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Effect of Voltage Dependent Load Model on Placement and Sizing of Distributed Generator in Large Scale Distribution System

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ABSTRACT:
Distribution system supplies power to variety of load depending upon the consumer's demand, which is increasing day by day and lead to high power losses and poor voltage regulation. The increase in demand can be met by integrating Distributed Generators (DG) into the distribution system. Optimal location and capacity of DG plays an important role in distribution network to minimize the power losses. Some researchers have studied this important optimization problem with constant power load which is independent of voltage. However, majority of consumers at load center uses voltage dependent load models, which are primarily dependent on magnitude of supply voltage. In practical distribution network, the assumption of constant power load can significantly affect the location and size of DG, which in turn can lead to higher power losses and poor voltage regulation. In this study, an investigation has been performed to find the increase in power loss due to the use of inappropriate load models, while solving the optimization problem. Furthermore, an attempt has been made in this study to reduce power losses occurring in large test bus systems with loads being dependent on voltage rather than the constant power load. Different test cases are created to analyse the power losses with appropriate load model and in-appropriate load model (constant power load model). The load at distribution network is not mainly dependent on any single type of load model, it is a combination of all load models. In this study, a class of mix load viz., combination of residential, industrial, constant power, and commercial load, is also considered. In order to solve this critical combinatorial optimization problem with voltage dependent load model, which requires an extensive search, Adaptive Quantum inspired Evolutionary Algorithm (AQiEA) is used. The proposed algorithm uses entanglement and superposition principles, which does not require an operator to avoid premature convergence and tuning parameters for improving the convergence rate. A Quantum Rotation inspired Adaptive Crossover operator has been used as a variation operator for a better convergence. The effectiveness of AQiEA is demonstrated and computer simulations are carried out on two standard benchmark large test bus systems viz., 85 bus system and 118 bus system. In addition to AQiEA, four other algorithms (Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Gravitational Search Algorithm (GSA), Grey Wolf Optimization (GWO), and Ecogeography-based Optimization (EBO) with Classification based on Multiple Association Rules (CMAR)) have also been employed for comparison. Tabulated results show that the location and size of DGs determined using in-appropriate load model (constant power load model) has significantly high power losses when applied in distribution system with different load model (other voltage dependent load models) as compared with the location and size of DGs determined using the appropriate load model. Experimental results indicate that AQiEA has a better performance compared to other algorithms which are available in the literature.

KEYWORDS: Power Loss, Industrial Load, Commercial Load, Residential Load, Distributed Generator, Voltage Dependent Load.

1. INTRODUCTION

Distribution system is continuously supplying power to the consumers at load centers based on their demand. The demand for electrical power is increasing day by day and leads to high power losses and poor voltage regulation. One alternative solution for the electric utilities to reduce the gap between demand and supply is integration of Distributed Generator (DG)

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into distribution system. DG is defined as the small scale power generation sources which are placed near load centers, typically their size varies from few kW to 100MW [1-3]. Improper size and location of DG can lead to poor reliability, voltage profile and high power losses in distribution system [4].

In actual distribution network, the probability of usage of voltage dependent loads is high as compared with constant power load [5]. Most of the loads used in distribution system are residential, commercial, and industrial, which are dependent on node voltages [6-9]. However, majority of the work done to minimize the power losses with integration of DG into distribution system had assumed only constant power load. If the location and capacity of DG optimized with constant power load is used in a practical distribution system, then the overall power losses incurred in the practical system would be higher than that predicted with theoretical calculations, due to wrong assumption of the load model.

In this study, an investigation has been performed to find the variation in power loss with inappropriate load models. Some authors have solved this important optimization problem with small bus systems. We have made an attempt to reduce the power losses on large test bus systems with loads being dependent on voltage rather than constant power load. The practical load model, which are dependent on voltages are shown in Fig. 1.

2. LITERATURE REVIEW

In this paper, load models with DG integration is divided into two types, first one is theoretical load model which varies linearly and with square of the voltage (Constant Current Load & Constant Impedance Load) [10-13] and the other type is termed as practical load model i.e., loads which are majorly used in practical distribution system (Residential, Commercial and Industrial) [15-24].

Banerjee et al. [10] used a voltage stability index method with theoretical load model to improve the voltage profile in distribution network. This method determines the most sensitive buses which are nearer to voltage collapse. However, the analytical method is time consuming and requires large computational efforts, especially on larger test bus systems. Roy et al. [11] also investigated the effect of load model on voltage profile by integrating Distributed Wind Generators with both static and composite loads, i.e., static load model refers theoretical load model, and composite load models refer to arrangement of small motors, static loads and electric loads based on load composition. Whereas, Banerjee et al. [10] used voltage stability index method to find the weakest bus near voltage collapse in the distribution network. However, we are using a different load model, which is dependent on voltage, i.e., practical load model with primary objective to reduce the power losses with larger test bus systems. Also, an investigation has been performed to find the effect of load model (Practical load model) on DG optimization with inappropriate model of loads.

Sattianadan et al. [12] studied the effect of theoretical load model to improve the voltage profile and increase the percentage power loss reduction with DG. Whereas Roy et al. [11] investigated his approach only on voltage profile improvement with Distributed Wind Generators on static and composite loads. In this paper, minimization of power losses on larger test bus systems is considered as primary objective. In addition, an investigation is performed on DG optimization problem with inappropriate loads. Manikanta et al. [13] also studied the effect of DG with same load model (theoretical load model) [12] to maximize the percentage power loss reduction in distribution system. Manikanta et al. [13] used multiple DGs, whereas Sattianadan et al. [12] used a single DG. The overall power losses obtained in Ref [13] is low as compared with Ref [12]. In this paper, multiple DGs are used with voltage dependent load models to reduce the losses. Further, an investigation is also performed to find the effect on the losses incurred in the system with inappropriate load models on DG optimization problem. Vinoth and Srinath [14] also investigated the effect of load models i.e., practical load model in distribution system with multiple DGs. Whereas, Manikanta et al. [13] used Type-I DG, which injects only active power into the distribution system. The main objective for Sattianadan et al. [12], Manikanta et al. [13], and Vinoth and Srinath [14] is to reduce the power loss with DG. However, Sattianadan et al. [12] tested the effectiveness on small bus system (33 bus system) with GA, whereas Manikanta et al. [13] tested the effectiveness on small bus and medium bus system (33 bus system & 85 bus system) with SOS. Vinoth and Srinath [14] tested the effectiveness on small bus system (25 bus system) with GA and used Multiobjective indices by combining weighed performance indices. Minimization of power loss is the main objective in [10, 12-14] with DG, however Banerjee et al. [10] used analytical method, Sattianadan et al. [12] Manikanta et al. [13] and Vinoth and Srinath [14] used metaheuristics to find the optimal placement and Capacity of DG. However, investigation on effect of practical load models on larger test bus systems with DG has not been adequately done in the available literature.

Deepender et al. [15], Devender et al. [16], and El-Zonkoly [17] studied the effect of practical load model with following indices: real and reactive power loss index, voltage profile index and MVA capacity index using multiobjective function. Kumar et al. [18] also studied the effect of DG on practical load model with multiple objectives. In addition to the above, the author added two more indices such as reliability index and shift factor index. In [15,] single DG with rating (0.63p.u.) is used to analyse the effect of load models, whereas [16], [17] uses multiple DG with rating (0.63p.u.). Ref [15-17] uses Type-I DG, which injects only active power into the system, whereas, in addition to Type-I DG, Ref [18] uses Type-II DG (which injects only reactive power) and Type-III DG (absorbs reactive power and delivers active power). However, Vinoth and Srinath [14] also used the above indices on a small bus system with multiple DGs. Investigation on effect of load models on larger bus systems was not considered. In this paper, we have investigated the effect of power losses incurred in the system, i.e., large bus systems on inappropriate placement and sizing of DG. Chandrasekhar et al. [19] used practical load model with minimization of cost, voltage deviation, and power losses as primary objectives by integrating DGs into distribution system. Whereas, Kumar et al. [18] studied the effect of voltage dependent loads by multiobjective function with different indices. Investigation on effect of load models with improper placement and sizing of DG on larger test bus systems is not considered in their efforts. In this paper, an investigation is performed to find the losses incurred in large test bus system with different load models due to improper utilization of DG.

Payasi et al. [20] & Swetha [21] studied the effect of practical load model with different types of DGs based on their terminal characteristics with an objective to reduce the real power loss and apparent power intake at substation. Chandrasekhar et al. [19] also studied the effect of load model with different types of DGs based on PQ mode. Analysis on improper placement and sizing of DG with different loads are not considered. In our case, an analysis is done on increment or decrement in power loss with improper placement and sizing of DGs. Khan and Malik [22-23] also used practical load model with optimal allocation of Photovoltaic (PV) based DGs in power system planning studies. Whereas, Payasi et al. [20] & Swetha [21] used different types of DGs other than PV, which injects only active power into the system in planning studies. Hizarci and Turkay [24] studied the effect of DG with both theoretical & practical load models for different indices such as Qualified Load Index, System Loadability Index, and Voltage Deviation Index. Khan and Malik [22-23] used only practical load model in planning studies to reduce the losses. From the above literature [15-24], it is evident that some research has been carried out on practical load model with DG integration to minimize the losses in distribution network. However, optimization of DG on inappropriate load model with large test bus systems has not been covered in the literature. Therefore, an investigation has been performed in this paper to find the effect of practical load model with DG when it is placed and sized using inappropriate load models.

Minimization of power losses in a distribution network with DG has attracted the interest of several researchers. Several optimization methods and techniques are implemented with DG. Many analytical and meta-heuristic techniques are used to solve this critical combinatorial optimization problem. Some meta-heuristic techniques used for optimal location and capacity of DG include Harmony Search Algorithm and Particle Artificial Bee Colony Algorithm (HS-PABC) [25], Ant Lion Optimization (ALO) [26], Wale Optimization Algorithm (WOA) [27], Stochastic Fractal Search algorithm [28], Grey Wolf Optimization [29], Gravitational Search Algorithm [30] and Multi Objective Particle Swarm Optimization (MOPSO) [31]. Kumar et al. [32] proposed a new algorithm EBOwithCMAR, which is the winner of CEC-2017 benchmark problems. Kaboli *et al.* [33] also proposed a new optimization algorithm which is used to solve the constrained optimization problems. Some other metaheuristic techniques which are recently used in DG planning stage are Co-operative Search Algorithm [34-35] and Back Tracking Search Algorithm [36-37].

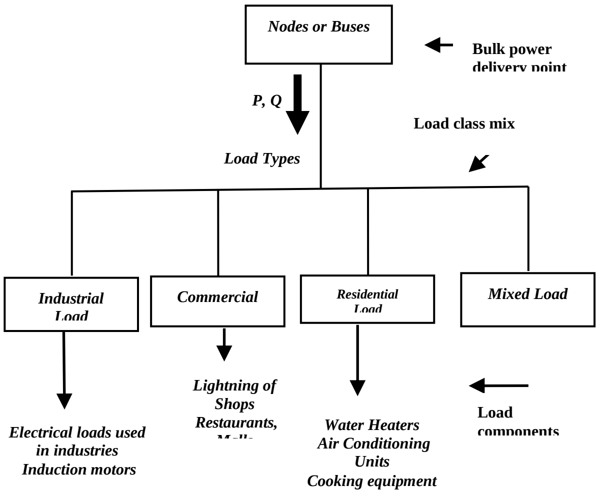

Fig. 1. Different voltage dependent load models.

Metaheuristic techniques often suffer from some limitation like premature convergence, slow convergence and stagnation to choice of parameter. In order to overcome these limitations a quantum inspired evolutionary algorithm is used. In this study, a quantum inspired evolutionary algorithm known as Adaptive Quantum inspired Evolutionary Algorithm (AQiEA) is used to find the optimal location and capacity of DG. AQiEA is a probabilistic EA and population based approach has been inspired by integrating some principles of quantum mechanics. It is a relatively new and powerful evolutionary intelligence method used for solving many engineering optimization problems. In recent times, AQiEA is applied on various engineering optimization problems with a measurement operator, which is a modified version of QiEA. AQiEA uses two sets of qubits, whereas QiEA uses a single set of qubit. Recently, AQiEA is applied on optimal location and size of Capacitors [38], Network Reconfiguration [39-41], Siting and sizing of Distributed Generator (DG) [42-43] and simultaneous implementation of both DG and capacitors [44].

