Multi-objective Optimal Allocation of Renewable Energy Distributed Generations and Shunt Capacitors in Radial Distribution System using Corona Virus Herd Optimization

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ABSTRACT:
This paper proposed the multiobjective optimal allocation of renewable distributed generation and shunt capacitors in the distribution system using corona virus herd optimization techniques. The work aimed to achieve a technical benefit, total electricity cost reduction, and enhancement of greenhouse safety. The objectives considered are real power loss, voltage profile index (VPI), voltage stability index (VSI), total electricity cost (TEC), and total greenhouse gas emission (TGHGe). Weight function was used to combine the objectives for the six cases considered with different priorities. The proposed CHIO is validated on the standard IEEE 33 bus system and implemented on Dada 46 bus, a Nigerian practical distribution network. Various cases were considered for the two test systems. For IEEE 33 bus, the proposed method achieved 89.44% and 86.77% reduction in real and reactive power, respectively, with 93.73% and 39.27% in TGHGe and TEC. Also, for Dada 46 bus system, 89.44% and 86.77% reduction in real and reactive power loss respectively was achieved with 98.66% and 64.42% in TGHGe and TEC. Furthermore, the highest level of greenhouse gas emission reduction was achieved (says 99.69%) when high priority was placed on the reduction in TGHGe; this shows the significant impact of renewable energy in the distribution system. The results obtained are compared with the existing methods, such as PSO, GA, ABC, GABC, WOA, WCA, to mention a few. In other to show the performance of the proposed CHIO compared to others, the outcome reveals the excellent performance of the proposed algorithm in terms of an optimal result.

KEYWORDS: Renewable Distributed Generation, Shunt Capacitor, Distribution System, Power Loss, Greenhouse Gas Emission, Corona Virus Herd Optimization Techniques, Voltage Profile Index.

1. INTRODUCTION

An electrical power system deals with generating, transmitting, and distributing electricity. In the distribution sector of the power system, electrical energy is distributed to the final consumer, who utilizes it for domestic, commercial, and industrial purposes. The distribution system is classified based on its configuration. Basically, they are of two types, radial configuration and ring configuration. In most distribution systems, a radial configuration is preferable because the ring configuration is more expensive, and more switches and conductors are required to construct the ring configuration than the radial system. Ring configuration is not preferred when the voltage level is low, and its construction cost is high. Due to these factors, the radial configuration is widely used in distribution systems and is called a Radial distribution network (RDN). The need for higher efficiency of the distribution system is a significant need that must be addressed as the rapid technology growth and demand for electricity increases [1,2]. The distribution system is known for high real and reactive power losses, low voltage profile, voltage instability, and power quality distortion due to the nature of loads that vary from one utility to another [2, 3]. To address these issues, many researchers have proposed different methods, such as the incorporation of distributed generations (DGs) [4,5,6], shunt capacitors (SCs) [2,7], distribution static compensator (DSTATCOM) [8,8,9], network reconfigurations [10] and so on. Incorporation of these devices required accurate sizing and location. The effectiveness of installing these devices on the

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distribution system depends on where they are placed in the network, and their sizes because wrong placement and sizing could adversely affect the distribution system. Many approaches have been proposed on how these devices can be allocated (such as conventional optimization method, heuristics approach, meta-heuristics approach, etc.), the type of these devices that can be used (such as renewable and non-renewable DGs, FACTs devices, shunt capacitor etc.) and their configurations (such as DGs only, SCs only, DSTATCOM only, DGs and SCs, DGs and DSTATCOM etc.) that can be utilized. Renewable energy-based DG is the DG type that uses renewable source(s) of energy. This category of energy includes the energy from the sun, wind, tidal, hydro, biomass, and so on [11].

1.2. Literature Review

Many scholars have proposed several approaches to how electrical power can be more efficient, cost-friendly, and environmentally safe. Ref. [2] proposed optimal placement and sizing of shunt capacitors using the whale optimization algorithm (WOA) to minimize power losses and improve power quality in the distribution system with economic benefit in view. Their approach achieved maximum power loss reduction and system improvement on IEEE 33 bus and DADA 46 bus distribution system. However, the algorithm's convergence characteristics and computational efficiency were not considered. Cost-benefit of placing DSTATCOM in distribution networks using an Ant-lion optimization algorithm is proposed by [9]. Ref. [12] offered the optimal placement of DGs using the flower pollination algorithm (FPA). The method used is based on the pollination process of flowering plants. Power loss minimization was considered as the objective function, and their proposed method has experimented on 15-bus, 34-bus, and 69-bus distribution networks. Their approach is computationally efficient and applicable to solving various complex optimization problems. However, convergence characteristics were not discussed, and the cost implication of DG incorporation was not factored into the objective function. Only the real power loss was considered. Authors in [13] proposed the application of a hybrid enhanced grey wolf optimizer and particle swarm optimization (EGWO-PSO) algorithm for optimal allocation of DGs and Capacitor Banks. EGWO and PSO were utilized to acquire their combined benefits. They considered the technical, economic, and environmental advantages of multiobjective functions (MOF). These are the minimization of active power losses, voltage deviation index (VDI), the total cost of electrical energy, and total emissions from generation sources and enhancing the voltage stability index (VSI); their results revealed the satisfactory performance of EGWO-PSO in placing DGs and Capacitor banks. Self-adaptive differential evolution algorithm (SADE) and Improved particle swarm optimization algorithm (WIPSO) are used for optimal allocation of DG and SC in IEEE 33 and 69 RDN by [14] with the power losses minimization in view. Renewable DGs were used which has the potential of reducing GHG emission. However, the significance of using renewable DGs and their effect on greenhouse safety were not discussed. Also, the cost implication of their method was not considered. Ref. [15] developed an available renewable energy potential-based hybrid enhanced gray wolf optimizer-particle swamp optimization (ARED-EGWO-PSO) algorithm for optimal allocation of DGs and SCs. In their work, several objective functions were considered including minimization of power loss, voltage deviation, generation cost of electrical energy, total emission from generation sources, and improvement of voltage stability index. Venkatesan et al (2021) proposed a hybrid enhanced grew wolf optimizer and particle swamp optimization (EGWO-PSO) for optimal allocation of DGs and SCs. Multiple objective functions cover the minimization of power losses, voltage deviation index (VDI), the total cost of electrical energy and total emission from generation sources, and improvement of VSI. Ref. [16] proposed the Dragonfly algorithm (DFA) as a method for the allocation of DGs and SCs for power loss reduction and voltage profile and VSI improvement. They considered real power loss as the objective function and their method achieved a significant reduction in power loss and improvement in voltage profile and VSI. However, the costs associated with DG and SC placement and their operating cost were not discussed. The application of fuzzy genetic algorithm (FGA) for sizing and placement of DGs and SCs in a radial distribution system is proposed by [17]. Sensitivity index and multiple objective functions for loss minimization and voltage profile and VSI improvement are considered in this approach, nevertheless, the computational efficiency of the approach is not discussed as their approach requires parameter tuning.

Authors in [18] used Salp Swarm Algorithm (SSA) for the optimal allocation of DGs and SCs in IEEE 33 and 69 bus distribution systems. Multiple objective functions are considered, such as technical, economic, and environmental benefits. The method used achieved satisfactory performance in terms of power loss reduction, generation cost reduction, and pollutant emission reduction. However, it has been found that salp swarm algorithm suffers from various problems including poor exploitation, slow convergence, and unbalanced exploration and exploitation operation. PSO was proposed by [19] for the optimal allocation of DGs and SCs in RDN. Real power loss minimization is considered with the reduction in power loss and regulation of voltage. In [20], the author used Gbest-Guided Artificial Bee Colony (GABC) to sized and placed DGs and SCs in 33 bus and 85 bus distribution systems to minimize the system's total real power loss. The author used the index vector method (IVM) with power loss index (PLI) to locate the optimal location of DGs and SCs, respectively, reducing the search space of the optimization technique used. Authors in [21] proposed water cycle algorithm (WCA) for the placement and sizing of DGs and Capacitor Banks in the distribution system. The objective functions considered are technical (such as real power loss, voltage deviation, and VSI), economic, and environmental benefits. The convergence characteristics for each case considered are discussed. The water cycle algorithm(WCA) is a simple and effective global optimization algorithm, mainly used for engineering optimization. However, It is easy for WCA to fall into the local optimal solution when solving some constrained problems.

