OPTIMAL AND STABLE OPERATION OF MICROGRID USING ENRICHED BIOGEOGRAPHY BASED OPTIMIZATION ALGORITHM

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Abstract: *This paper presents an Enriched Biogeography Based Optimization (EBBO) algorithm to minimize the fuel expenses during the grid-connected mode of operation in microgrid. The projected method also guarantees the stable mode of operation in island mode. In the stable operation, the economic power dispatch problem (EPD) with constraints such as non-dispatchable distributed generators (DG) reserve, inter-region flow limits and stable island operation are formulated. The constraints of stable island mode operation are formulated in accordance with constant droop and variable droop power sharing principles. The suggested EBBO technique is tested with 3-region 15- DG unit system. The result proposed that projected technique is better in solving economic power dispatch problem in the microgrid than the Direct Search Method (DSM). Further, it may project and apply to the practical microgrid operation of the Indian power system.*

Key words: *Enriched Biogeography Based Optimization, Microgrid, Economic Power Dispatch, Distributed Generators.*

1. Introduction

The power grids have been experiencing tremendous changes at present, due to the addition of Distributed Power Sources (DPS). These connections of DPS made a path for the creation of a microgrid. Meanwhile, the collective utilization of DPS comprising occasional non-conventional power sources, will pretend various disputes on the upcoming power grid operation, specifically concerning the distribution power system [1]. With the aim of solving the interlinking difficulties of discrete DGs, the model of microgrid has been anticipated [2]–[5]. The microgrid consists of small-DG units with enough power generation to supply all the load demand. Mainly, the microgrid is operated in the grid-connected otherwise island method of operation [6]. There are many technical problems associated with microgrid operation, comprising interconnection schemes between microgrid and the central grid [7]. This paper illustrates only the stable islanding operation of microgrid using power sharing principles.

Distributed Generators are categorized as dispatchable DGs and non-dispatchable DGs units based on their active power control [8]. Dispatchable DGs, uses thermal energy and fuel cells, etc., which are capable of producing controlled active power with micro turbines on power demand. Therefore, they are assigned the task of regulating the voltage and frequency during islanding operation [9]. In contrast, the renewable energy based DGs operate according to the maximum power-tracking theory, whether the microgrid is connected to the central power grid. Solar and wind DGs are non-dispatchable since the output power mainly depends on the weather condition rather than load. This paper focuses only on power sharing principle for dispatchable DGs, while non-dispatchable DGs are considered as negative load.

Many conventional approaches, including Lagrangian multiplier method [10] have been applied to solve EPD, but these methods require incremental cost curves that are monotonically increasing in nature. The dynamic programming [11] method, does not impose any restriction on the nature of the cost curves and solve both convex and non-convex economic dispatch problems but it aches from the dimensionality of the problem. Several methods such as Genetic Algorithm (GA) [12], Artificial Neural Networks (ANN) [13], Evolutionary Programming (EP) [14], Differential Evolution (DE) [15], Bacterial Foraging Optimization(BFO) [16,17], Biogeography Based Optimization (BBO) [18] etc. have been developed and applied successfully to only conventional EPD problems of large-scale operation of power system connected to main grid.

In Microgrid the optimal and stable operation of EPD is solved by the direct search method (DSM) [19]. Although, the DSM has efficaciously proposed to clarify this problem, these techniques have certain disadvantages. The chief limitations are resolving this problem leads to lag in convergence rate, the solutions fail to attain the global optimal point. The solution of these problems, improves enormously on finding the optimal solution in the initial phase and upsurge in system limitations which effects in complexity etc.

In recent years, an innovative optimization technique, specifically Biogeography Based Optimization (BBO) is projected to solve the problems in engineering domain [20]. In this technique, biogeography is defined as nature's method of distributing species (plant or living organism). In BBO, the island (land mass) of habitat over a high Habitat Suitability Index (HSI) is associated with the good (best) optimal solution and the landmass by progressions of a low HSI solution as a poor (worst) solution. The High HSI solutions fight to adapt better than low HSI solutions. The Low HSI solutions strived to counterfeit worthy characters from high HSI solutions. Cooperative characters endure in the high HSI solutions, although instantaneously acts as pioneering characters in the low HSI solutions. This ensues after explicit representatives (agents) of a species identified towards an environment, while other representatives continue in their original habitat. The solutions with poor characteristics support several innovative features from the worthy solutions. These accumulations of pioneering characters on low HSI solutions could encourage the superiority of the optimal results.

The BBO technique has guaranteed some unique capabilities astonished several shortcomings of the typical methods as exposed as follows. In the Genetic algorithm owing to the crossover process the worthy solution accomplishes initially, irregularly the solution may fail to achieve the optimality in later iterations. Likewise, in BBO has not any crossover technique and due to migration process the solution adjusted gradually. The furthermost significant procedure of BBO algorithm is Elitism. This elitism process maintains the best solution and made the proposed BBO technique more competent with the other techniques. Concerning the PSO algorithm, the resultant solutions are more feasible to group together in corresponding groups to explore the optimal solution. However, in BBO algorithm the solution does not cluster owing to its mutation process. Instantaneously, the limitation handling is significantly available when compared to BFO technique. Though the conventional BBO has an edge over other algorithms, it endures from poor convergence characteristics when deliberating the complex problems. In the BBO algorithm, the deprived solution acknowledges some new features from worthy solution; this enhances the supremacy of problem solutions. Comparably the acknowledgement of new qualities is an additional unique component of BBO technique, when related with other approaches.

