Abstract
Dynamic Power Dispatch (DPD) intends to schedule the online generators output with the forecasted load demand over a certain period of time, in order to operate an electric power system most economically within its operating limits. The behavior and the activity of honey bees during food foraging is implemented as a Honey Bees Searching Optimization (HBSO) technique in solving the DPD problem. The HBSO algorithm provides a balance between exploration and exploitation of a search space. Further, the HBSO is independent of control parameters when compared to other techniques. The DPD formulation includes ramp rate constraint, rectified sinusoidal effect, uniformity and disparity constraint, which normally present in the realistic power system. In order to express the efficacy of the HBSO algorithm a test case of 6 units DPD problem is considered and lower fuel cost is obtained when compared with other algorithm.

Keywords: Dynamic Power Dispatch, HBSO Algorithm, Power Balance Constraint, Ramp rate constraint, Valve Point Loading

1. Introduction
Dynamic power dispatch intends to schedule the online generators output with the predicted load demand considering major constraints over a certain period of time. In order to satisfy the necessity of power demand with losses and to obtain the minimum production cost DED is considered\(^1\). In the general Economic Power Dispatch problem the fuel cost function is assumed to be linear in nature by considering only the equality and inequality constraints\(^2\). In order to solve this smooth fuel cost function, traditional optimization method was used\(^3-5\). Even though the problem gets simplified, the traditional optimization technique has the drawback to get stuck up at the local optimal points in the cost function. So the solution which was obtained from these methods is not the exact optimal solution\(^6\). But in practical power dispatch problem there are much more constraints which normally convert the fuel cost function to be non convex\(^7,8\), which creates a real challenge to obtain the optimized solution. In order to overcome the drawback of the traditional optimization method and to find the optimal solution for the non smooth economic power dispatch problem evolutionary computation techniques were introduced\(^9-13\). The evolutionary computational techniques inbuilt have the nature to search the global optimum with any type of non convex cost function\(^14,21\). In this article the more advanced stage of EPD problem namely Dynamic power dispatch was considered by including more constraints and it was optimized with the help of Honey Bees Searching Optimization technique.

2. Problem Formulation
Dynamic Power Dispatch determines the most economical operation of the thermal units for a certain period of time, also by fulfilling all the constraints which makes
the problem to be non-convex in real time operation. Mathematically it was formulated as follows:

2.1 Dynamic Power Dispatch (DPD)

Problem Description

The problem statement for DPD will be stated in the form of quadratic function with fuel cost coefficients. Hence the aim of DPD is to minimize:

\[
F_{TC} = \sum_{h=1}^{H} \sum_{i=1}^{N} F_i(P_{ih})
\]

Where

\[
F_i(P) = a_i P^2 + b_i P + c_i
\]

\(a_i, b_i, c_i\) are the fuel cost coefficients of the \(i\)th unit

\(T\) is the number of hours

\(N\) be the no. of generating units

\(P_i\) is the output generation of \(i\)th unit

2.1.1 Uniformity Constraint

\[
\sum_{i=1}^{N} P_i = P_D + P_L
\]

Where

\(P_D\) – Total power required

\(P_L\) – Total power loss

2.1.2 Disparity Constraint

\[
P_{i_{\text{min}}} \leq P_i \leq P_{i_{\text{max}}}
\]

Where

\(P_{i_{\text{min}}}\) – min gen limit

\(P_{i_{\text{max}}}\) – max gen limit

2.2 Valve Point Loading

Depends on the sudden increase and decrease in power demand to be satisfied, it is necessary to adjust the fuel input supplied to the prime mover of the generator. In order to achieve this fuel admission valves are frequently opened and closed according to the load curve, this increases the throttling losses rapidly and rise in incremental heat rate suddenly. The above mentioned constraint creates the pumping nature in the normal fuel cost curve as shown in Figure 2.1.

By adding the sinusoidal component to the normal fuel cost equation that makes the traditional DPD problem to be non-convex as given below,

\[
F_i(P) = F_i(P_i) + e_i \sin(f_i[P_i^{\text{min}} - P_i])
\]

Where

\(F_i(P_i)\) – Valve point loading included fuel cost equation for \(i\)th unit

\(e_i, f_i\) – coefficients of the \(i\)th unit with valve point loading.

