Dynamic Analysis of AC-DC Microgrid with Aid of Golden Search with Flower Pollination Algorithm

Mythili S (drmythilisece@gmail.com)
Periyar University
Narasimhulu N
Srinivasa Ramanujan Institute of Technology

Research Article

Keywords: optimal power flow, cost function, power loss, DC microgrid, AC microgrid, golden search algorithm and stability.

Posted Date: October 25th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-823217/v1

Dynamic Analysis of AC-DC microgrid with aid of Golden search with Flower Pollination Algorithm

[1]*Dr. S. Mythili, [2]N. Narasimhulu

[1]*Electronics and Communication Engineering, Periyar University,

Palkalai Nagar, Salem, Tamil Nadu 636011.

drmythilisece@gmail.com

[2]Assistant Professor, Department of Electrical and Electronics Engineering,

Srinivasa Ramanujan Institute of Technology (Autonomous), Ananthapuramu-515701.

narasimhulun2014@gmail.com

Abstract: In recent years, the power system stability enhancement and power flow analysis are essential task in AC-DC microgrid system. Hence, in this paper, Golden Search-based Flower Pollination Algorithm (GSFPA) to solve the optimal power flow invention in AC-DC microgrid system. In the projected methodology, the objective functions are framed to enable the optimal power flow in microgrid system such as total cost of generation in AC as well as DC systems and cost of active power transmission to DC grid from AC microgrid. The objective functions are related with the constraints such as AC-DC power electronics converters limits, power flows and voltage magnitude limits. Additionally, power loss and voltage deviation of the microgrid system also reduced which enhance the system performance. The proposed methodology is utilized to select optimal control parameters for enabling the stable operation of microgrid system. The proposed methodology is validated by using IEEE 30 bus system which associated with 9-bus DC microgrids and 6-bus DC microgrids. The projected method is applied in MATLAB and performances are analyzed with normal as well as contingency conditions. The projected method is contrasted with the conventional methods such as Flower Pollination Algorithm (FPA), chaos based FPA (CFPA) and Levy Flight based Black Widow Optimization (LF-BWO) respectively.

Keywords: *optimal power flow, cost function, power loss, DC microgrid, AC microgrid, golden search algorithm and stability.*

1. Introduction

In recent years, DC microgrids has been gained a lot of concepts in the electricity grid as a wonderful way to integrate the distributed generation [1]. Normally, these autonomous systems can be related as solitary objects to the general distribution networks [2]. This microgrids have a variety of innovations, for example, photovoltaic structures [3] and wind generators and they work in conjunction with power devices [4], batteries in addition conventional high-pass synchronous generators [5]. The OPF is an excellent process aimed at regulating in addition operating a force structure question to various operational in addition organizational constraints. The ideal key stream contains a set of conditions depicting the power structure [6]. It changes the control factors to advance a specific target function.

Power system, level is normally addressed through state factors in addition autonomous parameters. Control factors can be any free factor in structure and are chosen depending on the reason for the choice. Safety Control OPF (SCOPF) is an all-encompassing OPF type that additionally covers the security requirements of the electrical system. Censorship of different SCOPF research works is found in [7]. In addition, the reliability of the voltage perspective is important in the safety choices of the thinking power system organization and operation. Estimation of the severity of voltage strength problems has been proposed using different execution records [8]. These codes can be used on-line or disconnected to determine the structure's proximity to a voltage break. In addition to the base individual value a standard voltage reliability report is used for voltage breakdown estimation [9-10]. This index can be estimated utilizing a power current of Jacobian, and is usually nil at the voltage break opinion. The downside of file can be which requires proper subgroups during regulatory interactions, which can trigger merger issues.

The load demands given in the OPF test include the processing of line flows and bus voltages in electric power networks. Different strategies have been proposed for the electrical current study of various kinds of electrical systems based on their properties. Most of them are derived from the Newton-Robson (NR) [14,15] methods, whereas others depend on essential electrical circuit theory. To determine the problem, Aptalogies et al. The three-level model of the OPF problem is proposed in [11] as the squarest streamlining problem, which adapts to the true properties of island MGs. The authors of [12] presented an in-point-based force stream approach intended to adjusted island-made microgrids, where the power flow develops into COP. Nevertheless, this calculation is subject to a reasonable framework. As a result, this calculation can rarely be used in OPF investigations because allocation structures are inherent in nature. In [13], the Newton-Trust region (NTR) calculation can be used to resolve the comprehensive minimum square progress issue. Although NTR's union can be superior to different ordinary practices, it touches deeply into the basic arrangement.

The remaining part of the paper is rearranged as follows. Section 2 given the existing work analysis of OPF in microgrid system. Section 3 provides the brief description of the proposed OPF in microgrid structure. The presented algorithm is explained in section 4. The result and discussion of the proposed method is explained in section 5. The conclusion of the paper is presented in section 6.

2. Literature Review

Many different kinds of methods are available to achieve optimal power flow in microgrid system. Some of the methods are reviewed in this section.

J. Jitendranath *et al.,* [16] have introduced the Point Estimate Method (PEM) to monitor the vulnerabilities for addressing the probabilistic-optimal power flow problem (POPF) with various objectives planned on the island microgrid. J. Jitendra Nath *et al.* [17] have presented technique goes towards optimizing the transmission practice of each DG in the microgrid by optimizing the hang borders on the transmissible DGs. Places considered vary in voltage profile from generation cost, discharge and similarity. Another variant of Multi-Object Particle Swarm Optimization (MOPSO) with Nonlinear Time Variation (NLTV) is all that has been mentioned since the introduction of NLTV-MOPSO to deal with the comprehensive problem Including things. Abhishek Kumar *et al.,* [18] have presented droop Controlled Island Microgrid. To solve the introduced constrained optimization problem (COP), DENGM (Epsilon-based differential evolution with Newton-Gas-based transformation) was proposed.

Abhishek Kumar *et al.,* [19] have introduced a direct non-linear of the standard state model of DGs. Furthermore, the reverse free PF calculation based on the enhanced Newton- Traub composition (INTC) was developed to deal with the PF issues of grid-related and island-made MGs. Strategy. Evangelos E. Pompodakis *et al.,* [20] provided precise power flow algorithms for island hybrid AC / DC microgrids (HMGs). A case study on a large 1024-bus island HMG further illustrates the excellent accuracy and computational efficiency of the approach provided against other existing electric flow methods.

3. System Model

The proposed system main objective function is maintaining the power flow management in AC-DC grid. The AC-DC gird system model can be presented in this section. The AC-DC grid contains of AC grid connected to a set of DC microgrid which formulated as follows,

$$M = \{1, \dots . |M|\} \tag{1}$$

The AC grid structure can be mathematically characterized through below,

$$O^{AC}(N^{AC} L^{AC}) \tag{2}$$

Where, $N^{AC} = \{1, \dots, |N^{AC}|\}$, L^{AC} can be described as groups of AC grid transmission lines and buses respectively. Similarly, the DC microgrid system is mathematically formulated as follows,

$$m \in M; \quad O_M^{DC}(N_M^{DC}, L_M^{DC}) \tag{3}$$

Where, L_M^{DC} can be described sets of lines in addition buses in DC microgrid. The microgrid structure is operated with the consideration of DC bus and converter operating power factor angel associated among AC bus. The converter can be utilized to changes AC voltage to DC voltage related on below equation,

$$V_S^m = K^1 A_{R,S}^m |V^R| \cos(\phi_{R,S}^m) \tag{4}$$

Where, $\phi_{R,S}^m$ can be described as power factor angle, $A_{R,S}^m$ can be described as transformer tap, DC level voltage is denoted by V_S^m, V^R can be described AC voltage,$|.|$ Is described as voltage magnitude, $K^1 = \frac{3\sqrt{2}}{\pi}$ can be considered as constant. To analysis purpose, the AC-DC converter losses are omitted, so the converter operating efficiency can be increase 90% variety. With the help of converter, the active power movement to DC bus from AC bus in DC microgrid. The power flow direction is computed with the consideration of operating point of DC microgrid and AC microgrid and four quadrant AC-DC converter such as pulse width modulation-controlled voltage source converter can be expected. This power flow is also acting as a controllable AC side reactive power consumption [21]. This four-quadrant converter can absorb and inject reactive power to improve stability, power factor in addition voltage regulation in AC grid. The converter power factor can be computed with the consideration of reactive and active powers which mathematically formulated as follows,

$$\cos(\phi_{R,S}^m) = \frac{P_{R,S}^m}{\sqrt{(P_{R,S}^m)^2 + (Q_{R,S}^m)^2}} \tag{5}$$

Where, $P_{R,S}^m$ can be described as real power of microgrid, $Q_{R,S}^m$ can be described as reactive power of microgrid, the upper bound of current amplitude can be changed through the maxiumum apparent power flow as the process constraint, the variations in the voltage magnitudes can be omitted in power grids. Additionaly, converter current amplitude can be a upper constraints. The AC bus apparent power flow is mathematically presented follows,

$$|S_{R,S}^{m}| = \sqrt{\left(P_{R,S}^{m}\right)^2 + \left(Q_{R,S}^{m}\right)^2} \leq S_{R,S}^{m,max} \quad (6)$$

Where, $S_{R,S}^{m}$ can be described as apparent power of microgrid, $S_{R,S}^{m,max}$ can be described as maximum power of apparent power. The general structure of the AC-DC microgrid is illustrated in figure 1.