This paper attempts and solves the EPD of microgrid in the DG using an enriched migration based EBBO technique [18]. The projected technique is used for minimization of fuel expense during grid-connected operation of a microgrid. The stable operation of the microgrid after islanding is maintained by tracking the inter region power flow limits using constant and variable droop power sharing principles. The proposed technique is validated on three DG region with 15 generating units to substantiate its competence. The results attained with the projected EBBO technique are related with the traditional DSM.

The articulation of the article is proposed as follows: Chapter 2 provides a brief description and mathematical formulation of economic dispatch in microgrid and stable operation of microgrid with taken constraints. Chapter 3 offers the detailed description about BBO technique. Chapter 4 comprises the detailed results of minimizing the extra operational expenses of microgrid. Chapter 5 encompasses the final inferences.

1. Economic Power Dispatch (EPD) Problem Formulation for Efficient Microgrid

The structure of the microgrid is formulated into following schemes they are Power Controlling approach and Power sharing principle. In the controlling mode the output of the system is controlled by two principles, they are Unit Power Control (UPC) mode and Feeder Flow Control (FFC) mode. In the UPC mode of operation the DG produces steady active power conferring to the power reference, whereas in FFC mode of operation DG output is restrained accordingly the real power flow in the feeder ruins perpetually.

In the power sharing principle, while the microgrid is detached from the central grid, DG needs to compensate the power from the central grid to encounter the power demand. Conventionally, power versus frequency droop regulation has been embraced to fortify that power demand is actively stabilized using the DGs. Usually, the droop constant of a DG is deliberated as a stable restriction, exposed as a result that the demand is imparted between DGs in relation to their graded amounts. However, in the recent power-sharing principle droop constants are intermittently adjusted bestowing the operational features of DG units. In this principle, the DGs assign the power permitting in the direction of their operative reserves, considerably than their competences. In this paper, the earlier approaches such as constant droop and the advanced approach as variable droop is articulate to the island process of microgrid in concurrence through the power-sharing principle.

In fig.1. the microgrid formulation with many FFC arrangement is illustrated. The demonstrated arrangement is best appropriate for microgrid with DGs are assertive.

In this paper, it is considered that the disparity of loads and non-dispatchable DGs power productions in each control region are balanced by the dispatchable DGs in the similar area. In the direction of achieving this, the major DG in every area functions in the FFC mode, whereas the others control on the UPC approach that is clear from Fig. 2.

The chief objective of EPD problem in microgrid is to reduce the entire expense of small-distributed generating units satisfying the constraints. The formulation is similar to that of basic EPD. The limitations of effectively coordinating the power demand and generation limits of the units are acquired into consideration. The minimizing total fuel cost objective function is expressed as

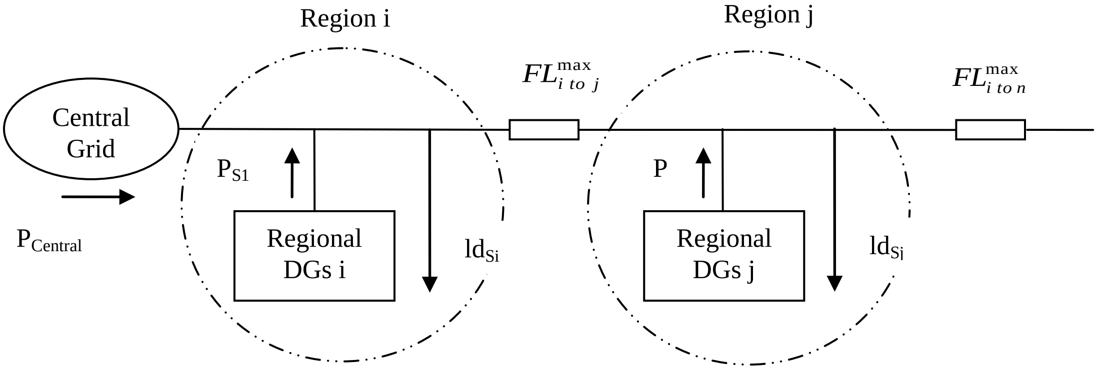

Fig. 1. Structure of Microgrid with several control regions

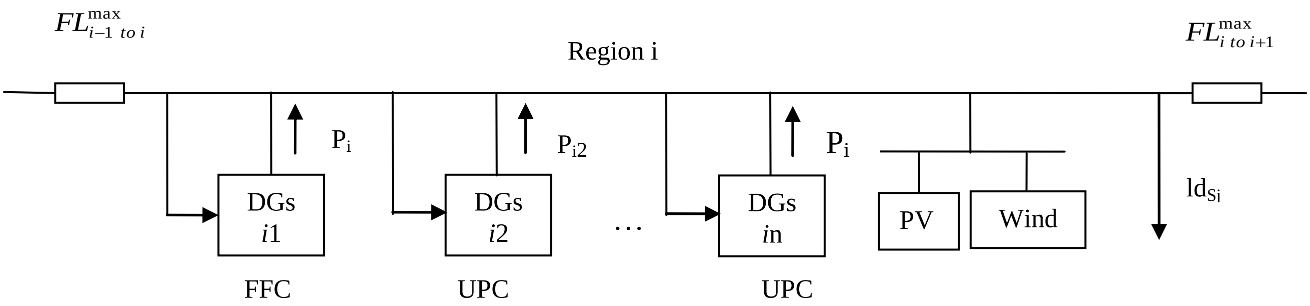

Fig. 2. Structure of the Microgrid control region

$$T_{FC} = \sum_{u=1}^{K_{gen}} F_u(P_u) \tag{1}$$

The fuel cost function is specified by

$$F_u(P_u) = a_u + b_u P_u + c_u P_u^2 \tag{2}$$

Where T_{FC} is the Total fuel cost, Fuel cost function is represented by $F_u(P_u)$, Number of generation units as K_{gen} and P_u indicates the power output of distributed generating units.