2.3 Ramp Rate Constraint

The upper limit and lower limit of ramp rate constraints of \(i\)th generator are given by

As generation increases,

\[
P_i - P_{i0} \leq UR_i
\]

As generation decreases

\[
P_i - P_{i0} \leq DR_i
\]

and

\[
\max(P_{i_{\text{min}}}, P_{i0} - DR_i) \leq P_i \leq \min(P_{i_{\text{max}}}, P_{i0} + UR_i)
\]

Where \(P_i\) is the current power output and \(P_{i0}\) is the power output in the prior interval of the \(i\)th unit. \(UR_i\) is the upper-ramp rate of the \(i\)th unit and \(DR_i\) is the down-ramp rate of the \(i\)th unit.

2.4 Multiple Fuels

Some generating units are capable of operating using different types of fuels. The use of multiple fuel types may result in multiple cost curves that are not necessarily parallel or continuous. The lower region of the resulting cost curve determines which fuel type is most economical to burn.
This cost function can be represented by a piecewise curve (see Figure 2.2), and the segments are defined by the range in which each fuel is used\(^{21}\). The ED problem with piece wise quadratic cost curves is very difficult to solve by standard techniques. Piecewise quadratic cost functions have as many segments as fuel types.

\[
F_i(P_G,i) = \begin{cases} 
    a_{i,1} + b_{i,1}P_G + c_{i,1}P_G^2, & P_G^1 < P_G^i \\
    a_{i,2} + b_{i,2}P_G + c_{i,2}P_G^2, & P_G^2 < P_G^i \\
    \vdots \\
    a_{i,k} + b_{i,k}P_G + c_{i,k}P_G^2, & P_G^k < P_G^i 
\end{cases} \tag{9}
\]

Where \(P_G^k\) and \(P_G^i\) are the lower and upper bound respectively of the \(k^{th}\) fuel of unit-i, and \(a_{i,k}, b_{i,k}, c_{i,k}\) are the \(k^{th}\) fuel cost coefficient of unit-i.

### 3. Honey Bees Searching Optimization Algorithm

HBSO algorithm for real bound optimization problem, is a recently introduced optimization technique which simulates the foraging behavior of bees in searching of their food which is called the nectar and sharing the information of food sources to the bees in the nest\(^{20,21}\). For solving the non convex optimization problems, an evolutionary computational technique with constraint handling method was incorporated with the algorithm.

Main steps of the HBSO algorithm for DPD problem are given below, here the food represents the power generation and the food source represents the limits of each generator.

- Initialize the position of food source.
- In their food source site a new food source is produced by each employed and exploits the better source.
- Depends on the quality of their solution, each onlooker bee selects a source, which produces a new food source in selected food source site and exploits the better source.
- Determine the source to be abandoned and allocate its employed bee as scout for searching new food sources.
- The best food source should be stored.
- Until the stopping criteria reached, repeat the steps 2 to 5.

### 4. Implementation of HBSO Algorithm

The flow chart of the HBSO algorithm is given below\(^{21}\):

![Flowchart of HBSO Algorithm](image)

Figure 3. HBSO algorithm.
The HBSO algorithm steps are presented as follows:

### 4.1 Initialization

In the search space a new percentage of population was sprayed randomly, and then it was applied to the fitness function which was termed as nectar amounts, which represents the proportion of employed bees to the total population. Once it gets settled in their positions in the search space, they are named as employed bees.

### 4.2 Move the Onlookers

Probability of food source selection should be calculated. For every onlooker bees, it is necessary to select the food source to move by roulette wheel selection and then find out their nectar amount.

### 4.3 Move the Scouts

The employed bees become scouts if there is no betterment in the solution obtained with the fitness function of the employed bees after the number of trials got over. Those food sources are neglected.

### 4.4 Update the Best Food Source Found So Far

The most optimal solution obtained from the search space and the position, which are found by the bees are stored.