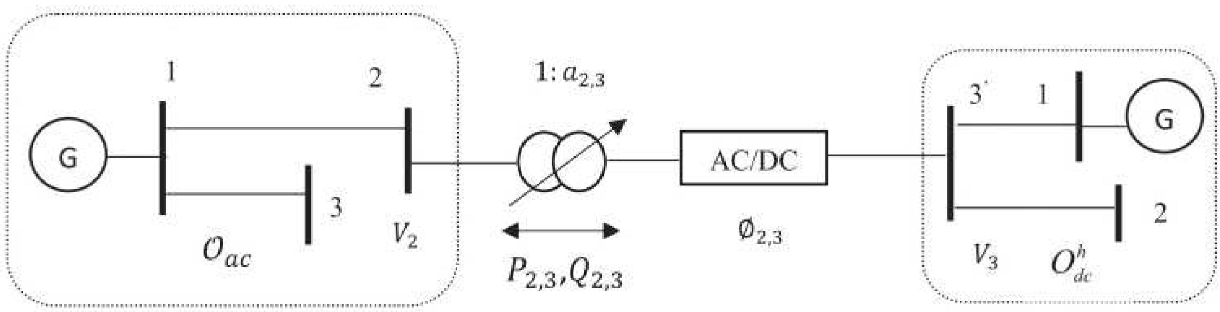


Figure. 1 AC-DC microgrid structure

From the figure 1, the AC grid linking toward a DC microgrdi through AC-DC converters among DC bus 3 in addition AC bus 2 in microgrid. The parameters are power angle, real power and reactive power represented as the converter parameter which computed in the AC-DC OPF. In microgrid system, transformer tap parameter is known. The power factor of the microgrid is computed based on equation (2).

3.1. Equivalent AC grid of AC-DC microgrids

Key motive of AC-DC optimal power flow can be to reduce the objective function like cost of related power transmission DC grid to AC grid in addition cost production in combined AC grid in addition DC microgrid related to network constraints, operating cnstraints and remaining constraints executed through the converters [22]. The correlation among voltage of microgrid of DC, kinds the non-linear issue aimed at the AC-DC microgrids.and AC grid bus voltage. The equivalent circuit model of the AC-DC microgrid is illustrated in figure 2.

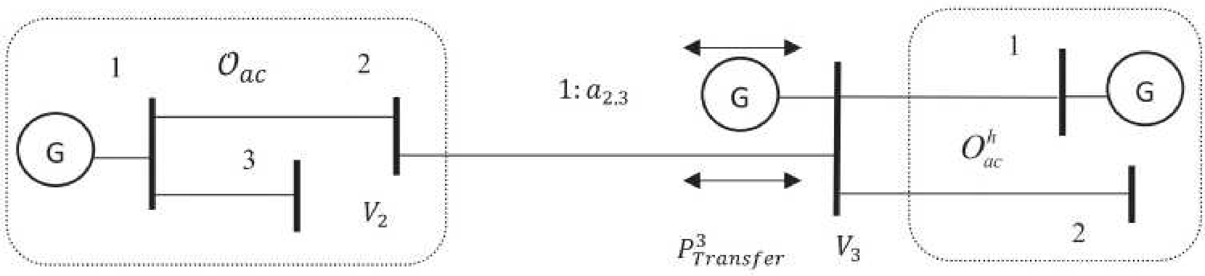


Figure. 2 The equivalent AC grid of normal AC-DC network

Here, consider a converter among DC bus and AC bus of DC microgrid. Intially, to remove the addiction of voltage magnitudes of DC and AC, S and R buses are joined towards design a novel bus. Towards this generator, reactive output power can be added in the bua and model of the conveter recompense characteristics. At last, the DC microgrid lines can be changed with individual resistive components. Additionaly, loads in addition DC sources with the consideration of system real power. The DC microgrids is expected as AC microgrids through active loads, active power outputs, generators and resistive transmission lines. Here, the DC microgrids are consdiered without loss of generality.The AC microgrid which related to DC microgrid. Nowadays, the DC microgrids are associated with the AC grid straight in the structure subsequently calculating the abovementioned procedures for complete converters. So, the equivalent AC grid can be designed containing of the AC grid and the AC microgrid.

3.2. Probelm formulation and objective function of AC-DC in microgrid

The major objective of the optimal power flow can be improve a specific objective topic relevant towards many inequality and equality constraints. The scientific representation of the optimal power flow in microgrid is formulated as follows,

$$Min\ Objective\ function\ (X.U) \tag{7}$$

This objective function is subject to,

$$G(X,U)=0 \tag{8}$$

$$m^{MIN} \leq m(X,U) \leq m^{MAX} \tag{9}$$

Where, U can be represented as vecctor control variables, shunt reactive power compensators (Q^{ck}), settings of tap changing transformers (T^{K}), voltage magnitude $(|V^{GN}|)$ in addition generator real power outputs (P^{GN}) beacsue of volt-amperes reactive (VAR) compensations, (V^{I},δ^{I}) can be described as load bus voltage magnitudes in addition load bus phase angels, (Q^{G}) can be described as generator reactive power outputs, x, P^{G} can be described as vector state varaibles of a power system network which consists the real power output of slack bus. The control parameters are mathematically formulated as follows,

$$U=[P^{G2},\dots,P^{GN},V^{G1},\dots,V^{GN},T^{1},\dots,T^{NT},Q^{C1},\dots,Q^{CS}\ ] \tag{10}$$

Where, CS can be described as count of shunt reactive power injections, NT can be described as number of tap changing transformers and N can be described as number of generator buses respectively. The objetive notation of the OPF issue in equivalent AC grid contains transfering power cost in DC grid in addition AC grid and, generation cost in DC grid in addition AC grid. The OPF issues in AC grid objective function is mathematically presented follows,

$$Objectie\ Function = MIN\text{: } \sum_{K=1}^{NG} F(P^{GK}) + \sum_{R=1}^{NR} F(P^{GR}) + \sum_{J\in JCON} \omega^{J} V^{J} P^{J}_{TRANSFER} \tag{11}$$

Where, Q^{GR} can be represented as reactive powers, P^{GK} can be described as active power in bus $K \in N^{equ}$. P^{DK} can be represented as active load, Q^{DK} can be represented as reactive load and I^K can be represented as injected current and V^K can be represented as load in bus $K \epsilon N^{equ}$. The generation cost functions of AC grid and DC grid is denoted by $F(P^{GK})$ and $F(P^{GR})$. V^J and $P^J_{TRANSFER}$ can be described as price from equivalent converter bus and transferred power of converter bus $J \in j^{con}$. ω^J can be described as weighting coefficients. The objective functions are related with different constraints which presented follows,

$$P^{GK} - P^{DK} = Re\{V^k, I^K_{ref}\}, \ \forall K \epsilon N^{equ} \tag{12}$$

$$Q^{GK} - Q^{DK} = Im\{V^k, I^K_{ref}\}, \ \forall K \epsilon N^{equ} \tag{13}$$

$$P^J_{TRANSFER} = \sum P^m_{S,J} \ \forall K \epsilon NJ^{equ} \tag{14}$$

$$P^{MIN}_K \leq P^{GK} \leq P^{MAX}_K \quad \forall K \epsilon N^{equ} \tag{15}$$

$$Q^{MIN}_K \leq Q^{GK} \leq Q^{MAX}_K \quad \forall K \epsilon N^{equ} \tag{16}$$

$$V^{MIN}_K \leq V^K \leq V^{MAX}_K \quad \forall K \epsilon N^{equ} \tag{17}$$

$$|S^{LM}| \leq S^{MAX}_{LM} \quad \forall K \epsilon L^{equ} \tag{18}$$

$$T^{MIN}_I \leq T^I \leq T^{MAX}_K \quad I = 1, .., NT \tag{19}$$

$$Q^{MIN}_{CI} \leq Q^{CI} \leq Q^{MAX}_C \quad I = 1, .., CS \tag{20}$$

$$L^J \leq L^{MAX} \quad J = NG + 1, \dots, NB \tag{21}$$

Where, $V^{MAX}_K, V^{MIN}_K, Q^{MAX}_K, Q^{MIN}_K, P^{MIN}_K, P^{MAX}_K$ can be represented as bus voltage, reactive power, upper bounds of generator active power and, lower bound of active power at bus k respectively. The maximum apparent power of the line is denoted by S^{LM}.The main objective of the work is reduce the over all flowing active powers, reactive output power of generators, active output power of the generators, magnitudes and voltage phases. The constraints should be met by the system. The power balance constraints are presented in equation 12 and 13. The input power to the equivalent converter bus is identical power flow of the bus which illustrated in equation 14. The operation constraints are mentioned in equation 15-20. The voltage stability index of the load bus, equivalent converter byses, apparent power flowing in the transmission lines, voltage magnitude and generator output power is mentioned in the equation 21.

4. Proposed Control strategy

In this work, the optimal control parameters are computed with the help of golden search-based FPA. The proposed algorithm is utilized to solve the problems by providing optimal control parameters with the consideration of objective function. With the help of the proposed algorithm, the optimal control parameters are achieved which enabling the system stable and reliable operation in microgrid. The proposed algorithm is a combination of FPA and a golden search algorithm. The golden search algorithm is utilized to enable the efficient operation of FPA in the DG placement allocation. The specific characteristics of golden search-based FPA are presented in this section.

4.1. Process of Flower Pollination Algorithm

FPA can be stimulated by the process of flow pollination of flowering plants [23]. FPA can be utilized towards solve optimization problems. To formulate the updating functions in FPA, four mentioned guidelines are changed into proper updating calculations. In the global pollination process, flower pollen is approved with the assistance of pollinators lick as insects. Additionally, the pollen can move over long-distance due bugs can move or fly in a much longer range. Hence, regulation 1 can be mathematically formulated as follows,

$$X_I^{T+1} = X_I^T + \gamma\, L(\lambda)(g^* - X_I^T) \tag{22}$$

Where, $L(\lambda)$ can be described as a parameter specially levy flight within step size which related to pollination strength, γ can be denoted as scaling factor which utilized to control step size, g^* can be considered as a current optimal solution from complete answers at the current iteration/generation and X_I^T can be mentioned as pollen I or solution vector X_I at iteration T.