Ref. [22] used Cuckoo search algorithm (CSA) to sized and placed DGs and SCs in IEEE 33 bus and Ayepe 34 bus distribution system, aimed to minimize the real power loss and improve the voltage profile and VSI. The method used reduced the system's power loss and improved the voltage profile. However, the cost implication and the environmental effect of incorporating DGs and SCs on the networks are not considered.

Ref. [23] utilized a hybrid combination of symbiosis organism search and neural network algorithm (SOS-NNA) for optimal allocation of DGs and SCs considering single and multiple functions. The objectives covered various aspects such as power loss, voltage stability, voltage deviation, load balancing, and reliability. the economic implication was also evaluated for a planning period of five years. However, the environmental impact of the DGs and SCs was not covered in their study. Spotted hyena optimizer (SHO) has been proposed by [24] for SC allocation in RDN with DG considering different load types and levels. The objective of the study was to minimize the energy losses cost, losses cost in peak load condition and capacitor cost. Although the SHO achieved better annual net savings compared to other techniques, their work ignored some technical and environmental benefits.

Ref. [25] presented the Genetic Algorithm (GA) for investigation of the impacts of renewable DGs and SCs on power loss and voltage profile of Adama real distribution with different scenarios of DGs and SCs connection. The net savings achieved by the allocation of DG and SC were also evaluated in their work. The author in [26] has proposed simultaneous placement of DG and synchronous condenser considering real and reactive power losses as objective functions. Ref. [27] proposed a thief and police algorithm (TPA) for simultaneous reconfiguration with optimal allocation of shunt capacitor, photovoltaic and wind turbine. The considered objectives were to minimize the power loss, operational cost, and improvement of VSI. Authors in [28] utilized constriction factor particle swarm optimization (CP-PSO) for allocation of DG and SC in RDN taking minimization of power loss, total voltage deviation (TVD), and improvement of VSI as objectives. Yuvaraj et al (2021) Ref. [29] performed the optimal integration of DGs and SCs in RDN considering load variation using Bat Algorithm (BA). The work introduced a unique multi-objectives function focused on the reduction of power loss with the maximization of VSI.

Authors in [30] proposed parameter-free improved Best-Worst Optimizers (BWO) for simultaneous DG and SCs allocation in RDN with the objective of minimizing power loss in the system. In [31], a hybrid local search genetic algorithm (HLS-GA) was developed for simultaneous DG and SG allocation. The work aimed at minimizing the real power losses and total voltage deviation so as to enhance the performance of the RDN. The economic assessment based on cost analysis was also evaluated in their work. A combination of distribution network reconfiguration and optimal allocation of renewable DG and SC has been implemented using SHADE optimization along with Switch opening and exchange method by [32]. The objective of the work was the maximization of the hosting capacity (HC) of the DGs, reduction of power losses, and improvement of the voltage profile.

The optimal allocation of DGs and SCs in RDN has been carried out using strength parento evolutionary algorithm 2 (SPEA 2) considering the minimization of real power loss, reactive power loss, and total system cost as the objective function by [33]. Authors in [34] proposed a two-stage method for simultaneous integration of DGs and SCs in grid-connected and islanded balanced distribution networks. An improved variant of the Jaya algorithm (IJaya) is proposed to solve the planning problem of simultaneous DG and CB allocation in the radial distribution networks concerning the minimization of real power loss and voltage deviation at the nodes with the objective function of minimizing power losses and voltage deviation. Ref. [35] has proposed the shuffled frog leaping algorithm (SFA) for optimal allocation of DGs and SCs in the RDN with the objective function including minimization of power loss, operational cost and energy not supplied (ENS). In [36], an adaptive quantum-inspired evolutionary algorithm (AQEA) approach was developed for the optimization of DGs and SCs with the objective of minimizing power losses. Authors in [37] worked on a comparative assessment of the optimal allocation of four different DG types with techno-economic and environmental benefits in view. In their work, Black widow optimization (BWO) technique was utilized for the allocation of the DGs.

The summary of the literature reviewed is presented in Table 1.

The stochastic behavior of the algorithm used in terms of best value, worst value, variance, and standard deviation are not discussed for all these methods reviewed. Also, the impact of renewable energy DGs in reducing the electricity cost as well as enhancement of greenhouse safety is not well analyzed. Furthermore, some of the authors placed more premium on the power loss reduction while the cost of the implication of incorporating DGs and SCs is not well considered. Hence this research is proposed to optimally allocate the renewable energy DGs and shunt capacitors using corona virus herd optimization technique to enhance technical benefits such as reduction in real and reactive power losses, improvement in VSI, VD, and VP, economic benefit, and greenhouse safety.

Table 1. Summary of the literature reviewed.

Authors (year)	Reference	Technique	Objectives	Devices	Research gap
Aman et al (2013)	[19]	PSO	Real power loss minimization and voltage regulation	DG and SC	The economic and environmental benefits of DG and SC were not considered
Reddy et al. (2016)	[12]	FPA	Power losses minimization	DG only	convergence characteristics were not discussed, and the cost implication of DG incorporation was ignored
Dixit et al (2017)	[20]	GABC	index vector method (IVM) with power loss index (PLI)	DG and SC	Cost and environmental benefits of DG and SC were not considered
Abdul'wafa (2018)	[26]		Minimization of real and reactive power losses	DG and SC	Only real and reactive power losses are considered, other technical factors such as VPI and VSI are not considered.
El-Ela et al (2018)	[21]	WCA	Minimization of power losses, voltage deviation, VSI, total electrical energy cost, and total emissions produced by generation sources	DG and SC	It was reported that it is easy for WCA to fall into the local optimal solution when solving some constrained problems.
Manikanta et al (2018)	[36]	AQEA	Minimization of power losses	DG and SC	The cost effect of DG and SC placement and their environmental impact were not considered
Gamp and Das (2019)	[17]	FGA	real and reactive power losses and improvement of branch current capacity, voltage profile, and stability	DG and SC	The cost and environmental benefits of DG and SC were not considered
Sudabattula et al (2019)	[16]	DSA	real power loss minimization	DG and SC	The cost associated with DG and SC placement and their environmental impact were not considered
Tolabi (2020)	[27]	TPA	power loss, operational cost, and VSI improvement	DG and SC	
Venkatesan et al (2021)	[15]	AREP-EGWO-PSO	Minimize power losses, voltage deviation, VSI, operational cost, and emission	DG and SC	Convergence is ignored
Venkatesan et al (2021)	[13]	EGWO-PSO	minimization of active power losses, voltage deviation index (VDI), VSI the total cost of electrical energy, and total emissions from generation sources	DG and SC	the significance of using renewable DGs and its effect on greenhouse safety is not discussed
Salimon et al (2021)	[22]	CSA	Minimization of power loss	DG only	A limited type of DG is considered. Also, economic cost and environmental implications are ignored
Nguyen et al (2021)	[23]	SOS-NNA	Minimization of power loss, voltage deviation, improvement of	DG and SC	The environmental benefit was neglected

			VSI, load balancing and reliability.		
Naderipour et al (2021)	[24]	SHO	Minimization of energy loss, costs, loss cost in peak load conditions, and capacitor cost	DG only	Limited DG type. Technical and environmental benefits were ignored
Mekonnen et al (2022)	[25]	GA	Minimization of Power loss and Voltage deviation	DG only	Limited DG type. Environmental benefit was not considered
Okelola et al (2022)	[2]	WOA	Minimization of Power loss, voltage profile, and cost with VSI improvement.	SC only	convergence characteristics and computational efficiency were not considered
Leghari et al (2021)	[34]	IJaya and Analytical Method	Minimization of power losses and voltage deviation.	DG and SC	Only the technical benefit was considered. The other benefits such as economic and environmental benefits were not considered
Yuvaraj et al (2021)	[29]	BA	Minimization of power loss with the maximization of VSI.	DG and SC	Economic and environmental benefits were not considered
Legbari et al (2022)	[30]	BWO	Minimization of power loss	DG and SC	Other technical benefits such as VSI and voltage profile were not considered. Also, economic and environmental benefits were ignored
Salimon et al (2023)	[37]	BWO	Minimization of power loss, voltage deviation (VD), VSI the total cost of electrical energy, and total emissions	DG only	The combined effects of DG and SC were not considered.

