Supported by tetfund TERTIARY EDUCATION TRUST FUND

REVIEW ON DISTRIBUTED GENERATION PLACEMENT METHODS FOR POWER LOSS REDUCTION IN DISTRIBUTION SYSTEMS

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Received: November 13, 2018 **Accepted:** March 22, 2019

Abstract: Power losses in distribution networks have increasingly resulted in economic loss during power delivery to consumers. In order to reduce such losses Distributed Generation (DG) connection to distribution systems have been identified as a means of solving such problem if properly placed in the networks. It is therefore, necessary to include power loss minimization as objective during planning and operation of distribution systems. This paper summaries various optimization methods utilized by researchers for power loss reduction with a view of giving an update in the area and at the same time identifying missing gaps such as investigations on varying nature of loads, development of dynamic placement techniques and improvement on heuristic optimization algorithms as further works for the maximization of the benefits associated with DG as well as minimizing its negative impacts on the entire distribution network.

Keywords: Distributed generation, power loss reduction, optimization, placement, sizing

Introduction

Distributed generation placement and sizing needs special attention of both planners and system operators as DG installation at non-optimal locations can lead to increase in system power losses which can result in increase in costs and hence having a negative impact opposite to desired. The selection of the best location and size in large complex systems is combinatorial optimization problem as reported by Borges *et al.* (2006). Researchers have employed various methods in addressing the placement problems.It has been observed that among all the methods reviewed so far analytical method is found to be the most accurate and more practical technique for placement.

However, obtaining a truly optimal solution has presented a challenge as some computational methods do not yield global solution instead local solutions tends to be the outcome of the optimization. Due to this problem, deterministic algorithms are considered to be the elegant options (Griffin *et al.*, 2000). However, unlike deterministic algorithms, Gandomkar *et al.* (2005) repoted that meta heusutic algorithms are derivitive free problems and can be solved without need for convexcity. In the same vein, Caprinelli *et al.* (2006) informed that meta heuristic algorithms are independent of initial solutions and the techniques are robust and can provide near optimal solution for large and complex systems.

On the other hand, meta heuristic methods have their own drawbacks, such asuse of trial and error approach during parameter tunning, high computational efforts for good solution and lack of guarantee for global solution attainment atimes ashighlighted by Akorede *et al*. (2010). The authors also reported the benefits and shortcomings of some of these optimal placement methods in which special attention was given to genetic algorithm optimization method. A lot of efforts were made by researcherstowards eliminating these shortcomings by combining more than one algorithms to form a hydrid algorithm. The efforts have yielded results with a lot of enhancements over the individual algorithms when utilized alone.

This paper surveyed published works on different optimization techniques for optimal DG placement in distribution networks that considers reduction of power losses as objective. The review also gives an update on researches conducted using different methods towards finding optimal DG locations. The survey concludes by identifying key areas for further research work.

Review Methodology

In this work, the papers under review are categorized based on optimization algorithms employed. The published research on placement and sizing based on IEEE Explore Digital library data are categorized based on annual number of papers. The analysis shows significant yearly improvement in terms of research activities. This gradual increase in published papers is a clear indication of growing interest of researchers willing to find solution to DG placement problems. The review further compares the methods employed in the placement methods with a view of finding the most frequently used techniques as shown in Fig. 1.

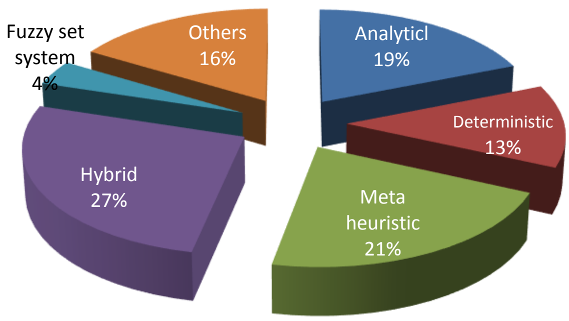

Fig. 1: Percentages of different methods for DG placement problem

From the figure, it is clear that hybrid method have the largest share of research activities due to their advantages. Meta heuristic method has reached saturation unless if new algorithms are discovered while analytical methods are usually employed due to its easy implementation and due to the adoption of simplified assumptions the solutions are fast to obtain. In the case of deterministic methods, the most efficient method found so far is the nonlinear programming followed by sequential quadratic programming and then the other methods that guarantees global optimum solution as a result of the extensive search involved (Hung, *et al*., 2010).