In the FPA, insect's mayfly and move towards a long distance with various distance steps. The moving scenario is named levy flight which is utilized to mimic the moving characteristic optimally. Hence, $L > 0$ is considered as levy distribution which formulated as follows,

$$L \sim \frac{\lambda \Gamma(\lambda) \sin\left(\frac{\pi\lambda}{2}\right)}{\pi} \frac{1}{M^{1+\lambda}}, \qquad (M \gg M_0 > 0) \tag{23}$$

Where standard gamma function is denoted as $\Gamma(\lambda)$ in addition this distribution function is legal in large process $M > 0$. In algorithm, which is needed that $|M_0| \gg 0$ then in real-time which considered very minor as 0.1 respectively [24]. Moreover, it is not participating to create pseudo random step sizes which surely concern this levy distribution function (8). From that, the Mantegna algorithm is an efficient one which utilized to drawing step size with the gaussian distributions O and P through the below transformation.

$$M = \frac{O}{|P|^{\frac{1}{\lambda}}}, \quad O \sim N(O, \sigma^2), \qquad P \sim N(0,1) \tag{24}$$

Where, $O \sim N(O, \sigma^2)$ can be described as samples computed from a Gaussian normal distribution with a variance of σ^2 and zero mean. The variance is computed by the below equation,

$$\sigma^2 = \left[\frac{\Gamma(1+\lambda)}{\lambda\Gamma\left(\frac{(1+\lambda)}{2}\right)} \cdot \frac{\sin\left(\frac{\pi\lambda}{2}\right)}{2^{(\lambda-1)/2}}\right]^{\frac{1}{\lambda}} \tag{25}$$

The variant formula is complex, but it can be considered a persistent value for λ. For instance, the function constant value is considered as 1, the gamma function become $\Gamma(1+\lambda) = 1, \Gamma\left(\frac{(1+\lambda)}{2}\right) = 1$ and which presented follows,

$$\sigma^2 = \left[\frac{1}{1\times 1} \cdot \frac{\sin\left(\pi \times \frac{1}{2}\right)}{2^0}\right]^{\frac{1}{1}} = 1 \tag{26}$$

After that, local pollination can be considered and which collaborates with rule 2 in addition rule 3. The local pollination is mathematically presented as follows,

$$X_I^{T+1} = X_I^T + \epsilon\left(X_J^T - X_K^T\right) \tag{27}$$

Where, X_J^T and X_K^T can be described as dissimilar flowers of the similar plant classes. This completely imitators the flower faithfulness in an incomplete neighborhood. The same pieces or choose from a similar population, this equally a local random movement with uniform distribution in [0,1]. In the FPA, local pollination process is enhanced with the help of a global search algorithm. The detailed information of golden search algorithms is presented as follows.

4.2. Process of Golden Search Algorithm

This golden search method can be applied when the objective function is a uni-model condition. The method has preferable for computing objective functions that are not variations or difficult to differentiate. The main objective is finding minimum $F(X), X\epsilon R$, within the period $[l, u]$. Initially, in the golden search method, compute two points $X_1, X_2 \epsilon [l, u]$ which presented as,

$$C = \frac{-1+\sqrt{5}}{2} \tag{28}$$

$$X_1 = cl + (1-c)u \tag{29}$$

$$X_2 = cl + cu \tag{30}$$

After that, the objective function is computed with these mentioned points. If $f(X_1) < f(X_2)$, then optimal variants related to $[l, u]$. Otherwise, the optimal variants related to $[X_1, u]$. The search process is proceeding until the termination conditions are satisfied. From the above discussions, identify the search sections $[X_1, u]$ and $[l, u]$ in each iteration. After that, the next iterations are only depending on the selection process. Hence, it is required to two sections with the same width. Additionally, the larger section is considered repeatable in different conditions and the convergence speed is minimized [25]. So, the initial iteration of golden section search algorithms is computing minimum point within the interval $[l, u]$. The convergence rate can be optimally formulated as follows,

$$P + Q = Q + R \tag{31}$$

$$\frac{P}{Q} = \frac{R}{Q} = \frac{(Q+R)}{P} = \frac{1}{C} = \emptyset \tag{32}$$

Based on the above equations, the convergence rate is computed within several iterations. So, the golden search-based method is utilized to improve the performance of convergence progress. The golden search algorithm is also utilized in the local search enhancement progress. The detailed procedure of the proposed method is presented in the section.

4.3. Process of the proposed algorithm

The proposed algorithm GSFPA is designed to the best selection of control parameters in the microgrid for reducing the generation and transmission cost. The optimal selection of control parameter is selected with the consideration of the objective function of cost minimization. The proposed algorithm is a combination of FPA and the golden search method. In the FPA, the local pollination process is enhanced with the help of the golden search method. The worst balance among exploitation and exploration may provide the result of a weak optimization technique that affects stagnation, trapping in local optima, and premature convergence. To improve the global convergence and to avoid traps on a local solution of the FPA, the GSFPA is developed. In the proposed algorithms, the local pollination of the FPA is enhanced which presented as follows,

$$X_I^{T+1} = X_I^T + \epsilon\left(X_J^T - X_K^T\right) \tag{33}$$

Where ϵ can be considered as the scaling factor which depends on the value of X_1 and X_2 respectively. The generation of a new source is a black-box process that depends on the scale factor. The main motive is updating the scale factor and generation of solutions which related to a certain probability. The scale factor is the optimal one to select high-quality solutions. In the proposed algorithm, the local search of FPA is optimally processed with a computing scaling factor to achieve the best performance. This algorithm is concentrating to minimize the cost function of the power system. The golden section algorithm is a classical local search algorithm for achieving the fitness function of power loss minimization. The scale factor applies the golden section to create a high-quality solution. The method proceeds in the interval $[S = -1, T = 1]$ and generates two intermediate points which presented as follows,

$$\epsilon^1 = b - \frac{b-a}{c}; \epsilon^2 = a + \frac{b-a}{c} \tag{34}$$

The scaling factor is optimally selected with the help of a golden search algorithm. The combined process of the projected algorithm is demonstrated in figure 2. The main step of initialization and fitness evaluation is presented in this section.

Initialization phase:

The control variables of the issue are selected initially before utilization of proposed algorithm to resolve the AC-DC microgrid OPF problem. Hence, initially set of control variables are initialized which mathematically formulated as follows,

$$U^T = [P^{G2}, \ldots, P^G N^G, V^{G1}, \ldots, V^G N^G, T^{t1}, \ldots, T^{tNt}, Q^{C1}, \ldots, Q^{CNC}] \quad (35)$$

Where, Q^{C1} can be described as shunt reactive power injection, V^{G1} can be described as generator voltage magnitude, P^{G2} can be described as generator active power outputs, P^{GI} can be described as slack unit and U^T can be described as control parameters. The optimal assortment of the population size is usually related on the OPF issue. So, based on control variables, the population is selected. The population of the proposed methodology is presented in below equation,

$$N^P = 20C \quad (36)$$

Where, C can be described as control variables. From equation (21), shall perhaps be adequate and it can be complex to achieve the best control variables of microgrid system.

Fitness Evaluation Phase:

To compute each optimal solution, the fitness value can be computed counting the penalty function to compute the excellence of the individual, the mathematical formulation is presented follows,

$$F^I = \frac{1}{(f^I + K^q f^{qI} + K^v f^{vi} + K^s f^{si} + K^l f^{li})} \quad (37)$$

$$f^{qI} = \sum_{L=1}^{NG} \left(\left| Q^{gil} - Q_{gil}^{lim} \right| \right)^2 \quad (38)$$

$$f^{vI} = \sum_{L=1}^{NPQ} \left(\left| V^{pqil} - V_{pqil}^{lim} \right| \right)^2 \quad (39)$$

$$f^{sI} = \sum_{L=1}^{NL} \left(\left| S^{il} - S_{pqil}^{lim} \right| \right)^2 \quad (40)$$

$$f^{li} = \sum_{J=NG+1}^{NPQ} \left(\left| L^J - L^{lim} \right| \right)^2 \quad (41)$$

Where, f^{li} can be described as voltage violation index of individual I, f^{sI} can be described as desecration of line power of separate I, K^q and K^v can be described as penalty coefficients, Q^{gil} and Q_{gil}^{lim} can be described as generator reactive power, V^{pqil} and V_{pqil}^{lim} can be described as violated upper in addition of lower bounds of the voltages of the load buses, NPQ can be described as total count of PQ buses, f^{vI} and f^{qI} can be described as amount of the voltages and reactive power of PQ buses with normalized changes solutions of generators, F^I can be described as system generating fuel cost respectively.