1.3. Paper Contributions

The significant contributions of this paper are:

- Application of renewable energy to the distribution system
- Evaluation of the environmental effect of using renewable energy DGs in the distribution system
- Analyze the effect of using CVOA for optimal allocation of DGs and SCs on the accuracy, optimal values, and convergence characteristics of the optimization technique used
- Evaluation of implication costs of incorporating DG and shunt capacitor in the distribution system
- Single and multiple objectives are considered for the optimal allocation of DGs/SCs to find the effectiveness of the proposed CVOA compared with other techniques.
- DG and shunt capacitor allocation impact on real and reactive power losses, voltage profile, VSI, and voltage deviation are analyzed.
- Implement the proposed method on standard IEEE bus and Practical Nigerian radial distribution system.
- Increasing the awareness of the importance of the application of DGs and SCs for solving power loss and power quality-related problems in distribution systems

2. SYSTEM MATHEMATICAL MODELLING

The basic system modeling and the mathematical formulation of the performance metrics are presented in the section.

2.1. Solar Photovoltaic Output-Generated Power

The power generated by solar photovoltaic (SPV) modules depends on the amount of solar irradiance reaching the panel and the operating temperature of the solar panels. Therefore, the output-generated power of SPV can be expressed as [38]:

$$P_{pv} = P_{stc} * G[1 + \alpha_T(T_t - T_{stc})] \quad (1)$$

$$G = \frac{I_{irr,t}}{I_{irr,stc}} \quad (2)$$

Where P_{stc} the power rating SPV module, $I_{irr,stc}$ is the solar irradiance at the standard condition (1000W/m^2), $I_{irr,t}$ is the irradiance during actual operation, temperature $T_{stc} = 25^oC$, T_t is the actual operating temperature and α_T represents the temperature coefficient of the SPV module.

The total power output of the SPV system depends on the number of modules installed.

2.2. Wind-Generated Output Power

The output power of the wind turbine depends on the instantaneous wind speed. Therefore, the output generated power of a wind turbine can be expressed as [39]:

$$Pwind\ (t) = \begin{cases} 0 & (v < v_{ci}) \\ \frac{P_r(v-v_{ci})}{v_R-v_{ci}} & (v_{ci} < v < v_R) \\ P_r & (v_R < v < v_{co}) \end{cases} \quad (3)$$

Where P_r id the power rating of the wind turbine, v is instantaneous speed, v_{ci} is cut-in speed (m/s),v_R is rated speed(m/s) and v_{co} is the cut-out speed of wind turbine (m/s)

This research focuses on the rated output generated power of the wind turbine under normal operating conditions.

2.3. Voltage Stability Index

The voltage stability index (VSI) is used to evaluate how stable a distribution network is, which determines the network security level. The buses with the lowest VSI are the less stable and weakest buses prone to voltage collapse. VSI can be expressed as given by [20]:

$$VSI(i+1) = |V_i|^4 - 4\left(P_{d,i+1} * R_{i,i+1} - Q_{d,i+1} * \right.$$
$$\left. \ldots X_{i,i+1}\right)^2 - \left(P_{d,i+1} * R_{i,i+1} - Q_{d,i+1} * X_{i,i+1}\right)|V_i|^4 \quad (4)$$

Where V_i is the voltage of ith bus (p.u.), $P_{d,i+1}$ is an active load of (i + 1)th bus (kW), $R_{i,i+1}$ is branch resistance between bus ith and (i + 1)th, $Q_{d,i+1}$ is the reactive load of (i + 1)th bus (kVAR) and $X_{i,i+1}$ is the branch reactance between bus ith and (i + 1)th.

2.4. Voltage Profile Index

The voltage Profile Index (VPI) analyzes the voltage level variation. Wide deviation in voltage level compared with the rated voltage shows the network's poor performance. The closer this index to zero (i.e. 0), the better the network performance. VPI can be evaluated using the equation given by [21]:

$$VPI = \sum_{i=1}^{nb} \left(\frac{V_i - V_0}{V^{max} - V^{min}}\right)^2 \quad (5)$$

Where V^{max} and V^{min} represent the minimum and maximum voltage of ith bus (p.u.).

V_0 is the rated voltage per unit, and is given as:

$$V_0 = 1.05\, p.u. \quad (6)$$

2.5. Real Power Loss Index

Real power loss of the network can be expressed as [21]:

$$RPL = \sum_{i=1}^{nl} R_i * |I_i|^2 \quad (7)$$

Where nl is the total number of lines, R_i is the resistance at line i and I_i is the value of current at line i.

The real power loss index is introduced to express the value of real power loss as a per-unit value. This is done to make real power loss relate equally with other functions such as VSI and VPI when the weight value is introduced for the multiobjective function. The real power loss before the installation of DGs and SCs (P_{loss}) is considered as base case for the conversion. Therefore, RPLI can be expressed as [40]:

$$RPLI = \frac{P_{loss,DG,SC}}{P_{loss}} \quad (8)$$

Where $P_{loss,DG,SC}$ is the real power loss after the installation of DGs and SCs.

2.6. Total Electricity Cost

The total electricity cost for the power generation can be expressed as [18]:

$$TEC = EC_{Grid} + \sum_{i=1}^{n_{DG}} EC_{DG} + \sum_{i=1}^{n_{SC}} EC_{SC} \quad (9)$$
$$EC_{Grid} = C_{Grid} + P_{Total} \quad (10)$$
$$P_{Total} = P_d + P_{loss} \quad (11)$$
$$EC_{DG,i} = \alpha + \beta * P_{DG} \quad (12)$$
$$\alpha = \frac{InitalCost_{DG}(\$/kW) * Capacity_{DG}(kW) * G_R}{LT_{DG}(years) * LF_{DG} * 8760} \quad (13)$$
$$\beta = OMCost_{DG}\left(\frac{\$}{kWh}\right) + FuelCost_{DG}(\$/kWh) \quad (14)$$

Where $EC_{DG,i}$ is the total cost of i DG, C_{Grid} is the cost of generation from the grid, P_{Total} is the total generated power from the grid, P_d is the total load demand, G_R is the annual rate of benefit (\$/h), LF_{DG} is the Load factor of DGs, LT_{DG} is the lifetime of DGs and $OMCost_{DG}$ is the operation and maintenance cost.

Since renewable energy is considered, there will be no fuel consumption. That is,

$$FuelCost_{DG}(\$/kWh) = 0; \quad (15)$$

Therefore:

$$\beta = OM\_Cost_{DG}\left(\frac{\$}{kWh}\right) \quad (16)$$
$$EC_{SC,i} = \frac{e_i + CapitalCost_{SC}(\$/kVAR) * Q_{SC}(kVAR)}{LT_{SC} * 8760} \quad (17)$$

Where $EC_{SC,i}$ is the total cost of i SC, e_i is the installation cost for SCs, Q_{SC} is the total reactive power of SCs and LT_{SC} is the lifetime of SCs.

2.7. Green House Safety

Greenhouse safety depends on the amount of greenhouse gas (GHG) emitted over some time. The most common GHGs are oxides of Carbon (the prominent one associated with non-renewable DGs is CO_2), oxides of Sulphur (such as SO_2), and oxides of Nitrogen (NO_x) [Dan monand et al]. These gases are attributed to harmful effects such as depletion of the ozone layer, causes of global warming, and increment in average earth temperature [41]. Non-renewable generators frequently produce them. Therefore to create a safer environment, it is expedient to seek ways to minimize the GHG emission in power systems. The total GHG emission ($Total_{GHGe}$) can be expressed as [21]:

$$Total_{GHGe} = E_{GHG,Grid} + \sum_{i=1}^{n_{DG}} E_{GHG,DG} \quad (18)$$

$$E_{GHG,Grid} = \left({CO_2}^{Grid} + {SO_2}^{Grid} + {NO_x}^{Grid}\right) * P_{Total} \quad (19)$$

$$E_{GHG,DG,i} = \left({CO_2}^{DG} + {SO_2}^{DG} + {NO_x}^{DG}\right) * P_{DG,i} \quad (20)$$

Where ${CO_2}^{Grid}$, ${SO_2}^{Grid}$ and ${NO_x}^{Grid}$ are the emission factors of the grid and are taken as 5.06(lb/MWh), 11.6(lb/MWh), and 2031(lb/MWh) respectively.

Since renewable DGs are considered, there will be no GHG emission as no significant emission is attributed to SPV and wind, therefore the GHG emission ($E_{GHG,DG}$) for DGs will be zero. That is;

$$E_{GHG,DG,i}=0; \quad (21)$$

Their equation (21) will become:

$$Total_{GHGe} = E_{GHG,Grid} \quad (22)$$

3. PROBLEM FORMULATION

This section discusses the objective functions and operational constraints that need to be satisfied for optimal allocation of DGs and SCs in distribution networks. They are explained in the following subsections.