The constraints for proficient microgrid is indicated as follows

(i) Power Balance Limits

In the Power Balance Limitation (PBL), the sum of non-dispatchable power of all units and power from the central grid must be equal to load demand. The effect of non-dispatchable DG is also considered in the power balance equation and is indicated below

$$\sum_{u=1}^{K_{gen}} P_u + P_{Central\ grid} = \sum_{ld=1}^{K_{load}} P_{ld} - \sum_{m=1}^{K_{nd}} P_{nd_m} \tag{3}$$

Where P_{nd} denotes the Power in non-dispatchable DGs, $P_{Central grid}$ signifies Power in the central grid and load demand power implies the P_{ld}, K_{load} denotes the number of generating units fulfilling the load and K_{nd} represents the number of non-dispatchable generating units.

(ii) Spinning Reserve Constraints

At present, the power system load demand and power outputs of the DG vary continuously. The variation of power generation is due to the fluctuating nature of available resources. In order to compensate these variations and operate the system in stable way the additional reserve required. The Spinning Reserve (SR) of microgrid, is assumed as a decrease in the maximum limit and an increase in the minimum limit of the unit that is given by the following equations.

For decrease in maximum limit the condition is offered by

$$P_{j1} \le P_{j1}^{\max} - \left(\frac{v}{100} \cdot \sum_{ld \in S_j} P_{ld} + \frac{w}{100} \cdot \sum_{m \in S_j} P_{nd_m} \right) \tag{4}$$

Condition for increase in minimum limit is obtainable by

$$P_{j1} \ge P_{j1}^{\min} + \left(\frac{v}{100} \cdot \sum_{ld \in S_j} P_{ld} + \frac{w}{100} \cdot \sum_{m \in S_j} P_{nd_m} \right),\ j = 2,3,\ldots\ldots n \tag{5}$$

Here j is the number of generating units taken from the 2nd distributed generating unit (considering the first generator as a Feeder Flow Regulator (FFR) mode) and

S is the selected region based power supply in DG.
In the above constraints, it is considered that the load demand varies with v % of the base value and the power output of non-dispatchable DG (m) varies with w % of base value.

(iii) Inter-region Flow Constraints

The power flow constraints between the region are termed as Inter-regional Flow Constraints (IFC). It is restricted by physical flow limits $FL^{\max}$ and it is formulated by assuming with n regions.

$$P_{S_1} = P_{ld_{S_1}} - P_{Central\ grid} + FL_{1\ to\ 2} \quad For\ \text{Region}_1 \tag{6}$$

$$P_{S_j} = P_{ld_{S_j}} + FL_{j\ to\ j+1} - FL_{j-1\ to\ j}$$
$$For\ \text{Region}_j \quad j = 2,3,\ldots,n-1 \tag{7}$$

$$P_{S_n} = P_{ld_{S_n}} - FL_{n-1\ to\ n} \quad For\ \text{Region}_n \tag{8}$$

$$-FL^{\max}_{j-1\ to\ j} \le FL_{j-1\ to\ j} \le FL^{\max}_{j-1\ to\ j} \quad j = 2,3,\ldots\ldots,n \tag{9}$$

(iv) Limitation for Stable Island Operation of Microgrid

During the power transition, the power output change in any DG will affect the power flow in the transmission lines and makes the system unstable. In-order to avoid this, the DGs should have reserve as much as $P_{Central\ grid}$. Due to the increase in power reserve, there is a restriction on power flow limits in the stable islanding mode of operation. Such restriction of flow limits will surge the operational expense during the grid-connected operation.

Therefore, the following methods are formulated to satisfy the above two objectives are minimized expense during the grid-connected and stable island operation. The following section presents the formulation of this constraint in accordance with two different power-sharing principles includes Constant Droop (CD) and Variable Droop (VD).

a) Limitation with Constant Droop Principle

In the limitation with CD, the changes in every DGs power output are inversely proportional to predetermined droop constant D_u. For this, the sum of power output changes must be equal to the magnitude $P_{Central\ grid}$.

The power selected up by a distributed unit u through the islanding operation is intended from

$$\Delta P^{IP}_u = \frac{DC_u^{-1}}{\sum_{i=1}^{K_{gen}} DC_j^{-1}} \cdot \left| P_{Central\ grid} \right| \tag{10}$$

The amount of power shared by a region j is calculated as the sum of all the units is given as

$$\Delta P^{IP}_{S_j} = \frac{\sum_{u \in S_j} DC_u^{-1}}{\sum_{j=1}^{K_{gen}} DC_j^{-1}} \cdot \left| P_{Central\ grid} \right| \tag{11}$$

Where DC_u is the droop constant of a particular unit and IP denotes Imported power from the central grid.
Based on operation mode the power supplied from the microgrid to central grid and vice-versa and their limitations are formulated.

