Al-Furat Journal of Innovations in Electronics and Computer
Engineering (FJIECE)
ISSN -2708-3985

An Approach for Hybrid Optimal Power Flow Strategies with Optimal Allocation of Distributed Generators for a Power Network

Ayat Saad Abdulkhaleq[1], Waleed Khalid Shakir Al-Jubori [2]

[1] Department of Electrical Power Engineering Techniques, Mussaib Technical College, Al-Furat Al-Awsat Technical University, Babylon, Iraq. ayat.saad.tcm.13@student.atu.edu.iq

[2] Department of Electrical Power Engineering Techniques, Mussaib Technical College AL-Furat AL-Awsat Technical University, Najaf, Iraq, waled_k@atu.edu.iq,wjubori@gmail.com

https://doi.org/10.46649/fjiece.v3.2.31a.10.6.2024

Abstract. *The OPF difficulties are characterized by the presence of four distinct objective functions which are: active power losses, fuel operating costs and voltage variations. The volatile and variable nature of distributed generator (DG) sources contributes to the convolution of the optimum power flow (OPF) issue. This paper employed bat algorithms to tackle the issue of optimum power flow (OPF) and PSO algorithm to optimal allocation of DG. The goal was to enhance the effectiveness of energy use, environmental sustainability, and cost efficiency of the electricity grid. The test cases include a wide range of scenarios, including the existence of Distributed Generation (DG), different locations of DG within the network, various kinds of load expansion, and occasional breakdowns of transmission lines. These possibilities are considered in order to address the problem presented by the suggested solution OPF. The incidents are assessed utilizing bus systems, such as the 30 bus system in MATLAB.*

Keywords: *Optimal power flow (OPF), Voltage profile, Distributed Generator (DG), Bat Algorithm (BA), Minimize fuel cost.*

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1. INTRODUCTION

The power system is considered to be complex and dynamic. It includes vast areas and includes multiple companies that are engaged in the administration of electrical networks. Power grids are subject to multiple constraints involving power transmission capacity and bus voltages. These constraints occur as a result of factors pertaining to stability, heat, and voltage. Economic0Dispatch (ED) does not take these limits into account. The topic of (OPF) combines the Economic Dispatch (ED) & power flow limits to evaluate the efficiency0of electric power systems. The problem of the (OPF) entails an intricate non-linear0optimization problem. The main0objective is to determine the most favourable parameters for each variable independent of the system[1].

Integrating DGs into a power system will result in substantial alterations to the framework, operations and control method used by the electrical network. In order to effectively automate the power grid and manage customer demand, it is crucial to consider the coordination between (DGs) and the control of electrical networks[2].

The management and operation of transmission networks will become progressively more complex. The integration0of distributed0generators (DGs) has transformed the0traditional electrical network model, shifting it from a passive recipient of0energy to an active network that actively0engages in energy exchange[3].

ATU-FJIECE, Volume: 3, Issue: 2, Jun 10, 2024, © 2020 FJIECE, All Rights Reserved

(OPF) is a widely employed method that seeks to reduce grid losses and decrease the overall cost of electrical networks. The basic objective of OPF is to reduce energy losses in the network and efficiently distribute power among different nodes, while ensuring that the security and stability for the entire system. Moreover, emissions of carbon are also considered as target for improvement, addition to these goals. To successfully achieve (OPF) using [DG], there is important to possess a comprehensive comprehension of their impact on electrical networks. [6] Investigated the0relationship between nodal-voltage0and the location of (DG). Two categories for (DGs) methods, namely predictive and stochastic, were created to tackle the inherent unpredictability. Many scholars have studied the impact of distributed generation (DG) on the power grid, but only a few have investigated the optimal operation of a power system that incorporates grid-connected DG[4].

Therefore, it is imperative to examine the optimal operation of the electrical system when integrating (DGs) into the network, especially in scenarios where there is broad DG connectivity to the electrical grid. This subject carries substantial theoretical and practical significance. The issue of (OPF) may require the application of multiple methodologies for its formulation and resolution. The Meta-heuristic technique can be extremely complex to understand. The study investigated algorithms that are appropriate for implementation based on criteria such as precision, optimal values, simulation length, and user-friendliness[5].

Bat echolocation inspired metaheuristic optimization approaches like BA and PSO. Numerous optimization issues have been solved using the optimization problem framework (OPF), although distributed generation (DG) OPF problems have some drawbacks [10]. Criticisms include insufficient robustness, imbalanced exploration and extraction, variable adjustment sensitivity, limited constraint management, and scaling issues. Scholars have suggested modifying and combining ways to improve their effectiveness in tackling OPF DG problems. These enhancements attempt to expand exploration, optimize limits, and scale.[6].

This study focuses on the subject of (OPF) for electrical power networks with (DG). It propose a comparison (without and with DG) for different cases. The target of (the OPF) is to get the most economically efficient method for utilizing and generating electrical power. This is implemented based on the optimization of multiple parameters, such as enhancing voltage stability, reducing costs associated with fuel and emissions, mitigating voltage swings, and reducing power losses. The study presents a novel approach that employs (BA) to address the (OPF) problem in transmission lines, while utilizing PSO to identify the most favourable locations for DG. This paper aims to address the lack of information in prior studies by examining how the location of generator (DG), increasing demand levels, and power system disruptions affect the operation of the power network. The approach is subsequently evaluated by doing simulations with IEEE 30bus network using MATLAB. The data acquired from the simulation were examined to evaluate the performance and effectiveness0of the suggested methodology. The proposed strategy can be a valuable tool for electrical network management to improve decision-making. It offers an efficient and affordable approach for managing the supply and demand of electricity in a power grid. This novel approach effectively tackles the challenges associated with the functioning of electrical systems and control.

2. OPTIMAL POWER FLOW (OPF)

An OPF, or Optimal Power Flow, is a highly intricate optimization problem that is neither linear nor convex. The objective of this approach is to reduce specific goals in the power system, while considering various equality and inequality limitations. In mathematics, the mathematical model of the OPF means can be stated as[7]:

reduce

$$M(x,y) \tag{1}$$

exposed to : $N(x\,,y)\ \leq 0$ (2)

$$L(\,x\,,y) = 0 \tag{3}$$

Let y represent the set that is independent or control variables, and let it also represent the set of dependent or state variables. The major objective function in the OPF issue is represented by M(x,u).The function N(x, y) represents the set of inequality constraints, while L(x, y) relates to the function representing a set of equality constraints.

a) The Independent Variables:

Variables that have the ability to control the electricity power flows of a network are represented by a vector u, which is defined as:

$$x = \left[P_{G1},.\,.P_{G_{NG}}\,,V_{G1}.\,.\,,V_{G_{NG}}\,,Q_{C1}.\,.\,,Q_{C_{NC}}\,,T_1.\,.\,,T_{NT}\right] \tag{4}$$

PG denotes the actual power output of the generator bus, without including the power generated by a swinging generator. The selection of bus 1 as a slack bus is purely symbolic, as any of the producing vehicles can function as the swinging bus. VGi represents the magnitude of the voltage on the ith photovoltaic bus, whereas T indicates the tap transformer ratio. Q_ ck represents the shunt compensation value at the k_th bus. NC, NT, NG represent the amounts of shunt VAR compensations, transformers, and generators, respectively.