3.1. Objective Function

In this research, the objective functions considered aimed to achieve Technical and economic benefits as well as Greenhouse safety.

i. Technical Objective functions

The technical objective functions considered are as follows:

a. Real power loss minimization: This aimed to reduce the total real power loss in the distribution system. It can be achieved using RPLI. This objective function is expressed as:

$$OF_1 = \min\,(RPLI) \quad (23)$$

b. VSI improvement: this aimed to improve the voltage stability of the system and it can be expressed as:

$$OF_2 = \min\left(\frac{1}{VSI}\right) \quad (24)$$

c. VPI improvement: the aim of this objective function is to improve the voltage profile of the system by minimizing the voltage deviation in the network. It can be expressed as:

$$OF_3 = \min\,(VPI) \quad (25)$$

ii. Economic Objective function

This aims to minimize the power generation's total electricity cost to enhance economic benefit (TEC after the compensation of DGs and SCs is divided with the one before the compensation to have its value as index). It can be expressed as:

$$OF_2 = \min\,(TEC) \quad (26)$$

iii. Greenhouse Safety objective function

This objective function aimed to minimize the GHG emission of the system to enhance Greenhouse safety ($Total_{GHGe}$ after the compensation of DGs and SCs is divided with the one before the compensation so as to have its value as an index). This can be expressed as:

$$OF_3 = \min\,(Total_{GHGe}) \quad (27)$$

3.2. Constraints

The equality and inequality constraints that need to be satisfied are presented in the following subsections.

3.2.1. Equality Constraints

The Equality constraint that must be satisfied is the power balance constraint. The real power (P_i) and reactive power (Q_i) flow through the network must satisfy the following:

$$\sum_{i=1}^{n} P_i - \sum_{i=1}^{n} P_{d,i} + \sum_{i=1}^{n} P_{DG,i} - P_{loss,i} = 0 \quad (28)$$

$$\sum_{i=1}^{n} Q_i - \sum_{i=1}^{n} Q_{d,i} + \sum_{i=1}^{n} Q_{SC,i} - Q_{loss,i} = 0 \quad (29)$$

3.2.2. Inequality constraints

The following are the inequality constraints that must be satisfied:

i. Bus Voltage limits

The voltage per unit at each bus must be within the specified limits. This limit is expressed as:

$$V^{min} \le V_i \le V^{max} \quad (30)$$

$V^{min} = 0.95\,p.u.$ while $V^{max} = 1.05\,p.u.$

ii. DGs operating limits

$$P^{min}{}_{DG,i} \le P_{DG} \le P^{max}{}_{DG,i} \quad (31)$$

$P^{min}{}_{DG,i} = 100kW$ while $P^{max}{}_{DG,i} = 3000kW$

iii. SCs operating limits

$$Q^{min}{}_{SC,i} \le Q_{SC} \le Q^{max}{}_{SC,i} \quad (32)$$

$Q^{min}{}_{SC,i} = 150kVAR$ while $Q^{max}{}_{SC,i} = 1500kVAR$

iv. Distribution line capacity limits

$$S_i \le S_i^{max} \quad (33)$$

3.3. Overview of Coronavirus Herd Immunity Optimizer (CHIO)

CHIO is a human-based optimization technique proposed by Al-Betar et al., 2020 [42]. It originated from herd immunity, an approach to control corona virus pandemic (COVID-19). Herd immunity implies that the population in a community has a large percentage of people who are immunized against the spreading of the virus. When the rate is greater than 60%, the population will be prevented from having more infected cases. This percentage is referred to as herd immunity threshold. The herd immunity population is classified into three types: susceptible, infected (also known as confirmed), and immuned (or recovered) individuals. The interrelation of the kind of herd immunity is shown in Fig. 1. In the optimization context, susceptible individuals take the most significant portions of the populations, followed by the infected, while the immune individuals carry the least or null. This order is called population hierarchy and is shown in Fig. 2.

The CHIO procedure can be discussed under the following sub-heading:

i. Initialization

The CHIO optimization problem is formulated as follows:

$$Obj = \min f(x), \quad x \epsilon [lb, ub] \tag{34}$$

Where $\mathrm{f}(x)$ is the immunity rate calculated for the cases:

$$x = x_1, x_2, x_3 \ldots x_n \tag{35}$$

$$x_i^j = lb_i + (ub_i - lb_i) * u(0,1) \tag{36}$$

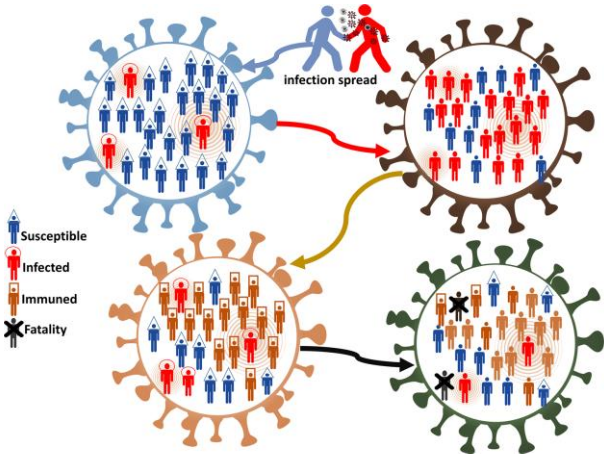

Fig. 1. The interrelation of the type of herd immunity.

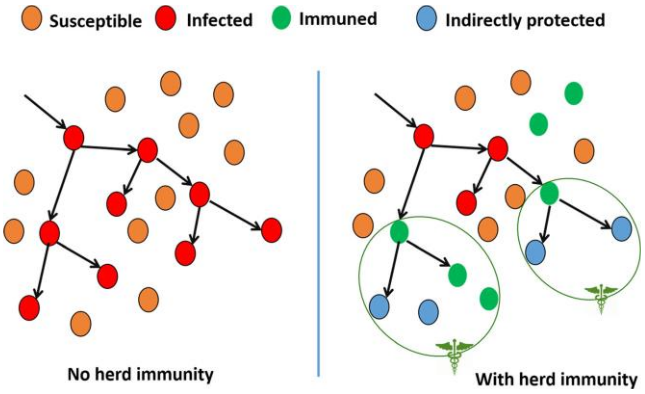

Fig. 2. Population hierarchy.

A random number is generated as the set of cases that constitute each row of the population. The immunity rate (i.e. the objective function) for each case is calculated using the equation (34) above.

ii. Corona virus herd immunity evolution

This is the main improvement loop of CHIO and it is based on the transition of genes (x_i^j) in herd immunity cases such as infected, susceptible, and immune cases from one case to another.

a. Infected case: This is the situation in which the virus is confirmed in a carrier and they can get the virus transmitted to susceptible individuals. This condition is expressed as:

$$r < \frac{1}{3} * BR_r \tag{37}$$

Where ‘r’ is the generated random number between 0 and 1 and BR_r is the basic reproduction rate. The new gene for infected cases is given as:

$$x_i^j(t+1) = C(x_i^j(t)) \tag{38}$$

$$C\left(x_i^j(t)\right) = x_i^j(t) + r * (x_i^j(t) - x_i^c(t) \tag{39}$$

$$c = \left\{{}^{i}/_{\zeta_i} = 1\right\} \tag{40}$$

Where ζ_i is the status vector.

b. Susceptible case: susceptible individuals are not infected by the virus but can be infected by their contact with other individuals when they do not follow the social distance. The condition for this case is given in equation (41), while the new gene for the susceptible case is expressed in equation (42)-(45):

$$r < \frac{2}{3} * BR_r \tag{41}$$

$$x_i^j(t+1) = N(x_i^j(t)) \tag{43}$$

$$N\left(x_i^j(t)\right) = x_i^j(t) + r * (x_i^j(t) - x_i^m(t) \tag{44}$$

$$m = \left\{ {}^{i}/_{\zeta_i} = 0 \right\} \tag{45}$$

c. Immune case: Immune individuals are not yet affected by the virus and are protected against it. They help the population to tame the spreading of the virus. The case whereby the value of the randomly generated number is less than the basic reproduction rate (i.e., $r < BR_r$) is referred to as an Immuned case. The new gene for an immune case is expressed as:

$$x_i^j(t+1) = R(x_i^j(t)) \tag{46}$$

$$R\left(x_i^j(t)\right) = x_i^j(t) + r * (x_i^j(t) - x_i^m(t) \tag{47}$$

3.4. METHODOLOGY: APPLICATION OF CVOA FOR OPTIMAL DG AND SC ALLOCATION.

The procedural steps for the implementation are given below:

Step 1: load the line and load data of the distribution network

Step 2: initialize the CHIO algorithm parameters such as: lb, ub, Max_iter, Co, HIS, and Max_age.