In distribution system, utilities are using load models which are mostly dependent on node voltages and the voltage variation is frequent in such systems. Therefore, characteristics of loads are important in distribution system. There are numerous methods and optimization techniques, which used DG to solve the power loss minimization problem [25-30]. However, majority of them have solved this critical problem with small bus systems and with constant power load model as the probability of load having constant power model is high in small bus system as compared to the large bus systems. If location and capacity of DG is considered with constant power load model in large bus system, under practical considerations, the distribution system may incur high power losses and poor voltage regulations. However, investigation on the effect of practical load model (percentage increment in power loss with inappropriate load model) with Distributed Generation has been not adequately covered in the above available literature.

The rest of the paper is organised as, ‘Problem formulation’ in Section III describes, modelling of different loads which depends on voltage and a class of mixed load model is also considered. An AQiEA approach is used to solve the combinatorial optimization problem, which has been explained in Section IV as ‘AQiEA’. The effectiveness of AQiEA on different load models as compared with other algorithms are explained in Section V ‘System under study, results’. Finally, the paper concludes with ‘Conclusions’ in Section VI.

3. PROBLEM FORMULATION

One of the advantages of placing a DG in the distribution system is to minimize the power losses. The reduction in power loss will improve the voltage profile of the system. Many authors have solved this important optimization problem with different approaches [25-30]. Minimization of power losses is considered as main objective; the overall and individual power losses obtained at each branch section is calculated as follows,

$$\text{Min. } \{P_{loss} = \sum_{m=1}^{N_b} I_m^2 * R_m \} \tag{1}$$

Sizing and siting of DG is an important non convex, non linear optimization problem. The power injected by DG into the system at a particular bus is given as follows

$$P_L(m) = P_L(m) - P_{DG}(m) \tag{2}$$

Constraint on Operation of DG between its minimum and maximum power output limits:

$$P_{DG}^{min}(m) \le P_{DG}(m) \le P_{DG}^{max}(m) \tag{3}$$

The total power injected by DG into the system should be within acceptable limits.

Power injection:

$$\sum_{m=1}^{k} P_{DG}(m) + P_{sub} = P_{load} + P_{loss} \tag{4}$$

The total power injected by different DGs along with substation power must be equal to its total load demand and losses of the system.

Table 1. Exponent factors with different load types.

Load Type	α	β
Constant power load	0	0
Industrial load	0.18	6.0
Residential load	0.92	4.04
Commercial load	1.51	3.40

Different types of voltage dependency load models are adopted for the study. Generally, loads encountered in distribution system are residential, commercial, industrial, etc. due to its voltage dependent characteristics [5-9]. The mathematical representation of different load models is considered as follows.

$$P_L(m) = P_{initial}(m) * V_{initial}^{\alpha}(m) \tag{5}$$

$$Q_L(m) = Q_{initial}(m) * V_{initial}^{\beta}(m) \tag{6}$$

In conventional power flow studies, it is assumed that $\alpha=\beta=0$ for constant power load model. The real and reactive loads for voltage dependency load model are dependent on real and reactive power exponents, which are used in the present work, are given in Table 1.

4. ADAPTIVE QUANTUM INSPIRE0D EVOLUTIONARY ALGORITHM (AQIEA)

Evolutionary Algorithms (EAs) works on Darwinian principle i.e., ‘survival of fittest’ and are inspired from nature’s law of biological evolution. In EA, every individual in the population will compete with one another and the fittest individual amongst them will move to the next generation. This process will be repeated until it meets termination or convergence criterion. Genetic Algorithm [15] is a commonly used for high quality solution, however it takes relatively large time to converge towards optima. Particle Swarm Optimization [17] is another metaheuristic from swarm intelligence, which is used to solve global optimization problem, however it gets trapped in local optima. In recent times, Gravitational Search Algorithm [30], EBOwithCMAR [32] and Grey Wolf Optimization Algorithm [29] are used to solve optimization problem with high dimensional search space. However, EA suffers from premature convergence, slow convergence, sensitivity to the choice of parameter. Quantum inspired Evolutionary Algorithm (QiEA) is used to overcome the limitations in EA as they tend to establish a better balance between exploration and exploitation. QiEAs are designed by integrating EA with some principles of quantum mechanics. It is a new type of EA which requires less time and small population size as compared with other EAs to find global optima. QiEA uses probabilistic representation of search space to improve diversity and uses a genotype, called qubit, which is quantum analogue of classical bit [39]. Quantum rotation gates are used to evolve new populations in the system. In canonical QEA, Quantum rotation gates / operators also behave independent of the information. In this paper, a new approach has been considered for designing QiEA. In the proposed approach (AQiEA), a different qubit representation is used along with entanglement principle and superposition principle [38]. It is a relatively new and powerful evolutionary intelligence method used for solving many engineering optimization problems. AQiEA uses a two quantum bit which is analogous classical bits. In AQiEA, two qubits are entangled with one another and represented in quantum system with respect to the superposition of basis state which increases the population diversity. The entanglement principle is unique and has no classical analogue that is if two or more qubits are entangled with one another, then quantum operation performed on any of the qubit would affect the state of the other qubits. AQiEA uses two qubits in which first qubit is used to store the solution vector and second qubit is used to store the scaled rank of the objective function value of the solution vector. In quantum representation, qubit is defined as the smallest unit of information and it is represented as:

$$|\Psi\rangle = A_1|0\rangle + A_2|1\rangle \tag{7}$$

Where, $(A_1, A_2) \in A$, A indicates the set of complex numbers and A_1 & A_2 are the two states, which represents the probabilistic amplitudes. The two complex numbers are influenced by quantum orthogonality and it is referred as follows:

$$|A_1|^2+|A_2|^2=1 \tag{8}$$

Table 2. Measured operator on qubit string.

j	***1***	***2***	***3***	***4***	**………..**	N_p
A_{1j}^2	*0.17*	*0.41*	*0.65*	*0.36*	**………..**	*0.56*
A_{2j}^2	*0.83*	*0.59*	*0.35*	*0.64*	**………..**	*0.44*
N_{rj}	*0.24*	*0.07*	*0.25*	*0.49*	**………..**	*0.12*
Q_{mj}	*0.83*	*0.41*	*0.65*	*0.64*	**………..**	*0.56*

Equation (7) represents the quantum superposition between these two states. In first set of qubit, the amplitude of kth variable A_{1k} is stored in Ψ_{1k} , the value varies between [0, 1]. The value of A_2 is found from the equation (8).

A measurement operator is used to generate a solution string from qubit string (A). In quantum computers, a resultant classical state is observed upon application of measurement operator, which results in collapse of superposition of states. However, in classic computers collapse of states does not occur naturally. In order to observe the qubit string, a new string with a random number, whose value varies between 0 and 1 is generated (N_r), which is of same length as that of qubit strings. Hence after measurement operation on the qubit string, a new measured value string (Q_m) is generated, which is of the same length as qubit string. The measured value in Q_{mj} is obtained by comparing the generated random number at N_{rj} to square of A_{1j} at jth generation. If N_{rj} is less than the square of A_{1j}, Q_{mj} is set to square of A_{1j} otherwise to the square of A_{2j} as shown in Table 2 [40].

Two qubits used in this approach are entangled with one another from the definition of entanglement, if any quantum operation is performed on any of the qubit, it would affect the state of the other qubit. Amplitude of second qubit is determined by influence of first qubit value i.e., scaled rank of the objective function of the solution vector [41]. Second qubit influences the first qubit by adaptive quantum rotation crossover operator.

$$|\Psi_{2k}(t)\rangle=f_1(|\Psi_{1k}(t)\rangle) \tag{9}$$

A variation operator which is known as adaptive quantum based crossover operator is used as follows [40]:

$$|\Psi_{1k}(t+1)\rangle=f_2(|\Psi_{2k}(t)\rangle, |\Psi_{2l}(t)\rangle, |\Psi_{1k}(t)\rangle, |\Psi_{1l}(t)\rangle) \tag{10}$$

The variation operator which is used in the above equation during the search provides a balance between exploration and exploitation. By using three rotation strategies (R-I, R-II, R-III), variation operator converges the search towards better solution.

Rotation towards the Best Strategy (R-I): In this method of rotation, all the solution vectors are rotated towards the best solution vector. By rotating all the solution vectors towards the best solution, it is expected that better candidate solution will be found for all other vectors.

Rotation away from the Worse Strategy (R-II): In this method of rotation, the best individual in the population will move away from all other vectors. In the population of individuals, as moving away from worse, the search takes place in all dimensions. This is motivated by the fact that there are better chances of finding a good candidate solution in the vicinity of the best individual.

Rotation towards the Better Strategy (R-III): In this method, two individuals are randomly selected and the individual which has inferior solution will move towards the better solution in a hope of improvement.

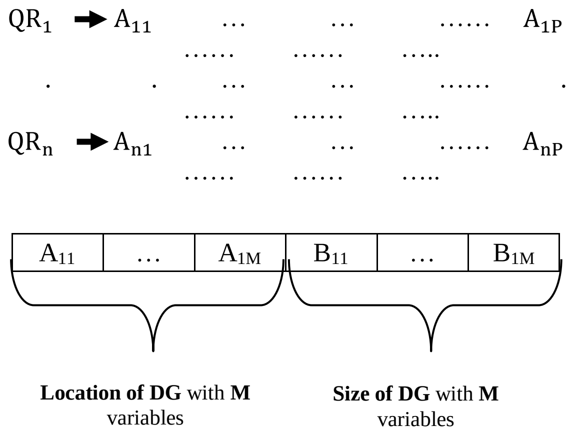

Fig. 2. Chromosome representation of AQiEA.

Quantum registers are used to store qubits. As two qubits are used for this approach, first qubit is used to store the amplitudes of the solution vector and second qubits is used to store scaled and ranking of solution vector. The fittest vector and worst vector in the second qubit are considered as values of 1 and 0. The remaining solution vectors in the second qubit are given scaled ranks between 1 to 0. Quantum registers are represented for a specified problem with number of variables.

The solution vector for implementation of DG to minimize the power losses is given as follows

$$Q_{DG} = \begin{bmatrix} DG_{L1}^{1} & \cdots & DG_{Li}^{1} & DG_{S1}^{1} & \cdots & DG_{Sj}^{1} \\ DG_{L1}^{2} & \cdots & DG_{Li}^{2} & DG_{S1}^{2} & \cdots & DG_{Sj}^{2} \\ \vdots & \dots & \vdots & \vdots & \cdots & \vdots \\ DG_{L1}^{p-1} & \dots & DG_{Li}^{p-1} & DG_{S1}^{p-1} & \cdots & DG_{Sj}^{p-1} \\ DG_{L1}^{p} & \cdots & DG_{Li}^{p} & DG_{S1}^{p} & \cdots & DG_{Sj}^{p} \end{bmatrix} \quad (11)$$

Measurement operator is used to generate the solution string from Qubit. Optimal placement and sizing of DG is a difficult combinatorial optimization problem which involves continuous (optimal sizing of DG) and discrete variables (optimal location of DG). Optimal size of DG is varied from P_{DG}^{min} *and* P_{DG}^{max}. Optimal placement of DG is varied from 1 toN_b.

Where, p represents the total population used in the system and i & j represents total number of variables used in the system for location of DG and size of DG. DG_{Li}^{p} represents the location of DG at i^th^ variable with p population. DG_{Sj}^{p} represents the size of DG at j^th^ variable with p population. The schematic representation of a quantum chromosome for implementation of DG is shown in Fig. 2.