State variables possess the capacity to assume any value within the specified range. Transformer taps are actually discontinuous. The tap settings provided below are measured in per unit (p.u) and do not account for the absolute voltage value. Thus, to enhance the process of studying and allow for comparison with previously documented results, control parameters such as tap settings are typically treated as continuous variables in the majority of study cases. The consideration of discrete increments for both transformers with shunt capacitors is restricted to a particular study scenario[8].

b) The Dependent Variable:

The status of the electrical system, x, can be represented by a vector that includes several state variables.

$$u = \left[P_{G1},.\,.P_{Gn},V_{L1}.\,.V_{L_{NL}},,Q_{G1},.\,.Q_{G_{NG}},,S_{l1}.\,.S_{l_{nl}}\right] \tag{5}$$

PG1 refers to the actual electric power generated by a generator on the slack (swinging) bus. QG represents the reactive power supply for the generators linked to the bus. VL represents the voltage at a load bus (PQ). Sl represents a line that is under load. "nl" and "NL" refer to a number of transmission cables and bus loads, respectively[9].

2.1. CONSTRAINTS

The topic of OPF encompasses both needs for inequity and equality that must be met. The limits are categorised and presented below[10].

a. Equality Costraints*:*

$$P_{G_i} - P_{D_i} - V_i \sum_{j=1}^{NB} V_j \left[G_{ij}\cos\left(\delta_{ij}\right) + B_{ij}\sin\left(\delta_{ij}\right)\right] = 0 \ \forall\, i \ \in NB \qquad (6)$$

$$Q_{G_i} - Q_{D_i} - V_i \sum_{j=1}^{NB} V_j \left[G_{ij}\ \sin\left(\delta_{ij}\right) - \ B_{ij}\cos\ \left(\delta_{ij}\right)\right] = 0 \ \forall\, i \ \in NB \qquad (7)$$

The variable δij represents the voltage angle variance among bus j and bus i. NB overall digit of buses. P_d refers to the real load demand, and Q_D represents the imaginary load demands. Gij represents the transfer conductance term, while Bij represents the susceptance value between buses j and i.

b. Inequality Constraints:

Inequality constraints in OPF indicate the realistic limitations imposed on elements in a power system, including restrictions on cables and bus loads, in order to assure the system's safety[11].

Generator Constraints:

$$V_{G_j}^{min} \le V_{G_j} \le V_{G_j}^{max} \ \forall\, j \ \in NG \qquad (8)$$

$$P_{G_j}^{min} \le \ P_{G_j} \ \le P_j^{max} \ \forall\, j \ \ \in NG \qquad (9)$$

$$Q_{G_j}^{min} \ \le Q_{G_j} \ \le \quad Q_{G_j}^{max} \ \forall\, j \ \in NG \qquad (10)$$

Where VG, PG, QG represent voltage magnitude, active power and reactive power respectively for generator

Transformer Constraints**:**

$$T_j^{min} \ \le \ T_j \le \ T_j^{max} \ \forall\, j \ \in NT \qquad (11)$$

T= tap ratio value

The Constraints of shunt compensator:

$$Q_{C_i}^{min} \ \le Q_{C_i} \le Q_{C_i}^{max} \ \forall\, i \ \in NC \qquad (12)$$

The constraint of security:

$$V_{L_n}^{min} \ \le \ V_{L_n} \le V_{L_n}^{max} \ \forall\, n \ \in N \qquad (13)$$

$$S_{ln}^{min} \ \le S_{l_n} \ \le S_{l_n}^{max} \ \forall\, n \ \in N \qquad (14)$$

2.2. THE OBJECTIVE FUNCTION

This study has optimised the five most prevalent objective functions, including voltage deviation, emissions, losses, plus fuel cost, in order to address OPF problems[12].

a) Minimise Fuel cost [$\$/h$]:

$$F_c = \sum_{j=1}^{N_G} f_j\left(P_{G_j}\right) = \sum_{j=1}^{N_G}\left(a_j P_{Gj}^2 + b_j P_{Gj} + c_j\right) \qquad \left[\frac{\$}{h}\right] \qquad (15)$$

The coefficientsa_i, b_i , and c_i are used to calculate price of fuel for generator.

b) Reduce total power losses [MW]

$$P_{loss} = \sum_{k=1}^{N_{nl}} G_{Ji}(V_J^2 + V_i^2 - 2V_J V_i \cos\delta_{Ji}) \quad (MW) \tag{16}$$

Where G = conductance of the line, V =voltage value for buses

c) Reduce The emission

The objective of this target function is to decrease the concentration of pollutants, such as NOx and sulphur dioxide (SO2) hence reducing the total emissions in the atmosphere. The mathematical representation of this goal function is expressed as

$$\mathrm{X_{em}} = \sum_{\mathrm{J}=1}^{\mathrm{N_G}} 10^{-2}\left(\alpha_{\mathrm{J}} + \beta_{\mathrm{J}}\mathrm{P_{GJ}} + \gamma_{\mathrm{J}}\,\mathrm{P_{GJ}^2}\right) + \zeta_{\mathrm{J}}\exp\left(\lambda_{\mathrm{J}}\mathrm{P_{GJ}}\right) \quad \left(\frac{\mathrm{Ton}}{\mathrm{h}}\right) \tag{17}$$

Here, it is necessary to specify the fuel emission coefficient for the generators, which are written to be αJ, βJ, γJ, ζJ, and λJ, as Xem represents fuel emission.

d) Reduce the voltage deviation:

Voltage deviation refers to the difference between the voltage measured on the PQ bus with a target level , 1.0 (p.u.). The aim of the present study is to identify the most effective method for enhancing voltage stability in the system by minimising voltage fluctuations across the loaded buses within 1.0 per unit [18]. The mathematical representation for this objective can be expressed as[13]

$$\mathrm{VD} = \sum_{j=1}^{N_{PQ}} \left|V_j - 1.0\right| \quad (\mathrm{p.u}) \tag{18}$$

VD denotes a ratio of voltage deviation, while Vj represents the magnitude of voltage at a bus.