Power Primarily Exported from Microgrid

In this grid-connected mode, the microgrid supplies power to the central grid. The DGs in microgrid will reduce their power productions during the changeover from grid-connected to the island mode operation. Therefore, the entire DGs must have an extra spinning reserve and this reserve escalates the minimum operating limit of a generating unit. This is expressed by

$$P_u^{\min} + \Delta P_u^{IP} \le P_u \le P_u^{\max} \tag{12}$$

The quantity of extra power flow from region $[j-1]$ to region $[j]$ is the summation of the power distributed by the DGs in the region j and the downstream regions from it. Therefore the downward Power Flow Limit (PFL) must be reduced by the quantity of extra flow, while the upward PFL continues to be unaffected.

$$-FL^{\max}_{j-1\ to\ j} \le FL_{j-1\ to\ j} \le \left(FL^{\max}_{j-1\ to\ j} - \sum_{s=j}^{n} \Delta P^{IP}_{S_s} \right) \tag{13}$$

for $j = 2,\ldots\ldots,n$

Power Primarily Imported to Microgrid

When connected in the grid-connected mode, if the power is taken from the central grid to microgrid, then the DGs will surge their power productions when it is disconnected from the central grid. All these DGs should have additional spinning reserve.

Consequently, the maximum bounds of the DGs and the bounds in upward flow supposed to minimize and expressed further

$$P_u^{\min} \le P_u \le P_u^{\max} - \Delta P_u^{IP} \tag{14}$$

$$-\left(FL^{\max}_{j-1\ to\ j} - \sum_{s=i}^{p} \Delta P^{IP}_{S_s} \right) \le FL_{j-1\ to\ j} \le FL^{\max}_{j-1\ to\ j} \tag{15}$$

for $j = 2,\ldots\ldots,p$

b) Limitations through Variable Droop Principle

In the CD, the impact of power reserve is resolute in advance to resolve the EDP problem. However, when the VD is employed the power output orientation of every DG is verified optimally. The impact of reserve for respective DG is calculated by permitting to its operational bound. Therefore, the power production bounds of DGs need not to be altered in VD power sharing principle instead the inter-regional flow limits should be modified.

Power Primarily Exported from Microgrid

If the output of generating unit u is denoted as P_u and the effective margin of this unit is $P_u - P_u^{\min}$. Then the Exported Power (EP) by unit u through the changeover is intended by

$$\Delta P_u^{EP} = \frac{P_u - P_u^{\min}}{\sum_{i=1}^{K_{gen}} \left(P_i - P_i^{\min}\right)} . \left|P_{Central\ grid}\right| \tag{16}$$

The quantity of power distributed by the region j is specified as

$$\Delta P_{S_j}^{EP} = \frac{P_S - P_S^{\min}}{\sum_{i=1}^{K_{gen}} \left(P_i - P_i^{\min}\right)} . \left|P_{Central\ grid}\right| \tag{17}$$

From the above equation, S exemplifies the system region

The downward flow bounds will be decreased, but in VD, the power pooled by every generating unit is undetermined until the EPD is cracked. Therefore, the reduced charge of the downward flow bounds would not be determined precisely in the case of CD.

The power flow from region $[j-1]$ to region $[j]$ throughout the grid-connected process is the addition of the variance amongst the loads and power outputs of the region j and from the downstream regions.

$$FL_{j-1\ to\ j} = \sum_{s=1}^{n} \left(P_{ld_{S_s}} - P_{S_S}\right) \tag{18}$$

Power Primarily Imported to Microgrid:

When the central grid supplies power to the microgrid, the power output of DGs and upward power flow limits will be amplified. The effective boundary of generating unit u in this instance is $P_u^{\max} - P_u$, the quantity of power shared by region j is deliberates as follows

$$\Delta P_{S_j}^{\max} = \frac{P_{S_j}^{\max} - P_{S_j}}{\sum_{u=1}^{K_{gen}} \left(P_u^{\max} - P_u\right)} . \left|P_{Central\ grid}\right| \tag{19}$$

The Power balance equation is the sum of power generated by all the units plus the power from the central grid, which is equal to the power demand.

$$\sum_{u=1}^{K_{gen}} P_u + P_{Maingrid} = \sum_{n=1}^{K_{load}} P_{ld_n} \tag{20}$$

The power flow limit between the short transmission lines within that region is

$$-\left(FL_{j-1\_j}^{\max} - \frac{\sum_{s=j}^{n} P_{S_s}^{\max} - \sum_{s=j}^{n} P_{S_s}}{\sum_{u=1}^{K_{gen}} P_u^{\max} - \sum_{n=1}^{K_{load}} P_{ld_n} + \left|P_{Central\ grid}\right|} . \left|P_{Central\ grid}\right| \right) \le \sum_{s=j}^{n} P_{ld_{S_s}} - \sum_{s=j}^{n} P_{S_s} \tag{21}$$

At the last step upward flow limit is computed by the equation

$$-\left(FL_{j-1\ to\ j}^{\max} - \left|P_{Central\ grid}\right| . \frac{\sum_{s=j}^{n} P_{S_s}^{\max} - \sum_{s=j}^{n} P_{ld_{S_s}} - FL_{j-1\ to\ j}^{\max}}{\sum_{u=1}^{K_{gen}} P_u^{\max} - \sum_{n=1}^{K_{load}} P_{ld_n}} . \right) \le FL_{j-1\ to\ j} \tag{22}$$

Entirely the variables in eqn. (19) and (22) are estimated from the system data. Consequently, the optimal values of inter-region flow limits are determined and then the EDP is resolved.

