE test systems that include IEEE 6-bus, 9-bus, 12-bus, 13-bus, 14-bus, 15-bus, 30-bus, 33-bus, 34-bus, 37-bus, 39-bus, 69-bus, 85-bus, 188-bus and 476-bus were considered respectively for the optimizations. The papers mostly considered static distribution system of standard IEEE for both radial and ring connected systems.

Keywords-Evolutionary algorithm, Jaya algorithm, Metaheuristic algorithms, Particle Swarm Optimization, Swarm Intelligence.

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I INTRODUCTION

Metaheuristic algorithms are considered as higher-level procedures or heuristic in computer science. The algorithms provide an acceptable solution in a mean time and are used to provide solutions to optimization problems. It is an essential part of artificial intelligence (AI) as they are employed in finding the optimal solutions to many problems in the field of electrical engineering such as optimal allocation of Distributed Generation (DG), unit commitment, coordination of relays among others. Application of AI aims at optimizing algorithms to determine the optimal location and capacity of DG in radial distribution systems (RDS) [1]. Hence, metaheuristics gain importance because it is defined and designed in a generic manner irrespective of the problem and it doesn't have any constraint on the formulation of the optimization problem. DGs have attracted a lot of interest to researchers as it has become an area of concentration that provide diverse services to utilities and consumers including standby generation, baseload generation, peaks smoothing capability and improved power reliability. Besides, they are linked directly to consumers at load points.

Integrating DG units in an operational system is essential as it comes with numerous advantages. However, to allocate DG at best position pose challenging tasks for utilities as well as clients. The principal aim of optimal DG allocation and sizing is improving the overall efficiency with low power loss, stable voltage, maximum system security and reliability. Analytical techniques perform better terms in attaining accuracy and convergence for vast and complex networks. However, several meta-heuristic approaches are performing better in terms of convergence and efficiency in these extensive large and complicated networks [2].

This paper presents a review on metaheuristic optimization techniques for optimal location and sizing of DG. It is aim at establishing an optimization methods that are still relevant and got researchers attention within three years (2017 to 2019) for solving problems involving optimal location and capacity of DGs in radial distribution networks using metaheuristic optimization method. This will provide a piece of in-depth knowledge and acts of best allocation of DG in a distribution system for researchers.

II. METAHEURISTIC ALGORITHM AND ITS CLASSIFICATION

Sources of motivation to use a population of preconfigured algorithms in optimization algorithms can be followed to Holland J. in 1962 as a mixture of automata theory and hypothetical hereditary properties. From that point forward some algorithms have been created that use a population of choice vectors and methods for the application of variety and exploration entities, this population is advancing to adapt to the environment. The environment that is represented by an assessment or objective function, manages which person of the population would be able to enter the next generation [3].

Exploitation and exploration are the two key elements of population-based algorithm. However, in exploration, different solutions have been determined to explore the search area in order to get the best solution at global level. On the other hand, utilizing the data to obtain the best result through local search is referred to as exploration. The choice of the best solution at global or local level is dependent upon the optimal operation that will be projected based on the variety of solution. Swarm intelligence is employed to mimic the biological behavior of certain animals [4]. Figure 1 summarizes some of the population-based algorithms.