3. OPTIMIZATION METHODS

i. Partical Swarm Optimization (PSO)

In 1995, Kennedy proposed the introduction of a stochastic algorithm known as PSO. The collaborative character of group animal, like bird communities, is the driving force behind this phenomenon. The Particle Swarm Optimisation (PSO) is frequently used to find best possible solution for Energy Distribution (ED) problems by effectively exploring a variety of power plants, owing to its adaptability and flexibility. It has been proven to be a useful way for calculating optimisation problems. Not applicable. To improve the model's capacity for both exploiting and exploring, some researchers have made adjustments to the first stage of the PSO algorithm. Others have introduced supplementary elements such as a constriction coefficient, an inertia weight force, and even mutation operations. The traditional Particle Swarm Optimisation (PSO) algorithm can be precisely defined using sizerate and position formulas given in equation (17, 18) below. [14]

$$x_{id}{}^{t+1} = w x_{id}^t + c_1 r_1\left(b_{best,id} - z_{id}^t\right) + c_2 r_2\left(g_{best,id} - z_{id}^t\right) \tag{19}$$

$$z_{id}^t = z_{id}^t + x_{id}{}^{t+1} \tag{20}$$

The letters i, d, and t represent the particle index, dimension, with discrete-time index, respectively. The names of $r1$, $r2$, $c1$, and $c2$ are assigned to represent the randomised settings, social and cognition components, with the inertia weight factor, accordingly. A particle index, dimension, & discrete-time index are followed[15].

ii. . THE BAT ALGORITHM (BA)

Bats utilise echolocation for communication and detecting prey. Yang harnessed this inherent occurrence to create the BAT algorithm. During the optimisation phase, it is imperative to verify that the position ui^t and velocities xi^t of each bat i are distinct and altered. The new solutions at a specific time step can be ascertained using the following equation[6].

$$h_i=h_{min} + (h_{max} - h_{min})\beta \quad (21)$$

$$x_i^t = x_i^{i-1}+(u^{i-1} - u^*)h_i \quad (22)$$

$$u_i^t = {u_i}^{i-1} + x_i^t \quad (23)$$

The rate of change in velocity, represented as hi λ_i, can be either h_i or λ_i. The value of z can be reused to restrict the rate of speed change while taking into account other factors λ_i (or h_i), depending on the specific problem being addressed. The optimal location or solution is denoted by u^*, and a random vector (0, 1) is symbolised by β. The execution employs h_min=1 and h_min=1, depending on the size of the problem domain. Initially, each bat is assigned an average frequency that sway unpredictably between the maximum and lowest values. In terms of the local search component, after selecting an option from the current best options, new result is generated for each bat using a customised random walk algorithm[16].

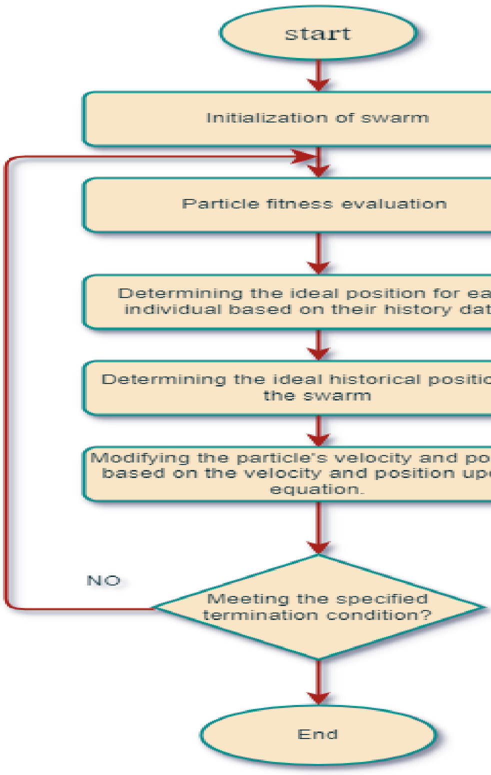

Figure 1: BAT algorithm flowchart

The population and iteration values for algorithms as shown in table below

Table 1: Control parameter of optimization techniques

The Parameters	Value	
	BA	PSO
Populations	30	30
Iterations	70	30

Efficiently managing distributed electrical generators (DGs) is crucial for minimising losses and enhancing reliability. An effective approach to address the challenges of incorporating DGs is to calculate their optimal location and size in close proximity to the load centres. The research strategy as showen in the flowchart below

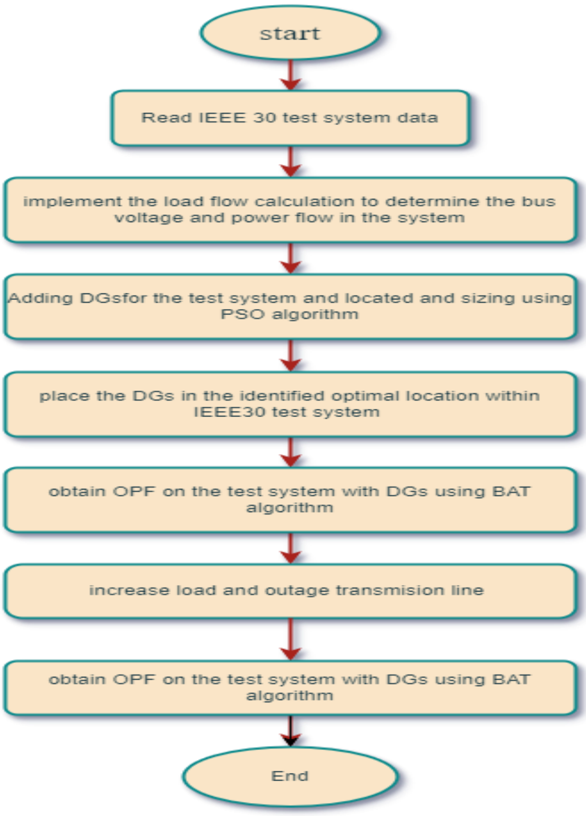

Figure 2: Work strategy flowchart

4. RESULTS AND DISCUSSION

a. RESULTS

This study presents a resolution for the Optimum Power Flow (OPF) issue by utilising the Bat Algorithm (BA) with Particle Swarm Optimisation (PSO) to calculate the optimal position of (DG). The proposed method is implemented through a MATLAB program. The effectiveness of a suggested BAT-based the OPF problem is assessed using the ordinary IEEE 30-bus network. There are a total of six generators, which are situated on buses numbered 1, 2, 5, 8, 11, and 13. All remaining buses are also fully loaded. Additionally, there are 4 transformers on branches "11, 12, 15, 36" that do not have a typical tapping ratio. The quantity of load demand is 283.3 megawatts (MW). The voltage limits for all buses of IEEE 30-bus framework are defined as a maximum of "1.05" per unit (P.U) and a minimum of "0.95" per unit (p.u)[17].

i. OPTIMAL DG PLACEMENT

In order to examine the effects of integrating distributed generation (DG) into electrical networks and the influence of DG locations on (OPF) solvers, the researchers utilized an IEEE 30-bus model for this study.