Power loss reduction objectives

The survey shows that most of the studies under this category are for minimizing the real losses of the lines that are subjected to various constraints or as a multi-objective optimization problem having many objectives and constraints as reported by Kim *et al.* (2008). In general optimization problem may be formulated a loss minimization problem with a single objective problem based on summation of all losses in a distribution system having *n* number of branches as the objective function (*f*) given by:

$$f = \sum_{i=1}^{n} P_i \qquad (1)$$

where p_i is the nodal injection of power at bus *i*, and *n* is the total number of buses

Power loss reduction was also optimized for radial distribution system by Lalitha *et al.* (2010) by summing all power losses value at each branch based on:

$$P_{losses} = \sum_{i=1}^{n} |I_i|^2 R_i \qquad (2)$$

Where *n* is the number of branches, I_i is the current magnitude and R_i is the resistance. The power losses reduction (PLR) due to the DGs, is determined as the difference of the power losses with DG and without DGs connected as:

$$PLR_i = P_{losses-new} - P_{losses} \qquad (3)$$

which can be expressed as:

$$PLR_i = -\sum_{i=1}^{n} (2JI_i I_{DG} + JI_{DG}^2) R_i \qquad (4)$$

where J=1 for feeder with DG connection, else J=0.

The bus that gives the highest value of PLR is selected as the optimal location of DG. The DG current that will give maximum loss reduction is given by;

$$I_{DGi} = -\frac{\sum_{i=1}^{n} I_{ai} R_i}{\sum_{i=1}^{n} R_i} \qquad (5)$$

Assuming no significant change in voltage as DG units are connected, the power that can be generated is expressed as;

$$P_{DGi} = I_{DG} . V_i \qquad (6)$$

The DG size from equation (6) must be located at bus *i* for maximum power loss reduction.

In the same direction, Wang and Nehrir (2004) have used the following objectives to find the optimal location of the DGs, in which the DG is located at *j* and the objective function is given as:

$$f_i = \sum_{i=1}^{j=1} P_{Li}(j)|S_{Li}|^2 + \sum_{i=j+1}^{N} R_{Li}(j)|S_{Li}|^2 j = 2,3\ldots N \quad (7)$$

where, $R_{Li}(j)$ is the equivalent resistance between bus 1 and bus *i* when a DG is located at bus j, for j ≠ 1, and S_{Li} is the complex power. $R_{Li}(j)$ is expressed as:

$$R_{Li}(j) = \begin{cases} Real(Z_{11} + Z_{ii} + 2Z_{Li}) i < j \\ Real(Z_{11} + Z_{(i-1)(i-1)} - +2Z_{1(i-1)}) i > j \end{cases} \quad (8)$$

where Z_{11}, Z_{ii}, Z_{1i} are the elements of impedance matrix .

If the DG is assumed to be located at bus 1 (j=1), the function f_i then becomes:

$$f_i = \sum_{i=1}^{N} R_{Li}(j)|S_{Li}|^2 \qquad (9)$$

The optimal bus is the bus where the objective function reaches its minimum value as:

$$f_1 = Min(f_j) j = 1, 2, \ldots\ldots\ldots\ldots\ldots N \qquad (10)$$

Similar work was also considered by Acharya *et al.* (2006) and the problem was formulated using total real loss P_L expressed based exact loss formula as:

$$P_L = \sum_{i=1}^{N}\sum_{i=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(P_iP_j - Q_iQ_j)] \quad (11)$$

A sensitivity factor for the real power loss with respect to real power injection is developed in this work. This factor is evaluated at each bus and ranked to form a priority list. It is based on this priority list that the locations for the DGs are identified.

Gözel and Hocaoglu (2009), optimally allocated DGs by minimizing the total power loss (P_{loss}) as a function of branch current injection indicated as:

$$P_{Loss} = \sum_{i=1}^{nb} |B_i|^2 R_i = [R]^T |[BIBC].[I]^2 \qquad (12)$$

where R_i is the ith branch resistance, *[R]* is the branch resistance row vector, nb is number of branches, BIBC is the bus-injection to branch-current matrix and *[I]* is the vector equivalent current injection for each bus except the reference bus. The method is based on the topological structure of the distribution systems and requires only one base case load flow to determine the optimum size and location of DG.

