Congestion reduction under IPFC based deregulated electricity market using AKH algorithm

Niharika Thakur1, Y K Awasthi2, A S Siddiqui3, Manisha Hooda1

1 Electrical Laboratory, Department of Electronics & Communication Engineering, Manav Rachna University, Faridabad, HR, 121004 India
2Department of Electronics & Communication Engineering, Manav Rachna International Institute of Research & Studies, Faridabad, HR, 121004 India
3Department of Electrical Engineering, Jamia Millia Islamia (Central University), New Delhi 110025, India

Abstract: With the Deregulation in the electric utilities across the globe there have been major issues faced viz., transmission losses, cost of generation and emission, voltage stability limits and congestion cost that have to be considered for reducing the congestion in the lines and consequently in power systems under the restructured framework. For achieving the said objective, this paper presents the Adaptive Krill Herd (AKH) algorithm-based model in which a support value is determined for optimization of the given objective functions. The FACTS device used is IPFC for reducing the congestion in the identified lines optimally by determining the parameters “Congestion Detection Index and Index of Total Congestion Cost”. The projected AKH optimizer model is compared with the conventional models viz PSO, GA, ABC algorithm based on IEEE 30 and 57 bus systems.

Keywords: Transmission loss, Generation cost, emission cost, Voltage stability limit, IPFC, CDI, ITCC, AKH algorithm.

Nomenclature:

| Abbreviation | Description                     |
|--------------|---------------------------------|
| AKH          | Adaptive Krill Herd Algorithm   |
| PSO          | Particle Swarm Optimisation     |
| GA           | Genetic Algorithm               |
| ABC          | Artificial Bee Colony           |
| CDI          | Congestion Detection Index      |
| ITCC         | Index of Total Congestion Cost  |
| GWO          | Grey Wolf Optimizer             |
| IPFC         | Interline Power Flow Controller |
| OPF          | Optimal Power Flow             |
| CM           | Congestion Management           |
| GSO          | Gravitational Search Algorithm  |
| TCSC         | Thyristor Controlled Series Capacitor |
| LMP          | Load Marginal price            |
| SV           | Support Value                   |
| VSL          | Voltage Stability Limit         |

1. Introduction

In the deregulated electric power industry, managing congestion is one of the main problems. The issue of transmission congestion is particularly prominent in deregulated and competitive markets, thus requiring an appropriate management strategy [1]. Out of many methods, the OPF is the widely used and appropriate method for CM constraints [2]. The OPF programs are also capable of solving very large and complex power systems optimization problems in much less time in comparison to conventional methods resulting in enhanced power transfer capabilities [3, 4]. Numerous methods have been applied in the deregulated market to minimize congestion [5].

The main congestion management methodologies are price-based, transaction-based and OPF based. The techniques based on OPF have high accuracy and can effectively manage congestion by generator rescheduling/load curtailment [6]. The price of electricity has also to be administered keeping congestion in line as the key factor and not affecting the benefits of deregulation [7]. Recently there has been growing interest in optimal placement of FACTS devices for achieving...
different objectives related to the congestion management [8]. There are several factors that affect the power transfer capability of line viz., stability limit, thermal limit and voltage limit which can be managed using FACTS devices and supply sufficient power according to the market needs [9, 10].

FACTS devices are one of the ways to reduce transmission congestion and allow better utilization of lines [11]. The FACTS devices can control the power flow in a transmission network without generator rescheduling or network reconfiguration, thus improving the performance [12]. The use of FACTS devices has certain issues like optimal location, suitable size, setting, cost, and modelling [13, 14]. The congestion alleviation method ensuring voltage stability, using load ability limits in pool electricity markets. This paper presents Congestion reduction by using the AKH algorithm model under IPFC based deregulated electricity markets.

2. Literature review

Akanksha Sharma et al [15] has presented OPF based methods for allocating TCSC using the method of congestion rent contribution based on LMP and GSO to manage congestion. The proposed models are then checked on varying loading conditions on “IEEE 30-bus and IEEE 57” test bus systems.