DG was included in three different scenarios with varying locations, as outlined in Table 2. This section utilizes PSO for allocation DG and the BA (Bat Algorithm) to effectively and accurately determine the most optimal solution to OPF issues in electrical networks that are0equipped with DG. The results suggest that both the DG and location systems directly influence the OPF solutions. Furthermore, the findings shown that the BA algorithm is a highly efficient solver for the (OPF) problems including Distributed Generation (DG). By incorporating Distributed Generation (DG) into the power networks for example a lower load value, the overall demand on the network will drop, resulting in a reduction in gearbox losses and operational costs associated with fuel use.

Table 2: Selection of the size and placemen t using (PSO) and comparison parameters on IEEE 30 bus

NO. of case	Distributed generator			Total power losses0 (MW)	Real Loss Reduction (%)0 (MW)	Minimum voltage p.u
	NO. of DGs	DG size in(MW)	Bus location			
Case 1	_	_	_	15.287878	_ _	0.950884
Case 2	3 DGs	7.76923	14	13.683045	1.605	0.978231
		5.461714	20			
		5.91318	27			

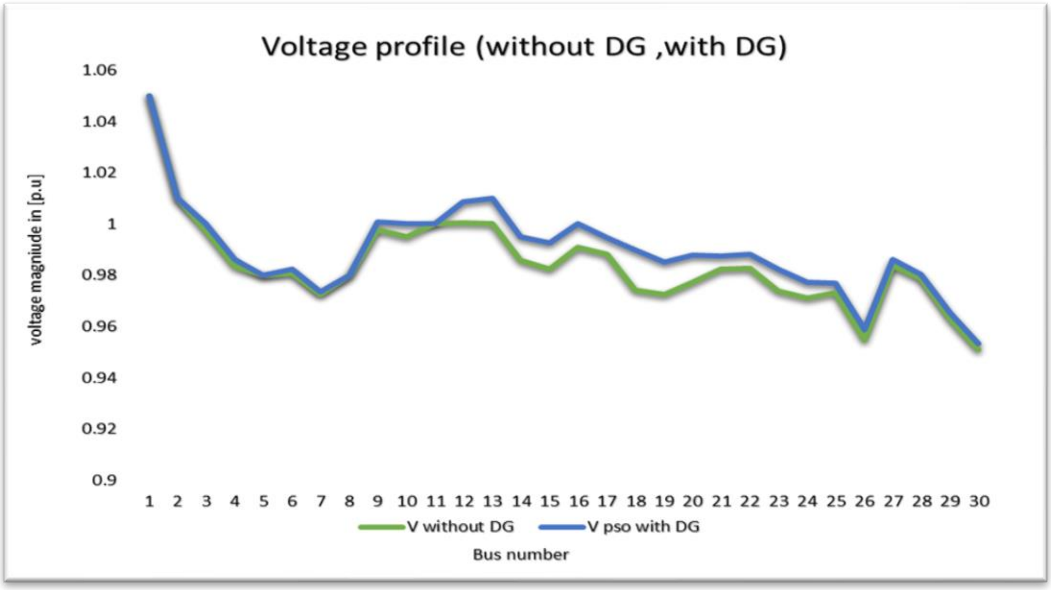

Figure 3: Examining the Voltage Profile Utilizing PSO (with DG and without DG)

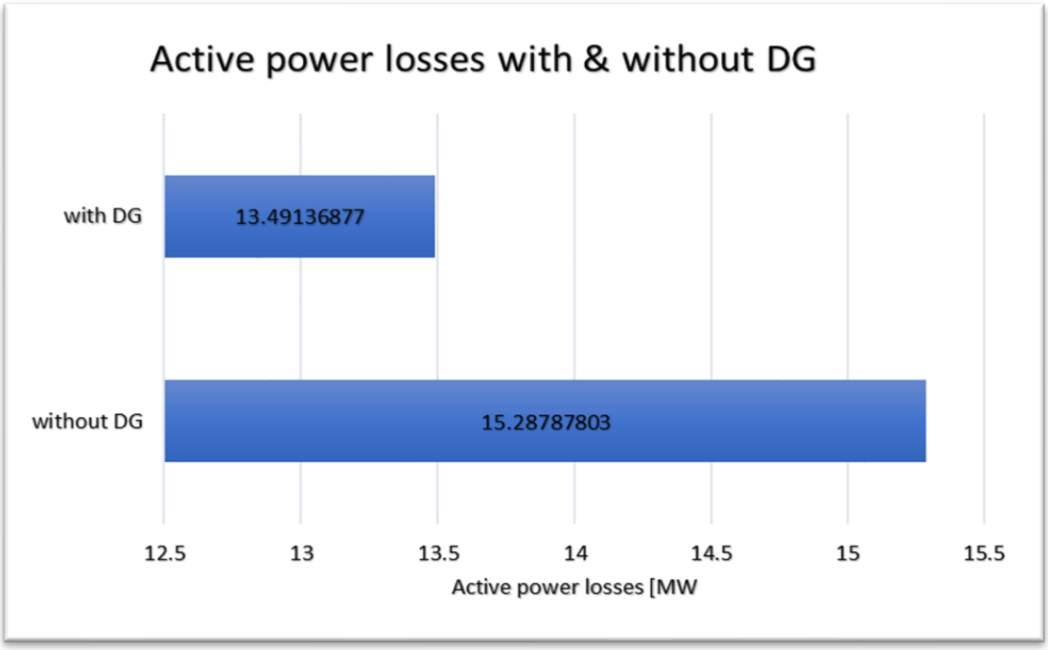

Figure 4: Examining the active power losses Utilizing PSO (with DG and without DG)

ii. OPF SIMULATION RESULTS

Case 1: NORMAL OPF ON IEEE 30 BUS WITH DG

This section presents the findings of the IEEE 30-bus model, which were achieved utilizing the recently presented metaheuristic optimization strategies for wholly the objective function instances. The objective functions are utilized for the purpose of comparing the outcomes. The values for transmission line losses, the emissions, fuel cost, & voltage variation are expressed in megawatts, tons per hour, dollars per hour, and per unit, respectively.