Step 3: Randomly generate the herd immunity population (HIP) as the initial size and location of DGs and SCs using equation (36) to form each row. HIP is expressed as:

$$HIP = \begin{bmatrix} SC_1^1 & \cdots & SC_{n_{SC}}^1 & DG_1^1 & \cdots & DG_{n_{DG}}^1 & LocSC_1^1 & \cdots & LocSC_{n_{DG}}^1 & LocDG_1^1 & \cdots & LocDG_{n_{DG}}^1 \\ SC_1^2 & \cdots & SC_{n_{SC}}^2 & DG_1^2 & \cdots & DG_{n_{DG}}^1 & LocSC_1^1 & \cdots & LocSC_{n_{DG}}^1 & LocDG_1^1 & \cdots & LocDG_{n_{DG}}^1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ SC_1^{HIS} & \cdots & SC_{n_{SC}}^{HIS} & DG_1^{HIS} & \cdots & DG_{n_{DG}}^1 & LocSC_1^1 & \cdots & LocSC_{n_{SC}}^1 & LocDG_{n_{DG}}^1 & \cdots & LocDG_{n_{DG}}^1 \end{bmatrix} \tag{48}$$

Step 4: Add the compensation of DGs and SCs to the network by removing the current size of SCs and DGs from the load demand at their respective current location as expressed in equation (49) and (50) below

$$P_d(LocDG_1^1) = P_d(LocDG_1^1) - DG_1^1 \tag{49}$$

$$Q_d(LocSC_1^1) = Q_d(LocSC_1^1) - SC_1^1 \tag{50}$$

Step 5: Run the load flow on the network after the compensation and evaluate the fitness value for each row of HIP using the defined objective function.

Step 6: Execute corona virus herd immunity evolution using equation (37) to (47) and update the herd immunity population.

Step 7: Repeat step 4 to 6 until the maximum number of iterations is reached. In this case, the total number of susceptible and immuned cases dominate the HIP.

Step 8: Stop.

4. SIMULATION RESULT AND DISCUSSION

Two radial distribution systems are considered in this study, they are the IEEE 33 bus and Nigerian 46 bus, a radial distribution network of IBEDC, located in Oshogbo, Osun state. IEEE 33 bus with real and reactive loads of 3715kW and 230kVAR is used to validate the proposed method while the proposed method is implemented on Nigerian 46 bus with real and reactive loads of 6250kW and 3155kVAR respectively. The line diagrams for the two systems considered are shown in Figs. 3 and 4. Back-forward sweep method proposed by Teng et al. [43] was used to perform the load flow analysis. The total real and reactive power loss for the IEEE 33 bus is 210.99kW and 143.13kVAR, while that of Dada 46-bus is 926.50kW and 177.92kVAR, respectively. The algorithm is developed in the MATLAB environment (R2021a version), and simulations were run on an Intel(R) Core(TM) i5-3340M @ 2.70 GHz, 8.00GB RAM.

The algorithm parameters used for the simulation is presented in Table 2.

In other to show the effectiveness of the proposed CHIO and to study the impact of DGs and SCs installation on the system performance, six operational scenarios are considered. They are:

- Scenario 1: optimal allocation of SCs considering real power loss as the objective function
- Scenario 2: optimal allocation of DGs considering real power loss as the objective function
- Scenario 3: optimal allocation of DGs and SCs considering real power loss as the objective function
- Scenario 4: optimal allocation of DGs and SCs considering RPLI, VPI, and VSI as a single objective function using weight function (such that $w_1 = 0.7, w_2 = 0.2\ and\ w_3 = 0.1$) as given below:
  $$OF = OF_1 * w_1 + OF_2 * w_2 + OF_3 * w_3 \tag{51}$$
- Scenario 5: optimal allocation of DGs and SCs considering RPLI and $Total_{GHGe}$ as a single objective function using a weight function (such that $w_1 = 0.8\ and\ w_2 = 0.2$) as given below:
  $$OF = OF_1 * w_1 + OF_4 * w_2 \tag{52}$$
- Scenario 6: optimal allocation of DGs and SCs considering RPLI, TEC and $Total_{GHGe}$ as a single objective function using weight function (such that $w_1 = 0.6, w_2 = 0.2\ and\ w_3 = 0.2$) as given below:
- $OF = OF_1 * w_1 + OF_4 * w_2 + OF_5 * w_3$ (53)

Table 2. Algorithm parameters.

Parameters	Description	Values
C_o	Initial infected cases	1
Max_iter	Maximum number of iterations	100
R	Number of runs	10
HIS	Population size	50
N	Problem dimensionality	12
Max_{age}	Maximum infected case age	100

SpreadingRate	Spreading rate parameter	0.05

4.1. IEEE 33-Bus Distribution System

The simulation results obtained for the scenarios considered for IEEE 33-bus distribution system are presented in Table 3. The system performance before installing DGs and SCs is referred to as the reference scenario (Ref. scenario). From Table 3, the optimal size of SCs obtained by the proposed CHIO for scenario 1 is 295kVAR, 1008kVAR, and 556Kvar at bus 15, 30, and 24, respectively. The real and reactive power losses are reduced to 138.97kW (22.24%) and 94.84kVAR (33.20%). It can be observed that a significant improvement in VP and VSI compared to ref. scenario is achieved even though only the real power loss is considered as the objective function. The comparison of the obtained result from the proposed CHIO with existing methods is presented in Table 4. It can be observed that the proposed method gives a better result. For scenario 2, the optimal size of the DGs obtained by the proposed CHIO are 990kW, 747kW, and 1076kW at bus 24, 13, and 30 respectively with 65.36% reduction in real power loss. Also, the power quality in terms of VP and VSI is achieved. The results are compared with the existing methods in Table 5 and the outstanding performance of the proposed CHIO is established. (24), (13), (30)

The optimal allocation of DGs and SCs as considered in scenario 3 gives 89.44% reduction in real power loss and 86.77% reduction in reactive power loss. A better power quality improvement is achieved as well. Table 6 presents the comparison of the obtained results with the existing methods. From Table 6, it can be observed that the proposed CHIO is very efficient in terms of power loss reduction and power quality improvement.

To further analyze the effectiveness of the proposed CHIO, scenarios 4,5, and 6 are considered with different combination of objective functions. Scenario 4 considered the combination of RPLI, VPI and VSI objective functions using weight function as specified in equation (51). High priority was placed on real power loss. From the result presented in Table 3, it can be observed that a remarkable reduction in power losses is achieved with better improvement in VP and VSI compared to ref. scenario.

Table 3. Simulation result for IEEE 33-bus distribution system.

Parameters	Ref. Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Total P_{loss} (kW)	210.99	138.97	73.08	22.28	23.22	39.87	40.14
Total Q_{loss} (kVAR)	143.13	94.84	50.90	18.94	20.10	34.59	32.05
SCs Size(location) (kVAR)	---	295(15),1008(30),556(24)	---	829(8),10(24),968(32)	345(15),685(24),1165(29)	459(20), 1401(7), 199(15)	113(25), 1072(30), 1262(7)
DGs Size(location) (kW)	---	---	990(24),747(13),1076(30)	1025(30), 967(24),738(15)	588(15),938(33),1472(23)	1561(6), 835(13), 908(25)	1030(2), 1565(27), 914(12)

% P_{loss} Reduction	---	34.13	65.36	89.44	89.00	81.10	80.97
% Q_{loss} Reduction	---	33.74	64.44	86.77	85.96	75.83	77.61
Min. Voltage Mag.(pu.)	0.9038 (18)	0.9301 (18)	0.9658(18)	0.9921 (25)	0.9876(9)	0.9706(33)	0.9858(25)
Min. VSI (pu.)	0.6685 (17)	0.7489 (17)	0.8706(17)	0.9761 (21)	0.9558(10)	0.8873 (32)	0.9522 (24)
TEC ($/hr)	310.64	433.61	235.83	239.47	219.98	202.13	188.66
TGHGe (lb/hr)	8039087.68	7891623.53	1996635.72	2062560.60	1515716.68	923236.76	504012.46
Average fitness	---	141.24	78.68	27.35	0.2920	0.1914	0.26179
Best fitness	---	138.97	73.08	22.28	0.2758	0.08139	0.3214
Worst fitness	---	143.25	83.08	33.50	0.3198	0.1233	0.2262
Standard deviation	---	1.349	3.6723	3.582	0.01412	0.060607	0.033437
Variance	---	1.8197	13.4856	12.83	0.0001995	0.0036732	0.001118

Table 4. Comparison of scenario 1 (SCs) with existing methods.