Saurav Raj, et al [16] has presented two algorithms that are based on the hunting behaviour of Humpback Whales and GWO based on the hunting behaviour of Grey wolf. The standard test bus systems have been adopted for testing purposes.

Fatma Sayed et al [17] presents CM using grey wolf optimizer (GWO) for improving the voltage profile and reducing active power losses by minimizing load shedding. The results obtained have depicted that the load shedding technique is a robust control action for congestion management. The developed model has been tested on IEEE 30 bus system.

Archana Shirbhate et al [18] presented a tool for analysis of the electricity market so as to solve congestion issues. This tool developed an interface to optimally compute the flow of power. The tool analyses these computed results, while larger case studies are done on the IEEE 30-bus system for simulating the power market and validating the power flow method.

Divya Asija et al [19] present an effective approach for managing congestion in a power transmission system by optimally placing distributed generators at the load end. The network security is managed by a multi-objective OPF problem. The objective functions in the power transmission system had lowered the overall price paid to market operators by assigning balanced weights to social welfare and network security enhancing the overall system performance.

2.1. Contribution

In the existing work, many studies have been carried out for determining the best techniques to prevent the transmission lines from congestion despite increased electricity demand. The main contribution of the proposed work is given below:

- The objective functions viz., transmission losses, cost of generation, emission cost, and voltage stability limit are minimised.
- The adaptive krill herd (AKH) is utilized for optimization to find the best line in the bus for FACT placement.
- The congested lines and corresponding cost factor are determined by calculating CDI and ITCC.

The overall structure of the paper is composed as pursues: Section-2 surveys the literature review. The section-3, a brief explanation about the proposed methodology is presented, the section-4 examines the preliminary outcomes and section-5 concludes the paper.

3. Congestion reduction under the deregulated electricity market

The proposed work is a two-step process which is depicted in the given figure 1.
3.1. Objective Function

The objective functions of the proposed approach are transmission loss minimization, generation cost, emission cost, and voltage stability limit which are determined below:

3.1.1. Transmission Loss Minimization: Load flow solution technique is used for calculating the transmission loss in each line. The net power shortfall is equivalent to the total intensity deficit in each line. The transmission loss is given in equation (1) as

\[
 f_{\text{loss}} = \sum_{k=1}^{N_L} (G_k (V_i^2 + V_j^2 - 2V_i V_j \cos \theta_{ij})) 
\]

(1)

Where \( N_L \) is the complete part of the power frameworks, \( G_k \) is the conductance of the \( k^{th} \) division, \( V_i \) and \( V_j \) are the voltage magnitudes of extreme buses, and \( \theta_{ij} \) is phase angles contrast relating them.

3.1.2. Generation Cost: To deliver power with least costs with the ascent in generation costs and the extended power loads is constrained by the generation cost of creating units as the valve stacking impacts can be communicated as in condition (2)

\[
 \text{generation cost} = \sum_{i=1}^{N_{\text{gen}}} (a_i P_{gi}^2 + b_i P_{gi} + c_i) 
\]

(2)

Where \( a_i, b_i, c_i \) are coefficients of generation cost of the \( i^{th} \) generator, \( P_{gi} \) is real power output of thermal unit \( i \).

3.1.3. Emission cost: An ever-increasing number of nations or locales are worried about natural insurance because of the inexorably difficult issue of air contaminations. It is important to decrease the discharges of barometrical poisons brought about by warm generation units which can be communicated as in equation (3):

\[
 \text{emission cost} = \sum_{i=1}^{N_{\text{gen}}} (\alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i + \eta_i \exp(\delta_i P_{gi})) 
\]

(3)

Where \( \alpha_i, \beta_i, \gamma_i, \) and \( \eta_i, \delta_i \) are emission constant coefficients of the \( i^{th} \) unit and \( P_{gi} \) is the real power output of “thermal unit \( i \)”.