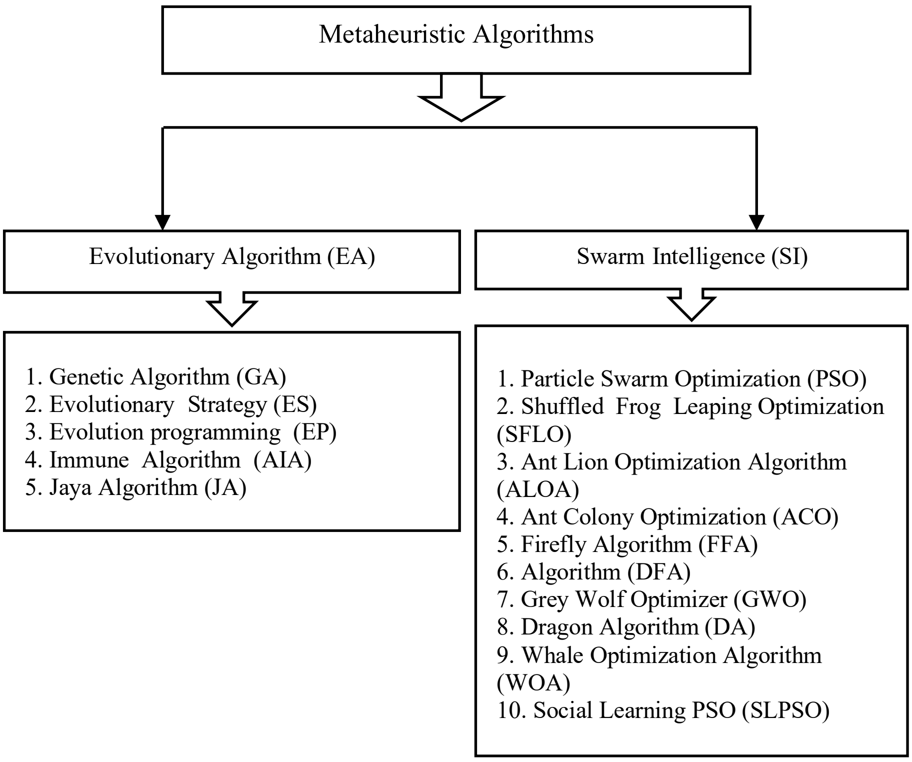

Figure 1. The population-based metaheuristic algorithm

III. OVERVIEW OF SELECTED METAHEURISTIC ALGORITHM

The implementation of common metaheuristic algorithms and their basic technicalities are addressed in this section. These include Jaya Algorithm, Genetic. Algorithm. (GA), Particle. Swarm. Optimization (PSO) algorithm and simulated annealing (SA) respectively.

Jaya Algorithm

Jaya algorithm is proposed by Venkata Rao in 2016 that has capability of either minimizing or maximizing OFn [5]. It is global search-based population technique for obtaining solutions involving constrained and unconstrained optimization problems. It is based on the idea that it always tries to reach the best solution and to avoid failure solutions. However, the algorithm deals with different optimum power flow (OPF) issues. Unlike other population-based optimization techniques, no other specific algorithm controls parameters as in this algorithm. Future works consider OPF a solution in that its generation cost is low, it is effective in reducing power loss and attains voltage sustainability.

Besides, Jaya algorithm can be implemented with controlling of number of generations and population size. The brief summary of this algorithm is defined in four categories [6]. The first stage involves initializing the algorithm with starting population together with the size of the population in which the individuals are haphazardly located within the search area. The second stage involve the elements of the population that is used to evolve a vector so as to improve the capability of the algorithm. However, the elements of the vector comprise the best as well as worst candidates through random numbers between zero and one. The values will project the solution towards ideal response. The third stage of the algorithm involve consideration of the component values of the third stage to be in a specified region within minimum and maximum value. The last stage deal with the OFn where the vector is compared to the individual values. The decision is to allow the lower function value to survive to the next generation. The OFn is designed to either be minimized or minimized.

However, the effect of DG is included in the OPF problem with the use of a modified formulation. To attain the best allocation of DG units, a sensitive-based process is incorporated.

Simulations are administered on the modified IEEE 30-bus and IEEE 188-bus networks to determine the effectiveness of the Jaya rule [7]. The only objective improvement cases are administered with no DG. For all instances place into thoughts, the results indicate that the Jaya algorithm will generate an optimum solution with fast convergence [8]. The statistical analysis is run to see the liableness of the Jaya algorithm. The best solution obtained from the Jaya algorithm is compared with numerous stochastic algorithms and demonstrates its effectiveness that surpasses them in terms of optimization and practicableness of the solution, providing efficiency and potential with better result for optimal placement of DGs [9]. The fitness of the Jaya algorithm is also supported by the fact that the algorithm seeks to achieve the best output in the shortest time possible thus considered as time-saving. Jaya algorithm provides one with multiple choices to select the most appropriate one in the reduction of power loss for every type and number of DG according to the number of phases in the distribution.

Genetic Algorithms (GA)