Optimization Method	SCs size (kVAr) and location	Base Ploss(kW)	Ploss (kW)	% Ploss Reduction
IP [29]	450 (09), 800 (29), 900 (30)	210.02	171.78	18.21%
BFOA [18]	349.6 (18), 820.6 (30), 277.3 (33)	202.6	144.04	28.90%
IMDE [30]	475(14), 1037(30)	202.6	139.7	31.05%
FRCGA [31]	25(28), 475(6), 300(29),175(8), 400(30), 350(9)	210.99	141.24	33.06%
WOA [2]	1223(30), 511(24), 435(11)	210.99	139.80	33.74%

CSA [29]	400(11), 400(24), 950(30)	210.99	138.54	34.3%
Proposed CHIO	**295(15),1008(30),556(24)**	**210.99**	**138.97**	**34.13%**

The power loss reduction is almost the same as scenario 3 (i.e. 23.22kW and 22.28Kw). However, the cost reduction is higher compared to scenario 3. Scenario 5 considered RPLI and TGHGe. The result revealed a better reduction in TGHGe compared to the previous scenario; however, the power loss reduction is lower compared to Scenarios 3 and 4. In scenario 6, RPLI, TGHGe and

Table 5. Comparison of scenario 2 (DGs) with existing methods.

Optimization Method	DGs size (kVAr) and location	Base Ploss (kW)	Ploss (kW)	% Ploss Reduction
PSO [22]	1176.8(8), 981.6(13), 829.7(32)	202.6	105.35	48.0%
HSA [32]	572.4(17), 107(18), 1046.2(33)	202.6	96.76	52.2%)
BFOA [21]	633(17), 90(18), 947(33)	210.99	98.3	53.4%
TM [33]	587.6(15), 195.7(25), 783(33)	202.6	91.305	54.9%)
BSOA [22]	632(13), 487(28), 550(31)	202.6	89.05	56.0%
IWO [34]	624.7(14), 104.9(18), 1056(30)	202.6	85.86	57.6%
IWD [18]	600.3 (9), 300 (16), 1011.2 (30)	202.6	85.78	57.66%
IMDE [30]	840(14), 1130(30)	210.99	84.28	60.06%
SA [34]	1112.4(6), 487.4(18), 867.9(30)	210.99	82.04	61.11%
ACO-ABC [22]	754.7(14), 1099.9(24), 1071.4(30)	202.6	75.4	62.80%
BA [33]	816.3(15), 952.35(25), 952.35(30)	202.6	75.5	62.70%
SKHA [18]	801.8118 (13), 1091.385 (24), 1053.6346 (30)	202.6	72.785	64.07%
HGWO [17] ns	802 (13), 1090 (24), 1054 (30)	202.6	72.784	64.08%
SSA [22]	753.6(13),1100.4(23), 1070(29)	202.6	71.46	64.73%
SSA [27]	854.6(14), 1101.7(24), 1181(29)	202.6	71.05	64.90%)
WCA [18]	854.6(14), 1101.7(24), 1181(29)	202.6	71.05	64.90%
WOA [34]	1072.8 (30), 772.5 (25), 856.7 (13)	210.99	73.75	65.0%
Proposed CHIO	**990(24),747(13),1076(30)**	**210.99**	**73.08**	**65.36%**

Table 6. Comparison of scenario 3 (SCs and DGs) with existing methods.

Optimization Method	SCs size (kVAr) and location	DGs size (kVAr) and location	Base Ploss (kW)	Ploss (kW)	% Ploss Reduction
GABC [22]	300(16), 150(17), 150(18)	1098(28), 132(29), 609(30)	210.99	93.72	55.6%
GA [21]	250(16), 250(22), 500(30)	300(15), 300(18), 300(29), 600(30), 300(31)	202.60	71.25	64.83%
BFOA [18]	163(18), 338(33), 541(30)	542(17), 160(18), 895(33)	202.60	41.41	80.4%
IMDE [30]	254.8(16), 932.3(30)	1080(10), 896.4(31)	210.99	32.08	84.8%
WCA [21]	465(23), 565(30), 535(14)	973(25), 1040(29), 563(11)	202.60	24.688	87.8%
Proposed CHIO	**829(8), 10(24), 968(32)**	**1025(30), 967(24), 738(15)**	**210.99**	**22.28**	**89.44%**

TEC is considered as a single function as presented in equation (53). In terms of TGHGe and TEC reduction, scenario 6 gives the best result compared to other scenarios.

Figs. 3-6 show the comparison of the performance metrics for the ref scenario with scenario 1-6. The convergence characteristics curve of one of the scenarios considered is presented in Fig. 7.

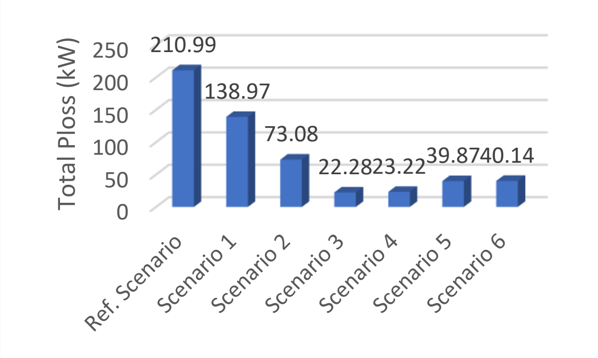

Fig. 3. Real power losses for all the scenarios considered for IEEE 33 bus network.

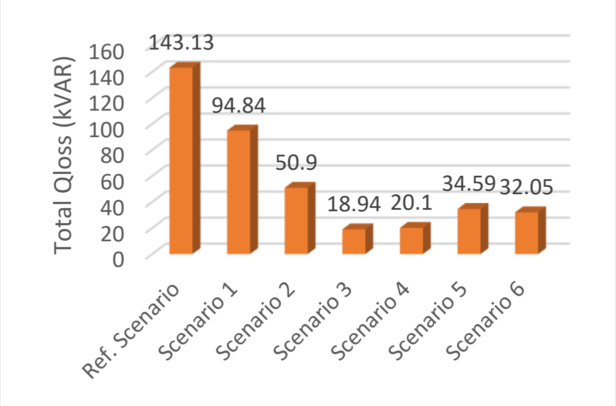

Fig. 4. Reactive power losses for all the scenarios considered for IEEE 33 bus network.

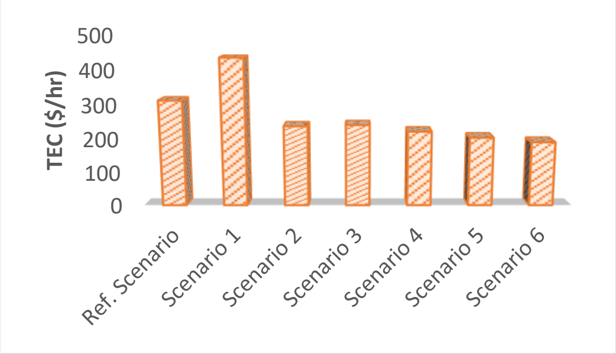

Fig. 5. Total Estimated Cost for all the scenarios considered for IEEE 33 bus network.

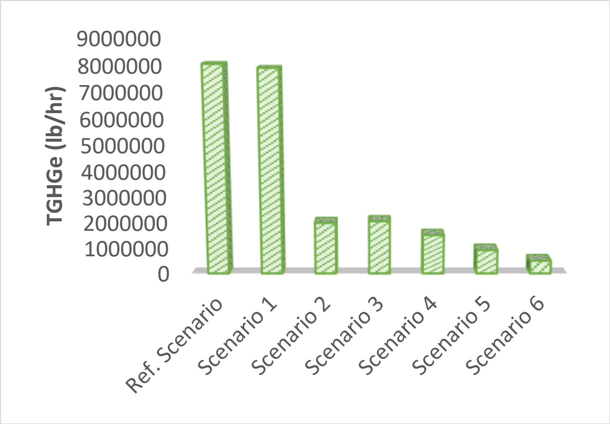

Fig. 6. Total Green House Gas emission for all the scenarios considered for IEEE 33 bus network.