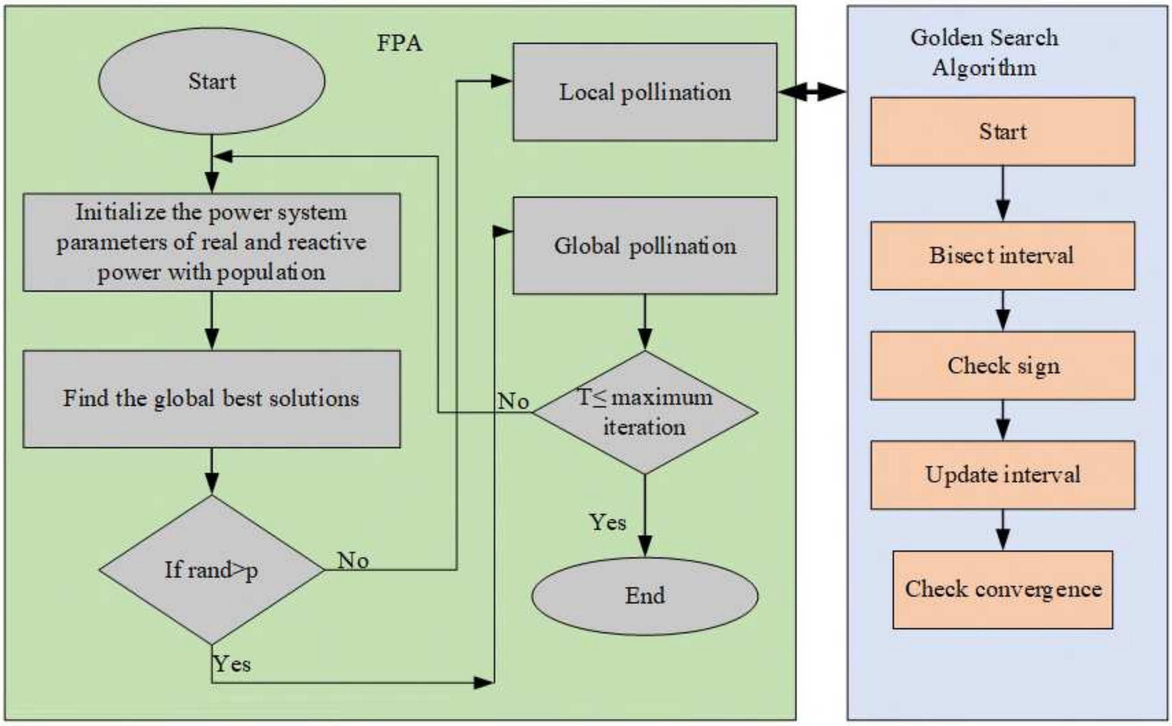


Figure. 3 Flow chart of the proposed algorithm

The FPA algorithm is processed with local pollination in addition global pollination. The local pollination is improved by optimizing the scaling factor which enabled the proper convergence operation and efficient solution. The proposed algorithm is providing the best control parameters in the power system that minimizes the generation cost and transmission cost of microgrid. The power loss reduction is enabling the proper stable operation in the power system. The reliability of the power system is also enabled with the consideration of the proposed algorithm through the optimal control parameters of microgrid. The presentation of the projected algorithm is presented as follows.

5. Performance Evaluation

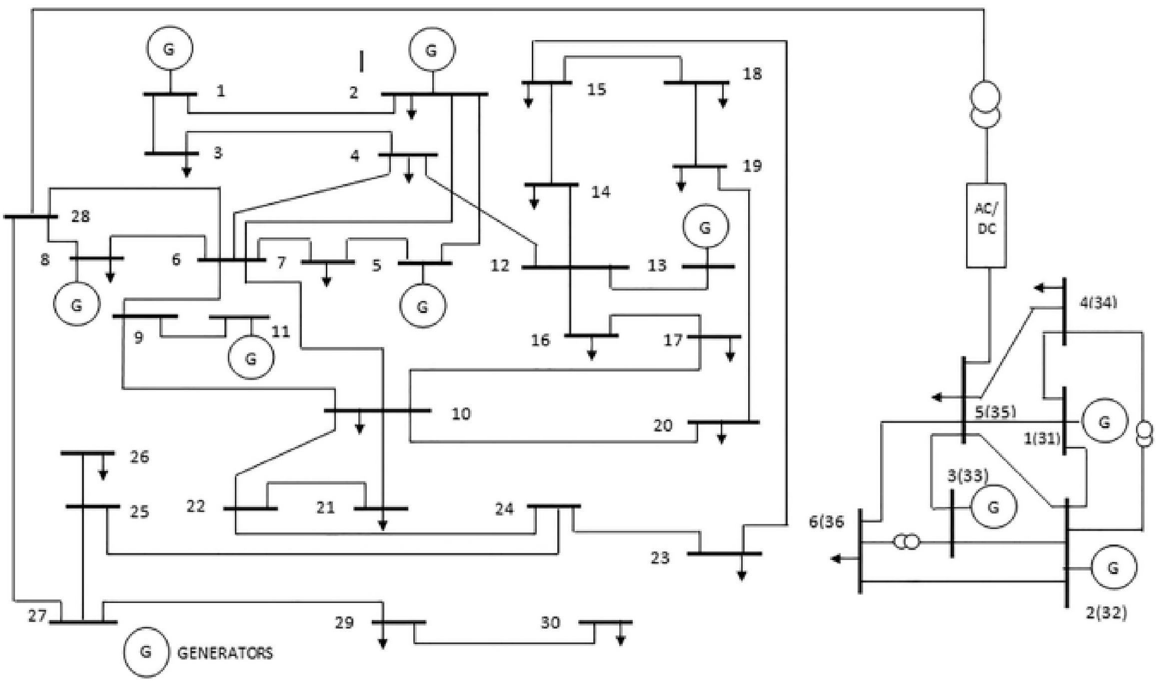
In this section, the projected technique is validated and justified in the section. The projected technique is executed in MATLAB and performances were evaluated. The proposed method is implemented on 32 GB of RAM and a 4GHz intel core i78 system. The proposed method is designed to enable the optimal power flow operation in microgrid system. This optimal control parameter is computing with the assistance of the projected approach. The proposed methodology can be utilized to finding optimal control parameters in microgrid system which completely enhance the power flow operation. The proposed method is compared with existing methods such as FPA and GSA. The proposed method's main objective is enabling stable operation by reducing the transmission cost of the microgrid. The proposed method is validated with the consideration of IEEE 30 bus system connected to 6 bus and 9 bus microgrid system which illustrated in figure 4. The implementation parameter of the proposed system is presented in table 1. The generator data and bus data of the test system is given in table 2.

Table. 1 Implementation parameters of the proposed method

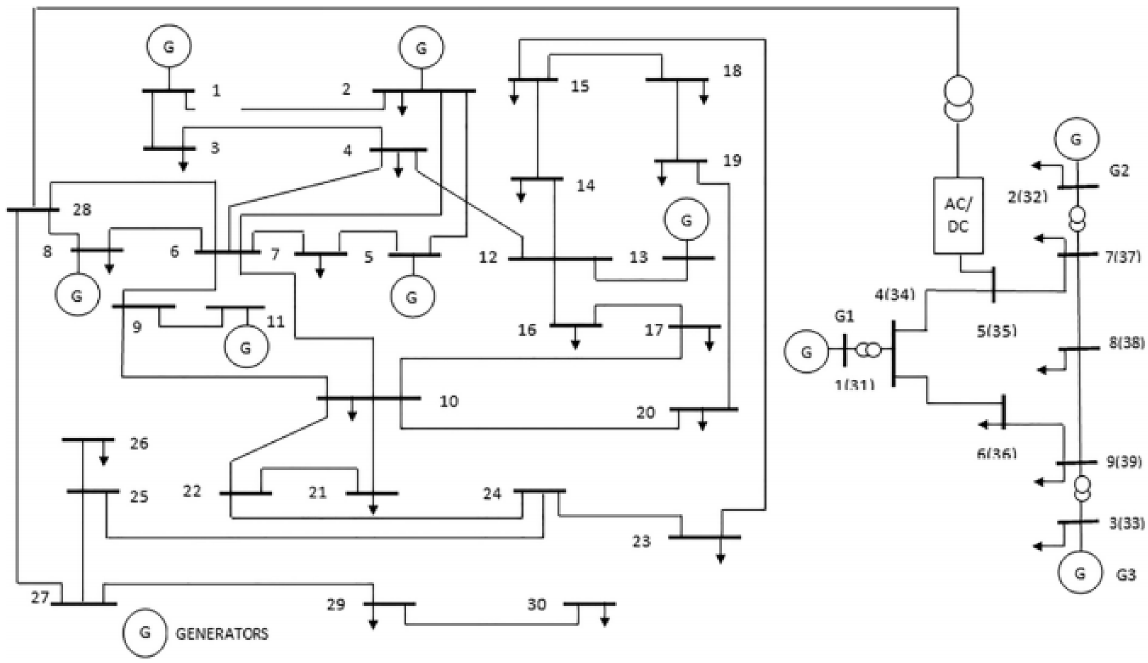
S. No	Description	Value
1	Population size	100
2	Number of iterations	100
3	Switching probability	0.8
4	Limit-Dimension	2
5	Lower bound	-100
6	Upper bound	100

Table. 2 Generator data and bus data of microgrid

S. No	DC-Micro grid	Unit	Cost coefficients			Generation Limits	
			A	B	C	PG (min)	PG (max)
1	9-Bus	PG1	0	130	0	0.50	1.25
2		PG2	0	110	0	0.50	1.25
3		PG3	0	60	0	0.50	1.25
4	6-Bus	PG1	0	60	0	0.02	0.07
5		PG2	0	110	0	0.02	0.07
6		PG3	0	130	0	0.02	0.07



(a)



(b)

Figure. 4 Analysis of IEEE 30 bus system (a) 6 bus microgrid and (b) 9 bus microgrid

Normally. the IEEE 30 bus system have a total demand is 283.4MW and 126.2MVAR. The bus system has the 41 lines and six generators. The fuel cost curves can be denoted by quadratic cost functions. The upper constraints of the voltage magnitude are 1.1. p.u in the generator buses such as 13,11,8,5 and 2. Similarly, lower voltage magnitude of buses is 0.5 p.u for all buses. The bus 1 is considered as slack bus. The tap changing transformer ranges is ∓10%. The tap changing connected locations are 28-27, 4-12, 6-10 and 6-. The shunt reactive power compensations can be consumed in the different buses such as 2,24,23,21,20,17,15 and 10. The bus data, lime data, MVA line flow limits, maximum constraints of real power generations, minimum constraints of real power generations and cost coefficients are gathered from the reference [26]. To authenticate the projected methodology, three different cases are analyzed which presented follows,

- **Case 1:** Connected with 6 bus system and resistive lines in DC microgrid-1 (contingency as well as normal condition)
- **Case 2:** Connected with 9 bus system and resistive lines in DC microgrid-2 (contingency as well as normal condition)

In this validation analysis, minimization of three different objective functions are considered aimed at resolving the OPF analysis. The objective functions can be cost related with the power transmission among the DC grid in addition AC grid, cost of sustainable sources in DC microgrid in addition quadratic fuel cost function of AC grid. These functions should be meet the equality in addition inequality constraints. Combined with the main functions, power loss in addition voltage deviations also analyzed. In the two cases, the 100 iterations are considered to achieve the optimal control parameters for enabling the optimal power flow operation in two conditions such as normal and contingency conditions. The network contingency is considered as outage of line at 3-4 buses. The proposed algorithm is designed to compute optimal control parameters for enabling the optimal power flow operation.