2. Steps Involved In Enriched Biogeography Based Optimization (EBBO) Algorithm

Biogeography algorithm describes the biological species migration from one island to another. The proposed EBBO algorithm encompasses of two chief steps, specifically the enriched migration and mutation is expressed as follows

3.1 Enriched migration model

The fitness of the projected solution is augmented by a monotonic downturn and the surge in degrees of immigration and emigration. This regulates that as a rise in the species count consequences more fitness of the solution, the bonding characteristic probability from additional solutions decreases. However, recently biogeography is witnessed in certain pioneer plant species, in this an initial rise in species numbers imports in a primary increase and decrease of immigration and emigration rates. Meanwhile, the first explorers have enriched the new unfavorable circumstantial surroundings of the island. The first explorers categorize it additional generous to additional species. i.e., the advanced consequence of increased diversity owing to the first immigration restricts the negative effect of enlarged size of species populations. In Biogeography Based Optimization (BBO) algorithm this outcome causes a primary growth in immigration rate, in this the suitable deprived candidate solution predominantly progresses the fitness of solution [16]. Such phase is supposed as a momentary progressive feedback technique in BBO. The utmost deprived aspirant solution acknowledges the characters from further solutions. When fitness of the solution is improved, subsequently it increases the probability of accepting additional features from the other solutions. This inspiration comes from biogeography. The immigration rate α and emigration rate β of the proposed EBBO algorithm is estimated as follows

$$\alpha = \frac{I}{2}\left(\cos\left(\frac{\left(S_h * \pi\right) + \xi}{S_{\max}} \right) + 1 \right) \tag{23}$$

$$\beta = \frac{E}{2}\left(-\cos\left(\frac{(S_h * \pi) + \xi}{S_{\max}} \right) + 1 \right) \quad (24)$$

Where S_h is the species count of each habitat and element of S, E & I is the maximum emigration and immigration rate (generally assumed as 1), ξ is the amount of momentary positive immigration rate feedback usually between $[-\pi/2, 0]$ and Smax represents the maximum number of species.

Employing this enhanced model, the fitness is normalized to $[0, 1-\beta/\alpha]$. With the projected approach, the immigration primarily intensifies with the fitness of the solution. It usually contributes refining solutions, i.e. the momentum that they need to remain improving. When the immigration primarily surges, the solution remains to improve appropriately. The immigration rate initiates to decrease to contribute lesser fitness solutions reasonably. It recommends immigrating worthy solutions to the problem.

3.2 Mutation of Species

The mutation process inclines to amplification among the species. Every species probability is considered by means of the differential equation is specified as

$$\dot{P_S} = \begin{cases} -(\alpha_s + \beta_s)P_s + \beta_{s+1}P_{s+1} \ldots S = 0 \\ -(\alpha_s + \beta_s)P_s + \alpha_{s-1}P_{s-1} + \beta_{s+1}P_{s+1} \ldots 1 \le S \le S_{\max} - 1 \\ -(\alpha_s + \beta_s)P_s + \alpha_{s-1}P_{s-1} \ldots S = S_{\max} \end{cases} \quad (25)$$

After the alteration, the extremely possible solutions inclined to more accomplishing in the considered species. The mutation approach produces the low HSI solutions likely to modify; this offers it a process of refining.

Similar to the BBO technique the mutation relates to high Habitat Suitability Index (HSI) solutions, which growths beyond that. The elitism process is used to maintain the worthy solution in the EBBO technique. Consider if the mutation remains, their HSI is conserved and produce after if necessary. Mutation operation is necessary for both poor and good solutions. In this, the average solutions are optimistically enhanced already and therefore the mutation process is avoided.

4. EBBO Technique for Economic Power Dispatch Problem of Microgrid

In this chapter, a new method to solve EPD problem using BBO algorithm is described.

Illustration of SIVs: In EPD problem the decision variables are real power generations, they are used to signify the individual habitat. The number of SIV is initialized as n. The SIV in a habitat is characterized by active power output of all the generators.

Initialization of SIVs: The SIV of every habitat set H is set randomly within the effective real power operating limits.

4.1 Steps to solve EDP of microgrid using BBO

Step 1

Initialize the number of generator units (u), minimum and maximum capacity of the distributed generators($P_u^{\min}$ & $P_u^{\max}$), power demand (P_{ld}) and the BBO parameters like, mutation probability (P_s), maximum immigration (I) & emigration rate (E) and set the maximum number of iterations.

Step 2

SIVs of the given habitat are initialized, here for considered problem the SIVs are real power outputs of DGs.

Step 3

Compute the HSI of every habitat for proposed enriched emigration and immigration rates. The HSI reveals fuel expense of the distributed generators for specified power demand. There are g distributed generators functioned and produced power to the microgrid and utilized to the load. Then the considered habitat is articulated as shown below

$$HB^i = \left[SIV^{i1}, SIV^{i2}, \ldots SIV^{ig}\right] = [P_u^{i1}, P_u^{i2}, \ldots, P_u^{ig}] \quad (26)$$

Where i signifies the number of distributed generating unit and g indicates the no of habitats, which is analogous to the no of generators in this considered problem.

Step 4

From the deliberated HSI value the elite habitats is known. These habitats characterize the DGs power generated output of the habitat, which offers the minimum fuel cost. The extent of elite habitat recollected is depends on the elitism parameter.

The objective function of considered economic power dispatch of proficient microgrid is framed as

$$Min\ T_{FC} = \left[\sum_{u=1}^{K_{gen}} F_u(P_u) + \lambda(\text{PBL}) + \mu(\text{SRC}) + \phi(\text{IFC}) \right]^{-1} \quad (27)$$

Also the objective function with deliberated stable island operation of microgrid when power initially exported is termed as

$$= \left[P_u^{EP} + \lambda(CD\ or\ VD) + \mu(SR) + \phi(PFL) \right]^{-1} \quad (28)$$

Similarly the power exported imported to the microgrid is characterized.