Genetic algorithms (GA) are a popular methodology of metaheuristic technique which is applied in optimal location and sizing of DG [10]. It entails evolutionary algorithms with different applications. GAs are widely applied in metaheuristic optimization compared to other methodologies due to its effectiveness in handling different types of data [11]. The method has been in use since the 1960s, and it has gone significant improvements [12]. Initially, it was based on the natural solution of Charles Darwin theory. However, the methodology is based on the context of encoding of solutions as character strings or arrays of bits, manipulation of the strings through the application of genetic operators together with selection based on fitness in need of establishing potential solutions to existing problems [13]. A specific procedure has been outlined to facilitate the implementation of GA in optimal location and capacity of DG. In each respective iteration which provides a new population commonly referred to a generation, the fixed-length character strings are applied in most GA at each generation. Currently, there is substantial research on the variable-length strings and coding structures which have been formulated to facilitate the process. The OFn is coded using either binary arrays or real-valued arrays in adaptive GA. The essential component of the process is creating a suitable fitness function (FFn) which facilitates a process of obtaining the criteria for the selection in a particular problem [14]. During minimization of the function with the application of the GA, the simple way of constructing a FFn is to apply the simplest form FFn = B – c such that B is a large constant and c = f (x) [15]. The primary objective of maximizing FFn is to eventually minimize the objective function f(x). Multiple ways of defining FFn have been established such as assigning individual relative to the whole problem as in equation 1.

$$F(x_i) = {f(\zeta_i)}\Big/{\sum_{i=1}^{N} f(\zeta_i)} \qquad (1)$$

In the equation, ζ_i represents the phenotypic significance of individual i while N is the population size. The type of FFn should ensure that chromosomes bearing higher fitness are chosen more often compared to those with lower fitness. Poor fitness is usually avoided since it leads to meaningless solutions.

During the optimal location and capacity of DGs, the choice of the population size is quite essential. In case the population size is small, evolution does not occur, and therefore there is a risk of the population size converging prematurely [16]. According to the ecological theory, species of the small population are in danger of getting extinct. The system is therefore driven to a local optimum as opposed to the global optimum. Thus, more evaluations of the OFn are required whenever the population is large, and as such indicating that extensive time will be necessary.

Particle Swarm Optimization (PSO) Algorithm

This algorithm consists of a swarm which consists of particles. The search process in this method is same to that of flying. birds when in search of food. The individual. bird referred to as swarm or particle flies in optimization problem in search of the optimal food. location [17]. The algorithm consists of two vectors also known as position vectors as well as velocity particles. The two particles are constantly adjusting within the two particle and individual experience simultaneously. [18]. The particle position changes by its social and individual experience. Whereas the velocity vector is assigned to the particle for which to determine the solution to the optimization problem. Besides, the position and velocity vector are updated based on the previous values of particles.

Simulated annealing (SA)

Simulated annealing is a metaheuristic algorithm that is based on metal annealing process. The algorithm is employed in optimal location and capacity of DG since unlike the gradient-based methods as well as another deterministic search the methodology avoids being trapped in local optima [19]. The techniques include dropping some balls bounce over a landscape, and as the balls bounce and lose energy, they are installed in some local minima. Allowing the balls to bounce long enough and lose energy slowly enough, makes some fall into globally lowest locations, therefore, facilitating, therefore, reaching the global minimum. Simulated annealing highly embraces the concept of Markov Chain in the process of optimal location and capacity of DG [20]. This facilitates convergence under appropriate conditions. During application of the technique, the actual search moves trace a piecewise path. The acceptance probability is evaluated with each move to ensure that it does not only accept changes in the process of improving the OFn [21]. However, the methodology also keeps some changes which do not improve the OFn. The acceptance probability p is presented in equation 2.

$$P = \exp\left[{}^{\Delta E}/_{k_B T}\right] \quad (2)$$

In equation 2, the k_B represents the Boltzmann's constant, T is the temperature required to control the annealing process and ΔE is the energy change. The concept also relies on statistical mechanisms which are embraced in Boltzmann distribution in the process of obtaining transition probability [22]. There exists a relationship between the OFn and the change in energy is related with equation 3.

$$\Delta E = r\Delta f \quad (3)$$

In the equation, r represents the real constant as both p and T approaches to zero. This indicates that the systems perform negatively whenever the temperature is approximately low [23]. It is recommended that the temperature is controlled as it directly dictates how the method functions [24]. Temperature also determines the efficiency of the system. In the process of optimizing the location and sizing distributed generation, the concept adopts various methodologies of controlling the cooling rate. The linear and geometric mechanism is employed in the process of regulating the temperature [1]. The final cooling schedule is therefore obtained in equation 4.

$$T = T_0 - \beta t \quad (4)$$

In the equation, T_0 is the starting temperature while t is a pseudo time which replaces the iterations, βt represents the cooling rate that will be identified in T→Tf if t→tf. This happens for the maximum number of N iterations [25]. Besides, if T is given as a temperature then several evaluations of the OFn are required. In the process of optimal location and sizing of DG, various evaluations are recommended. This minimizes the chances of the concept being unstable. The method is considered essential indicating whey it is widely applied in optimal location and sizing of DGs [26].