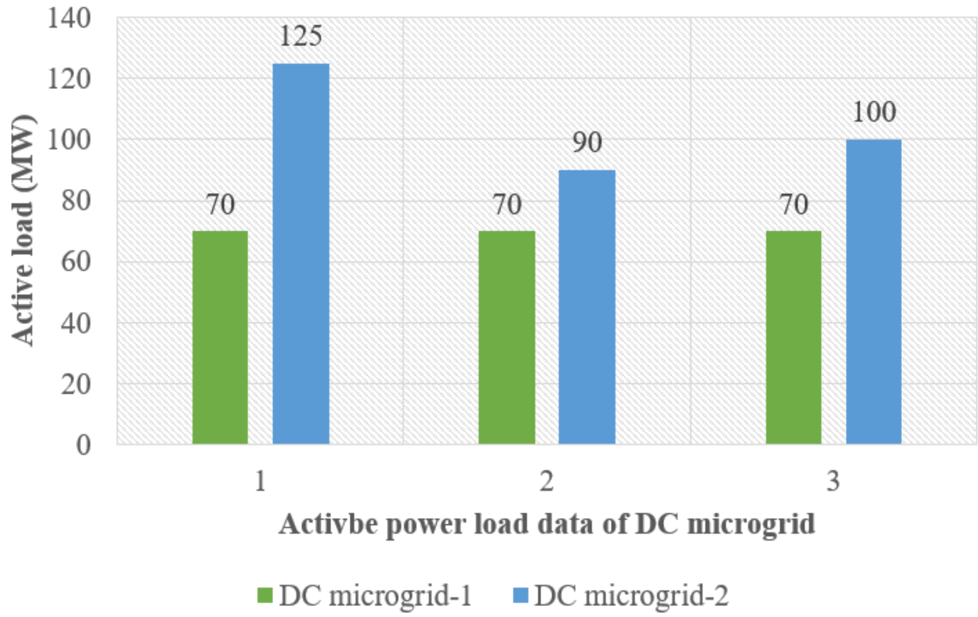


Figure. 5 Analysis of active power load data of DC microgrid

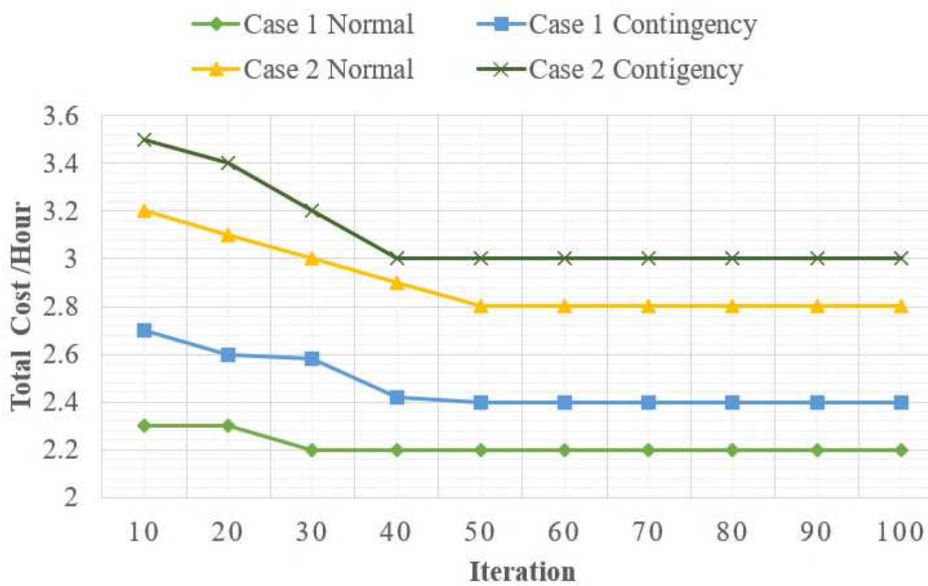


Figure. 6 Analysis of convergence in total cost of IEEE 30 bus system

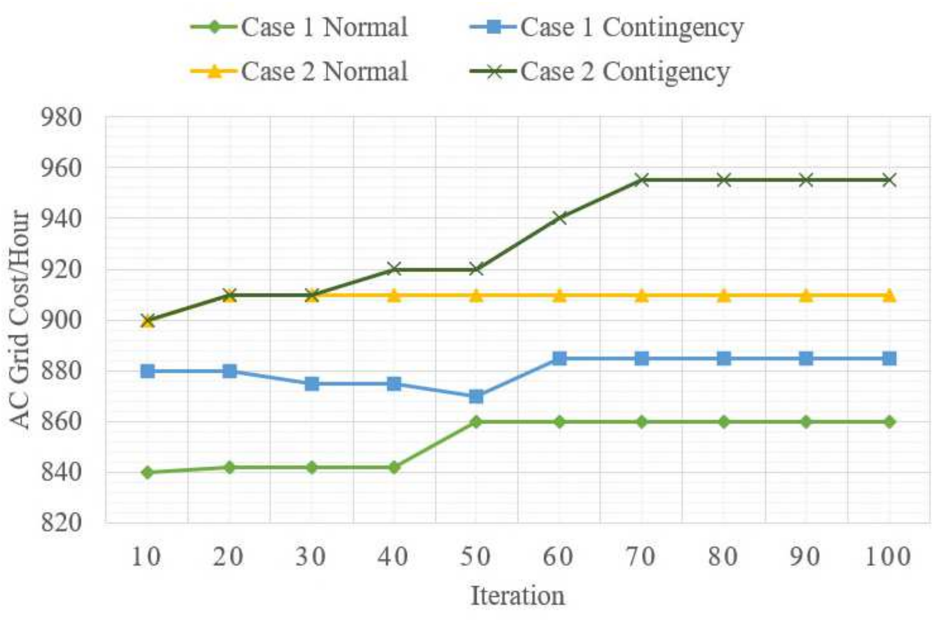


Figure. 7 Analysis of IEEE 30 bus system convergence in AC grid cost

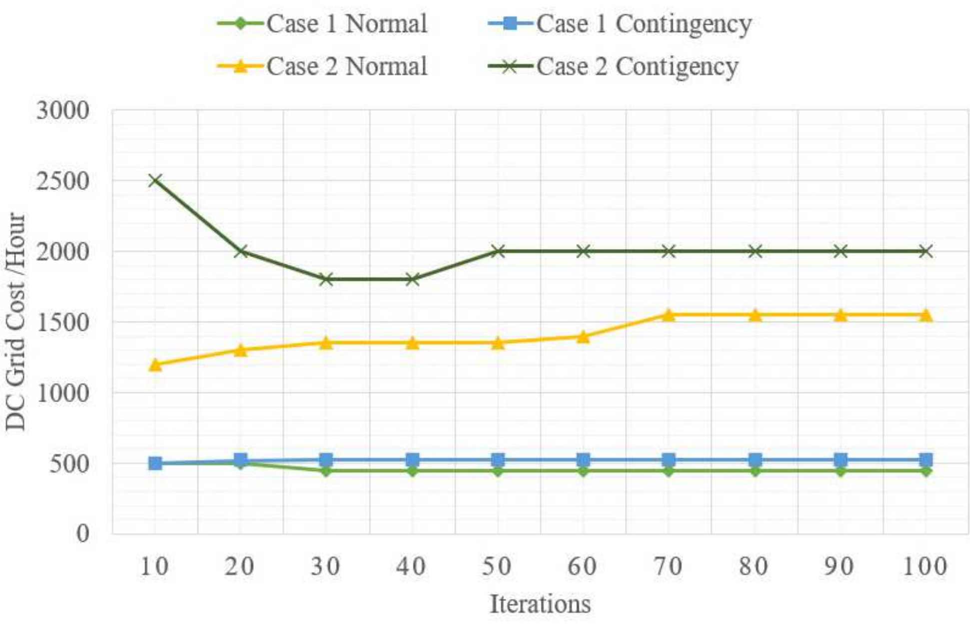


Figure. 8 Analysis of IEEE 30 bus system convergence in DC grid cost

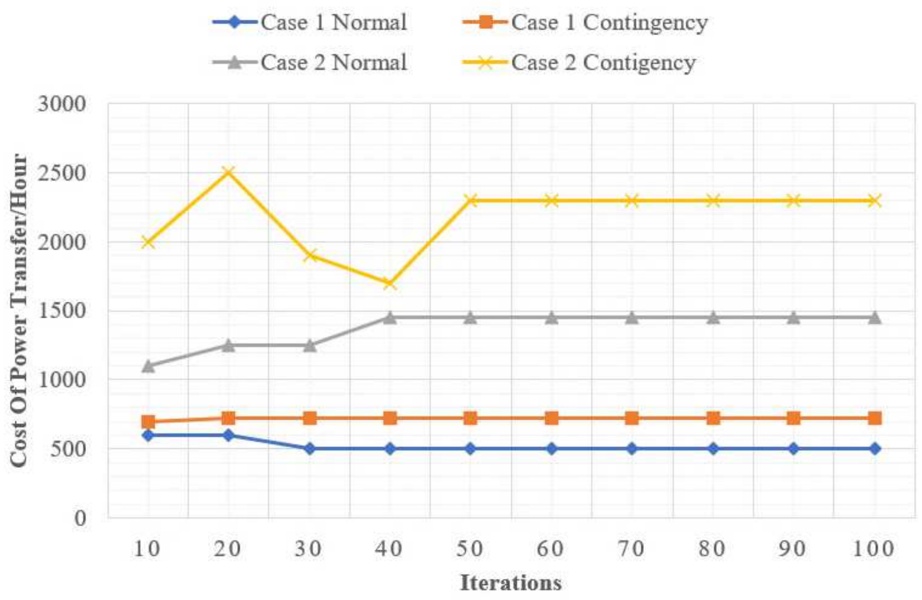


Figure. 9 Analysis of IEEE 30 bus system cost in power transmission to DC grid from AC grid

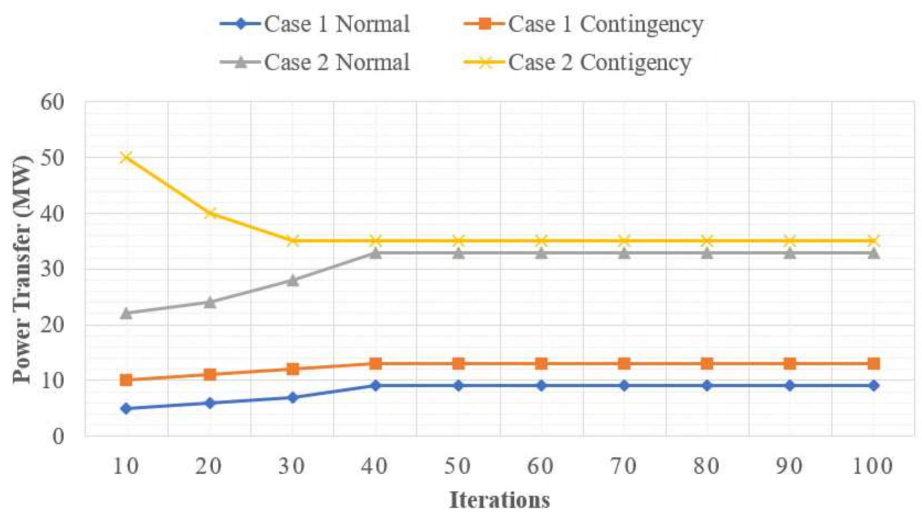


Figure. 10 Analysis of IEEE 30 bus system power transmission to DC grid from DC grid

Table. 3 Analysis of the proposed methodology

S. No	Control Variables	6 bus microgrid		9 bus microgrid	
		Contingency	Normal	Contingency	Normal
1	PG1	0.0451	0.9999	1.1523	1.4215
2	PG2	0.1416	0.287	0.7800	0.6214
3	PG3	0.1397	0.1015	0.1256	0.1254
4	PG4	0.1212	0.0774	0.2017	0.1520
5	PG5	0.0850	0.0604	0.4354	0.3214
6	PG6	0.0376	0.0550	0.3800	0.9500
7	P(WT)	0.1175	0.1320	1.1000	0.1240
8	P(PV)	0.1160	0.1420	0.7541	0.014
9	P(FC)	0.1237	0	0.5412	0.0845
10	VG1	1.0237	1.1000	1.0000	0.1173