Optimization algorithms

Several optimization methods were employed for DG placement and sizing. These methods utilised six basic techniques as shown in Fig. 2. Each of these techniques is further sub-divided into specialized sub-groups as shown in the figure.

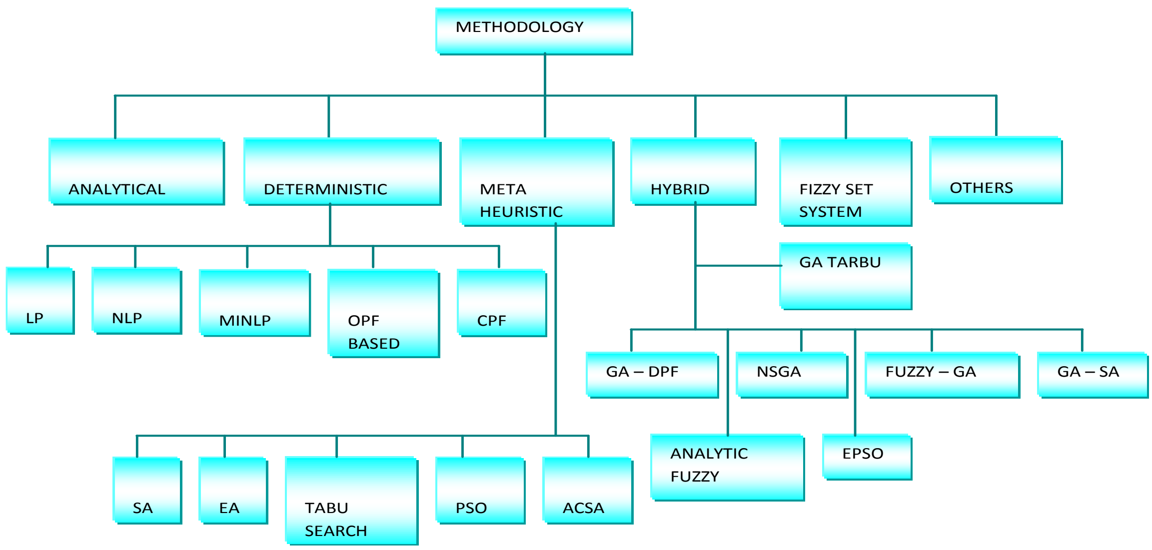

Fig. 2: Methods for placement and sizing algorithms

Researchers have proposed different methods for solving placements problems and these methods are always dependent on the objectives and the solution techniques employed. Generally out of these methods, meta-heuristicis found to be the most effective method in solving optimization problems with appreciable feasible search space as reported by Caprinelli *et al.* (2003). An overview of these methods is briefly highlighted.

Analytical methods

Analytical methods are easy to implement, but their results are only indicative, since the solutions are associated with many assumptions. One of such method is that proposed by Wang and Nehrir (2004) that places the DGs by considering various loads topologies in order to minimize real power losses. The DGs were assumed to have unity power factor, and only the overhead distribution lines with neglected shunt capacitances were considered. Even though the allocation was successfully done based on equivalent current injections, the optimal DG sizing was not in their formulation.

Acharya *et al.* (2006) uses sensitivity factor for incremental change of power losses with respect to change in injected real power to find the bus that will cause optimal losses when DG is hosted. Optimal real power of DG was obtained by equating the sensitivity factor to zero. The sensitivity factor was applied to all the buses, and ranked accordingly. The proposed method only considers single DG placement, and the process of finding the candidate bus location is lengthy. This is a major drawback, part from the fact that only real power was optimized.

In the study proposed by Gözel and Hocaoglu (2009), the topology of the distribution system was considered in implementing the load flow analysis and DG was optimally located on bus with minimum power loss while optimal size was obtained by placing DG at each bus and power losses recalculated. The bus with minimum power losses gives the optimal size. One of the short comings of this technique is that power loss was the only factor that was used in determining the optimal DG size. The size can be too large and can lead to limit violations of voltage and line loading of the system.

As part of further work, Hung *et al*. (2010) modified the formula developed by Acharya *et al.* (2006) for finding the optimal DG size and location. This modified model was further improved by considering different types of DGs that have different terminal characteristics in terms of real and reactive power capabilities. However, the complex nature and big size of distribution systems can render such to lack robustness.