Figure 1: The proposed work Flow diagram
3.1.4. Voltage stability limit: The CPF technique is used for calculating the VSL which introduces the “load parameter (λ)” stated as the percentage increase in load and generation from its base value. The voltage limit ranges from 0 to 1. If the value exhibits close to 1.0, it implies that system is approaching its instability point. Buses approaching to instability point are considered as weak buses. Maximum voltage stability limit is achieved when voltage stability index has minimum value in the bus system. The resulting equations in terms of the load parameter are as in equation (4):

\[
V(\lambda_{\text{max}}) = \frac{1}{\lambda_{\text{max}}} = \text{VSL}
\]  

(4)

The parameter lambda “λ” represents the load data (real and reactive power) of both the bus systems. The maximum values of lambda are considered to calculate VSL which should come minimum after optimization. If the VSL is increased means the congestion is increased and the bus is considered as weaker bus.

3.2. Adaptive krill herd optimization

The support value-based krill herd optimization algorithm to find the fitness value function [3]. This support value is considered to be adaptive therefore the optimization algorithm is called the Adaptive AKH Algorithm.

Support value calculation:

The support value is calculated based on the objective function as given in equation (5).

\[
SV = \frac{f_{\text{loss}} + \text{generation cost} + \text{emission cost} + V(\lambda_{\text{max}})}{f_{\text{loss}} \times \text{generation cost} \times \text{emission cost} \times V(\lambda_{\text{max}})}
\]

(5)

The steps for AKH are given below:

Step 1

First, the support value from equation (5) is calculated to find the fitness value function for each distinct krill as per the calculated support measure.

Step 2

The fundamental cycle of calculation begins by basically placing krill from most prominent to the most outrageous noticeably terrible individual.

Step 3

Later, the updates in movement as given below are calculated for all krill utilizing the associate conditions.

a) Foraging movement

Following equations are used for updating:

\[
F_a(t + 1) = F_a(t) + \omega I_F A_a(t)
\]

\[
\beta_a = \beta_a^{\text{food}} + \beta_a^{\text{best}}
\]

(6)

(7)

Here, “F_a” is the “foraging speed”, “\omega I” is the “inertia weight”, “\beta_a^{\text{food}}” is the “food attractive”, “\beta_a^{\text{best}}” is the “best solution” for the \( a \)th krill individual.

b) Induced motion

It is specified as,

\[
M_a(t + 1) = I_a M_{\text{max}} \alpha_a + \omega I M_a(t)
\]

\[
\alpha_a = \alpha_a^{\text{local}} + \alpha_a^{\text{target}}
\]

(8)

(9)

Here, “I_a” is “most outrageous induced speed”, “\omega I” is “inertia weight”, “\alpha_a^{\text{local}}” is nearby “impact of the \( a \)th krill” has on its neighbours, “\alpha_a^{\text{target}}” is the “finest sorting” of the \( a \)th krill.
c) **Physical diffusion**  
It is denoted by,

\[ D_a(t + 1) = D_0 \left( \frac{1}{t_{max}} \right) \delta \]  

Here “\(D_0\)” is “most excessive diffusion speed” and a “random directional vector” in \([-1, 1]\).

**Step 4**

The above-mentioned motions are utilized to find the individual position of the krill in the middle of the time to \(i + \Delta t\) as given as,

\[ K_a(\hat{t} + \Delta \hat{t}) = K_a(\hat{t}) + \Delta \hat{t} \frac{dK_a}{dt} \]  

In which, “\(\Delta \hat{t}\)” is essential constants to be best tuned concerning the optimization in the real world. The Most excellent krill is returned at the final of the algorithm.

**Step 5**

Finally, the end condition is utilized for the fulfilment of a confined number of capacity evaluations. The flow chart of krill enhancement calculation is given in figure 2.

![Flowchart of AKH algorithm](image)

Figure 2: Flowchart of AKH algorithm

Here, the proposed optimization is done using support value-based krill herd algorithm which is called adaptive krill herd algorithm. The fitness value calculation for the proposed work is determined using equation (5) and the best line is identified. The optimum location of the IPFC device on the best line to reduce the congestion is explained in sections below.