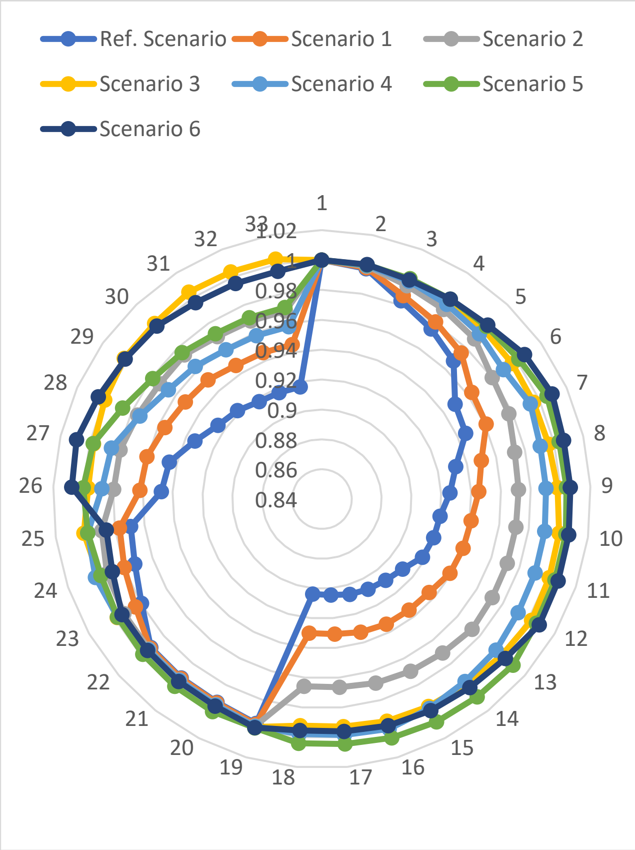

Fig. 7. Voltage profile of all scenarios considered compared with the ref scenario.

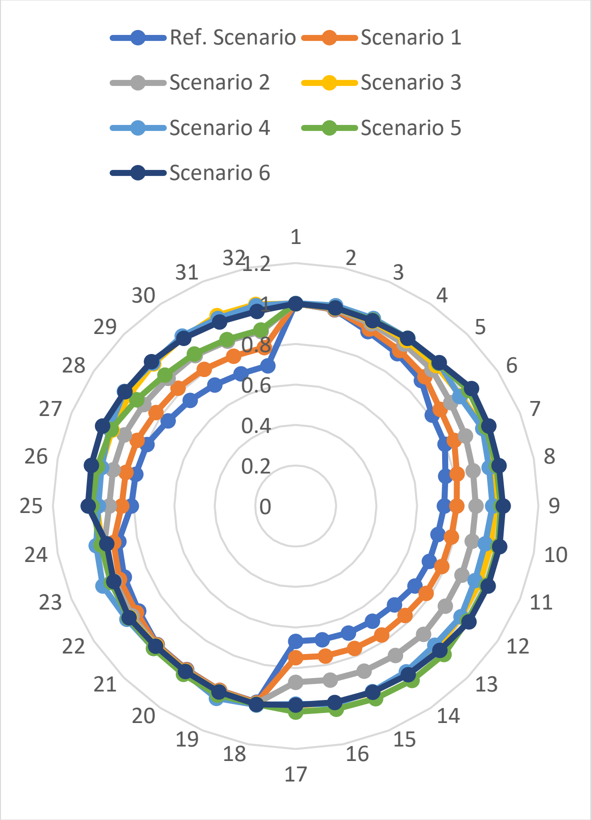

Fig. 8. Voltage Stability Index of all scenarios considered compared with the ref scenario.

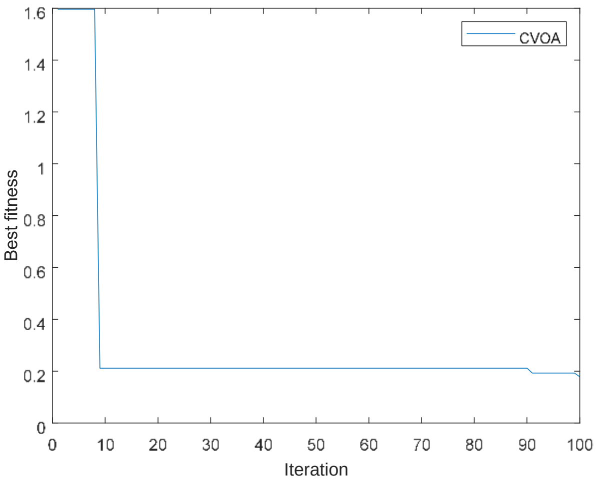

Fig. 9. Convergence characteristics curve.

4.2. Dada 46-bus distribution system

The simulation results obtained for the scenarios considered for Dada 46 bus distribution system are presented in Table 7. From Table 7, the optimal size of SCs obtained by the proposed CHIO for scenario 1 are 469kVAR, 1205kVAR and 1447kVAR at bus 41, 27 and 12, respectively. The real and reactive power losses are reduced to 720.48kW (34.13%) and 138.38kVAR (33.74%) respectively. It can be observed that a significant improvement in VP and VSI compared to ref. scenario is achieved despite the fact that only the real power loss is considered as the objective function.

For scenario 2, the optimal size of the DGs obtained by the proposed CHIO is 2417kW, 2585kW, and 916kW at bus 37, 12, and 27, respectively, with 83.55% reduction in real power loss. Also, the power quality in terms of VP and VSI is achieved.

The optimal allocation of DGs and SCs as considered in scenario 3 gives 98.41% reduction in real power loss and 97.96% reduction in reactive power loss. A better power quality improvement is achieved as well.

To further analyze the proposed CHIO's effectiveness, scenarios 4,5, and 6 are considered with different combinations of objective functions. Scenario 4 considered the combination of RPLI, VPI and VSI objective functions using the weight function as specified in equation (51). High priority was placed on real power loss. The result presented in Table 7 shows that a remarkable reduction in power losses is achieved with better improvement in VP and VSI compared to ref. scenario. The result revealed a better reduction in TGHGe compared to the previous scenario; however, the power loss reduction is lower compared to Scenarios 3 and 4. In scenario 6, RPLI, TGHGe, and TEC are considered as a single function as presented in equation (53). In terms of TEC reduction, scenario 6 gives the best result compared to other scenarios considered while in terms of TGHGe reduction, scenario 5 gave the highest. Figs. 9-15 compare the performance metrics for ref scenario with scenario 1-6. Finally, the convergence characteristics curve of one of the scenarios considered is presented in Fig. 16.

Table 7. Simulation result for Dada 46-bus distribution system.

Parameters	Ref. Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Total P_{loss} (kW)	926.50	720.48	152.43	14.65	24.93	22.23	54.44
Total Q_{loss} (kVAR)	143.13	138.38	29.36	2.92	4.895	4.378	10.56
SCs Size(location) (kVAR)	---	469(41),1205(27),1447(12)	---	483(40),1110(37),1413(12)	1678(26),20(20),1573(11)	836(14),861(36)873(37),	1699(23),1968(2), 716(17)
DGs Size(location) (kW)	---	---	2417(37),2585(12),916(27)	2682(12),40(46),3387(28)	1011(20),2467(15),2554(37)	3593(11),1019(28),1638(37)	275(20),1598(16),4335(28)
% P_{loss} Reduction	---	22.24	83.55	98.41	97.31	97.60	94.12
% Q_{loss} Reduction	---	33.20	79.49	97.96	96.58	96.94	92.62
Min. Voltage Mag.(pu.)	0.9038 (18)	0.8604 (44)	0.9873 (44)	0.9983 (10)	0.9980 (10)	0.9914 (44)	0.9984 (10)
Min. VSI (pu.)	0.6685 (17)	0.5482 (43)	0.9505 (43)	0.9973 (4)	0.9959 (9)	0.9661 (43)	0.9522 (24)
TEC ($/hr)	567.75	680.99	234.90	206.96	215.24	202.27	202.00
TGHGe (lb/hr)	14695031.84	14273185.34	991945.48	318727.26	497436.44	45525.64	197472.61
Average fitness	---	721.86	154.92	18.90	0.21748	0.034629	0.10641
Best fitness	---	720.49	152.43	22.28	0.2107	0.0156	0.0949
Worst fitness	---	723.39	159.72	33.50	0.2228	0.0513	0.1234

Standard deviation	---	1.0021	2.4457	2.6945	0.0036507	0.011632	0.0081078
Variance	---	1.0042	5.9816	7.2602	1.3328e-05	0.0001353	6.5737e-05