Figures [6-9] show the objective function for optimal power flow on IEEE 30 bus network with DG

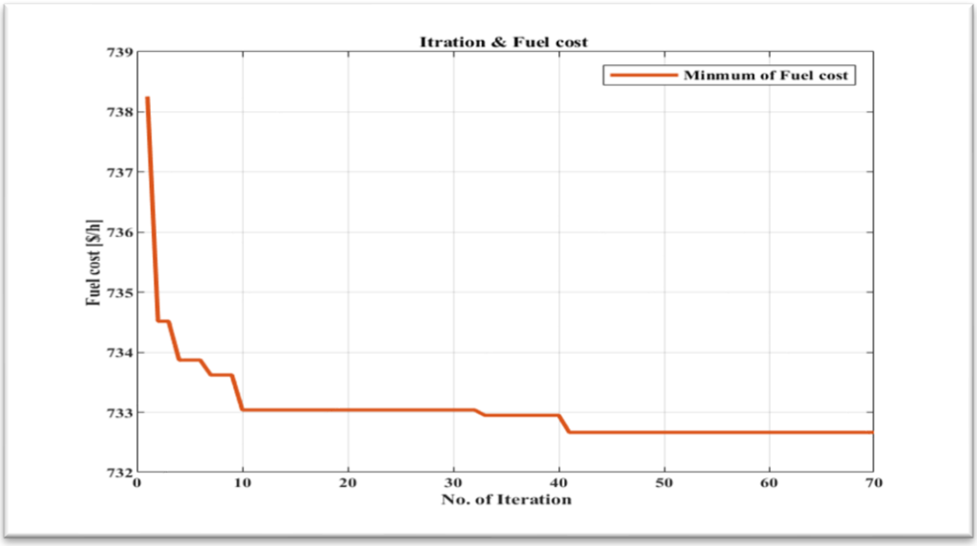

Figure 5: Fuel Cost for IEEE 30 with DG

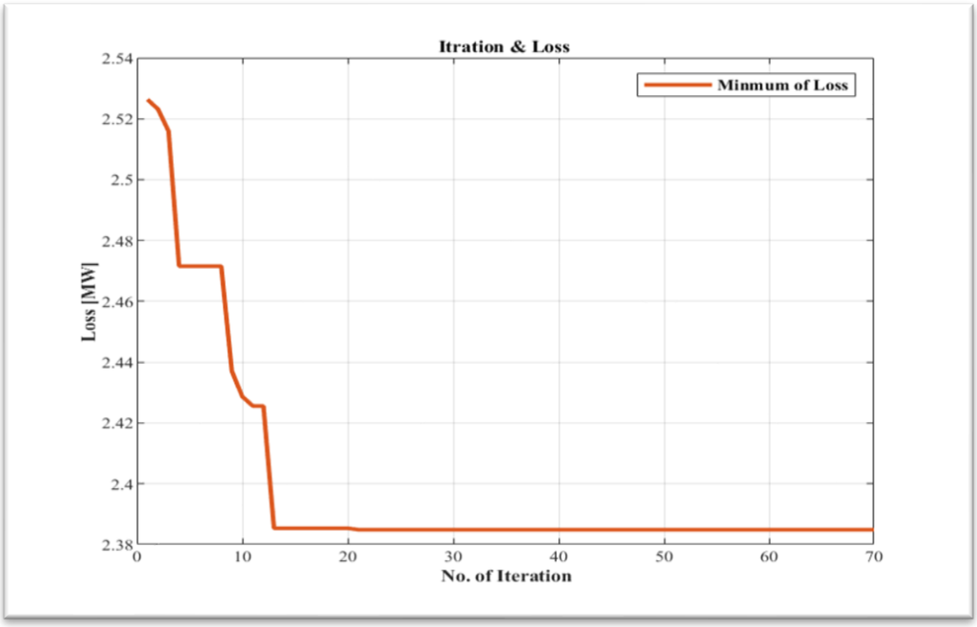

Figure 6: Losses on IEEE 30 Bus with DG

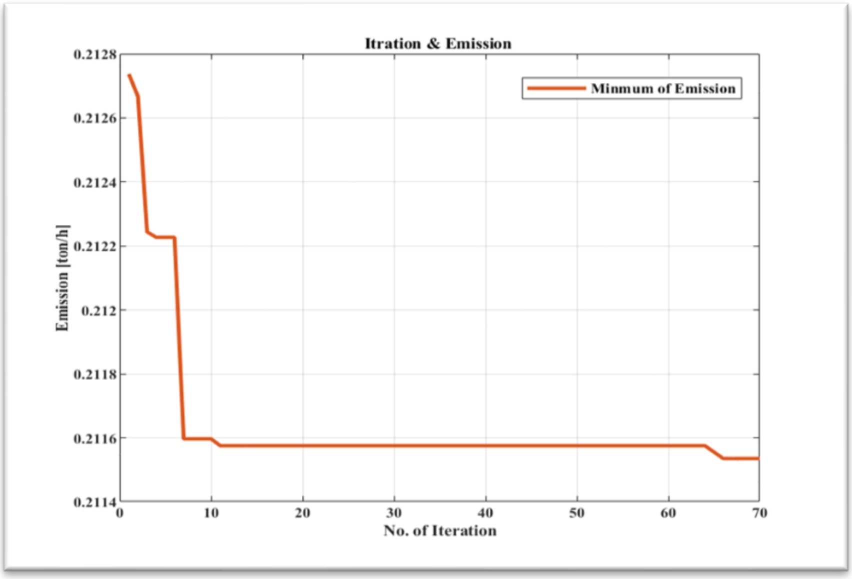

Figure 7 : the emission on IEEE 30 bus with DG

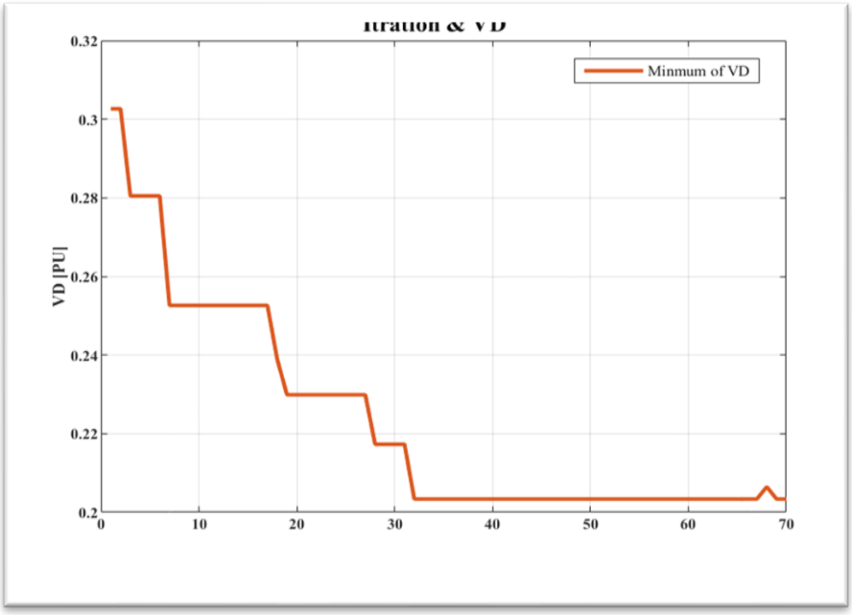

Figure 8 : voltage variation on IEEE 30 bus with DG

Case 2: INCREASE LAOD ON IEEE 30 BUS

The electricity demand is seeing a substantial annual increase as a result of the transition towards the electrical conversion of transportation, the rising level of electricity usage in households due to the utilization of electricity-intensive appliances like heating system and air conditioning, and the expanding populace. That will exert additional strain on the power network's structure and suppliers of energy. Currently, distribution network operators are confronted with a significant challenge: the rising demand for electricity, which can result in power outages and an inability to meet the required load demand. Figures [10-13] show the objective function for OPF with DG on IEEE 30 BUS network in case increase load