The pseudo code of the proposed algorithm along with description is given as follows:

```
t ← 0
    a.  Initialize (QR_1 (t))
While (! termination_criteria)
{
    b.  Q_m = Measurement_operation(QR_1 (t))
    c.  f(x)= Compute_fitness (Q_m(t))
    d.  QR_2(t)= Rank_Scaled (f(x))
    e.  QR_1c= AQRC_(QR_1(t), (QR_2(t))
    f.  Tourn_Selection (QR_1(t), f(x))
t ← t+1
}
```

Description:

a) No of variables and population size is initially assigned for quantum register, in this approach two qubits are used, first qubit QR_1 is used to store the amplitude of solution vector and second qubit QR_2 stores scaled ranks for solution vector.

b) New string with a random number, whose value varies between 0 and 1 is generated (N_r), which is of same length as qubit strings. Hence, after measurement operation on the qubit string, a new measured value string (Q_m) is generated, which is of the same length as qubit string.

c) Placement and capacity of DG is a combinatorial optimization problem. In this approach, quantum register Q_m computes the fitness of the solution vector.

d) Second qubit QR_2 stores scaled and ranked for solution vector with value [1, 0]. The fittest vector and worst vector in the second qubit are considered as values of 1 and 0. The remaining solution vectors in the second qubit are arranged between 0 to 1.

e) Three rotation strategies (R-I, R-II, R-III) are used for converging the solution towards better solution.

f) By applying tournament selection between individuals in the population, the fittest one will move to next generation.

5. SYSTEM UNDER STUDY, RESULTS & DISCUSSIONS

The consistency and efficacy of the proposed algorithm is tested on two benchmark test bus systems viz, 85 bus system and 118 bus system with population size of 50 and 80 respectively. Experimental results for AQiEA are carried out on MATLAB (2017a) with system configuration 4.0 GB RAM, windows-8.1 and @1.48 GHz. The line data and load data for the benchmark test cases are considered from appendix, Table 3 and 4 show the complete data of 85 bus system and 118 bus system for mixed load model. The minimum and maximum allowable size of DG for 85 bus system and 118 bus system are 0 to 1MW [13] and 0 to 1.5MW [28], respectively. In the proposed approach, different types of load models which are based on exponential characteristics of voltage are used to minimize the power losses. In each case, a fixed load is modelled i.e., if a residential load is modelled with test bus system, then the total load supplied to the system is pure residential. Similarly, the same approach is considered for other load models. The consumer at load centre did not use a single type of load model, it is a combination of all loads i.e., residential, constant power, commercial and industrial loads. In this study, a class of mixed load is also modelled to reduce the power losses. Table 2 shows the parameters used by GA, PSO, GSA, GWO, EBOwithCMAR and AQiEA to reduce the power losses. Population size used for GA, PSO, GWO, GSA and AQiEA are 50 with maximum iteration 200. The total power losses in the system with & without optimal placement of DG for different load models are demonstrated in Tables 5-6.

5.1. 85 Bus System

The 85 bus system, which is a medium scale system, includes 84 branches and 85 nodes. The total real and reactive power load acted on the benchmark test bus system for different load models without DG are 2.57MW and 2.62MVAr for constant power load, 2.4MWand 1.61MVAr for industrial load, 2.27MW and 1.81MVAr for residential load, 1.26MW and 1.9MVAr for commercial load and 2.65MW and 2.02MVAr for mixed load. In a normal operation, the overall active power losses incurred in the system are 316.13kW, 166.38kW, 174.69kW, 182.5kW and 240.63kW for constant power, industrial, residential, commercial and mixed loads.

The proposed algorithm is applied on different load models including mixed load and simulation results for this test bus system are presented in Table 3. For constant power load model, AQiEA has maximum percentage power loss reduction in comparison with state of art techniques such as GA, PSO, GSA, GWO and EBOwithCMAR. Proposed algorithm has minimum DG size i.e., active power injected into the system with maximum reduction. Overall active and reactive power losses obtained by AQiEA for constant power load are 151.892kW and 93.885kVAr. Whereas, other algorithms such as GA, PSO, GSA, GWO and EBOwithCMAR are also performing well on this test bus system but AQiEA has maximum percentage power loss reduction. The maximum percentage power loss reduction produced by AQiEA is 51.95% followed by EBOwithCMAR, GWO, GSA, PSO and GA. Optimal placement and capacity of DG not only minimizes the power losses but also improves the overall voltage profile. AQiEA has maximum improvement in voltage profile in comparison with other algorithms except PSO. For constant power load model, PSO has maximum improvement in voltage profile with minimum voltage of 0.957p.u at 84th bus. Whereas, the proposed algorithm has minimum voltage of 0.9545p.u at 54th bus.

For industrial load model, AQiEA has maximum percentage power loss reduction of 68.88% in comparison with other load models. The optimal location of DG for industrial load with AQiEA is 32, 85 and 63 with sizing of 739kW, 308kW & 773kW. Real and reactive power losses obtained by AQiEA with industrial load are 51.78kW and 31.0869kVAr, whereas active and reactive power losses obtained with other algorithms are 60.41kW & 35.02kVAr for GA, 56.07kW & 33.696kVAr for PSO, 55.83kW & 32.94kVAr for GSA, 54.91kW & 32.6kVAr for GWO and 54.32kW & 32.26kVAr for EBOwithCMAR. GA has minimum percentage power loss reduction as compared with other algorithms.

For residential load, proposed algorithm has maximum reduction in power loss of 66.477kW with optimal location 64, 85, 34 and capacity of 776kW, 305kW and 583kW. GA has minimum reduction in power loss with 73.02kW at optimal locations 28, 62, 8 and capacity of 884kW, 438kW and 347kW. Whereas overall power losses obtained with other algorithms are 73.02kW & 43.89kVAr for GA, 70.13 & 42.29kVAr for PSO, 72.62kW & 43.52kVAr for GSA, 69.53kW & 42.2kVAr for GWO and 68.28kW & 41.45kVAr for EBOwithCMAR. AQiEA has maximum improvement in voltage profile of 0.9671p.u at 42nd bus for commercial load in comparison with other load models. Maximum reduction in power loss is also observed with AQiEA from tabulated results. Overall active power loss was obtained with AQiEA for commercial load is 73.29kW. Whereas active power loss obtained with other algorithms are 80.62kW for GA, 78.96kW for PSO, 76.49kW for GSA, 75.63kW for GWO and 75.99kW for EBOwithCMAR.

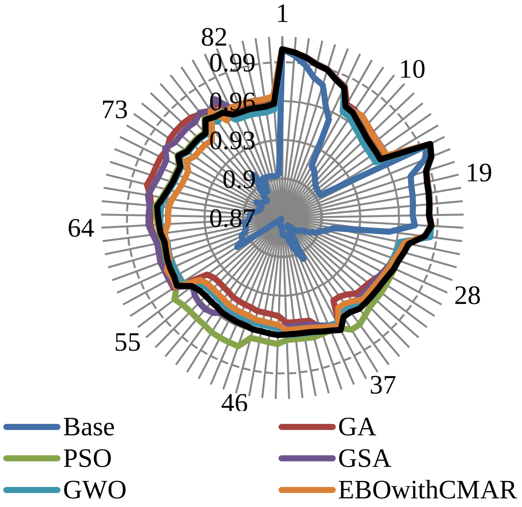

Fig. 3a. Voltage profile of 85 bus system with Constant power load.

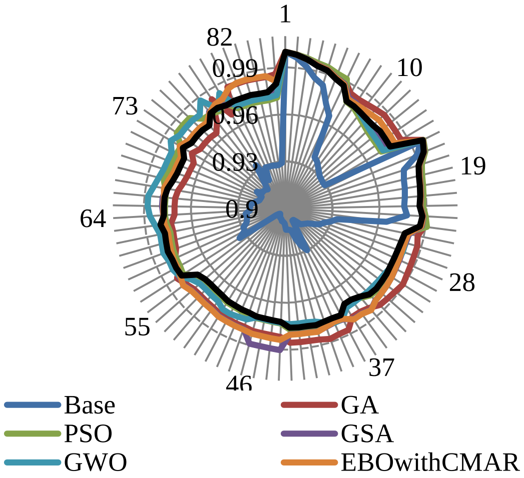

Fig. 3b. Voltage profile of 85 bus system with Industrial load.

For mixed load, it is observed from tabulated results that AQiEA has minimum active and reactive power losses in comparison with other algorithms. AQiEA has maximum reduction in power losses followed by EBOwithCMAR, GWO, GSA, PSO and GA. For constant power load, residential load, commercial load and mixed load AQiEA has maximum percentage power loss reduction of 51.95%, 60.92%, 59.84% and 65.06% respectively. Total power losses in the system with AQiEA is 84.07kW and 51.56kVAr with location 67, 25 and 35 with sizing 684kW, 954kW & 644kW.

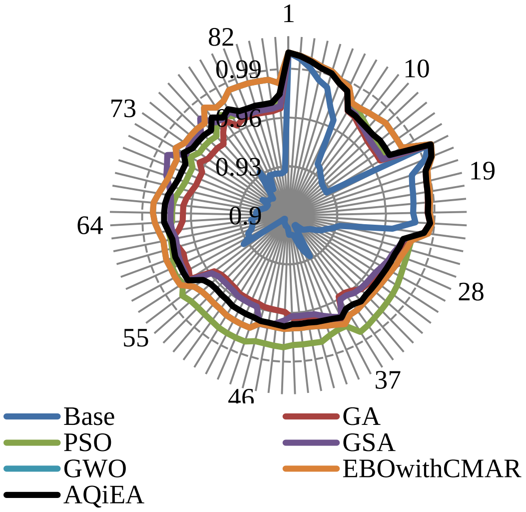

Fig. 3c. Voltage profile of 85 bus system with Residential load.

The power losses in the system with different algorithms are 93.18kW for GA followed by 91.93kW for PSO followed by 90.12kW for GSA followed by 89.3kW for GWO followed by 88.51 for EBOwithCMAR. Improvement in voltage profile is also observed with AQiEA. Tabulated results in Table 3 shows that, the proposed algorithm has maximum reduction in power losses for all load conditions including mixed load.

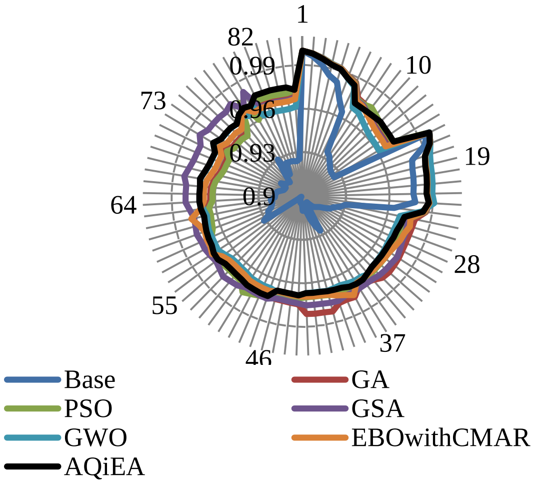

Fig. 3d. Voltage profile of 85 bus system with Commercial load.

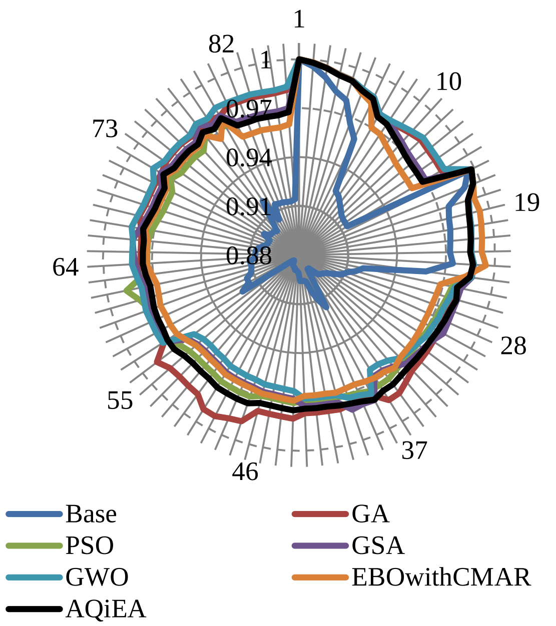

Fig. 3e. Voltage profile of 85 bus system with Mixed load.

