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Congestion Management in a Deregulated System with Market Analysis Using DEKH Algorithm

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Abstract :- **This paper presents the market analysis in the interregional congestion management process. It proposes that the market analysis calculates the impact factors in each zone. The assessment of market analysis plays a vital role in the deregulated electricity market. The IEEE 30-bus system is classified into three zones and the most congested zone is identified. The rescheduling of both real and reactive power to minimize the congestion cost is done by using differential evolution krill herd migration algorithm (DEKH). The numerical results on an IEEE 30-bus system is found and the congestion cost is minimized.**
Keywords: **Congestion management, Deregulated market, Zonal congestion management, Market analysis, Impact factors, Generator sensitivity, TCDF's factors, DEKH.**

I. INTRODUCTION

The Power utilities in our world are undergoing a transformation towards a deregulated environment. Most of power system operators seek to apply their systems in high costs of power systems [1], increase in power demand, environmental and violating limits, weak deliver of reactive power, rise in dynamic loads and at last huge amount of dealings which have the transforms to be operated in load flow in deregulated electricity markets.

The transmission system is said to be "congested" when it is operated beyond one or more transfer limits. The Independent System Operator (ISO) and Regional Transmission organization (RTO) plays an important role to manage congestion in a deregulated system as it threatens system security and may cause rise in electricity price resulting in market efficiency [2]. Market analysis is used to calculate the impact factors. It plays a vital role in congestion management method [3]. Based on locational marginal prices, economic transmission rights, and price area zones, generation rescheduling, the market based approaches can be classified. The congestion management is mostly based on redispatching of generators. It is based on system, with redispatch, security restrained OPF, zonal based congestion management approach with sensitivity factors, and by using FACTS devices to minimize transmission congestion cost. Bialek et al. [4] proposed better result in National Electricity Regulatory Commission's (NERC). Transmission Loading Relief (TLR) procedure is based on Real Power Transfer Distribution Factors (PTDF's) and congestion management process is done by allowing multilateral trades. Congestion management with injection of FACTS devices has been presented in [5]. So far many algorithms such as harmony search (HS) [6], cuckoo search (CS) [7], evolutionary strategy (ES) [8], differential evolution (DE) [9], imperialist competitive algorithm (ICA) [10], ant colony optimization (ACO) [11], bat algorithm (BA) [12], animal migration optimization (AMO) [13], particle swarm optimization (PSO) [14], artificial bee colony (ABC) [15], probability-based incremental learning (PBIL) [16], genetic programming (GP) [17], big bang-big crunch algorithm [18], biogeography-based optimization (BBO) [19], charged system search (CSS) [20], and the KH algorithm [21].

To overcome the limitations, this paper proposed Differential evolution Krill Herd Migration (DEKH) algorithm to minimise the congestion cost in the most sensitive zone. The proposed method utilizes two types of sensitivity indexes termed as Real Transmission Congestion Distribution Factors (PTCDFs) and Reactive Transmission Congestion Distribution Factors (QTCDFs) [22], for congestion management in competitive power markets. The most sensitive zones have been identified based on the Transmission Congestion Distribution Factors (TCDFs) and the congestion cost is minimized by using DEKH algorithm. The DEKH method provide an effective method when compared to other algorithms even with BBKH algorithm. The proposed method has been tested on a 30-bus system. Thus the problem is formulated and has been solved in MATLAB programming.

II. CONGESTION MANAGEMENT METHOD

Congestion is defined as the overloading of transmission lines and transformers in the power system. Congestion management in regulated market is easy when compared to deregulated electricity market. Congestion occurs when the transmission system is violated by

1. Stability limits.
2. Voltage limits.
3. Thermal limits.

Congestion management means managing the power flow in transmission line within its transfer limits. Congestion management can be done by following methods given by

1. Rescheduling of generators.
2. Curtailment of loads.

3. Injecting FACTS devices.

Congestion management in deregulated market is based on Independent System Operator (ISO) and Regional Transmission Organization (RTO). The ISO covers small areas whereas RTO plays a vital role in Zonal congestion management.

III. GENERATOR SENSITIVITY FACTORS

The generator sensitivity factors describe the rescheduling of generators. It is stated as follows:

A change in real power flow in a transmission line k connected between bus i and bus j due to change in power generated by generator 'g' can be termed as generator sensitivity factor to congested line (GS) [7].

$$GS_g = \frac{\Delta P_{ij}}{\Delta P_g} \quad (1)$$

Where

ΔP_{ij} = change in the real power flow of the congested line.