Here from the λ, μ & ϕ are the penalty functions greater than zero.

Step 5

Accomplish the migration operation on SIVs of non–elite habitat, designated for migration. The immigration step is appropriate further down.

i) *Choose the better and worse restrictions for the immigration rate* α_{better}, α_{Lower}

ii) *Estimate the number of species by the following loop*

For $i = 1 : S$
{

If (Habitat Suitability Index $HSI_i < \infty$)
{
Species count of habitat $S_h = S - i$
}
Else
{
Species count of habitat $S_h = 0$
}
End
}
End

iii) Once again evaluate the immigration and emigration rate for every habitat through the logic given

For $i = 1:S$
{
$\alpha(i) = I * (1 - \mathrm{S_h} \ / \ \text{Habitat size HB})$

$\beta(i) = E * (\mathrm{S_h} \ / \ \text{Habitat size HB})$
}
End

iv) Selection of new SIV for migration (mg) operation

For $i = 1:S$
{
If (Habitat Suitability Index $HSI_i < \infty$)
{
Species count of habitat $S_h = S - i$
}
Else
{
Species count of habitat $S_h = 0$
}
End
}
End

v) Once again evaluate the immigration and emigration rate for every habitat through the logic given

For $i = 1:S$
{
$\alpha(i) = I * (1 - \mathrm{S_h} \ / \ \text{Habitat size HB})$

$\beta(i) = E * (\mathrm{S_h} \ / \ \text{Habitat size HB})$
}
End

vi) Selection of new SIV for migration (mg) operation

For $mg = 1:S$
{
if the randomly generated number is less than the habitat modification probability P_{mod}, then following operation is done as

$\alpha_{Norm} = \alpha_{Lower} + (\alpha_{Upper} - \alpha_{Lower}) *$
$(\alpha(l) - \alpha_{Min}) / (\alpha_{Max} - \alpha_{Min})$

For $l = 1:n$
{
if the randomly generated number < α_{Scale}
{
random Number= rand * sum (β)
calculate the Emigration rate for each generator $\beta(i)$
While [random Number $> \beta(i)$] & [calculated $\beta <$ S]
{
Increment the Emigration rate $\beta + 1$
Calculated β rate = Calculated rate + β (Incremented Emigration rate)
}
End
Newly generated habitat (mg, l) = old habitat (Calculated β rate, l)
else
Newly generated habitat (mg, l) = old habitat (mg, l)
}
End
}
End
}
End

After the migration operation, new habitat set is generated. For economic dispatch problem in microgrid, these denote the modified power generation (P_u) values of distributed generators.

The operating limitations for stable operation of microgrid after islanding is solved using the proposed technique is as follows.

Primarily, for the CD operation estimate the change in position value of each species by using the droop constant of each species. Deduct the change in value of the maximum specified value of species when power is exported. Augment the change in value with a minimum specified value of species when power is imported. Check the minimum and maximum flow change rate between the regions of the particular species.

Secondly, in adjustable droop calculate the change in position value of each species based on the position value of all species in the region. Take off the change in value from the maximum specified value of species when power is exported. Enhance the change in value with a minimum specified value of species when power is imported. Examine the minimum and maximum flow change rate between the regions of the particular species.

vii) Operating limit constraint can be satisfied as

If

The value of species position i.e., power generated in each DG unit is greater ($P_u > P_u^{\max}$) than the maximum position value of species, then set $P_u = P_u^{\max}$

Else if

The position value of species i.e., generated DG power is less than the minimum position value of species, $P_u < P_u^{\max}$ then set $P_u = P_u^{\min}$

Else

Retain $P_u = P_m$

End

viii) Examine the power balance limit

If the sum of the best position value of each species is supplemented with the power from main grid should be equal to the sum total load demand supplied by all the species and reduce the value of non dispatchable DGs (species).

Then precede the result with incorporated limitation

Else

Repeat the above steps

Step 6

For every habitat, the species count probability is simplified by means of the eqn. (25) of the projected EBBO algorithm. Mutation operation is proficient on non-elite habitats. If the arbitrarily generated number is smaller than the mutation rate for some habitat, then that specific habitat is nominated and mutation process is accomplished. Again, the limits are substantiated by step (5) and the distributed generator fuel cost is considered.

Step 7

In this step, the assessment is completed for the maximum number of iterations. If this is condition satisfied stop the process, else go to step (3). Subsequently the every habitat is improved. All SIV must fulfill mentioned effective limitations of generators connected to the microgrid is verified and the generator with minimum fuel expense is evaluated.

5. Results and Discussion

The considered test DG structure encompassing the three control regions and 15 DG unit [19] is used for the analyzing the technique. It is assumed that 5 DG are set up in every region, among these regions the first unit is acted as a FFR mode and rest other units are operated as a Unit output Power Regulator (UPR). The taken problem is solved by EBBO technique. Primarily, the recorded load demands of selected DG at a particular day are illustrated in fig. 3. Also for ease, the considered load demands comprise the consequences of non-dispatchable DGs. The significance of every limitation on the expense differs permitting to load sharing. In this paper, the Load Distribution Factor (LDF) is considered as 25%, 35% and 45%.