IV. CONTRIBUTION MADE FOR OADG USING METAHEURISTIC OPTIMIZATION

The metaheuristic optimization contributions based on Evolutionary Algorithm and swarm intelligence are grouped and tabulated on Tables 1 and 2 respectively.

Table 1. Metaheuristic optimization Contributions based on Evolutionary Algorithm

Ref	Published	Algorithm	Contribution
EVOLUTIONARY ALGORITHMS			
[27]	2018	GA	Optimal SVC Allocation in Power Systems for Loss Minimization and Voltage Deviation Reduction using Voltage Profile Index (VPI) was used using GA and is implemented ion IEEE 9-Bus and 30-bus Test System.
[28]	2018	GA	GA is implemented in which DG is installed on a distribution system to reduce power losses on the power system on IEEE 30 bus.
[29]	2017	Cuckoo Search Optimization Algorithm (CSOA)	A new approach to determining the optimal position and size of DG and the STATic COMpensator Distribution (DSTATCOM) was resolved simultaneously using CSOA. The Loss Sensitivity Factor (LSF) and Voltage Stability Index (VSI) are used to pre-define the optimal position of DG and DSTATCOM respectively and are implemented in IEEE 12-bus, 34-bus and 69-bus.
[30]	2017	Differential Evolution (DE)	A multi-objective operation based on the system performance indices is formulated and applied to the DE for calculating the optimum size for each location at a power unit power factor. The IEEE 14-bus model has been used as a test system.

[31]	2017	GA	The most suitable location of Static Var Compensator (SVC) and sizing of SVC to enhance the voltage profile is solved using GA; and is implemented on IEEE 30 bus system where the MATLAB program with MATPOWER were used.
[32]	2017	GA	Solves the cost function to find cost-effective solution for DG placement as well as sizing problem in distribution network on IEEE-33 bus system.
[33]	2017	Differential Evolution Algorithm (DEA)	The optimization of energy loss cost (ELC) distribution costs (DN) with the optimal allocation and dimensioning of DSTATCOM to maximize total net profit (TNP) / cost savings is determined using the DEA per year and the system installation time horizon DSTATCOM installation. Applies to IEEE 30, 33 and 69-bus.
[34]	2017	GA	It solves the optimal size as well as location of the DG in the radial distribution networks where the optimal position of the DG is determined using the stress sensitivity coefficient and the voltage stability index. Applied to IEEE 69-bus.
[35]	2017	Neuro-genetic Algorithm	This examination and resolution of the DG positioning as a problem of optimization using the neuronal genetic network and applied to South-East Nigeria 60-bus 33 kV distribution system.
[36]	2017	JAYA Algorithm	A multi-objective decision making (MODM) algorithm viz. Multi-Objective JAYA (MOJAYA) algorithm has been used to solve for the optimal location of DG for reducing power loss, improving voltage profile and stability. It is implemented on IEEE 33 bus.
[37]	2017	War optimization (WO)	It determines the best sites to place DG which are defined by the WO method, and the sizing is given by an optimal power flow tool. It is implemented on IEEE 69 and 476 busbars.
[38]	2017	Differential Evolution (DE) Algorithm	Solution of the Multiple DG's problem on Best Distributed system Reliability and Power Loss were applied Using DEA where reliability indices were determined.

Table 2. Metaheuristic optimization Contributions based on swarm intelligence

Ref	Published	Algorithm	Contribution
SWARM INTELLIGENCE			
[39]	2019	Whale Optimization Algorithm (WOA)	Power loss and cost minimizations with maximization of voltage stability index were solved using WOA and is implemented on IEEE 69.
[40]	2019	PSO	PSO-based algorithms are applied to decide the optimal size as well location for the DG to minimize loss and improve voltage stability and economic benefits. Applied to the IEEE 34-bus.
[41]	2019	Adaptive PSO (APSO)	APSO was employed to efficiently solve the problem ofi simultaneous allocation of DG and circuit breaker in radial distribution system to revamp voltage magnitude and reduce power losses. It is implemented on IEEE 30-bus, 33-bus and 69-bus.
[42]	2018	Modified Shuffled Frog Leaping Optimization Algorithm (MSFLA)	MSFLA was used to optimize DG capacity, where the DG Induction Generator model (wind energy production units) has been tested and implemented on an IEEE-30 bus.
[43]	2019	Firefly Algorithm (FFA)	The algorithm was applied to solving power loss minimization together with improving the voltage profile at each bus using load flow analysis and is implemented on IEEE 33-bus.
[44]	2018	Whale Optimization Algorithm (WOA)	Active Power Dissipation and Voltage Deviation (VD) minimizations for a micro electric system connected to a network with non-stationary small power plants were solved using WOA and applied to the IEEE 6 and 14 bus systems.
[45]	2018	Social Learning Particle Swarm	The optimal location and sizing of single as well as multiple distributed generation (DG) units in radial distribution