Deterministic methods

The deterministic methods can solve DG sizing problems by formulating an objective function that is nonlinear and subjected to nonlinear equality and inequality constraints. It is a numerical methods that employees various techniques for handling the nonlinear optimization problems. Keane and O'Malley (2007) proposed use of linear programming (LP) to solve optimal DG sizing by linearizing the nonlinear constraints before the implementation. The approach seems to work but has a drawback of inaccuracy in terms of power losses that resulted in an inadequate capability of finding the exact solution. Another algorithm proposed by Zhang *et al.* (2007), uses nonlinear programming (NLP) method employed in reactive planning concept to place DG in an existing network. The method was slow in convergence due to zigzag search direction associated with the finding of optimal solution for bus locations to install the DG units. The authors also consider minimization of system active power losses and their formulation only considers power flow equality constraints, whereas the boundary conditions and the inequality constraints were not considered. In the same direction El-Khattam *et al*. (2005) proposes use of mixed-integer non-linear programming (MINLP) method to place a DG based on General Algebraic Modeling System (GAMS) by using planner's experience. The same model was further improved by Kumar and Gao (2007) in order to determine location and number of DGs in a pool as well as in hybrid electricity market. The work successfully achieved the placement based on real power nodal price and real power loss sensitivity index which are economical and operational indicators. Optimal fuel mix of different types of renewable DG units in order to minimize the annual energy losses without violating the system constraints were carried out by Atwa *et al.* (2010). Uncertainties associated with renewable DG source such as wind were adequately taken care up in the study.

Meta heuristics

The Meta heuristic method is an intelligent search which deals with local minimum problems and uncertainties in Meta heuristic approach involving intelligent searches that combines different concepts derived from artificial intelligence for the improvement of system performances. Various algorithms under this method are found to be practical approaches for handling optimization problem. The implementation requires some form of stochastic optimization in handling problems associated with uncertainties. The main advantage of meta-heuristics is it makes few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions according to Acharya *et al.* (2006). However, the methods do not guarantee that an optimal solution can ever be found.

The population based methods tend to have a lot of overlap or similarities between the algorithms. The most common feature is that most of the algorithms are naturally inspired and involves some form of scattered search when looking for global minima. Some of the evolutionary algorithms use evolutionary strategies while some employ some form of estimation for the distribution algorithms. The Particle swarm optimization (PSO) is a typical population-based and self-adaptive method introduced by Kennedy and Eberhart (1995). It is inspired by the social behaviour of bird flocking or fish schooling. This stochastic-based algorithm handles a population of individuals, in parallel, to areas of a multidimensional space everywhere the optimal solution is searched. The individuals are called particle while the population is called swarm. Each of the particle in the swarm moves towards the optimal point with adaptive velocity. In the population each of the particles is treated as a mass-less and volume -less point in an n-dimensional space. The position of particle in an n-dimensional vector is represented as;

$$X_m = (X_{m,1}, X_{m,2}, X_{m,3} \cdots\cdots\cdots X_{m,n}) \quad (13)$$

The velocity of the particle in n-dimension vector is;

$$V_m = (V_{m,1}, V_{m,2}, V_{m,3} \cdots\cdots\cdots V_{m,n}) \quad (14)$$

The best position related to the lowest value (for minimization objective) of the objective function for each particle is

$$P_{best_m} = \left(P_{best_{m,1}}, P_{best_{m,2}}, P_{best_{m,3}}, \cdots P_{best_{m,n}}\right) \quad (16)$$

While the global best position among all the particles or best P_{best} is

$$G_{best_m} = \left(g_{best_{m,1}}, g_{best_{m,2}}, g_{best_{m,3}}, \cdots g_{best_{m,n}}\right) \quad (17)$$

The position and the velocity of each particle is updated after each iteration. A typical application of such algorithm is that proposed by Jain *et al.* (2010) which uses cumulative performance index to achieve voltage profile improvement, loss reduction and voltage stability index improvement. The system loss minimization was implemented by considering constant power as well as voltage dependant load models.