### 3.3. IPFC Model
The basic model of IPFC consists of three buses $V_i$, $V_j$, and $V_k$ and two transmission lines connected to the common bus "i". The IPFC circuit is shown in Fig. 3. "$Zse_{ij}$" is the "series transformer impedance" and "$Pse_{ij}$" is the "active power exchange" for each converter. "$P_i" and "$Q_i" as given in (12) and (13) are the aggregate of the dynamic and responsive power streams going away from "i". The IPFC branch has "active" and "reactive" power which is leaving the bus n and denoted as "$P_{ni}$" and "$Q_{ni}$" as given in (14) and (15). "$I_{ji}$" and "$I_{ki}$" are the IPFC branch currents of branches "$j-i" and "$k-i" leaving bus j and k, respectively. For optimally placing IPFC, two lines minimally should be connected to the common bus [1].

\[
P_i = V_i^2 g_{ii} - \sum V_i V_n [g_{in} \cos (\theta_i - \theta_n) + b_{in} \sin (\theta_i - \theta_n)] - \sum V_i V_n e_{in} [g_{in} \cos (\theta_i - \theta e_{in}) - b_{in} \sin (\theta_i - \theta e_{in})]
\]

(12)

\[
Q_i = -V_i^2 b_{ii} - \sum V_i V_n [g_{in} \sin (\theta_i - \theta_n) - b_{in} \cos (\theta_i - \theta_n)] - \sum V_i V_n e_{in} [g_{in} \sin (\theta_i - \theta e_{in}) - b_{in} \cos (\theta_i - \theta e_{in})]
\]

(13)

\[
P_{ni} = V_n^2 g_{nn} - V_n V_i [g_{in} \cos (\theta_i - \theta_n) + b_{in} \sin (\theta_i - \theta_n)] + V_n V_n e_{in} [g_{in} \cos (\theta_i - \theta e_{in}) - b_{in} \sin (\theta_i - \theta e_{in})]
\]

(14)

\[
Q_{ni} = -V_n^2 b_{nn} - V_n V_i [g_{in} \sin (\theta_i - \theta_n) - b_{in} \cos (\theta_i - \theta_n)] + V_n V_n e_{in} [g_{in} \sin (\theta_i - \theta e_{in}) - b_{in} \cos (\theta_i - \theta e_{in})]
\]

(15)

The equivalent circuit of IPFC is given in figure 3.

![Figure 3: Equivalent circuit of IPFC model](image)

3.4. IPFC Placement:

In the IPFC placement, CDI and ITCC are the two parameters to be considered as given in equation (16) and (17) below:

3.4.1. Congestion Detection Index (CDI): It is used to recognize the lines in a system that are most congested and also to decide the ideal area for IPFC (for example set in the most blocked line) in order to decrease the blockage in the framework. Position of IPFC at the line which is most congested gives the most astounding advantages to the framework.

\[
\text{Congestion detection index} = e^{-\left(1 - \frac{S_{ij}}{S_{ij}^{max}}\right)}
\]

(16)

Where, "$S_{ij}$" is base case MVA for a certain line and "$S_{ij}^{max}$" is a max value of MVA between entire lines.

3.4.2. Index of Total Congestion Cost (ITCC): This is calculated to locate the ideal number of IPFC important in a characterized power framework. The detailing of ITCC is given below:

\[
\text{ITCC} = \frac{\text{Congestion cost (CC)}}{\text{Generation cost (GC)}}
\]

(17)

After the FACTS device placement, the CDI and ITCC are determined. The table 1 shows the results for IEEE 30 bus and IEEE 57 bus system after IPFC placement for the proposed approach.
In Table 1, the congested line and congestion cost are given as 4, 6 and 117.2565 for IEEE 30 bus and 4, 5, and 120.1161 for IEEE 57 bus respectively. The comparison of the proposed and existing models is given in table 7.