11	VG2	1.0360	1.0042	1.0024	0.1250
12	VG3	0.677	1.0585	0.8754	0.0488
13	VG4	0.953	0.9837	0.8851	0.1634
14	VG5	1.0097	0.9673	0.9214	0.1424
15	VG6	0.9835	0.9328	1.1014	0.0145
16	TT1	1.0314	0.9377	0.8547	0.9964
17	TT2	0.9774	0.9715	0.8847	0.9830
18	TT3	1.0399	1.0024	0.0750	1.0836
19	TT4	1.0632	1.0113	0.0255	1.0836
20	QC10	0.0234	0.0200	0.0122	1.0031
21	QC12	0.0251	0.0266	0.0574	1.0179
22	QC15	0.0292	0.3844	0.0322	0.9964
23	QC17	0.3901	0.2975	0.0629	0.7845
24	QC21	0.5000	0.3650	0.1104	0.9854
25	QC22	0.1699	0.5341	0.1274	0.8812
26	QC23	0.2043	1.2434	0.1738	1.0414
27	QC24	0.52077	0.9999	0.0936	1.0214
28	QC29	1.2777	0.287	0.0750	0.2547
29	Total cost ($/h)	2326.7	2255.0	29485.0	29114.0
30	DC grid cost ($/h)	754.8440	688.3279	26815.0	26287.0
31	AC grid cost ($/h)	906.2130	858.7893	956.656	886.6195
32	DCPTr cost (MW)	665.6220	707.8667	1712.5	1939.8
33	DCPTr Cost ($/h)	13.3124	14.1574	34.2494	38.7966

DC grid cost ($/h): generation cost of DC grid

AC grid cost ($/h): generation cost of AC grid

DCPTr cost (MW): Power transmission DC grid from AC grid

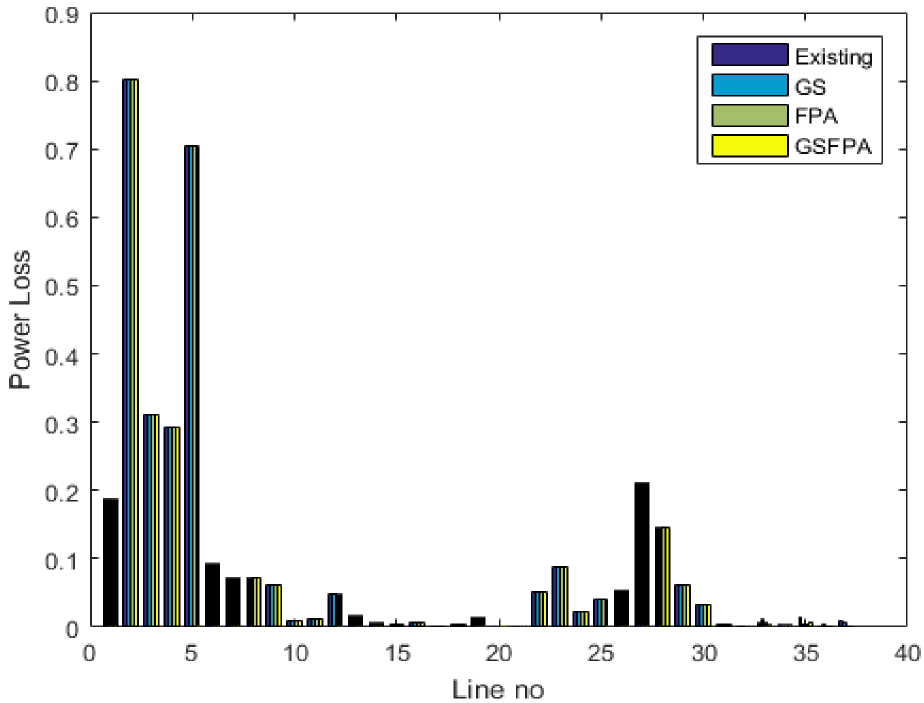
DCPTrCost ($/h): Cost of power transmission DC grid from AC grid