In another application proposed by Sutthibun and Bhasaputra (2010) a model for optimal location and sizing of DG was formulated for the purpose of minimizing losses, emission and contingency using simulated annealing as optimization tool. The algorithm escaped local minima by incorporating a probability function capable of accepting or rejecting new solutions. So far much work has been done on evolutionary algorithms like Genetic algorithms for optimal placement of DG by Singh *et al*. (2009) for handling of single objective problem, while Celli *et al.* (2005) and Caprinelli *et al.* (2005) handled DG placement as a multi-objective optimization problem for radial systems by employing $\in-$ constraint techniques. In a related work proposed by Sedighizadeh *et al*. (2007), DG placement for radial distribution system carried out based on voltage profile improvement and loss reduction in the distribution network. The fitness values for sensitivity in the Genetic Algorithm (GA) process require load flow for decision-making. The load flow was combined with GA so that the load flow algorithm runs within the GA algorithm when ever evaluation need arises in the main path of the GA. Two DG resources were successfully installed for the improvement of network indexes. However, the proposed algorithm can only solved for the DG allocation problems. In another development, Nimain *et al*. (2013) proposes installation of DG resources (DGRs) and reactive power sources (RPs) in distribution systems along with tap positions of voltage regulators by using the Tabu Search algorithm. The approach has successfully minimized the cost of power, energy losses and the total reactive power required subject to a specified total of distributed generations. In addition, a novel technique for determining the candidate buses to install active sources based on clustering system buses in view of assigning DGRs (RPSs) also presented by the same authors.

Hybrid algorithms

Hybrid approach is as a result of drawbacks of individual methods that led researchers to combine methods for better solution. The hybrid methods combine one meta heuristic with any other techniques to produce an improved algorithm that will yield better results compared to the method alone. In hybrid methods, the weakness of the two individual methods are eliminated at the same time the individual strengths are combined together to produced a more efficient and better quality solution**.** Typically Akorede *et al*. (2010) combined GA and Fuzzy to form fuzzy genetic algorithm for the deployment of DG by taken into cognizance and the peculiarities of radial distribution systems, such as high R/X ratio, voltage dependency and composite nature of the loads which most of the earlier works did not consider. The authors reported that the system accuracy has greatly improved and processing time was less when compared to earlier techniques.

Fuzzy set systems

The fuzzy set theory are usually employed for the handling of DG types that are associated with uncertainties like wind speed and solar irradiance. Other cases that are similar in nature are load and electricity market which can also be implemented by fuzzy set due to their uncertain nature as reported by Jain *et al.* (2010). If enough information are lacking for some decision making, fuzzy set may be a better tool for compromised solutions during selection of best location for DG based on objective function. In the same trend Kim *et al*. (2008) have employed fuzzy set for the modeling of the DG in order to determine the power loss cost in distribution systems. The objective function together with the constraints was handled as a multi-objective problem for the purpose of evaluating their imprecise nature. A similar problem was solved by Lalitha *et al.* (2010) by employing fuzzy set for evaluating the power loss index and nodal voltage to determine suitability index.

Other approaches

Any approached that could not be classified under any of the sections already discussed, is considered as other approaches in this work. As reported by Elnashar *et al.* (2010), employs visual optimization as objective functions to place DG by using simplified method. The method is flexible but the analysis was limited to few constraints.

General overview and contributions on dg placements

The solutions of the DG problems to date are used to determine the optimal locations and sizes based on different objectives subject to many constraints. Table 1 shows the published works based on the objectives, method employed and the specific contributions of the work to optimal DG placement (ODGP) and sizing problems DG. The table summarizes achievements made so far in the area.

It is observed from Table 1 that the hybrid method is popularly adopted by many researchers; this is due to its advantage of efficiency, robustness and better solutions when compared to individual solution methods.