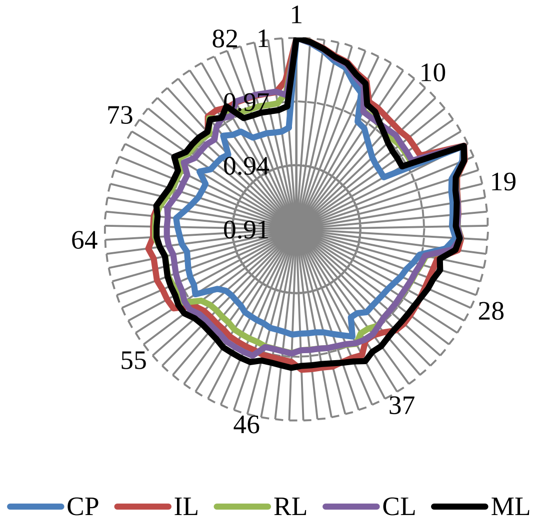

Fig. 3f. Improvement in voltage profile for 85 bus system with AQiEA for all load models.

Overall voltage profile improvement for the proposed approach as compared with other algorithms is shown in Fig. 3a-3f. It has been observed from the graph that the voltage profile for base case is falling below tolerance value after implementing DG the voltage profile improvement is in acceptable limits.

Comparative analysis of AQiEA with other algorithms for different load models is shown in Fig. 5. Graphical representation shows that AQiEA has maximum reduction in power loss as compared with GA, PSO, GSA, GWO and EBOwithCMAR for all load models. After implementing DG into distribution system with different algorithms, GA has maximum power losses in comparison with other algorithms. GA has power loss of 161.12kW, 60.42kW, 73.02kW, 80.62kW & 93.18kW for constant power load, industrial load, residential load, commercial and mixed load. PSO has power loss of 158.05kW for constant power load, 56.07kW for industrial load, 70.13kW for residential load, 78.97kW for commercial load & 91.94kW for mixed load. Whereas proposed algorithm has minimum power loss of 151.89kW for constant power load, 51.78kW for industrial load, 66.48kW for residential load, 73.29kW for commercial load & 84.07kW for mixed load.

5.2. 118 Bus System

The 118 bus system, which is a large scale system, includes 117 branches and 118 nodes. The overall load acted on the system for different load models without DG are 22.71MW and 17.04MVAr for constant power load, 22.49MW and 12.53MVAr for industrial load, 21.61MW and 13.78MVAr for residential load, 20.94MW and 14.23MVAr for commercial load and 21.9MW and 14.73MVAr for mixed load. Under normal operating conditions without installing DG the total real and reactive power losses obtained by the test bus system is 1298.09kW and 978kVAr for constant power load, 966.67kW and 735.71kVAr for industrial load, 936.59kW and 717.32kVAr for residential load, 896.13kW and 689.31kVAr & 1021.52kW and 787.91kVAr respectively.

It is observed from tabulated results that the overall power losses obtained with GA for constant power load is 716.22kW whereas PSO, GSA, AQiEA, GWO and EBOwithCMAR are performing better in comparison with GA. Tabulated results show that AQiEA has maximum power loss reduction in comparison with other algorithms which are available in the literature. The optimal location of DG for proposed algorithm has 39, 109, 68, 110 & 74 with sizing of 1.5MW, 1.496MW, 1.5MW, 1.498MW & 1.5MW, respectively. For constant power load, overall real and reactive power obtained by AQiEA is 686.234kW followed by EBOwithCMAR of 694.44kW, followed by GWO of 697.88kW, followed by GSA of 696.487kW, followed by PSO of 705.401kW. Placing DG at optimal location with optimal size not only reduces the losses but also improves the overall voltage profile in the system. AQiEA has maximum improvement in voltage profile in comparison with other algorithms except GWO. GWO has maximum improvement in voltage profile with minimum voltage of 0.9405p.u at 38th bus. Whereas AQiEA has minimum voltage of 0.93348p.u at 42nd bus. AQiEA has maximum percentage power loss reduction in comparison with other algorithms. The percentage power loss for constant power load after implementing DG with different algorithms are 44.82% for GA followed by 45.65% for PSO followed by 46.23% for GWO followed by 46.34% for GSA followed by 46.51% EBOwithCMAR followed by 47.13% with AQiEA.

For industrial load model, AQiEA has maximum percentage power loss reduction of 57.96% in comparison with other load models. It is observed from tabulated results that AQiEA has minimum active and reactive power losses in comparison with other algorithms for all loads. AQiEA has maximum reduction in power losses followed by EBOwithCMAR, GWO, GSA, PSO and GA. Total real losses induced in the system after implementing DG with different algorithms are 432.58kW for GA, 426.8kW for PSO, 421.29kW for GSA, 418kW for GWO, 415.46kW for EBOwithCMAR & 406.335kW for AQiEA, respectively. Improvement in voltage profile is also observed with AQiEA. Tabulated results in Table 6 shows that, the proposed algorithm has maximum reduction in power losses for all load conditions including mixed load.

Voltage profile improvement in the system for the proposed approach as compared with other algorithms is shown in Fig. 4a-4f. Optimal location and sizing of DG not only reduces the power losses but also improves the voltage profile in the system.

The proposed algorithm has maximum reduction in power loss as compared with other algorithm which is available in literature as shown in Fig. 6. Graphical representation shows that AQiEA has maximum reduction in power loss as compared with GA, PSO, GSA, GWO and EBOwithCMAR for all load models.

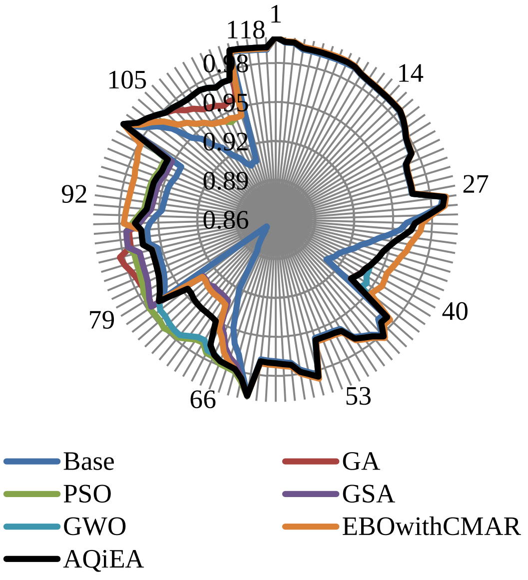

Fig. 4a. Voltage profile of 118 bus system with Constant power load.

The percentage power loss reduction with AQiEA for different load models are 47.13% for constant power load, 57.96% for industrial load model, 52.83% for residential load model, 50.52% for commercial load model and 51.77% for mixed load model. Whereas, GA, PSO, GSA, GWO and EBOwithCMAR have percentage power loss reduction of 44.82%, 45.65%, 46.34%, 46.23% 46.51% for constant power load, 55.25%, 55.84%, 56.42%, 56.71% 57.02% for industrial load, 50.55%, 50.92%, 51.61%, 51.97% 52.19% for residential load, 46.88%, 47.23%, 48.09%, 48.85% 49.19% for commercial load, 48.42%, 48.94%, 50.48%, 50.12% 51.21% for mixed load.

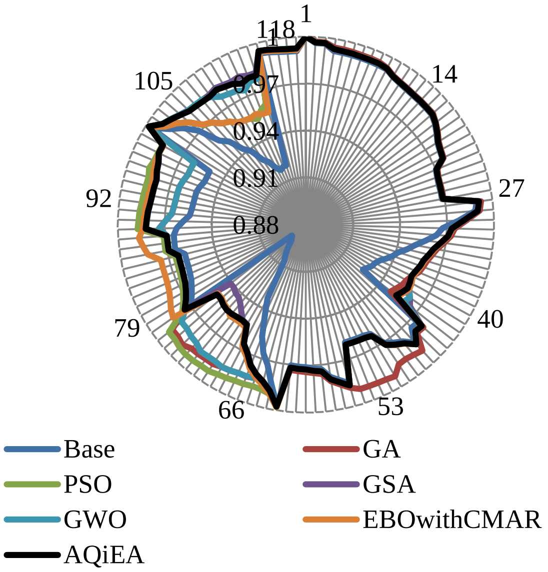

Fig. 4b. Voltage profile of 118 bus system with Industrial load.

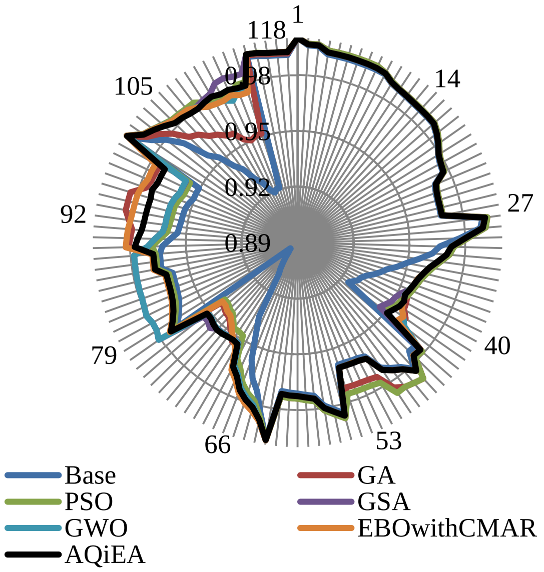

Fig. 4c. Voltage profile of 118 bus system with Residential load.

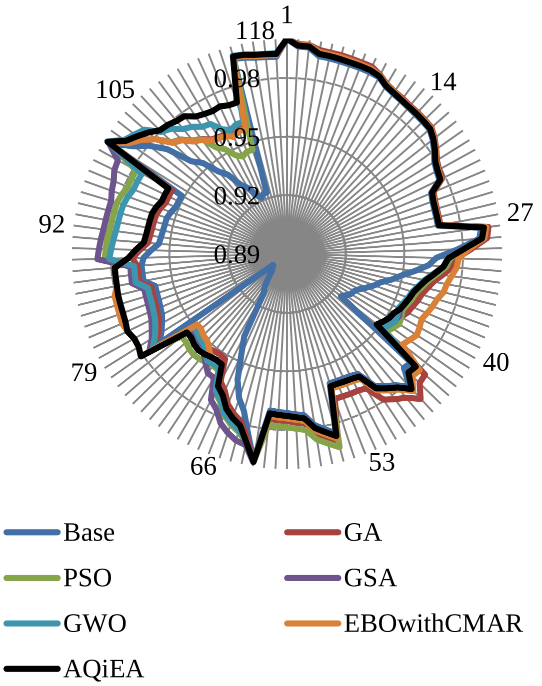

Fig. 4d. Voltage profile of 118 bus system with Commercial load.

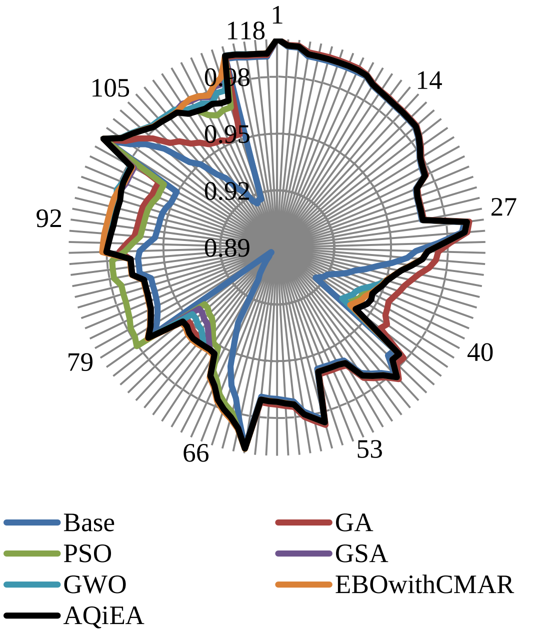

Fig. 4e. Voltage profile of 118 bus system with Mixed load.

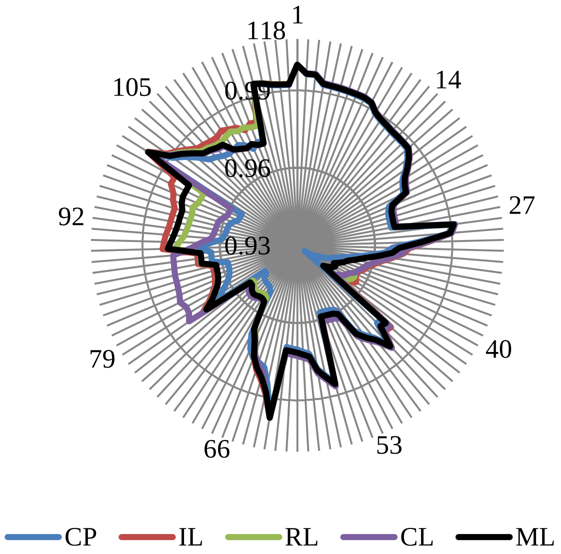

Fig. 4f. Improvement in voltage profile for 118 bus system with AQiEA for all load models.