Total cost ($/h): Total cost of generation in DC grid and AC grid

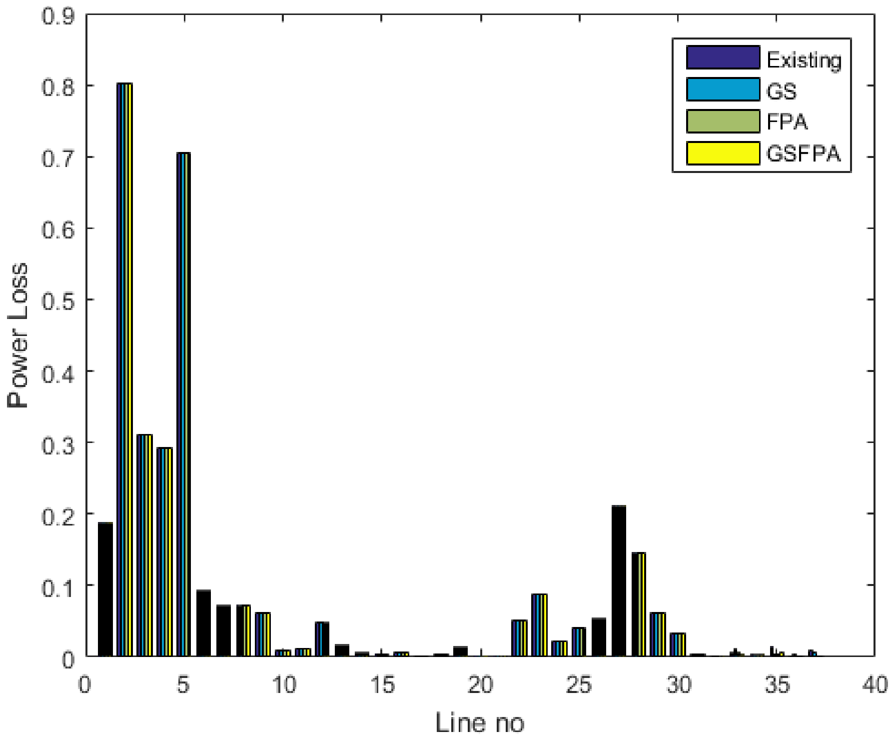
The active load demand of the IEEE 30 microgrid test system is illustrated in figure 5. Similarly, the convergence characteristics of the proposed method with their objective functions are presented in this section. The total cost of the microgrid system with two cases is presented in figure 6. The AC grid cost of the proposed system with microgrid convergence analysis is presented in figure 7. The DC grid cost of the convergence analysis in microgrid system is illustrated in figure 8. The cost of power transfer of the proposed system conditions with convergence analysis is illustrated in figure 9. The power transfer analysis of the proposed method convergence analysis is illustrated in figure 10. The complete analysis of the proposed method and objective function values are presented in table 3. The total cost**,** DCPTrCost, DCPTr cost, AC grid cost and DC grid cost is 29114.0, 1939.8, 38.7966, 886.6195 and 26287.0 for normal conditions in 9 bus microgrid. Similarly, the objective functions of contingency condition and 6 bus microgrid is presented in table 3.

5.1. Comparison Analysis

The comparison is an essential part to validate the proposed methodology effectiveness for enabling the optimal power flow of the microgrid system. The proposed method is compared with the existing methods such as FA, FPA and GSA. The proposed method is compared with different functions such as power loss, voltage deviation and cost function.

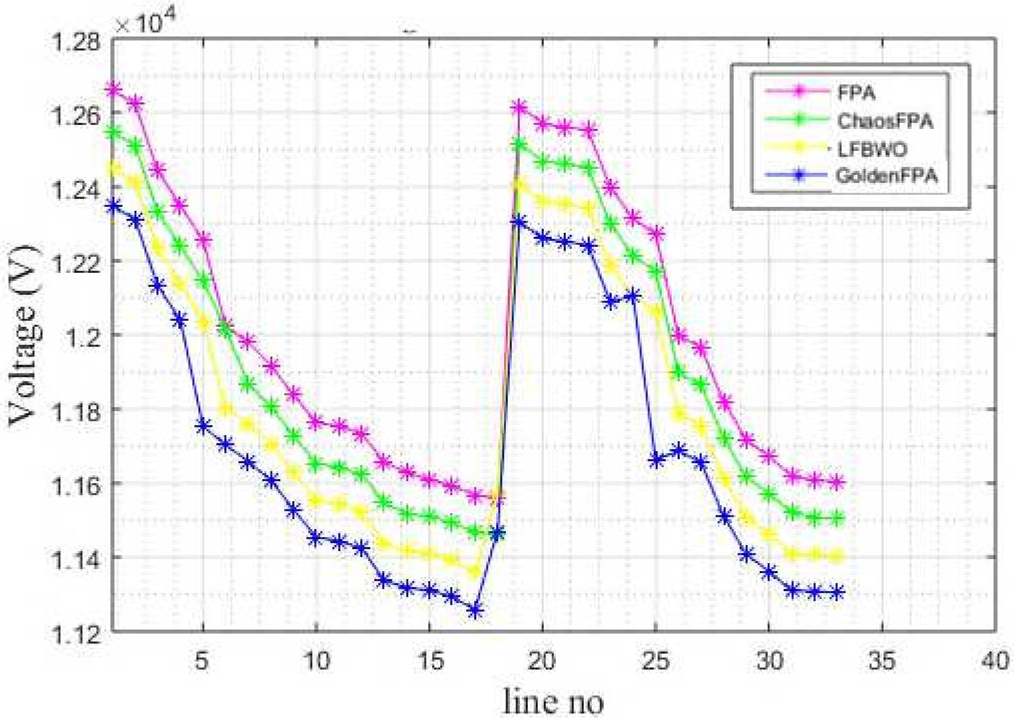


(a)

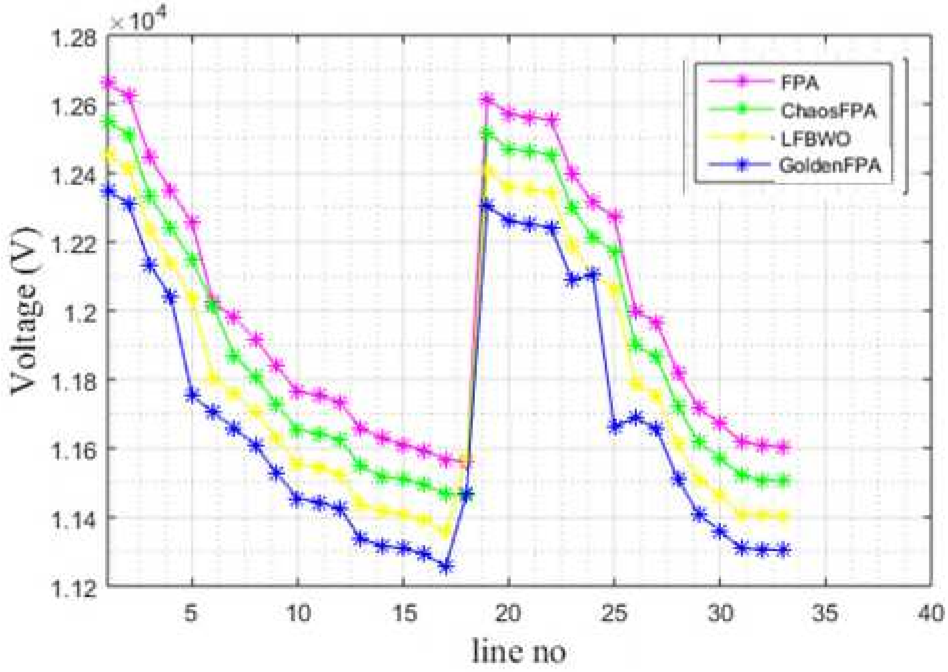


(b)

Figure. 11 Analysis of Power loss (a) case 1 and (b) case 2

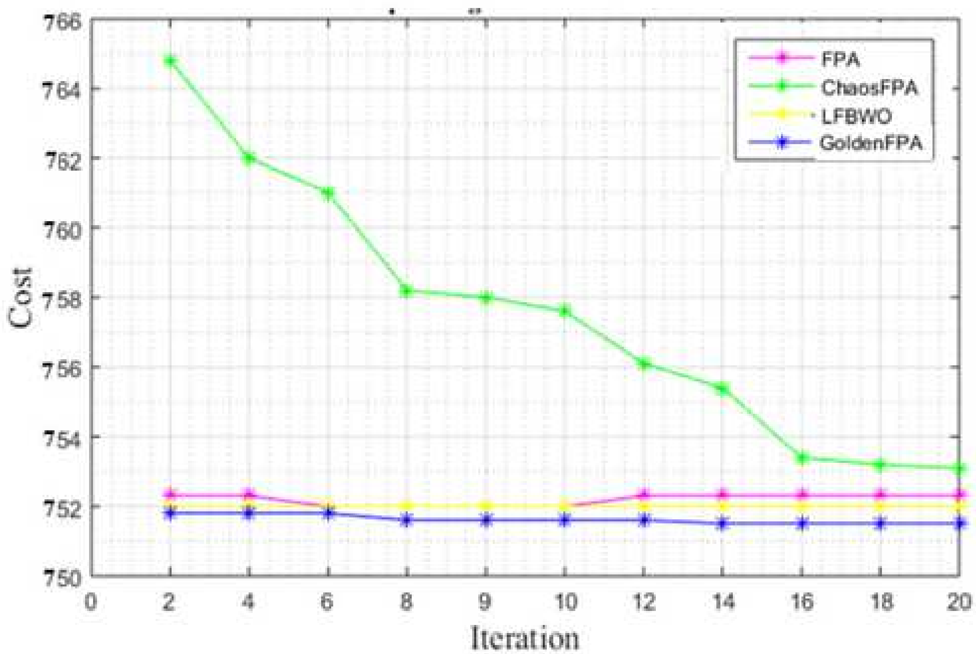


(a)

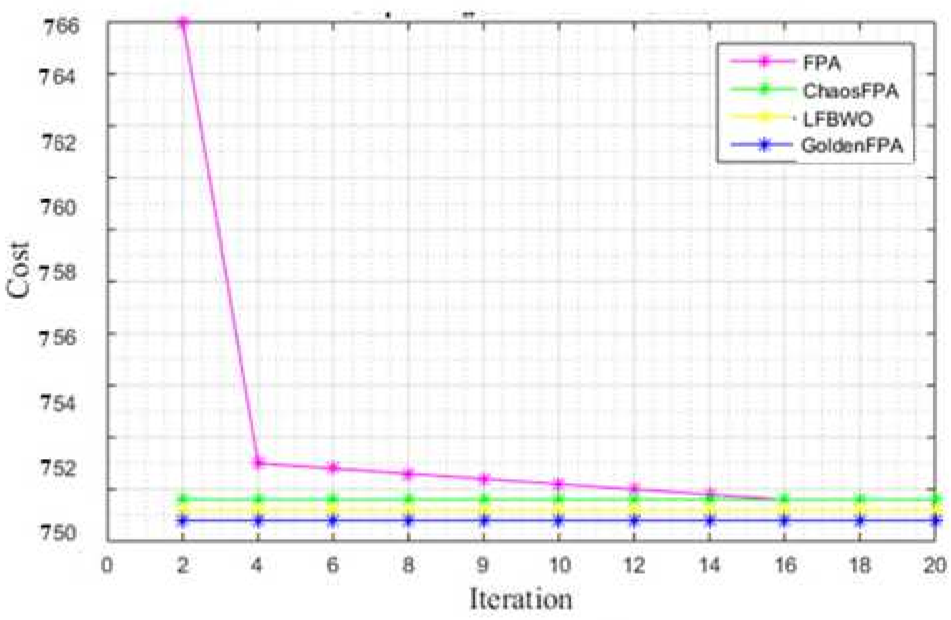


(b)