Table 1 Published works objectives, methods and contribution

S/N	Reference	Objective	Method	Contribution
1	Willis *et al*. (2000)	Minimization of power losses	Analytical	DG location and sizing in radial feeder with uniformly distributed load.
2	Nara *et al*. (2001)	Minimization of power losses	Meta heuristic	Optimal DGPlacement (ODGP) for uniform load with unity power factor
3	Gandomkar *et al*. (2005)	Minimization of power losses	Hybrid	ODGP solved using hybrid GA and TS for improvement of premature convergence of GA
4	Zhu *et al*. (2006)	Minimization of power losses and maximization of reliability	Others	ODGP for reliability and effective assessment of time very load
5	Haesen *et al*. (2007)	Multi-objective for technical and economic issues	Hybrid	ODGP model for integration of stochastic DG
6	Hedayati *et al*. (2008)	Minimization of power losses	Others	ODGP model using CPF to determine bus close to voltage collapse
7	Ochoa *et al*. (2008)	Multi-objective for energy export, losses and short circuit level.	Meta heuristic	ODGP model for integration of wind power using NSGA
8	Costa & Matos (2009)	Min power losses	Analytical	Optimal allocation and sizing of micro generators
9	Lee and Park (2009)	Minimization of power losses	Hybrid	ODGP solved using analytical method combined with Kalman filter
10	Dent *et al*. (2010)	Maximization of DG capacity	Deterministic	ODGP that limits voltage step change during sudden disconnection
11	El-Ela *et al*. (2010)	Multi-objective with weights	Meta heuristic	ODGP model for various objectives solved using GA
12	Ghosh *et al*. (2010)	Multi-objective with weights	Analytical	ODGP model for multi objective with weighting factors optimized
13	Khan and Choudhry (2010).	Minimization of power losses	others	ODGP model for over loaded networks at non-unity power factor
14	Alhajri *et al*. (2010)	Minimization of power losses	Deterministic	DG placement based on pre-specified and unspecified power factor
15	Atwa and El-Saadany (2011)	Minimization of energy losses	Others	Allocation of wind based DG using probabilistic approach
16	Prommee and Ongsakul (2011)	Minimization of power losses	Meta heuristic	ODGP model for better search using improved PSO
17	Ochoa and Harrison (2011)	Minimization of energy losses	Deterministic	Multiple renewable DG sites with time variation of demand for effective control
18	Abu-Moutiand El-Hawary (2011)	Minimization of power losses	Meta heuristic	ODGP problem solved by heuristic curve-fitted technique combined with a sensitivity test
19	Abu-Mouti and El-Hawary (2011)	Minimization of power losses	Meta heuristic	Optimal DG location, size and power factor using ABC
20	Liu *et al*.(2011)	Multi-objective with weights	Hybrid	ODGP for probability distribution function using Monte Carlo – GA
21	Hamedi and Gandomkar (2012)	Minimization of power losses	Analytical	ODGP for ranking of non- supplied energy and line losses
22	Rotaru *et al*. (2012)	Multi-objective for time varying voltage and loss sensitivity factor	Deterministic	DG placement using two stage iterative method
23	Arya *et al*. (2012)	Minimization of power losses	Meta heuristic	ODGP for voltage stability using differential evolution
24	Lalitha *et al*. (2016)	Minimization of power losses	Meta heuristic	ODGP for improved reliability
25	Ontoseno *et al*. (2017)	Minimization of power losses	others	ODGP based K-Means Clustering and Loss Sensitivity Factor method

Review findings on dg placements

Despite all the active researches on DG placement and sizing problems for the many years, the review has identified some missing gaps for future work. Notably, these areas are:

- Different types of DGs and their operating modes have to be studied from the point of view of varying load condition especially with anticipated penetration of electric vehicles in distribution networks.
- The existing DG placement techniques are static methods which require placement of DG in existing networks. It is necessary to develop dynamic placements scheme that will consider placement for longer period.
- Since most of the renewable resources available are associated with uncertainties that are either natural or man-made, more optimization work is required to accommodate such in future DG planning activities.
- For the purpose of improving power loss reduction and voltage profile, a coordinated reconfiguration of power system network is required for simultaneous placement of DGs, FACTS devices, capacitors and protection devices as the operations of these devices are dependent on each other.
- Further improvements in optimization methods through adaptive and automatic tuning of parameters for the heuristic algorithms which are based on trial and error require urgent attention for their performance improvement.

Conclusions

In this paper an overview of DG placement and sizing techniques based on power loss reduction objectives is presented. The state of art models and optimization methods related to DG placements were reviewed and classifications of current research works were carried out. This review has shown that use of hybrid method is more than any other method due to its advantages. The paper also identified some gaps such as investigations on varying nature of loads, development of dynamic placement techniques and improvement on heuristic optimization algorithms as areas that can trigger future researches.

Conflict of Interest

The author declares that there is no conflict of interest related to this study.

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