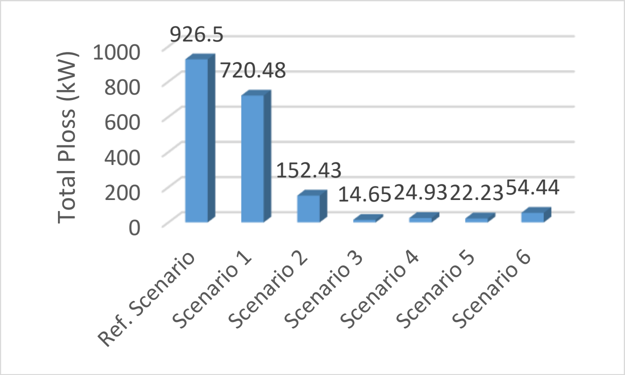

Fig. 10. Real power losses for all the scenarios considered for Nigerian Dada 46 bus network

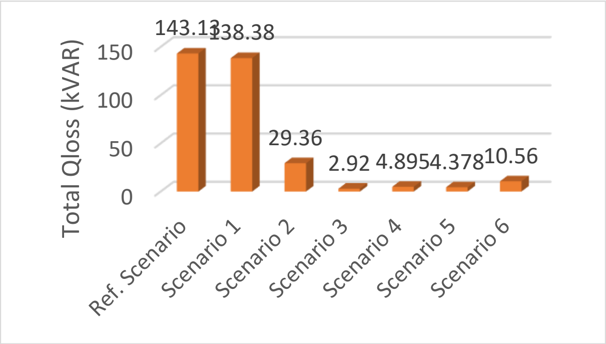

Fig. 11. Reactive power losses for all the scenarios considered for Nigerian Dada 46 bus network.

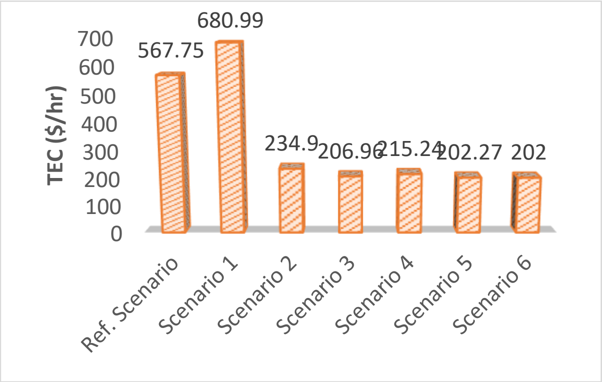

Fig. 12. Total Estimated Cost for all the scenarios considered for Nigerian Dada 46 bus network.

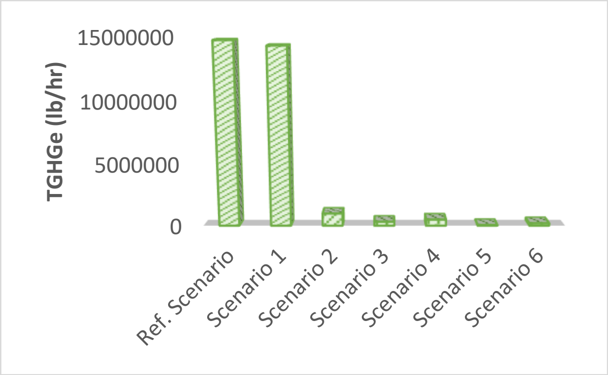

Fig. 13. Total Green House Gas emission for all the scenarios considered for Nigerian Dada 46 bus network.

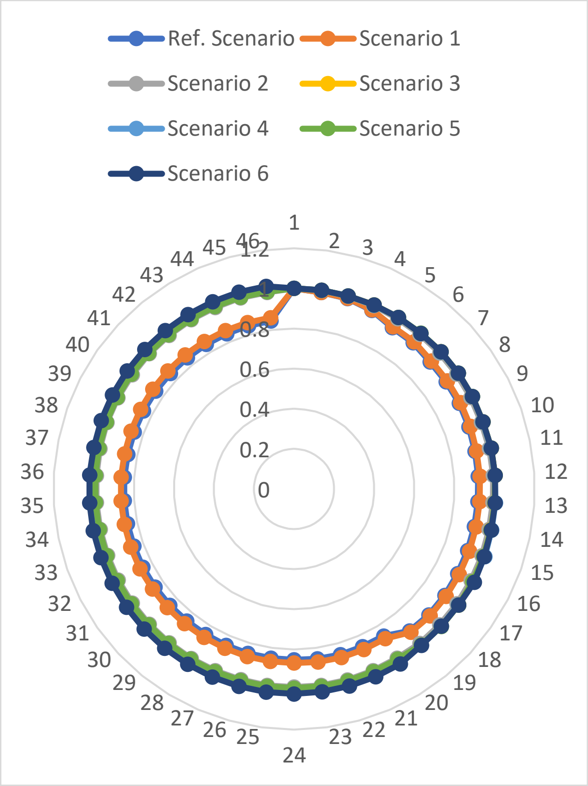

Fig. 14. Voltage profile of all scenarios considered compared with the ref scenario.

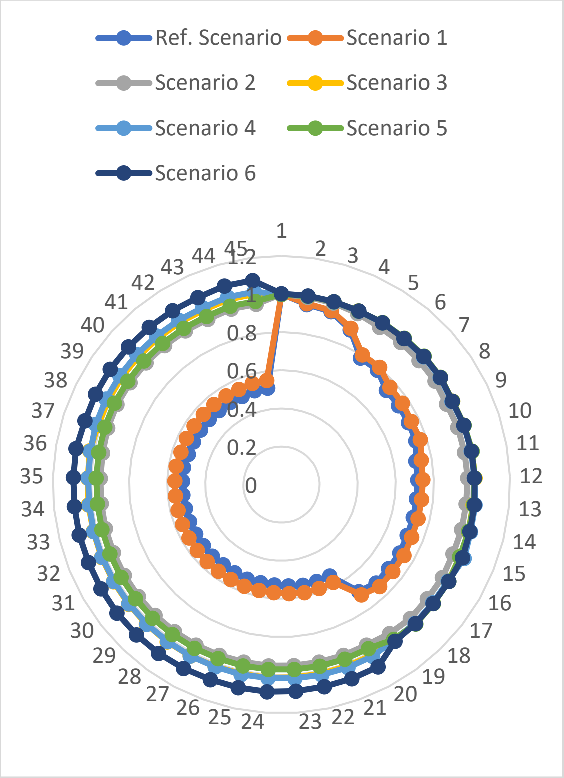

Fig. 15. Voltage Stability Index of all scenarios considered compared with the ref scenario.

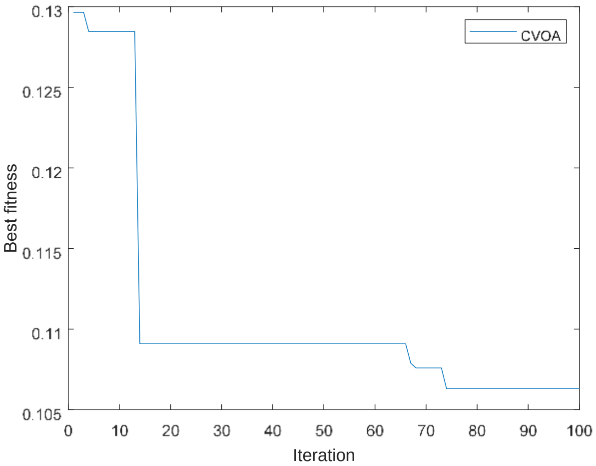

Fig. 16. Convergence characteristics curve.

5. CONCLUSION

This work presents the application of corona virus herm optimization technique for optimal allocation of renewable DGs (such as wind turbines and PV) and shunt capacitors for power loss minimization, voltage profile improvement, enhancement of voltage stability, total electricity cost reduction, and greenhouse safety enhancement. Six (6) scenarios were considered with different objective functions combined using the weight function. From the outcome of this research, it can be concluded that the incorporation of renewable DGs and shunt capacitors optimally placed and sized using CHIO can reduce the power losses, total electricity cost, and total greenhouse gas emission of the system and also improve the voltage profile. Also, from the results presented, it is established that weight function can affect the optimal result as the variable with high priority tends to have a better result, as observed in the optimum values of power losses for scenario 3 and scenario 4-6 presented in Table 3 and 4.

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