### 4.5 Termination Checking

Once after finding the solution from the fitness function, check for the stopping criteria and terminate the program if condition is satisfied, or else repeat from step 2.

\[
P_i = \frac{F(\theta_i)}{\sum_{k=1}^{S} F(\theta_k)}
\]

where

- \( \theta_i \) - \( i^{th} \) employed bee position
- \( S \) - No. of employed bees and
- \( P_i \) - probability of selecting the \( i^{th} \) employed bee.

\[
x_j(t+1) = \theta_j + \phi(\theta_j)(t - \theta_k(t))
\]

where

- \( x_j \) - Position of the \( j^{th} \) onlooker bee
- \( t \) - No. of iteration
- \( \theta_k \) - Randomly chosen employed bee
- \( j \) - dimension of the solution and

\[\phi(.) - \text{series of random variable between [-1, 1].}\]

\[\theta_j = \theta_{j_{\text{min}}} + r(\theta_{j_{\text{max}}} - \theta_{j_{\text{min}}})\]

where \( r \) is a random number and \( r \in [0, 1] \).

### 5. Data and Results

The unit characteristics data are given. The variation load curve is shown in Figure 5.1. The constraints which have been included are uniformity & disparity, Valve point loading, Ramp Rate constraint, and transmission losses.

The output power for each generator among the six units has been represented below and also the total power along with the fuel cost has been calculated after considering the above mentioned constraints. Comparison has been made for the calculated result in HBSO with General Algebraic Modeling system (GAMS) in Table 5.1 and graphically shown in Figure 5.2.

**Table 1.** With valve point effect & losses

| Time in Hours | Power (MW) | Total MW |
|---------------|------------|----------|
| 1             | 256.35     | 100      |
| 2             | 433.562    | 142.364  |
| 3             | 385.554    | 138.156  |
| 4             | 362.345    | 118.352  |
| 5             | 362.345    | 118.352  |
| 6             | 336.512    | 115.431  |
| 7             | 436.826    | 145.874  |
| 8             | 433.562    | 142.364  |
| 9             | 436.826    | 145.874  |
| 10            | 436.826    | 145.874  |
| 11            | 436.826    | 145.874  |
| 12            | 385.554    | 138.156  |
| 13            | 362.345    | 118.352  |
| 14            | 362.345    | 118.352  |
| 15            | 362.345    | 118.352  |
| 16            | 362.345    | 118.352  |
| 17            | 362.345    | 118.352  |
| 18            | 362.345    | 118.352  |
| 19            | 362.345    | 118.352  |
| 20            | 362.345    | 118.352  |
| 21            | 362.345    | 118.352  |
| 22            | 362.345    | 118.352  |
| 23            | 362.345    | 118.352  |
| 24            | 362.345    | 118.352  |

**Figure 4.** Daily load curve.

**Figure 5.** Convergence cure for 6 unit system.
Table 1. Convergence results for 6 generating units With valve point effect & losses