### Table 1: After IPFC placement the congested line and congestion cost for IEEE 30 bus and IEEE 57 bus system

| Techniques | IEEE 30 bus system | IEEE 57 bus system |
|------------|-------------------|-------------------|
|            | Congested line    | Congestion cost   | Congested line    | Congestion cost after IPFC placement |
| Proposed (AKH) | 4                 | 6                 | 117.2565          | 4                 |
| IEEE 57 bus system | 5                 | 120.1161          |

4. Results and discussion

The implementation of the proposed work is done in the MATLAB platform. In this paper, two transmission test systems (IEEE 30 and 57 bus test systems) have been selected. The power flow and power loss analysis has been done for proposed and existing models. Then transmission loss minimization, emission cost, Generation cost, Voltage stability limit, fitness value, congestion line, and the congestion cost are also calculated.

### Table 2: The power flow for IEEE 30 bus and 57 bus system for the proposed work

| Generator No. | From | To | P(MW) | Q(MVAR) | P(MW) | Q(MVAR) |
|---------------|------|----|-------|---------|-------|---------|
| IEEE 30 bus system | | |       |         |       |         |
| 2             | 2    | 6  | 21.7   | 12.7    | 22.8595| 13.8845 |
| 5             | 5    | 7  | 94.2   | 19      | 96.0169| 20.4921 |
| 8             | 28   | 8  | 0.1622 | 0.8     | 0.1376 | 3.8246 |
| IEEE 57 bus system | | |       |         |       |         |
| 3             | 3    | 4  | 40     | -1      | 46.7899| 1.0029  |
| 6             | 6    | 7  | 0      | 0.8     | 1.63   | 2.2035  |
| 8             | 8    | 9  | 450    | 62.1    | 457.5454| 70.1963 |
| 9             | 9    | 10 | 0      | 2.2     | 1.321  | 3.8246  |

In Table 2, the power flow of the proposed model for a single generator on both bus systems is calculated. For IEEE 30, the generator is considered as 2, 5, and 8 and the selection lines are between 2 to 28. The P (MW) is the real power and Q (MVAR) is the reactive power. Consider the bus number of the generator as 2 and the selection lines from 2 to 6, the power flow for the normal mode of P and Q is 21.7MW, 12.7MVAR and after optimization, the P and Q are 22.8595MW, 13.8845MVAR.

For IEEE 57, the generator is considered as 3, 6, 8, 9 and the selection lines are between 3 to 10. The bus number of the generator is 3 and selection lines from 3 to 4 the power flow for the normal mode of P and Q is 40MW, -1MVAR and after optimization, the P and Q are 46.7899MW, 1.0029MVAR. Here the optimization value is high therefore the power flow is increased in both the bus systems and similarly for other generators and selection lines, the same is determined.

### Table 3: The power loss of the IEEE 30 bus and 57 bus system for the proposed work

| Generator No. | From | To | Normal (MW) | After Optimization (MW) |
|---------------|------|----|-------------|-------------------------|
| IEEE 30 bus system | | | | |
| 2             | 3    | 4  | 0.2971      | 0.2869                  |
| 6             | 6    | 7  | 0.1395      | 0.1237                  |
| IEEE 57 bus system | | | | |
| 3             | 3    | 4  | 0.2971      | 0.2869                  |
| 6             | 6    | 7  | 0.1395      | 0.1237                  |
In table 3, the power loss of the AKH model is calculated. For IEEE 30 bus system, the generator is considered as 2, 5, 8 and selection lines are from 2 to 28. For the given generator 2 and selection lines 2, 6 the power loss of the proposed model after optimization of power loss is 2.1642MW and normal is 3.1157MW.

For IEEE 57 bus system, the generator is examined as 3,6,8,9 and the selection lines are from 3 to 10. For given generator 3, 4 and selection lines 3, 4 power loss is 0.2971, 0.2869 respectively. Hence, the optimization value is small and consequently, the power loss is reduced for the proposed model. For other generator and selection lines, the same is determined.