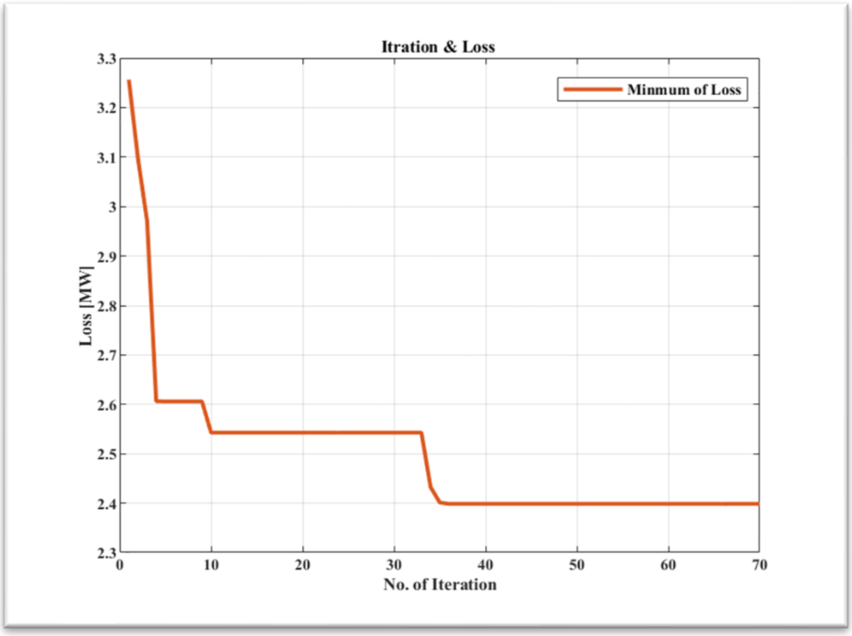

Figure 9: losses on IEEE 30 bus with DG

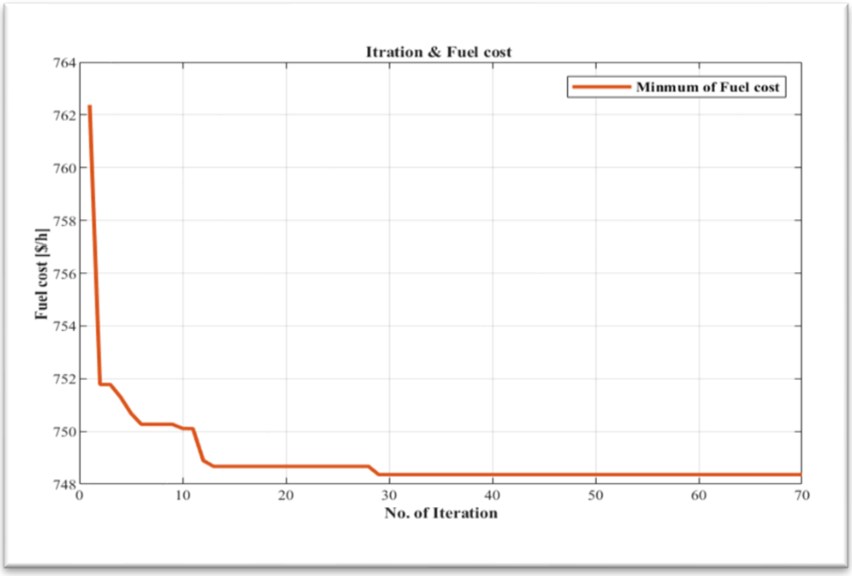

Figure 10: fuel cost on IEEE 30 with DG

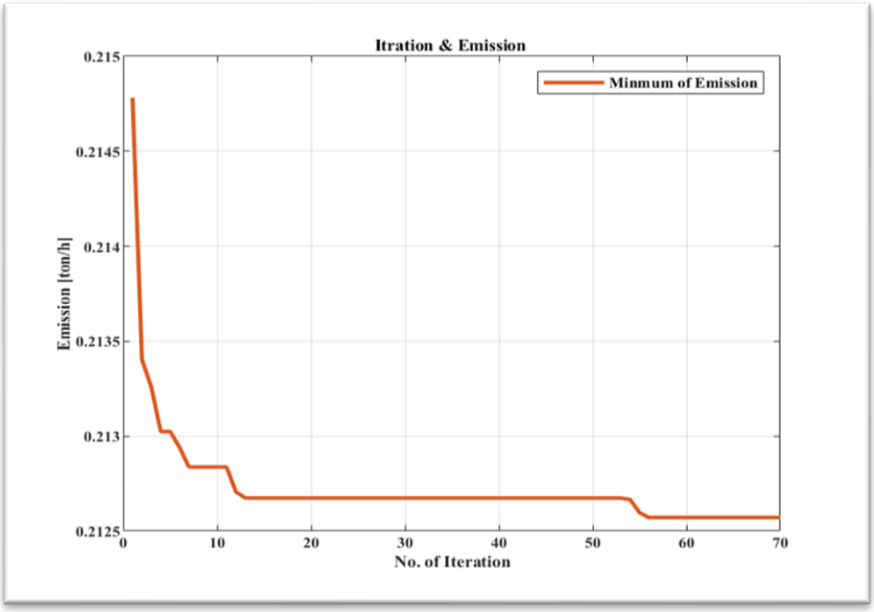

Figure 11: the emission on IEEE 30 bus with DG

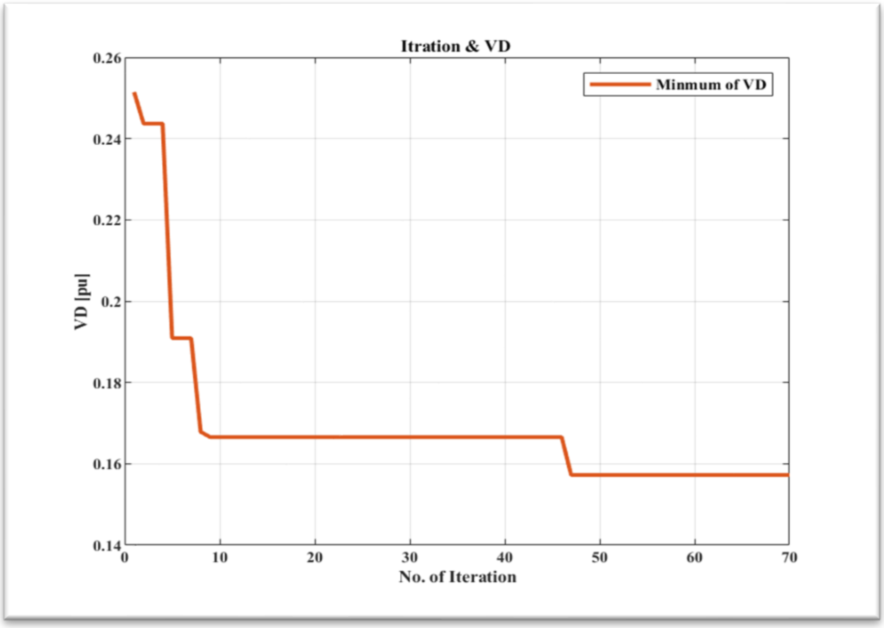

Figure 12: voltage deviation on IEEE 30 bus with DG

Case 3: OUTAGES OF TRANSMISSION LINES:

After the lifting of the weaker transmission lines from the network, the results of objective function for OPF are below in figures [14-17]