Figure. 12 Analysis of voltage deviation (a) case 1 and (b) case 2



(a)



(b)

Figure. 13 Comparison analysis of (a) case 1 and (b) case 2

The power loss of the microgrid system is illustrated in figure 11. The proposed methodology is compared with the existing methods such as CFPA, FPA, and LFBWO respectively. The power loss of the CFPA is a value of 0.75, power loss value of CFPA is 0.55, and power loss value of FPA is 0.35. The proposed method is achieved the power loss value is 0.22. From the analysis, the proposed method is achieved best results in terms of power loss. The voltage deviation of the microgrid system is illustrated in figure 12. The proposed methodology is compared with the existing methods such as CFPA, FPA, and LFBWO respectively. The voltage deviation of the CFPA is a value of 0.0126, voltage deviation value of LFBWO is 0.0125, and voltage deviation value of CFPA is 0.0127. The proposed method is achieved the voltage deviation value is 0.0123. From the analysis, the proposed method is achieved best results in terms of voltage deviation. The cost function of the microgrid system is illustrated in figure 13. The proposed methodology is compared with the existing methods such as CFPA, FPA, and LFBWO respectively. The cost function of the CFPA is a value of 758, cost function value of LFBWO is 756, and cost function value of FPA is 754. The proposed method is achieved the cost function 750. From the analysis, the proposed method has achieved the best results in cost function.

6. Conclusion

In this paper, GSFPA to solve the optimal power flow preparation in AC-DC microgrid networks. In the projected methodology, the objective functions are expressed to empower the optimal power flow in microgrid system such as total cost of generation in AC as well as DC systems and cost of active power transmission to DC grid from AC microgrid. And, the objective functions are related with the constraints such as AC-DC power electronics converters limits, power flows and voltage magnitude limits. Additionally, power loss and voltage deviation of the microgrid system also reduced which enhance the system performance. The proposed methodology is utilized to select optimal control parameters for enabling the stable operation of microgrid system. The proposed methodology is validated by using IEEE 30 bus system which associated with 9-bus DC microgrids in addition 6-bus DC microgrids. The projected technique is executed in MATLAB and performances are analyzed with normal as well as contingency conditions. The projected method is contrasted with the conventional techniques such as FPA, CFPA and LF-BWO respectively. From the contrast analysis, the projected technique has achieved the best performance in the microgrid system. In future, microgrid system stability will be analyzed with different load and contingency conditions.

Data Availability Statement

Not Applicable

Funding

Not Applicable

Conflicts of interest/Competing interests

Not Applicable

Availability of data and material

The data used to support the findings of this study are included within the article.

Code availability

Not Applicable

References

[1]. Lingyu Ren and Peng Zhang, "Generalized microgrid power flow", IEEE Transactions on Smart Grid, (2018) 9(4):3911-3913.

[2]. Yoash Levron, Josep M. Guerrero, and Yuval Beck, "Optimal power flow in microgrids with energy storage", IEEE Transactions on Power Systems, (2013) 28(3):3226-3234.

[3]. Chendan Li, Sanjay K. Chaudhary, Mehdi Savaghebi, Juan C. Vasquez, and Josep M. Guerrero, "Power flow analysis for low-voltage AC and DC microgrids considering droop control and virtual impedance", IEEE Transactions on Smart Grid, (2017) 8(6):2754-2764.

[4]. Alejandro Garcés, "On the convergence of Newton's method in power flow studies for DC microgrids", IEEE Transactions on Power Systems, (2018) 33(5):5770-5777.

[5]. Eajal. A, Abdelwahed. M, El-Saadany. E and Ponnambalam. K, "A unified approach to the power flow analysis of AC/DC hybrid microgrids." IEEE Transactions on Sustainable Energy, (2016) 7(3):1145-1158.

[6]. Ernauli Aprilia, Ke Meng, H. H. Zeineldin, Mohamed Al Hosani, and Zhao Yang Dong. "Modeling of distributed generators and converters control for power flow analysis of networked islanded hybrid microgrids." Electric Power Systems Research, (2020) 184:106343.

[7]. Mahdi Zolfaghari, Mehrdad Abedi, and Gevork B. Gharehpetian, " Power Flow Control of Interconnected AC-DC Microgrids in Grid-Connected Hybrid Microgrids Using Modified UIPC", IEEE Transactions on Smart Grid (2019) 10(6):6298-6307.

[8]. Mohammed Elsayed Nassar, Amr A. Hamad, M. M. A. Salama, and Ehab F. El-Saadany, "A novel load flow algorithm for islanded AC/DC hybrid microgrids", IEEE Transactions on Smart Grid, (2019) 10(2):1553-1566.

[9]. Mahmoud A Allam, Amr A. Hamad, and Mehrdad Kazerani, "A sequence-component-based power-flow analysis for unbalanced droop-controlled hybrid AC/DC microgrids", IEEE Transactions on Sustainable Energy, (2019) 10(3):1248-1261.

[10]. Mohammad Abuhilaleh, Li Li, and M. J. Hossain, "Power management and control coordination strategy for autonomous hybrid microgrids", IET Generation, Transmission and Distribution, (2020) 14(1):119-130.

[11]. Yoash Levron, Josep M. Guerrero, and Yuval Beck, "Optimal power flow in microgrids with energy storage", IEEE Transactions on Power Systems, (2013) 28(3):3226-3234.

[12]. Ehsan Naderi, Mahdi Pourakbari-Kasmaei, and Hamdi Abdi, "An efficient particle swarm optimization algorithm to solve optimal power flow problem integrated with FACTS devices", Applied Soft Computing Journal, (2019) 80:243-262.

[13]. Morad Mohamed Abdelmageed Abdelaziz, Hany E. Farag, Ehab F. El-Saadany, and Yasser Abdel-Rady I. Mohamed, "A novel and generalized three-phase power flow algorithm for islanded microgrids using a newton trust region method", IEEE Transactions on Power Systems, (2013) 28(1):190-201.

[14]. Jia Li, Feng Liu, Zhaojian Wang, Steven H. Low, and Shengwei Mei, "Optimal power flow in stand-alone DC microgrids", IEEE Transactions on Power Systems, (2018) 33(5):5496-5506.

[15]. Oscar Danilo Montoya, Walter Gil-González, and Alejandro Garces, "Optimal power flow on DC microgrids: A quadratic convex approximation", IEEE Transactions on Circuits and Systems II: Express Briefs, (2018) 66(6):1018-1022.

[16]. Jithendranath. J, Debapriya Das, and Josep M. Guerrero, "Probabilistic optimal power flow in islanded microgrids with load, wind and solar uncertainties including intermittent generation spatial correlation", Energy, (2021) 222:119847.

[17]. Jithendranath. J and Debapriya Das, "Multi-Objective Optimal Power Flow in Islanded Microgrids with Solar PV Generation by NLTV-MOPSO", IETE Journal of Research, (2021): 1-14.

[18]. Abhishek Kumar, Bablesh Kumar Jha, Swagatam Das, and Rammohan Mallipeddi, "Power Flow Analysis of Islanded Microgrids: A Differential Evolution Approach", IEEE Access, (2021) 9:61721-61738.

[19]. Abhishek Kumar, Swagatam Das, and Rammohan Mallipeddi, "An Inversion-free Robust Power Flow Algorithm for Microgrids", IEEE Transactions on Smart Grid (2021).

[20]. Evangelos E, Pompodakis, Georgios C. Kryonidis, Charis S. Demoulias, and Minas C. Alexiadis, "A generic power flow algorithm for unbalanced islanded hybrid ac/dc microgrids", IEEE Transactions on Power Systems, (2021) 36(2):1107-1120.

[21]. Sivasubramani. S and Swarup K.S, “Multi-objective harmony search algorithm for optimal power flow problem”, International Journal of Electrical Power and Energy Systems, (2011) 33(3):745-752.

[22]. Jyothilal Nayak Bharothu, M. Sridhar, and R. Srinivasa Rao, "Modified adaptive differential evolution based optimal operation and security of AC-DC microgrid systems", International Journal of Electrical Power and Energy Systems, (2018) 103:185-202.

[23]. Adithiyaa. T, Chandramohan. D and Sathish. T, "Flower Pollination Algorithm for the Optimization of Stair casting parameter for the preparation of AMC", Materials Today: Proceedings, (2020) 21:882-886.

[24]. Trong-The Nguyen, Jeng-Shyang Pan, and Thi-Kien Dao, "An improved flower pollination algorithm for optimizing layouts of nodes in wireless sensor network", IEEE Access, (2019) 7:75985-75998.

[25]. Dimas Aji Nugraha, and Kuo-Lung Lian, "A novel MPPT method based on cuckoo search algorithm and golden section search algorithm for partially shaded PV system", Canadian Journal of Electrical and Computer Engineering, (2019) 42(3):173-182.

[26]. University of Washington. Power systems test case archive. [Online]. Available: http://www.ee.washington.edu/research/pstca.