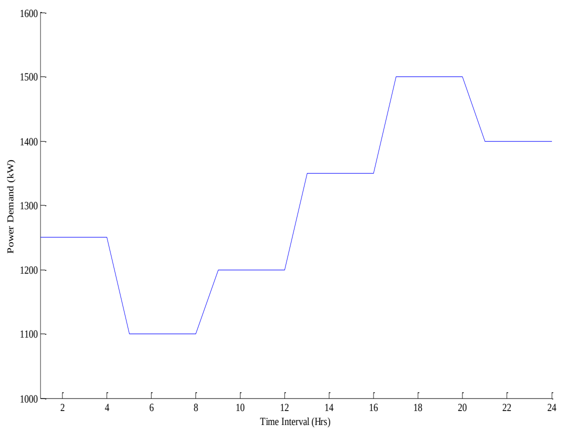

Fig. 3. Power demand pattern recorded from of a particular day of 3 region 15-DG unit

Examination 1: Inter-Region power Flow Limit and Load Variation by EBBO Technique

This examination is deliberated to consider the influence of inter region power flow limit and the variation in expense of the power generated by the projected EBBO technique. For achieving this, the entire fuel expenses were considered for several situations of proper sharing of load, reserve and inter-regional power flow limit. This examination ignores the power injected through the central grid. The fuel expense for considering the LDF with different percentage of v values is shown in fig.4.

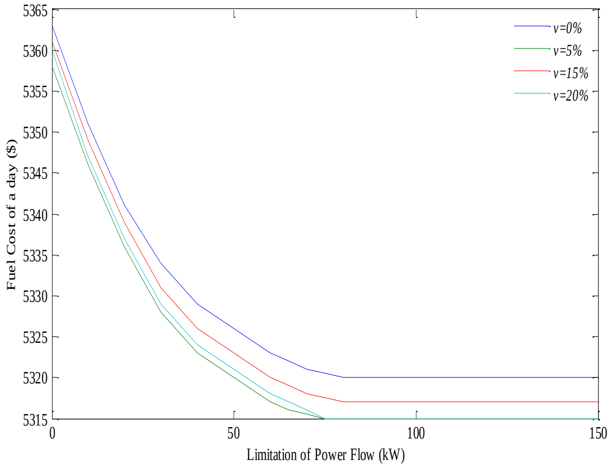

Fig. 4. Results of inter-region flow limitations with considered Load Distribution Factor

The inclusion of the LDF factors is detailed below. Suppose the inter-region power flow turn out slightly which increases expenses in the power generation. The generating station with advanced incremental cost would surge their power generation as the flow limit reduces. In the 15- DG system, the DG in the region 2 has comparatively poorer incremental cost. However, the quantity of load limit of this region in the taken LDF is merely 0.25 portions of the power demand. Consequently, in direction to minimize the entire expense of a generation, the DGs in the region 2 must yield further power than the limited load demand. This transfers the excess power to new ranges in the region. The inter region power flow is limited in this instance, when the system load is considered as 1500kW, the electric power remains transported from region 2nd to 1st and 3rd region correspondingly. Though the constraint of inter-region power flow reduces, the transported power from 2nd region is controlled. Similarly, the generating units in region 2 and 3 with better incremental cost would surge their power yields besides it surges the whole generation expenses.

It is observed that the expense revealed an attraction to surge with the reserve requirement concerning the deviation in load. The power FFR in DG at every region would be controlled to reimburse for the load deviation from spinning reserve constraints. Meanwhile the incremental costs of FFR remain moderately worse and the escalation in the generation reserve lead to increased generation expenses. From the fig.5, it is clear that the outcome of the power inter-region flow bound is succeeded in the taken LDF.

Examination 2: Power reserve for the constant Islanding process by EBBO Technique

The consequence of the reserve for the constant islanding process is examined by replicating over several load stages and $P_{Central\ grid}$. This analysis accesses the situations with divergent load distributions and $FL^{\max}$ values. For every situation the value of $P_{Central\ grid}$ is changed from –100 to 100 kW in 10 kW steps and is deliberated as follows

Situation 1) Allocation of Load at considered LDF and $FL^{\max}$ =40kW

Situation 2) Allocation of Load at considered LDF and $FL^{\max}$ =80kW

The experimented results by the projected EBBO for situation 1 at load demand of 1500 kW with the differed minimum and maximum power demand is shown in table 1. It is observed that the 40 kW of power would remain transported from region 2 to regions 1 and 3, correspondingly.

Table 1
Imported Power output of DG by Proposed EBBO Algorithm

Region	Load Demand (kW)	Generation (kW)		Flow limits between Regions			
		Excl. Limitations	Limitations Incl.	Regions		Power flow Limits (kW)	
				From	To	Without Limitation	With Limitation
R 1	525	385	442.30	1	2	0	23.30
R 2	375	465	401.69	2	3	40	40
R 3	600	555	555	2	1	35	0

In the stable islanding process, the power transported from region 2 to region 3 is –0.8kW, i.e., it transmits the power from region 3 to 2. From these the considered corresponding power flows in FFR mode of DG at every region is –100kW, –40kW and –0.8kW. From these cases, the improved power flow limit feasibly escalates the running expenses. Meanwhile the DG with lesser expense in region 2 would reduce the power production.