5. Evaluation and comparison

The comparison of transmission loss minimization, emission cost, Generation cost, Voltage stability limit for the AKH model with the existing ones is done for both bus systems as given in Table 4.

| TECHNIQUES       | IEEE 30 BUS SYSTEM | IEEE 57 BUS SYSTEM |
|------------------|---------------------|---------------------|
|                  | Transmission loss   | Generation cost     | Emission cost | Voltage stability limit|
| WITHOUT          | 17.52796            | 5114.469            | 4003.728      | 0.065789               |
| KH               | 13.3012             | 4495.268            | 3698.113      | 0.041258               |
| PSO              | 13.89825            | 4667.601            | 3779.813      | 0.057038               |
| ABC              | 15.10054            | 4983.57             | 3884.668      | 0.062422               |
| PROPOSED(AKH)    | 13.0688             | 4428.297            | 3664.129      | 0.031857               |
|                  | 22.703              | 15012.04            | 4388.038      | 0.038462               |
| KH               | 20.81308            | 14112.4             | 4289.559      | 0.03165                |
| PSO              | 20.96516            | 14249.24            | 4291.82       | 0.037624               |
| ABC              | 21.43244            | 14328.56            | 4365.993      | 0.039825               |
| PROPOSED(AKH)    | 20.74582            | 14068.82            | 4225.685      | 0.029960               |

The transmission loss, emission cost, Generation cost and Voltage stability limit of the proposed model is 13.0688, 4428.297, 4003.728 and 0.065789 and 20.74582, 14068.82, 4388.038 and 0.039825 for IEEE 30 and 57 systems respectively. Compared to the existing ones, the proposed model transmission loss, emission cost, Generation cost and Voltage stability limit is reduced. Figure 4 depicts the transmission losses for the proposed and existing models both the bus systems. Compared to the existing ones, the proposed model depicts the reduced transmission loss with IPFC.

![Figure 4: Transmission loss for (a) IEEE 30 bus and (b) 57 bus system](image)
In Figure 5, the generation cost is compared with the existing models and it is clearly reduced for our proposed model using AKH. In figure 6, the emission cost for the proposed and existing models is compared which is reduced for the proposed model for both the bus systems. Figure 7 compares the voltage stability limit of the proposed and existing models for the IEEE 30 and 57 bus systems and shows better performance for the proposed model.

**Table 5** Power Flow Comparison for both bus systems

| Techniques    | Power flow | Normal | After optimization |
|---------------|------------|--------|--------------------|
|               | Gen No.    | From   | To     | P(MW) | Q(MVAR) | P(MW) | Q(MVAR) |
| IEEE 30 bus system |           |        |        |       |         |       |         |
| KH            | 5          | 5      | 7      | 94.2  | 19      | 95.714| 22.1802 |
| PSO           | 5          | 5      | 7      | 94.2  | 19      | 95.6617| 21.8915 |
| ABC           | 5          | 5      | 7      | 94.2  | 19      | 95.4496| 21.5735 |
| PROPOSED(AKH) | 5          | 5      | 7      | 94.2  | 19      | 96.1365| 22.294  |
| IEEE 57 bus system |         |        |        | 450   | 62.1    | 453.2631| 69.9003 |

Figure 5: Generation cost for (a) IEEE 30 bus and (b) 57 bus system

Figure 6: Emission cost for (a) IEEE 30 bus and (b) 57 bus system

Figure 7: Voltage Stability Limit for (a) IEEE 30 bus and (b) 57 bus system
In Table 5, the comparison of the power flow for proposed and existing models is done on both bus systems. For IEEE 30, the generator is considered as 5, and the selection lines are from 5 to 7 for which the normal mode power flow for P and Q is 94.2MW, 19MVAR, and after the optimization is 96.1365MW, 22.294MVAR. Likewise, for IEEE57, the generator is considered as 8, and the selection lines are from 8 to 9 for which the normal mode power flow for P and Q is 450MW, 62.1MVAR, and after the optimization is 457.5454MW, 70.1963 MVAR. Similarly, the values for P and Q are determined for other existing models and compared.