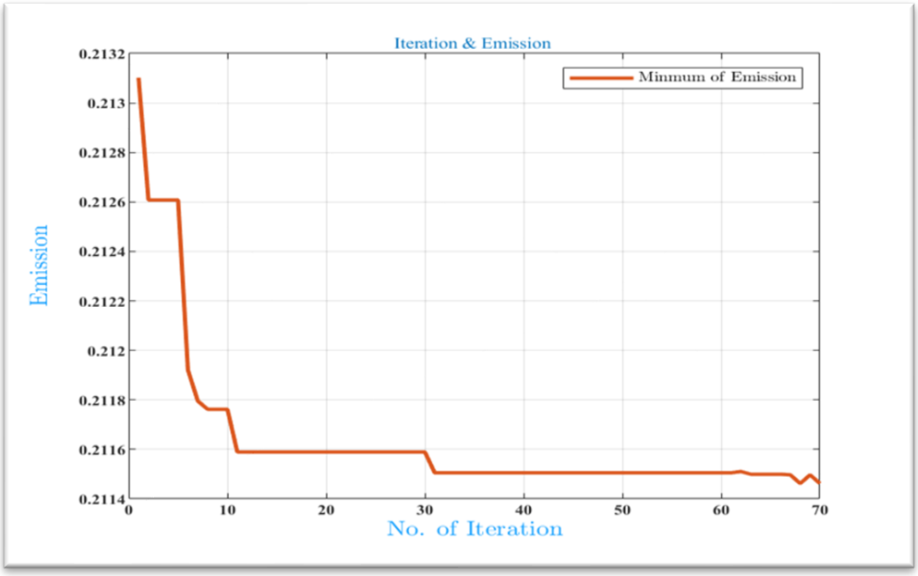

Figure13: the   Emission on IEEE 30 bus with DG

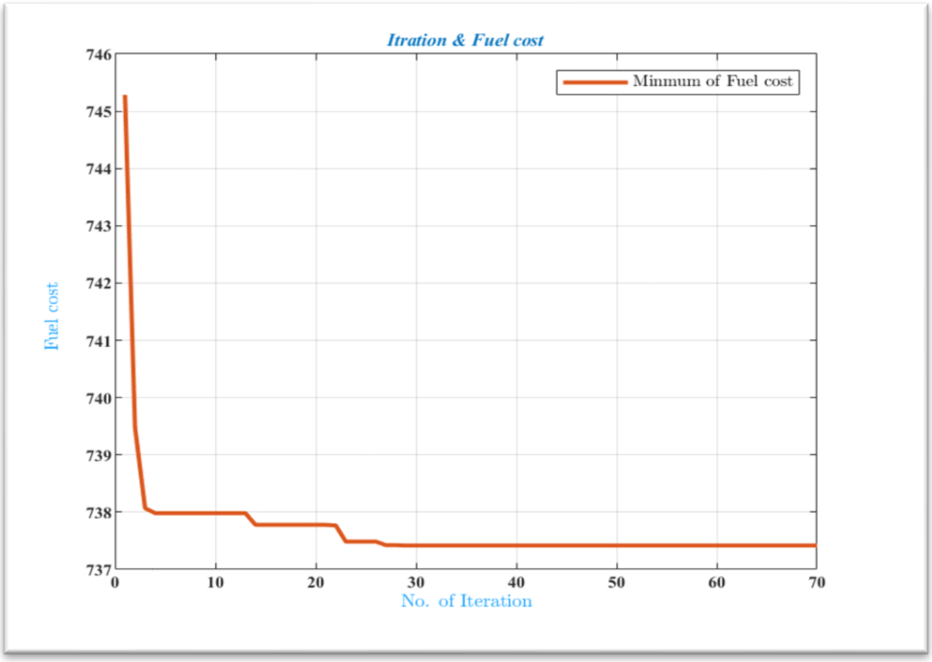

Figure 14: the fuel cost on IEEE 30 bus with DG

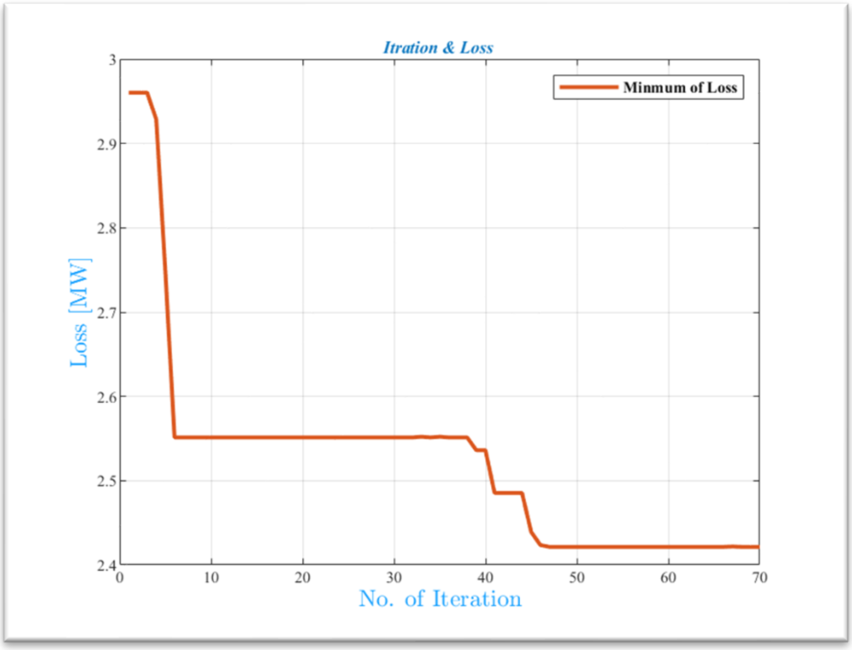

Figure 15: the losses on IEEE 30 bus with DG

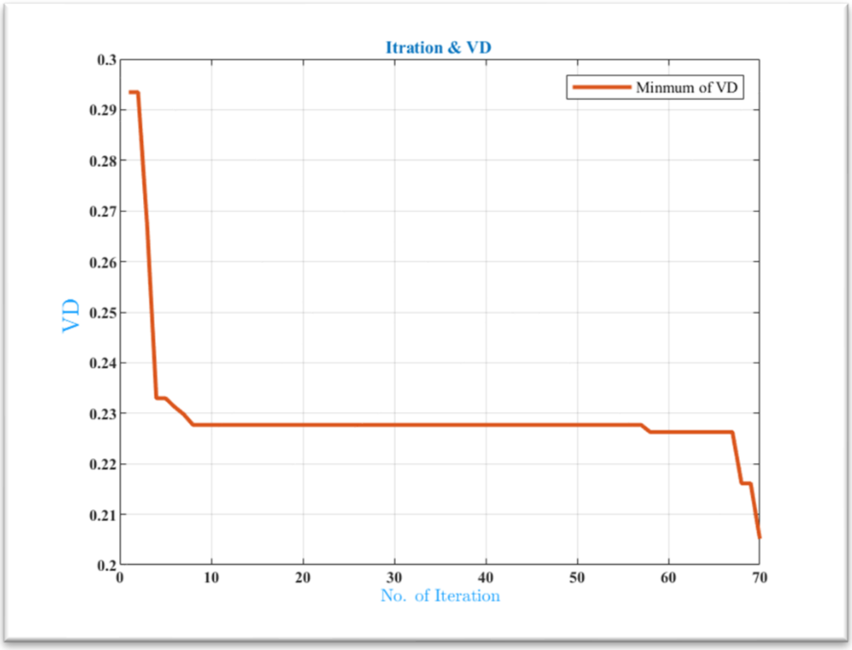

Figure 16: the voltage varaition on IEEE 30 bus with DG

After applying the cases and extracting the results for each case, the results were compared for each objective function (fuel cost, emissions, losses and voltage deviation) as shown below in table 3

Table 3: Comparison of the objective function's values across all cases

Objective Function	Case 1	Case 2	Case 3
Fuel cost ($/h)	755.3037	794.317	763.7927
Active power losses (MW)	6.202258	5.933206	7.96197
Emission (ton/h)	0.225056	0.225139	0.218504
VD (p.u)	0.985978	0.885512	1.184657

Normal OPF: Represents the fundamental level of performance achieved through the optimization of the emission levels, voltage profiles, cost of fuel, electrical losses, and voltage variations.

Increased Load: Demonstrates the consequences of more demand, resulting in elevated fuel expenses, emission levels, power losses, and voltages deviations. However, optimization still yields enhancements compared to scenarios that are not optimized.

Transmission line outages demonstrate the fluctuation and potential difficulties in maintaining ideal performance owing to interruptions, resulting in increased costs, emission levels, losses, and deviations relative to the standard optimal power flow scenario.

These comparisons emphasize the significance of employing robust optimization techniques such as Bat Algorithm (BA) for effectively and Particle Swarm Optimization (PSO) controlling various scenarios and ensuring efficient, stable, and economical operations of power networks.

b. DISCUSSION

An efficient control of power solution has emerged as a crucial tool for creating a cost-efficient and eco-friendly power distribution network. Due to the scarcity of research on the application of metaheuristic algorithms to OPF problems. This article offering the introduction of a new optimization algorithm named the bat algorithm (BA). The purpose of this algorithm is to explain multi-objective problems related to (OPF) that involve the integration of (DG) using PSO algorithm. The main objectives of this algorithm are to improve the energy efficacy, environmental performance, and cost effectiveness of the power network. Building a cost-in effect and ecologically friendly power source grid requires an essential power management system. There is a scarcity of research on the application of metaheuristic algorithms for (OPF) issues. To tackle multi objectives OPF issues involving (DG), the bat algorithm (BA) has been introduced. The study focused on the OPF difficulties and identified lost power, fuel operational costs, and deviations in voltage as the primary objective functions. The implementation of bat algorithms is intended