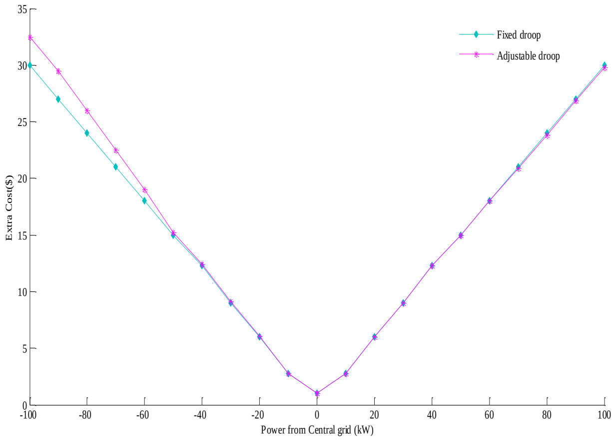

Fig. 5. Extra fuel expense owing to power reserve for stable islanding mode for considered flow limit 40 kW

Table 2
Power output of DG when exported by Proposed EBBO Algorithm

Region	Load Demand (kW)	Generation (kW)		Flow limits between Regions			
		Excluding Limitations	Limitations Inclusive	Regions		Power flow Limits (kW)	
				From	To	Without Limitation	With Limitation
R 1	525	555	545	2	1	40	40
R 2	375	485	454.21	2	3	39	0
R 3	600	561	600.39	3	2	0	0.39

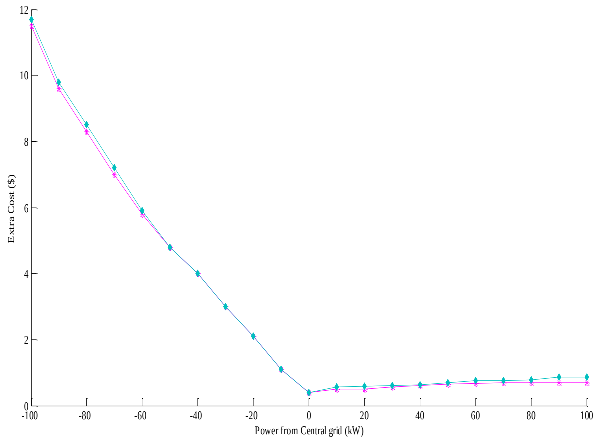

Fig. 6. Extra fuel expense owing to power reserve for stable islanding mode for considered flow limit 80 kW

The extra cost owing to this limit is scheming with the following situations and shown in the fig. 5 & fig. 6. Normally the extra expense intensifies the central grid power ($P_{Central\ grid}$) increases; from this, the exhaustive conclusions are clear. From above figures the consequence of limitation is dominant for sharing the load at considered LDF. Furthermore, if the load allocations are equal, then the consequence of the limitations might reduce. The microgrid operates efficiently during the grid connected and islanded mode the extra expenses are 0.9% less than the fuel cost.

Table 3
Total expense comparison of power imported from every region

Region	DSM[15]		EBBO	
	Fuel Expense ($)		Fuel Expense ($)	
	Excluding Limitations	Limitations Inclusive	Excluding Limitations	Limitations Inclusive
R 1	92.16	117.93	92.06	115.20
R 2	164.10	124.78	164.30	130.71
R 3	256.84	256.84	252.84	252.88
Total Expense	513.89	499.55	509.20	498.89

Table 4
Total expense comparison of power exported from every region

Region	DSM[15]		EBBO	
	Fuel Expense ($)		Fuel Expense ($)	
	Excluding Limitations	Limitations Inclusive	Excluding Limitations	Limitations Inclusive
R 1	183.74	183.74	168.72	162.89
R 2	164.10	138.76	174.10	159.57
R 3	256.84	289.63	256.84	288.23
Total Expense	604.68	612.13	603.66	610.69

The projected technique is simulated for 200 iterations with 30 trail runs and the best results are shown in table3. The entire expense incurred in importing power using the DSM and EBBO technique is compared. While the power is imported from the main grid to microgrid, the fuel expense decreases from 499.55 $ to 498.89 $ which is evident from the tables 1 & 3. The decrease in fuel expense including limitations is 0.99%. Through this, the fuel expense of participating fuel cell generators is minimized. In addition, it decreases the whole operating expense of entire DGs and in turn drives the DG system efficiently. By utilizing the proposed technique the fuel expense can be saved by 29.96 % per month or used as a reserve and utilized during the grid-connected mode. Even though the steps involved with DSM are less, sometimes the solution may struck within the local optimal solution. From the proposed technique, the change in species locations produces the global optimal solution with stipulated iterations when compared with DSM.

Similarly, when it is exported, the total fuel expense decreases from 612.13 $ to 610.69 $. From the table 2 & 4 it is clear that the percentage increase in fuel expense including additional limitations is 0.123%. This increase in expenses may compensate the fuel expense incurred in islanding operation and it makes the system stable. Furthermore, the projected EBBO technique saves the fuel expense by 29.92% per month. It is concluded that the presented technique minimize the fuel expenses gradually.

6. Conclusion

The economic power scheduling of microgrid is articulated by using EBBO algorithm in this paper. The constraint includes the reserve for non-dispatchable DGs, flow limits between regions and reserve for the stable island operation to appropriate the formation of the efficient microgrid. This paper proceeds with an extra limitation for the stable island operation of microgrid and the described formulation is done with efficient power sharing principle. The generation expense is related with power flow constraints, import and export from the microgrid. The examination is accomplished by considering three regions with 15 small-distributed units through available energy sources from that region. It is clear from the results that the anticipated technique produces the superior quality results when compared with direct search technique. The projected EBBO technique decreases the extra expenses by optimal scheduling. This paper proposes the idea for deployment and operation of the microgrid operation in the Indian power system.

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