6. DISCUSSIONS

In this study, an investigation has been performed to find the effect of DG on inappropriate load model, while solving DG placement and sizing optimization problem. Different test cases are created to analyse the power loss between appropriate load model and in-appropriate load model with optimal placement and sizing of DG. It has been observed from the tabulated results that inappropriate location and sizing of DG leads to more power losses into the system with poor voltage regulation. Table 5 compares the losses incurred between the cases of using appropriate load model and corresponding in-appropriate load model (constant power load model) while finding the placement and capacity of DGs for 85 bus system. In each test case, in-appropriate load model (constant power load model) has significantly high power losses as compared with appropriate load model (other voltage dependent load models) with AQiEA which is shown in Fig. 7.

The optimal location and sizing of DG obtained with constant power load model is 66, 25 & 34 with capacity of 684kW, 953kW and 642kW respectively. If this location and capacity of DG is implemented in industrial load, it leads to high power losses. Whereas, industrial load model has optimal location of 32, 85 & 63 with sizing 739kW, 308kW & 773Kw, respectively. In case of industrial load model, the active and reactive power losses produced by optimal location and capacity of DG with in-appropriate load model (constant power load model) are 55.166kW and 33.1kVAr respectively. Whereas, in case of the appropriate load model (Industrial load model), the active and reactive power losses are 51.784kW and 31.08kVAr, respectively. The percentage total loss reduction for appropriate load model (68.87%) is high as compared with in-appropriate load model (66.84%). Similarly, in case of residential load model, the active and reactive power losses produced with in-appropriate load model is 70.51kW and 43.05kVAr with percentage power loss reduction of 59.63%, respectively. The optimal location of DG for residential load model is 64, 85 & 34 with sizing 776kW, 305kW & 583Kw, respectively. The optimal location and sizing of DG obtained with constant power load model is 66, 25 & 34 with capacity 684kW, 953kW and 642Kw, respectively. If this location and capacity of DG is implemented in residential load, it induces high power losses.

However, the appropriate load model (Residential load model) has active and reactive power losses 66.477kW and 40.788kVAr with percentage power loss reduction of 61.94%. Similarly, the optimal location and capacity of DG obtained with constant power load model is implemented on commercial load. It has been observed that high power losses are induced in the system. The optimal location of DG with commercial load is 67, 80 & 48 with capacity of 538kW, 539kW and 620kW. In case of commercial load model, active and reactive power losses produced with in-appropriate load model is 77.2kW and 47.331kVAr with percentage power loss reduction of 57.701%. Appropriate load model (commercial load model) has high percentage power loss reduction of 59.84% with active and reactive power losses of 73.29kW and 45.259kVAr, respectively. In case of mixed load model, the power losses produced with constant power load model is approximately similar to the losses produced by mixed load model with AQiEA. It has been observed from the tabulated results that high power losses are occurring in the system with inappropriate optimization of DG, majority of authors have solved the optimization problem of DG with constant power load model. If the optimal location and capacity obtained with constant power load model is implemented on practical load, it leads to more power losses.

Table 6 compares the power losses incurred between the appropriate load model and corresponding in-appropriate load model (constant power load model) while finding the placement and capacity of DGs for 118 bus system. Different test cases are created to analyse the power losses between appropriate load model and in-appropriate load model (constant power load model). It has been observed from tabulated results that in each test case, in-appropriate load model (constant power load model) has significantly high power losses as compared with appropriate load model (other voltage dependent load models) which is shown in Fig. 8.

The optimal location and sizing of DG obtained with constant power load model is 39, 109, 68, 110 & 74 with capacity 1.5MW, 1.4968MW, 1.5MW, 1.498MW & 1.5MW, respectively. If this location and capacity of DG is implemented in industrial load, it induces high power losses. Whereas, industrial load model has optimal location of 74, 110, 98, 108 & 41 with sizing of 1.5MW, 1.438MW, 1.5MW, 1.4654MW & 1.4394MW, respectively. In case of industrial load, the active and reactive power losses produced with in-appropriate load model is 415.469kW and 336.320kVAr, respectively. Whereas, appropriate load model (industrial load model) have active and reactive power losses of 406.351kW and 335.892kVAr. The percentage loss reduction with in-appropriate load model is 57.02%, however appropriate load model have percentage loss reduction of 57.92%. Similarly, in case of residential load, the active and reactive power losses produced with in-appropriate load model is 449.960kW and 358.045kVAr with percentage power loss reduction of 51.95%, respectively.

The optimal location of DG for residential load model is 111, 109, 96, 40 & 74 with sizing 1.25MW, 1.45MW, 964kW, 1.5MW, 1.468MW, respectively. The optimal location and sizing of DG obtained with constant power load model is 39, 109, 68, 110 & 74 with capacity of 1.5MW, 1.4968MW, 1.5MW, 1.498MW & 1.5MW respectively. If this location and capacity of DG is implemented in residential load, it induces high power losses. However, appropriate load model (residential load model) have active and reactive power losses as 441.745kW and 362.397kVAr with percentage power loss reduction of 52.83%. Similarly, the optimal location and capacity of DG obtained with constant power load model is implemented on commercial load. It has been observed that high power losses are induced in the system. The optimal location of DG with commercial load is 74, 111, 107, 81 & 39 with capacity of 1.4968MW, 1.3452MW, 1.1291MW, 1.5MW and 1.5MW, respectively. In case of commercial load model, the active and reactive power losses with in-appropriate load model are 459.256kW and 361.142kVAr with percentage power loss reduction of 48.75%. Appropriate load model (commercial load model) has high percentage power loss reduction of 50.52% with minimum active and reactive power losses 443.386kW and 349.764kVAr. The optimal location and sizing of DG obtained with constant power load model is 39, 109, 68, 110 & 74 with capacity of 1.5MW, 1.4968MW, 1.5MW, 1.498MW & 1.5MW respectively. If this location and capacity of DG is implemented in mixed load, it induces high power losses. Whereas, mixed load model has optimal location of 97, 111, 74, 107 & 40 with sizing 1.24MW, 1.35MW, 1.5MW, 1.499MW & 1.5MW, respectively. In case of mixed load model, it is observed that in-appropriate load model (constant power load) has increased power losses. The power losses produced with in-appropriate load model is 508.589kW and 410.421kVAr with percentage power loss reduction of 50.21%. Whereas, the appropriate load model (mixed load) have active and reactive power losses of 492.703kW and 407.116kVAr with percentage power loss reduction of 51.77%.

After doing rigorous analysis on two large bus benchmark test cases with different voltage dependent load models, it has been observed that in-appropriate load model (constant power load) with AQiEA have high power losses when the same location and capacity are used with other voltage dependent load models.

7. **CONCLUSIONS**:

The load at distribution network is not fixed and it is well known that it varies during the day or night. Some authors have studied this important optimization problem (minimization of power losses with implementation of DG) with constant power load model which is independent of voltage. Few authors have used voltage dependent load model with DG to reduce the power losses. In this study, an investigation has been performed with implementation of DG in distribution network to reduce the power losses with different voltage dependent load models. In addition to constant power load model, four different test cases including mixed load i.e., Industrial load, Residential load and Commercial load model are created to analyze the power losses incurred in the system. It has been observed from tabulated results that total active and reactive power load in the system for voltage dependent load model are different. Similarly, total power losses incurred in the system for all load models are also different. Optimal location and capacity of DG is not fixed for any load model, with respect to the load location and capacity of DG is changing. Optimal location and capacity of DG are two major factors which play key roles to reduce the power losses. Inappropriate location and capacity of DG induces poor voltage regulation and high power losses in the system. In this study an investigation has been performed on different load models which are dependent on voltage with optimal placement and sizing of DG. Different test cases are created with voltage dependent load models. In each test case, it has been observed that in-appropriate load model (constant power load model) has higher power losses as compared to the appropriate load model (other voltage-dependent load models). The tabulated result shows that placement and sizing of DG with appropriate load model has minimum power losses as compared with in-appropriate load model (constant power load model). Optimal location and capacity of DG is a difficult non linear, non differentiable combinatorial optimization problem, quantum inspired evolutionary algorithm is used to solve this difficult optimization problem. AQiEA has been used to minimize the power losses with implementation of DG on different voltage dependent load models. The effectiveness of proposed algorithm is demonstrated on two IEEE benchmark test bus systems. After doing rigorous analysis on two large benchmark test cases with different voltage dependent load models including mixed load, it has been found that inappropriate load model with AQiEA has more power losses in comparison with appropriate load model. The computational results demonstrate that the proposed algorithm has better performance in comparison with other algorithms which are available in the literature.

Table 2. Parameter for different algorithm 'State of art' technique.

GA	PSO	GWO	GSA	EBOwithCMAR	AQiEA
Population Size=50	Population Size=50	Number of Agents N=50	Number of Agents N=50	$PS_{1,max} = 18D$ $PS_{1,min} = 4$	Population Size=50
Number of Generations =100					
Mutation probability= 0.02	Acceleration factor C_1=C_2=2			$PS_{2,max} = 46.8D$ $PS_{2,min} = 10$ $PS_3 = 4 + (3\log(D))$	
Crossover probability=0.8	Inertia weights W_{max}=0.9 W_{min}=0.4	$Iter_{max}$=200	$Iter_{max}$=200	CS=100 $prob_{ls} = 0.1$ $cfe_{ls} = 0.25 * FE_{max}$	$Iter_{max}$=200

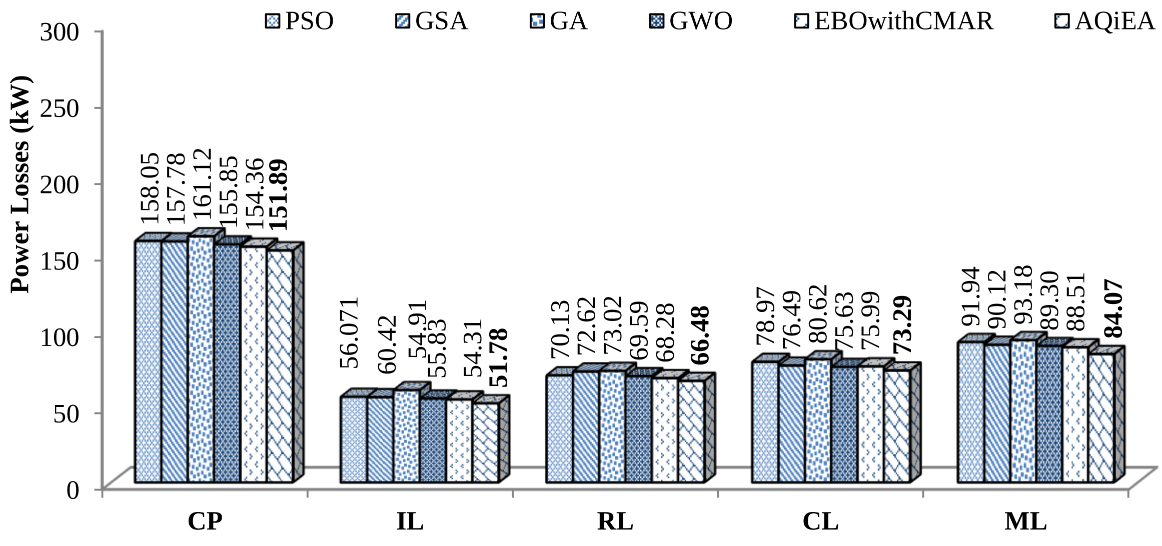

Fig. 5. Comparative analysis of power losses with different load models for 85 bus system.