to optimize energy efficiency, minimize environmental impact, and improve cost effectiveness in the power network. To address the issues presented by OPF, a range of scenarios were examined, encompassing varied locations for distributed generation (DG), levels of load growth, and intermittent breakdowns of transmission lines. The study conducted experiments on different scenarios in order to tackle the difficulties associated with (OPF) concerns. The scenarios encompassed various placements for (DG) throughout the network. Different levels of load growth were implemented to evaluate the effect on the power control method. The suggested OPF technique was evaluated for its robustness by simulating occasional breaks of transmission lines. These scenarios were crucial for comprehending and enhancing energy efficacy, conservational consequences, cost-efficiency of the power grid.

5. CONCLUSIONS

OPF is a process that seeks to improve the distribution generators on the power system, considering both operational and economic limitations. This is achieved by allocating the workload among the generators in a manner that minimizes the overall cost, while ensuring that the effort levels remain below acceptable bounds and do not exceed the capacity of the transit lines. Additionally, it aims to enhance the capacity factor. When there is an increase in the online load, it is necessary to recalculate the (OPF) in demand to handle this increase. Additional generators may be necessary to run or boost the production of the existing generator. They may also be needed to redirect energy flows, transfer loads to prevent overloading on transmission lines, and make alterations to the attempt control system. When a section of the transmission line is removed from service, there is a notable alteration within distribution for flows on the overall network. It is necessary to reroute the energy flowing through the remaining lines, redistribute generator production to prevent overloading, potentially experience considerable changes in effort levels, and minimize some loads in order to maintain system stability. When integrating distributed generation (DG) into the system, the (OPF) strategy seeks to leverage DG to enhance system efficiency by minimizing transmission losses, optimizing workload distribution, and enhancing system resilience. The management of the energy flow from the distributed generation (DG) is likewise handled in the opposite direction. When there is an increase in pregnancies or a rise in a transmission line, Distributed Generation (DG) can be utilized to offset the decrease in transport capacity and alleviate strain on the remaining lines. The existence of distributed generation (DG) presents more difficulties, including the need to predict its production, handle the inverse flow of energy, address its effects on safety measures, and coordinate control across the units of DG and central generators.

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