		Optimization (SLPSO) algorithm	network using SLPSO algorithm was investigated and implemented on IEEE 33-bus system.
[46]	2018	PSO	The problem of optimal location and size of DG units in a distribution system are solved on the basis of a multi-objective strategy. The algorithm is implemented on IEEE 13-bus and 12 buses.
[47]	2018	Crow Search Algorithm (CSA)	The CSA is used for the size and positioning of the DG in radial distribution networks where loss sensitivity factor (LSF) is applied to initially identify most of the candidate buses for 3 DGs. The algorithm is applied to the actual Egyptian distribution system.
[48]	2018	PSO	The investigation of an optimal allocation and sizing of DG was implemented on IEEE 33 bus using PSO algorithm where the voltage deviation (VD) and total power loss in a radial distribution system were each minimized.
[49]	2019	Ant Lion Algorithm (ALOA)	ALOA is implemented for Minimization of power losses and improving voltage profile in distribution systems by optimal allocation of 3 DG units on IEEE 33-bus using MATLAB.
[50]	2017	Shuffled Frog Leaping Algorithm (SFLA)	This is implementation of Shuffled Frog Leaping Algorithm (SFLA) algorithm for solving of optimal DG placement in distribution system. The locations found from Power Loss Reduction (PLR) method and sizes are found by SFLA algorithm and is implemented on IEEE 33 bus and 69 bus.
[51]	2017	Grey Wolf Optimizer (GWO)	An implementation of GWO for optimal placement and sizing of multiple DG, aimed at reducing active and reactive energy losses in the distribution system on15- and 33- bus system.
[52]	2017	PSO	The optimum allocation of DG that resulted in the best possible operation of distribution network was implemented using PSO to ascertain the minimum value of the defined objective functions and is implemented on IEEE 37 bus.
[53]	2017	Autonomous Group PSO (AGPSO)	AGPSO is implemented to solve power loss minimization in radial distribution system on IEEE 69 bus system.
[54]	2017	Firefly Algorithm (FFA)	Optimal sizing of renewable hybrid system considering reliability criteria is solved using FFA
[55]	2017	Moth Flame Optimization Technique (MFO)	Solves novel multi-objective optimization technique called MFO for determining the optimal location and size of Distribution Generation units (DGs) in distribution systems. It is implemented on IEEE 14-bus and IEEE 39 using MATLAB simulation program.
[56]	2017	Ant Lion Optimization (ALO)	Solve the optimal sizing and siting problem of DG in a distribution system (DS) using ant lion optimizer (ALO) with considering different objectives. The algorithm is implemented on IEEE 33 and 69-bus IEEE networks.
[57]	2017	Dragonfly Algorithm (DA)	A new swarm intelligence optimization technique is proposed, called DA to resolve DG placement and size problem in which three cases are being considered. Applied to an IEEE 33 test case.
[58]	2017	Ant Lion Optimization Algorithm (ALOA)	The optimal location and size of DG-based renewables for different distribution systems were determined using ALOA by examining Loss Sensitivity Factors (LSFs). IEEE 33-bus and 69-bus are applied.

V. CONCLUSION AND FUTURE DIRECTIONS

This paper presents a review on metaheuristic optimization methods for optimal allocation of DG. Metaheuristic optimization is a presented as a strategy which deals with the optimization of problems with the application of metaheuristic algorithms. Optimization is an essential technique in diverse fields ranging from engineering, economics, and approximately all our daily activities. In the optimal location and sizing of DG, metaheuristic optimization is necessary. There are various metaheuristic methodologies which are applied in the process such as Genetic Algorithm, Jaya Algorithm, Ant Colony Optimization, Particle Swarm Optimization, Dragon Algorithm and Whale

Optimization Algorithms amongst others. The effectiveness of the methodologies in location optimization and sizing on distributed differs from one technique to another. Genetic algorithms are amongst the best method indicating why various researchers mostly prefer. Besides, various existing static distribution networks of standard IEEE distribution network are considered for analysis. This call for the need for concentration of dynamic models of distribution system.

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