| Hour | \(P_{G1}\) | \(P_{G2}\) | \(P_{G3}\) | \(P_{G4}\) | \(P_{G5}\) | \(P_{G6}\) | Power Demand (MW) | Power Loss (MW) | Total Power O/P (MW) | Generation cost ($/hr) |
|------|------------|------------|------------|------------|------------|------------|-------------------|-------------------|--------------------|---------------------|
| 1    | 256.35     | 100        | 50         | 142.542    | 197.21     | 53.898     | 800               | 7.652             | 807.652            | 3201.99            | 3186.75            |
| 2    | 293.933    | 100        | 50         | 170.642    | 216.764    | 78.526     | 900               | 9.865             | 909.865            | 3614.327           | 3576.84            |
| 3    | 305.685    | 100        | 50         | 190.524    | 266.648    | 99.613     | 1000              | 12.47             | 1012.47            | 4045.941           | 3968.52            |
| 4    | 336.512    | 115.431    | 52.546     | 184.278    | 311.57     | 114.523    | 1100              | 14.86             | 1114.86            | 4496.908           | 4428.64            |
| 5    | 378.654    | 126.423    | 68.532     | 227.516    | 330.985    | 136.54     | 1250              | 18.65             | 1268.65            | 5203.722           | 5184.78            |
| 6    | 336.512    | 115.431    | 52.546     | 184.278    | 311.57     | 114.523    | 1100              | 14.86             | 1114.86            | 4496.908           | 4428.64            |
| 7    | 358.071    | 112.874    | 55.456     | 219.54     | 298.645    | 120.864    | 1150              | 15.45             | 1165.45            | 4728.766           | 4666.21            |
| 8    | 362.345    | 118.352    | 67.425     | 230.657    | 310.648    | 128.563    | 1200              | 17.99             | 1217.99            | 4964.366           | 4885.64            |
| 9    | 380.645    | 140.641    | 85.264     | 249.463    | 357.112    | 157.335    | 1350              | 20.46             | 1370.46            | 5693.768           | 5621.56            |
| 10   | 433.562    | 142.364    | 92.745     | 274.514    | 364.842    | 164.523    | 1450              | 22.55             | 1472.55            | 6199.03            | 6104.54            |
| 11   | 435.642    | 170.451    | 97.72      | 268.984    | 374.54     | 178.123    | 1500              | 25.46             | 1525.46            | 6457.408           | 6385.62            |
| 12   | 433.562    | 142.364    | 92.745     | 274.514    | 364.842    | 164.523    | 1450              | 22.55             | 1472.55            | 6199.03            | 6104.54            |
| 13   | 436.826    | 145.874    | 84.512     | 248.154    | 348.268    | 156.846    | 1400              | 20.48             | 1420.48            | 5944.489           | 5876.28            |
| 14   | 336.512    | 115.431    | 52.546     | 184.278    | 311.57     | 114.523    | 1100              | 14.86             | 1114.86            | 4496.908           | 4428.64            |
| 15   | 362.345    | 118.352    | 67.425     | 230.657    | 310.648    | 128.563    | 1200              | 17.99             | 1217.99            | 4964.366           | 4885.64            |
| 16   | 362.345    | 118.352    | 67.425     | 230.657    | 310.648    | 128.563    | 1200              | 17.99             | 1217.99            | 4964.366           | 4885.64            |
| 17   | 378.654    | 126.423    | 68.532     | 227.516    | 330.985    | 136.54     | 1250              | 18.65             | 1268.65            | 5203.722           | 5184.78            |
| 18   | 385.554    | 138.156    | 72.622     | 246.152    | 332.643    | 142.123    | 1300              | 17.25             | 1317.25            | 5446.851           | 5398.54            |
| 19   | 436.826    | 145.874    | 84.512     | 248.154    | 348.268    | 156.846    | 1400              | 20.48             | 1420.48            | 5944.489           | 5876.28            |
| 20   | 433.562    | 142.364    | 92.745     | 274.514    | 364.842    | 164.523    | 1450              | 22.55             | 1472.55            | 6199.03            | 6104.54            |
| 21   | 362.345    | 118.352    | 67.425     | 230.657    | 310.648    | 128.563    | 1200              | 17.99             | 1217.99            | 4964.366           | 4885.64            |
| 22   | 336.512    | 115.431    | 52.546     | 184.278    | 311.57     | 114.523    | 1100              | 14.86             | 1114.86            | 4496.908           | 4428.64            |
| 23   | 256.242    | 100        | 50         | 182.241    | 238.665    | 132.963    | 950               | 10.111            | 960.111            | 3827.712           | 3796.56            |
| 24   | 187.794    | 100        | 50         | 146.452    | 195.212    | 76.54      | 750               | 5.998             | 755.998            | 3002.983           | 2976.11            |

6. Conclusion

In this paper, a more realistic non convex dynamic power dispatch problem including valve point loading and ramp rate limits were discussed. On subjecting the above mentioned problem to the Honey Bees Searching Optimization algorithm, it was found best suited for the fuel cost functions of non-smooth cost functions when compared with the results presented in the literature. The proposed method assures the global optimal solution in the search space with low computation burden. The research work is under way in order to incorporate more security issues of power system in the DPD model with other constraints.

7. References

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