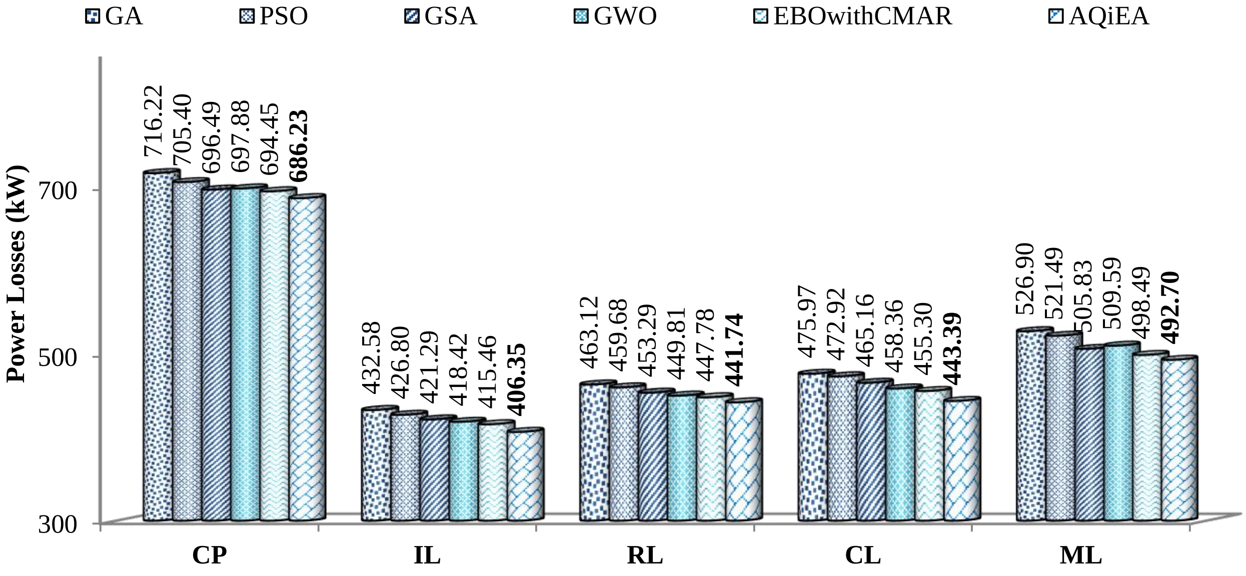

Fig. 6. Comparative analysis of power losses with different load models for 118 bus system.

Table 3. Performance of AQiEA with Different load models for 85 bus system.

		Base	*GA [15]*	*PSO [17]*	*GSA [30]*	*GWO [29]*	*EBOwithCMAR [32]*	*AQiEA*
Constant Power Load (CP)	*Location (Size (MW))*	……	68 (0.8642)	48 (0.9369)	10(0.7948)	64 (0.8439)	59 (0.7482)	66 (0.6849)
			9(0.7843)	8(0.6342)	67(0.9842)	32 (0.9643)	10 (0.8938)	25 (0.9537)
			28(0.7392)	66(0.724)	53(0.5386)	24 (0.5092)	33 (0.6496)	34 (0.6422)
	Ploss(kW)	**316.14**	161.12	158.05	157.78	155.85	154.35	**151.89**

	Qloss(kVAr)	198.61	97.89	96.49	96.51	95.69	95.13	93.88
	Min Voltage (p.u)	0.871 (54)	0.939 (54)	0.957 (84)	0.952 (47)	0.949 (54)	0.946(54)	0.954 (54)
	% Reduction	…..	49.03	50.01	50.09	50.7	51.17	**51.95**
Industrial Load (IL)	*Location (Size (MW))*		12 (0.6315)	7 (0.9018)	9 (0.6743)	27 (0.5849)	34 (0.8416)	32 (0.7397)
		………	30 (0.8491)	32 (0.7882)	44 (0.8125)	65 (0.9312)	79 (0.4983)	85 (0.3085)
			26 (0.6198)	73 (0.5584)	65 (0.4571)	50 (0.3592)	81 (0.5638)	63 (0.7734)
	Ploss(kW)	**166.38**	60.42	56.07	55.83	54.91	54.32	**51.78**
	Qloss(kVAr)	104.91	35.03	33.69	32.94	32.61	32.26	31.08
	Min Voltage (p.u)	0.904 (54)	0.965 (75)	0.968 (54)	0.972 (76)	0.972 (84)	0.974(75)	0.968(54)
	% Reduction	**…..**	63.69	66.31	66.44	66.99	67.35	**68.88**
Residential Load (RL)	*Location (Size (MW))*		28 (0.8841)	58 (0.9163)	46 (0.3598)	80 (0.6496)	28 (0.7386)	64 (0.776)
		……	62 (0.4372)	36 (0.5481)	8 (0.8139)	48 (0.4819)	49 (0.2429)	85 (0.3051)
			8 (0.3467)	33 (0.3758)	71 (0.5613)	77 (0.7892)	59 (0.8674)	34 (0.5838)
	Ploss(kW)	**174.69**	73.02	70.13	72.62	69.53	68.28	**66.47**
	Qloss(kVAr)	110.18	43.89	42.24	43.52	42.20	41.45	40.78
	Min Voltage (p.u)	0.903 (53)	0.955 (53)	0.966 (76)	0.957 (54)	0.968 (47)	0.966(76)	0.964 (53)
	% Reduction	…..	58.20	59.85	58.43	60.19	60.92	**61.95**
Commercial Load (CL)	*Location (Size (MW))*		40 (0.7854)	10 (0.8376)	67 (0.8843)	34 (0.7457)	62 (0.5281)	67 (0.5388)
		…..	57 (0.3659)	25 (0.4694)	54 (0.2865)	18 (0.4398)	35 (0.419)	80 (0.5399)
			25 (0.7493)	51 (0.5437)	30 (0.6439)	67 (0.6849)	26 (0.8476)	48 (0.62)
	Ploss(kW)	**182.51**	80.62	78.96	76.49	75.63	75.99	**73.29**
	Qloss(kVAr)	115.16	48.19	47.65	46.44	46.75	46.30	45.26
	Min Voltage (p.u)	0.901 (53)	0.957 (75)	0.956 (75)	0.966 (83)	0.961(83)	0.962(75)	0.967 (42)
	% Reduction	…..	55.82	56.73	58.08	58.55	58.36	**59.84**
Mixed Load (ML)	*Location (Size (MW))*		50 (0.9381)	35 (0.6913)	66 (0.7856)	12 (0.8697)	23 (0.5469)	67 (0.6841)
		…..	68 (0.6458)	8 (0.7748)	25 (0.6957)	30 (0.673)	67 (0.9194)	25 (0.9546)
			12 (0.7879)	62 (0.8452)	26 (0.9528)	67 (0.8499)	34 (0.8788)	35 (0.6439)

	Ploss(kW)	**240.63**	93.18	91.93	90.12	89.30	88.51	**84.07**
	Qloss(kVAr)	151.59	55.86	54.86	54.18	54.64	53.82	51.56
	Min Voltage (p.u)	0.884 (53)	0.974 (61)	0.967 (75)	0.962 (53)	0.957 (53)	0.959(83)	0.967 (83)
	% Reduction	…..	61.27	61.79	62.54	62.88	63.21	**65.06**

Table 4. Performance of AQiEA with Different load models for 118 bus system.

		Base	***GA [15]***	***PSO [17]***	***GSA [30]***	***GWO [29]***	***EBOwithCMAR [32]***	***AQiEA***
Constant Power Load (CP)	*Location (Size (MW))*	…..	85 (1.5)	39 (1.499)	86 (1.5)	74 (1.5)	41 (1.5)	39 (1.5)
			110 (1.5)	110 (1.5)	110 (1.5)	42 (1.498)	74 (1.5)	109 (1.4968)
			75 (1.4968)	75 (1.5)	75 (1.4949)	109 (1.5)	111 (1.5)	68 (1.5)
			104 (1.5)	80 (1.4976)	109 (1.5)	108 (1.5)	35 (1.5)	110 (1.498)
			39 (1.4894)	73 (1.5)	39 (1.5)	73 (1.4787)	99 (1.5)	74 (1.5)
	Ploss(kW)	**1298.09**	716.22	705.40	696.48	697.88	694.44	**686.23**
	Qloss(kVAr)	978.78	548.57	533.58	539.54	543.51	537.21	540.87
	Min Voltage (p.u)	0.868 (76)	0.930 (73)	0.933 (42)	0.930 (73)	0.941 (38)	0.931(76)	0.933 (42)
	% Reduction	……	44.82	45.65	46.34	46.23	46.51	**47.13**
Industrial Load (IL)	*Location (Size (MW))*	…..	113 (1.5)	43 (1.489)	111 (1.5)	73 (1.4913)	41 (1.5)	74 (1.5)
			71 (1.497)	96 (1.5)	108 (1.4798)	70 (1.5)	88 (1.5)	110 (1.438)
			38 (1.496)	71 (1.5)	98 (1.4839)	42 (1.5)	73 (1.5)	98 (1.5)
			75 (1.5)	74 (1.5)	71 (1.5)	106 (1.5)	97 (1.5)	108 (1.4654)
			50 (1.5)	113 (1.499)	43 (1.5)	112 (1.5)	111 (1.498)	41 (1.4394)
	Ploss(kW)	**966.67**	432.58	426.80	421.29	418.41	415.46	**406.35**
	Qloss(kVAr)	735.71	342.91	334.91	340.56	337.18	335.86	335.89
	Min Voltage (p.u)	0.891 (76)	0.949 (42)	0.954 (110)	0.941 (76)	0.956 (38)	0.951(76)	0.952 (76)
	% Reduction	……	55.25	55.84	56.42	56.71	57.02	**57.96**
Residential Load (RL)	*Location (Size (MW))*	……	48 (1.5)	72 (1.398)	81 (1.5)	43 (1.5)	91 (1.5)	111 (1.25)
			42 (1.5)	39 (1.5)	110 (1.5)	106 (1.4256)	106 (1.3946)	109 (1.45)
			71 (1.467)	49 (1.5)	111 (1.2986)	81 (1.5)	70 (1.4879)	96 (0.964)
			93 (1.35)	107 (1.4829)	38 (1.5)	112 (1.4864)	111 (1.5)	40 (1.5)
			109 (1.5)	112 (1.5)	75 (1.4984)	74 (1.5)	42 (1.5)	74 (1.468)
	Ploss(kW)	**936.59**	463.12	459.69	453.29	449.81	447.78	**441.74**
	Qloss(kVAr)	717.32	366.34	374.86	353.54	351.08	358.43	362.39

	Min Voltage (p.u)	0.874 (76)	0.9425 (76)	0.939 (76)	0.946 (42)	0.951 (76)	0.941(76)	0.951 (42)
	% Reduction	……	50.55	50.92	51.61	51.97	52.19	**52.83**

		Base	***GA [15]***	***PSO [17]***	***GSA [30]***	***GWO [29]***	***EBOwithCMAR [32]***	***AQiEA***
Commercial Load (CL)	*Location (Size (MW))*	……	39 (1.5)	55 (1.3989)	65 (1.5)	103 (1.5)	82 (1.5)	74 (1.4968)
			111 (1.4762)	107 (1.5)	40 (1.5)	41 (1.4358)	41 (1.3918)	111 (1.3452)
			46 (1.5)	74 (1.5)	71 (1.5)	72 (1.5)	35 (1.5)	107 (1.1291)
			74 (1.4463)	41 (1.4992)	100 (1.4431)	91 (1.258)	72 (1.5)	81 (1.5)
			45 (1.39)	91 (1.5)	99 (1.3689)	109 (1.5)	110 (1.4399)	39 (1.5)
	Ploss(kW)	**896.14**	475.98	472.92	465.16	458.36	455.31	**443.39**
	Qloss(kVAr)	689.32	377.54	370.75	366.64	364.46	346.39	349.76
	Min Voltage (p.u)	0.899(76)	0.9512 (76)	0.945 (110)	0.952 (42)	0.951 (76)	0.948(76)	0.948(42)
	% Reduction	……	46.88	47.23	48.09	48.85	49.19	**50.52**
Mixed Load (ML)	*Location (Size (MW))*	……	73 (1.5)	109 (1.398)	40 (1.5)	107 (1.5)	39 (1.4682)	97 (1.24)
			65 (1.38)	38 (1.5)	108 (1.44)	112 (1.5)	74 (1.5)	111 (1.359)
			42 (1.5)	71 (1.46)	96 (1.28)	36 (1.49)	113 (1.3986)	74 (1.5)
			110 (1.5)	107 (1.5)	71 (1.5)	72 (1.5)	109 (1.5)	107 (1.499)
			33 (1.499)	80 (1.5)	112 (1.5)	96 (1.399)	91 (1.5)	40 (1.5)
	Ploss(kW)	**1021.52**	526.91	521.48	505.83	509.59	498.49	**492.71**
	Qloss(kVAr)	787.91	407.27	410.81	411.81	415.57	407.51	407.12
	Min Voltage (p.u)	0.893 (76)	0.951 (76)	0.937 (76)	0.942 (76)	0.933 (42)	0.939(42)	0.942 (42)
	% Reduction	……	48.42	48.94	50.48	50.12	51.21	**51.77**

Table 5. Comparative analysis of Constant power load with other load models for 85 bus system.