Table 6: Comparison of power loss for both the bus systems

| Techniques | Gen No. | From | To | Normal (MW) | After opt (MW) |
|------------|---------|------|----|-------------|----------------|
| KH         | 5       | 5    | 7  | 2.9454      | 2.7489         |
| PSO        | 5       | 5    | 7  | 2.9454      | 2.789          |
| ABC        | 5       | 5    | 7  | 2.9454      | 2.877          |
| PROPOSED(AKH) | 5 | 5    | 7  | 2.9454      | 2.6133         |

IEEE 57

| Techniques | Gen No. | From | To | Normal (MW) | After opt (MW) |
|------------|---------|------|----|-------------|----------------|
| KH         | 8       | 8    | 9  | 3.0788      | 2.9737         |
| PSO        | 8       | 8    | 9  | 3.0788      | 3.0094         |
| ABC        | 8       | 8    | 9  | 3.0788      | 3.0332         |
| PROPOSED(AKH) | 8 | 8    | 9  | 3.0788      | 2.7077         |

In Table 6 the power loss of the proposed model is compared with the existing algorithms such as KH, PSO, and ABC, for both bus systems. For IEEE 30, the generator bus number is considered as 5 and selection lines from 5 to 7 for which the normal, and after optimization, power loss comes out to be 2.9454 and 2.6133. Likewise, for 57 bus system, the generator is considered as 8, and the selection lines are from 8 to 9 for which it comes to be 3.0788 and 2.7077 respectively. The optimized value is small compared to the existing models. Therefore, the power loss of the proposed work is reduced.

Table 7: Congestion cost for the proposed and existing models

| TECHNIQUES | Congestion lines 30 bus system | Congestion lines 57 bus system | Congestion cost 30 bus system | Congestion cost 57 bus system |
|------------|-------------------------------|--------------------------------|-------------------------------|-------------------------------|
| WITHOUT    | 125.4594                      | 124.5099                       | 125.4594                      | 124.5099                      |
| KH         | 120.2575                      | 122.5045                       | 120.2575                      | 122.5045                       |
| PSO        | 121.6821                      | 123.6853                       | 121.6821                      | 123.6853                       |
| ABC        | 124.0725                      | 125.8373                       | 124.0725                      | 125.8373                       |
| PROPOSED   | 117.2565                      | 120.1161                       | 117.2565                      | 120.1161                       |

In Table 7, the congestion cost for the proposed and existing algorithms for both the bus systems is compared. Without the IPFC device, the congestion cost comes out to be 125.4594 and 124.5099 whereas after the proposed AKH optimization model the cost comes out to be 117.2565 and 120.1161 for IEEE 30 and 57 bus systems respectively. The same is calculated for the other existing models and is compared which shows that it is reduced for the proposed model.
Figure 8: Congestion cost for the without IPFC and proposed, existing algorithm for (a) IEEE 30 bus and (b) 57 bus system

Figure 9: Comparison of the fitness value function for the proposed and existing algorithm for (a) IEEE 30 bus and (b) 57 bus system

Figure 8 shows the graph for congestion cost for the proposed and existing algorithm for considered bus systems which show the results of Table 7 clearly. Figure 9 shows the comparison of the final fitness value for the proposed and existing models. Here the optimization for the proposed work is improved by reducing the fitness value for both bus systems respectively.

6. Conclusion

The Congestion reduction under IPFC based deregulated electricity markets using the AKH algorithm has been presented. After the optimization and placement of IPFC, the active power flow for the proposed model is 0.44, 0.49, 0.71 and 0.94, 1.21, 1.26 percent better than KH, PSO and ABC based models for IEEE 30 and IEEE 57 system respectively. The power loss is reduced to 2.6133 and 2.7077 as compared to higher values for other existing models. The congestion cost is also consequently lowered to 117.2565 and 120.1161 for IEEE 30 and 57 bus systems respectively which are higher for the existing models. Therefore, the AKH algorithm will be found suitable for current electricity market.

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