	Industrial Load		***Residential Load***		***Commercial Load***		***Mixed Load***	
	CP	***IL***	***CP***	***RL***	***CP***	***CL***	***CP***	***ML***
Location (Size (MW))	66 (0.6849)	32 (0.7397)	66 (0.6849)	64 (0.776)	66 (0.6849)	67 (0.5388)	66 (0.6849)	67 (0.6841)
	25 (0.9537)	85 (0.3085)	25 (0.9537)	85 (0.3051)	25 (0.9537)	80 (0.5399)	25 (0.9537)	25 (0.9546)
	34 (0.6422)	63 (0.7734)	34 (0.6422)	34 (0.5838)	34 (0.6422)	48 (0.62)	34 (0.6422)	35 (0.6439)
P_{loss}(kW)	*55.17*	**51.78**	*70.51*	**66.48**	*77.20*	**73.29**	**83.91**	**84.07**
Q_{loss}(kVAr)	33.10	31.08	43.05	40.79	47.33	45.26	51.49	51.57
Min Voltage (p.u)	0.979	0.949	0.978	0.963	0.976	0.967	0.966	0.966
% Reduction	66.84	**68.87**	59.63	**61.94**	57.70	**59.84**	**65.12**	**65.06**

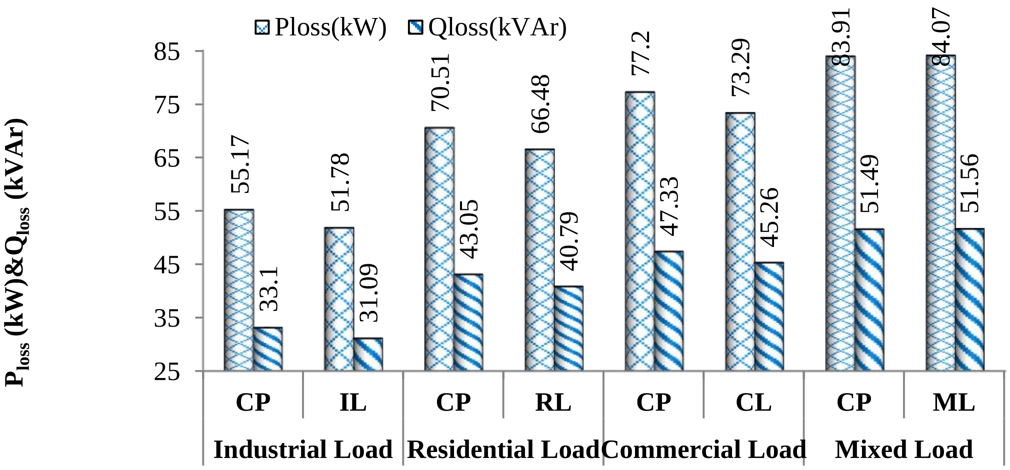

Fig. 7. Comparative analysis of power losses with Constant power load for 85 bus system.

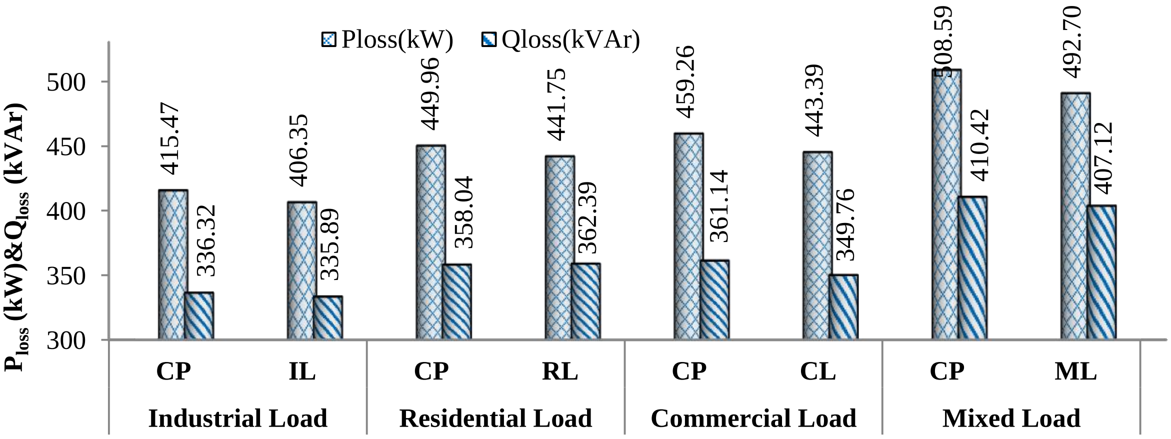

Fig. 8. Comparative analysis of power losses with Constant power load for 118 bus system.

Table 6. Comparative analysis of Constant power load with other load models for 118 bus system.

	Industrial Load		***Residential Load***		***Commercial Load***		***Mixed Load***	
	CP	***IL***	***CP***	***RL***	***CP***	***CL***	***CP***	***ML***
Location (Size (MW))	39 (1.5)	74 (1.5)	39 (1.5)	111 (1.25)	39 (1.5)	74 (1.4968)	39 (1.5)	97 (1.24)
	109 (1.4968)	110 (1.438)	109 (1.4968)	109 (1.45)	109 (1.4968)	111 (1.3452)	109 (1.4968)	111 (1.359)
	68 (1.5)	98 (1.5)	68 (1.5)	96 (0.964)	68 (1.5)	107 (1.1291)	68 (1.5)	74 (1.5)
	110 (1.498)	108 (1.4654)	110 (1.498)	40 (1.5)	110 (1.498)	81 (1.5)	110 (1.498)	107 (1.499)
	74 (1.5)	41 (1.4394)	74 (1.5)	74 (1.468)	74 (1.5)	39 (1.5)	74 (1.5)	40 (1.5)
P_{loss}(kW)	*415.46*	**406.35**	*449.96*	**441.74**	*459.25*	**443.38**	*508.59*	**492.70**
Q_{loss}(kVAr)	336.32	335.89	358.04	362.39	361.14	349.76	410.42	407.11
Min Voltage (p.u)	0.949	0.952	0.948	0.951	0.948	0.948	0.939	0.943
% Reduction	57.02	**57.96**	51.95	**52.83**	48.75	**50.52**	50.21	**51.77**

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Appendix:

The load at distribution system is a combination of all loads (dependent and independent of voltage). The effectiveness of the proposed algorithm is validated with two benchmark test bus system by combination of practical load, which are shown in Table 1& Table 2 as follows.

Table 1. Combination of different loads along with line and load data for 85 bus system.

S.No	From	To	R (ohm)	X (ohm)	P (kW)	Q (kVAr)	Load Type
1	1	2	0.108	0.075	0	0	**……**
2	2	3	0.163	0.112	0	0	**……**
3	3	4	0.217	0.149	0	0	**……**
4	4	5	0.108	0.074	56	57.13143	***Industrial Load***
5	5	6	0.435	0.298	0	0	**……**
6	6	7	0.272	0.186	35.28	35.9928	***Constant power Load***
7	7	8	1.197	0.82	0	0	**……**
8	8	9	0.108	0.074	35.28	35.9928	***Industrial Load***
9	9	10	0.598	0.41	0	0	**……**
10	10	11	0.544	0.373	0	0	**……**
11	11	12	0.544	0.373	56	57.13143	***Commercial Load***
12	12	13	0.598	0.41	0	0	**……**
13	13	14	0.272	0.186	0	0	**……**
14	14	15	0.326	0.223	35.28	35.9928	***Constant power Load***
15	2	16	0.728	0.302	35.28	35.9928	***Commercial Load***
16	3	17	0.455	0.189	35.28	35.9928	***Industrial Load***
17	5	18	0.82	0.34	112	114.2629	***Constant power Load***
18	18	19	0.637	0.264	56	57.13143	***Industrial Load***
19	19	20	0.455	0.189	56	57.13143	***Constant power Load***
20	20	21	0.819	0.34	35.28	35.9928	***Residential Load***
21	21	22	1.548	0.642	35.28	35.9928	***Commercial Load***
22	19	23	0.182	0.075	35.28	35.9928	***Industrial Load***
23	7	24	0.91	0.378	56	57.13143	***Industrial Load***
24	8	25	0.455	0.189	35.28	35.9928	***Industrial Load***
25	25	26	0.364	0.151	35.28	35.9928	***Residential Load***
26	26	27	0.546	0.226	56	57.13143	***Industrial Load***
27	27	28	0.273	0.113	0	0	**……**
28	28	29	0.546	0.226	56	57.13143	***Residential Load***
29	29	30	0.546	0.226	0	0	**……**
30	30	31	0.273	0.113	35.28	35.9928	***Industrial Load***
31	31	32	0.182	0.075	35.28	35.9928	***Residential Load***
32	32	33	0.182	0.075	0	0	**……**
33	33	34	0.819	0.34	14	14.28286	***Industrial Load***
34	34	35	0.637	0.264	0	0	**……**
S.No	**From**	**To**	**R (ohm)**	**X (ohm)**	**P (kW)**	**Q (kVAr)**	**Load Type**

35	35	36	0.182	0.075	0	0	**……**
36	26	37	0.364	0.151	35.28	35.9928	***Industrial Load***
37	27	38	1.002	0.416	56	57.13143	***Commercial Load***
38	29	39	0.546	0.226	56	57.13143	***Constant power Load***
39	32	40	0.455	0.189	56	57.13143	***Industrial Load***
40	40	41	1.002	0.416	35.28	35.9928	***Commercial Load***
41	41	42	0.273	0.113	0	0	**……**
42	41	43	0.455	0.189	35.28	35.9928	***Industrial Load***
43	34	44	1.002	0.419	35.28	35.9928	***Commercial Load***
44	44	45	0.911	0.378	35.28	35.9928	***Residential Load***
45	45	46	0.911	0.378	35.28	35.9928	***Residential Load***
46	46	47	0.546	0.226	35.28	35.9928	***Residential Load***
47	35	48	0.637	0.264	14	14.28286	***Commercial Load***
48	48	49	0.182	0.075	0	0	**……**
49	49	50	0.364	0.151	0	0	**……**
50	50	51	0.455	0.189	36.28	37.013	***Residential Load***
51	48	52	1.366	0.567	56	57.13143	***Industrial Load***
52	52	53	0.455	0.189	0	0	**……**
53	53	54	0.546	0.226	35.28	35.9928	***Constant power Load***
54	52	55	0.546	0.226	56	57.13143	***Constant power Load***
55	49	56	0.546	0.226	56	57.13143	***Residential Load***
56	9	57	0.273	0.113	14	14.28286	***Constant power Load***
57	57	58	0.819	0.34	56	57.13143	***Constant power Load***
58	58	59	0.182	0.075	0	0	**……**
59	58	60	0.546	0.226	56	57.13143	***Residential Load***
60	60	61	0.728	0.302	56	57.13143	***Constant power Load***
61	61	62	1.002	0.415	56	57.13143	***Constant power Load***
62	60	63	0.182	0.075	56	57.13143	***Residential Load***
63	63	64	0.728	0.302	14	14.28286	***Industrial Load***
64	64	65	0.182	0.075	0	0	**……**
65	65	66	0.182	0.075	0	0	**……**
66	64	67	0.455	0.189	56	57.13143	***Industrial Load***
67	67	68	0.91	0.378	0	0	**……**
68	68	69	1.092	0.453	0	0	**……**
69	69	70	0.455	0.189	56	57.13143	***Commercial Load***
70	70	71	0.546	0.226	0	0	**……**
71	67	72	0.182	0.075	35.28	35.9928	***Residential Load***
72	68	73	1.184	0.491	56	57.13143	***Industrial Load***
73	73	74	0.273	0.113	0	0	**……**
74	73	75	1.002	0.416	56	57.13143	***Commercial Load***
75	70	76	0.546	0.226	35.28	35.9928	***Residential Load***
76	65	77	0.091	0.037	56	57.13143	***Industrial Load***
77	10	78	0.637	0.264	14	14.28286	***Constant power Load***
78	67	79	0.546	0.226	56	57.13143	***Residential Load***
79	12	80	0.728	0.302	35.28	35.9928	***Residential Load***
80	80	81	0.364	0.151	56	57.13143	***Residential Load***
81	81	82	0.091	0.037	0	0	**……**
82	81	83	1.092	0.453	56	57.13143	***Constant power Load***
83	83	84	1.002	0.416	35.28	35.9928	***Industrial Load***
84	13	85	0.819	0.34	14	14.28286	***Commercial Load***
85	85	…	….	…..	35.28	35.9928	***Residential Load***

Table 2. Combination of different loads along with line and load data for 118 bus system.

S.No	From	To	R (ohm)	X (ohm)	P (kW)	Q (kVAr)	Load Type

1	1	2	0.036	0.01296	133.84	101.14	……
2	2	3	0.033	0.01188	16.214	11.292	***Commercial Load***
3	2	4	0.045	0.0162	34.315	21.845	***Commercial Load***
4	4	5	0.015	0.054	73.016	63.602	***Constant power Load***
5	5	6	0.015	0.054	144.2	68.604	***Constant power Load***
6	6	7	0.015	0.1025	104.47	61.725	***Commercial Load***
7	7	8	0.018	0.014	28.547	11.503	***Industrial Load***
8	8	9	0.021	0.063	87.56	51.073	***Industrial Load***
9	2	10	0.166	0.1344	198.2	106.77	***Constant power Load***
10	10	11	0.112	0.0789	146.8	75.995	***Industrial Load***
11	11	12	0.187	0.313	26.04	18.687	***Residential Load***
12	12	13	0.142	0.1512	52.1	23.22	***Industrial Load***
13	13	14	0.18	0.118	141.9	117.5	***Constant power Load***
14	14	15	0.15	0.045	21.87	28.79	***Commercial Load***
15	15	16	0.16	0.18	33.37	26.45	***Commercial Load***
16	16	17	0.157	0.171	32.43	25.23	***Residential Load***
17	11	18	0.218	0.285	20.234	11.906	***Industrial Load***
18	18	19	0.118	0.185	156.94	78.523	***Commercial Load***
19	19	20	0.16	0.196	546.29	351.4	***Industrial Load***
20	20	21	0.12	0.189	180.31	164.2	***Industrial Load***
21	21	22	0.12	0.0789	93.167	54.594	***Commercial Load***
22	22	23	1.41	0.723	85.18	39.65	***Industrial Load***
23	23	24	0.293	0.1348	168.1	95.178	***Constant power Load***
24	24	25	0.133	0.104	125.11	150.22	***Constant power Load***
25	25	26	0.178	0.134	16.03	24.62	***Commercial Load***
26	26	27	0.178	0.134	26.03	24.62	***Industrial Load***
27	4	29	0.015	0.0296	594.56	522.62	***Commercial Load***
28	29	30	0.012	0.0276	120.62	59.117	***Commercial Load***
29	30	31	0.12	0.2766	102.38	99.554	***Constant power Load***
30	31	32	0.21	0.243	513.4	318.5	***Commercial Load***
31	32	33	0.12	0.054	475.25	456.14	***Constant power Load***
32	33	34	0.178	0.234	151.43	136.79	***Residential Load***
33	34	35	0.178	0.234	205.38	83.302	***Residential Load***
34	35	36	0.154	0.162	131.6	93.082	***Constant power Load***
35	31	37	0.187	0.261	448.4	369.79	***Industrial Load***
36	37	38	0.133	0.099	440.52	321.64	***Industrial Load***
37	30	40	0.33	0.194	112.54	55.134	***Industrial Load***
38	40	41	0.31	0.194	53.963	38.998	***Residential Load***
39	41	42	0.13	0.194	393.05	342.6	***Constant power Load***
40	42	43	0.28	0.15	326.74	278.56	***Constant power Load***
41	43	44	1.18	0.85	536.26	240.24	***Industrial Load***
42	44	45	0.42	0.2436	76.247	66.562	***Residential Load***
43	45	46	0.27	0.0972	53.52	39.76	***Commercial Load***
44	46	47	0.339	0.1221	40.328	31.964	***Residential Load***
45	47	48	0.27	0.1779	39.653	20.758	***Commercial Load***
46	36	49	0.21	0.1383	66.195	42.361	***Commercial Load***
47	49	50	0.12	0.0789	73.904	51.653	***Residential Load***
48	50	51	0.15	0.0987	114.77	57.965	***Residential Load***
49	51	52	0.15	0.0987	918.37	1205.1	***Industrial Load***
50	52	53	0.24	0.1581	210.3	146.66	***Constant power Load***
51	53	54	0.12	0.0789	66.68	56.608	***Industrial Load***
S.No	**From**	**To**	**R (ohm)**	**X (ohm)**	**P (kW)**	**Q (kVAr)**	**Load Type**
52	54	55	0.405	0.1458	42.207	40.184	***Industrial Load***
53	54	56	0.405	0.1458	433.74	283.41	***Residential Load***

54	30	58	0.391	0.141	62.1	26.86	***Industrial Load***
55	58	59	0.406	0.1461	92.46	88.38	***Residential Load***
56	59	60	0.406	0.1461	85.188	55.436	***Residential Load***
57	60	61	0.706	0.5461	345.3	332.4	***Constant power Load***
58	61	62	0.338	0.1218	22.5	16.83	***Constant power Load***
59	62	63	0.338	0.1218	80.551	49.156	***Industrial Load***
60	63	64	0.207	0.0747	95.86	90.758	***Commercial Load***
61	64	65	0.247	0.8922	62.92	47.5	***Residential Load***
62	1	66	0.028	0.0418	478.8	463.74	***Residential Load***
63	66	67	0.117	0.2016	120.94	52.006	***Commercial Load***
64	67	68	0.255	0.0918	139.11	100.34	***Constant power Load***
65	68	69	0.21	0.0759	391.78	193.5	***Residential Load***
66	69	70	0.383	0.138	27.741	26.713	***Constant power Load***
67	70	71	0.504	0.3303	52.814	25.257	***Residential Load***
68	71	72	0.406	0.1461	66.89	38.713	***Commercial Load***
69	72	73	0.962	0.761	467.5	395.174	***Commercial Load***
70	73	74	0.165	0.06	594.85	239.74	***Commercial Load***
71	74	75	0.303	0.1092	132.5	84.363	***Commercial Load***
72	75	76	0.303	0.1092	52.699	22.482	***Commercial Load***
73	76	77	0.206	0.144	869.79	614.775	***Industrial Load***
74	77	78	0.233	0.084	31.349	29.817	***Industrial Load***
75	78	79	0.591	0.1773	192.39	122.43	***Constant power Load***
76	79	80	0.126	0.0453	65.75	45.37	***Industrial Load***
77	67	81	0.559	0.3687	283.15	223.22	***Industrial Load***
78	81	82	0.186	0.1227	294.55	162.47	***Commercial Load***
79	82	83	0.186	0.1227	485.57	437.92	***Constant power Load***
80	83	84	0.26	0.139	243.53	183.03	***Commercial Load***
81	84	85	0.154	0.148	243.53	183.03	***Industrial Load***
82	85	86	0.23	0.128	134.25	119.29	***Residential Load***
83	86	87	0.252	0.106	22.71	27.96	***Residential Load***
84	87	88	0.18	0.148	49.513	26.515	***Constant power Load***
85	82	89	0.16	0.182	383.78	257.16	***Industrial Load***
86	89	90	0.2	0.23	49.64	20.6	***Constant power Load***
87	90	91	0.16	0.393	22.473	11.806	***Commercial Load***
88	68	93	0.669	0.2412	62.93	42.96	***Residential Load***
89	93	94	0.266	0.1227	30.67	34.93	***Industrial Load***
90	94	95	0.266	0.1227	62.53	66.79	***Residential Load***
91	95	96	0.266	0.1227	114.57	81.748	***Residential Load***
92	96	97	0.266	0.1227	81.292	66.526	***Industrial Load***
93	97	98	0.233	0.115	31.733	15.96	***Commercial Load***
94	98	99	0.496	0.138	33.32	60.48	***Industrial Load***
95	95	100	0.196	0.18	531.28	224.85	***Residential Load***
96	100	101	0.196	0.18	507.03	367.42	***Commercial Load***
97	101	102	0.1866	0.122	26.39	11.7	***Residential Load***
98	102	103	0.0746	0.318	45.99	30.392	***Residential Load***
99	1	105	0.0625	0.0265	100.66	47.572	***Commercial Load***
100	105	106	0.1501	0.234	456.48	350.3	***Residential Load***
101	106	107	0.1347	0.0888	522.56	449.29	***Constant power Load***
102	107	108	0.2307	0.1203	408.43	168.46	***Constant power Load***
103	108	109	0.447	0.1608	141.48	134.25	***Commercial Load***
104	109	110	0.1632	0.0588	104.43	66.024	***Residential Load***
S.No	**From**	**To**	**R (ohm)**	**X (ohm)**	**P (kW)**	**Q (kVAr)**	**Load Type**
105	110	111	0.33	0.099	96.793	83.647	***Commercial Load***
106	111	112	0.156	0.0561	493.92	419.34	***Industrial Load***

107	112	113	0.3819	0.1374	225.38	135.88	***Constant power Load***
108	113	114	0.1626	0.0585	509.21	387.21	***Constant power Load***
109	114	115	0.3819	0.1374	188.5	173.46	***Constant power Load***
110	115	116	0.2445	0.0879	918.03	898.55	***Residential Load***
111	115	117	0.2088	0.0753	305.08	215.37	***Commercial Load***
112	117	118	0.3201	0.0828	54.38	40.97	***Industrial Load***
113	105	119	0.6102	0.2196	211.14	192.9	***Residential Load***
114	119	120	0.1866	0.127	267.009	53.336	***Residential Load***
115	120	121	0.3732	0.246	162.07	90.321	***Industrial Load***
116	121	122	0.405	0.367	48.785	29.156	***Industrial Load***
117	122	123	0.489	0.438	33.9	18.98	***Residential Load***

Nomenclature	**Acronyms**
ALO	Ant Lion Optimization
AQiEA	Adaptive Quantum inspired Evolutionary Algorithm
CL	Commercial Load
CP	Constant Power Load
DG	Distributed Generation
EA	Evolutionary Algorithm
GA	Genetic Algorithm
GSA	Gravitational Search Algorithm
GWO	Grey Wolf Optimization
IL	Industrial Load
ML	Mixed Load
PSO	Particle Swarm Optimization
QiEA	Quantum inspired Evolutionary Algorithm
RL	Residential Load
SOS	Symbiotic Organism Search
WOA	Wale Optimization Algorithm
I_m	Magnitude of current at mth bus
N_b	Total number of buses in the system
$P_{initial}(m)$	Initial real power load at mth bus
$P_{DG,m}$	Injected active power of DG at mth bus
$P_{DG,m}^{max}$	Maximum allowable limit for active power injection at mth bus
$P_{DG,m}^{min}$	Minimum allowable limit for active power injection at mth bus
$P_L(m)$	Real load in the system at mth bus
P_{loss}	Total active power loss on the system
P_{load}	Total power demand in the system
P_{Sub}	Total substation power
$Q_{initial}(m)$	Initial reactive power load at mth bus
$Q_L(m)$	Reactive load in the system at mth bus
R_m	Magnitude of resistance at mth bus
$V_{initial}(m)$	Initial voltage at mth bus