ΔP_g = change in the real power generated by the generator.

IV. PROBLEM FORMULATION

The objective function is formulated as:

Minimize f(x) = CC (2)

$$CC = \sum_{g}^{NG} C_{pg}(\Delta P_g)\Delta P_g + \sum_{g}^{NG} C_{qg}(\Delta Q_g)\Delta Q_g \quad (3)$$

Subject to

$$\Delta P_g^{\min} \le \Delta P_g \le \Delta P_g^{\max} \quad g = 1, 2, \ldots\ldots\ldots NG \quad (4)$$

$$\Delta Q_g^{\min} \le \Delta Q_g \le \Delta Q_g^{\max} \quad g = 1, 2, \ldots\ldots\ldots NG \quad (5)$$

$$V_i^o - V_i^{\min} \le \Delta V_i \le V_i^{\max} - V_i^o \quad i = 1, 2\ldots\ldots N_b \quad (6)$$

$$\left(P_{ij} + \sum_g PTCDF_g^k * \Delta P_g\right)^2 + \left(Q_{ij} + \sum_g QTCDF_g^k * \Delta Q_g + \sum_c QTCDF_c^k * \Delta Q_c\right)^2 \le \left(S_{ij}^{\max}\right)^2 \quad (7)$$

Here $ij€N_l$

Where

$$C_{qg}(\Delta Q_g) = \left[C_{pg}(S_{G,\max}) - C_{pg}\left(\sqrt{S_{G,\max}^2 - \Delta Q_g^2}\right)\right]k \quad (8)$$

$$C_{pg}(P_{Gi}) = a_i + b_i P_{Gi} + c_i P_{Gi}^2 \quad (9)$$

CC = total Congestion Cost.

ΔP_g, ΔQ_g =real and reactive power adjustments of generator at bus-g.

N_g = Number of generators.

N_b = number of buses in the system.

N_l = denotes the number of transmission lines in the system.

a_i, b_i, c_i = fuel cost coefficients of i^{th}generator.

P_{ij} and Q_{ij} = real and reactive power flow in line-K (between bus-i and bus-j).

$S_{G,max}$ = apparent power of generator.

C_{pg},C_{qg} = cost of active power and reactive power generation respectively.

$PTCDF_g^k$, $QTCDF_g^k$ =real and reactive power flow sensitivities of line i-j.

V. ZONAL CONGESTION MANAGEMENT

The congestion or overload in transmission network is alleviated by rescheduling the active and reactive power generation of generators. The rescheduling of all the generators for effective management of congestion is a difficult task for the system operator in the complex systems [2]. To simplify the problem, real and reactive power transmission congestion distribution factors (PTCDFs and QTCDFs) have been proposed to identify the congested zones[22]. The real and/or reactive powers of the generators in the most sensitive zone alone are rescheduled to provide optimal solution interest. A congestion clusters based methods are identified by the real and reactive power Transmission Congestion Distribution Factors (PTCDFs and QTCDFs)[2],[7] [22].

A. TCDF

The congestion zones are formed based on Transmission Congestion Distribution Factors (TCDFs) values. Real and Reactive Transmission Congestion Distribution Factors denote how much active and reactive power flow over a transmission line would change due to change in real and reactive power injections/ transaction between buyer and seller[2],[22].

B. PTCDF

The Real Transmission Congestion Distribution Factor's (PTCDF) are defined as the change in the real power flow (ΔPij) in a transmission line 'k' connected between bus-i and bus-j due to unit change in the power injection(ΔPn) at bus-n[2],[22]. Mathematically, the PTCDFs for line-k can be written as

$$PTCDF_n^k = \Delta P_{ij} / \Delta P_n \quad (10)$$

C. QTCDF

The Reactive Transmission Congestion Distribution Factor's (QTCDF) are defined as the change in the reactive power flow (ΔQij) in a transmission line 'k' connected between bus- i and bus-j due to unit change in the reactive power injection (ΔQn) at bus-n[2],[22]. Thus

$$QTCDF_n^k = \Delta Q_{ij} / \Delta Q_n \quad (11)$$

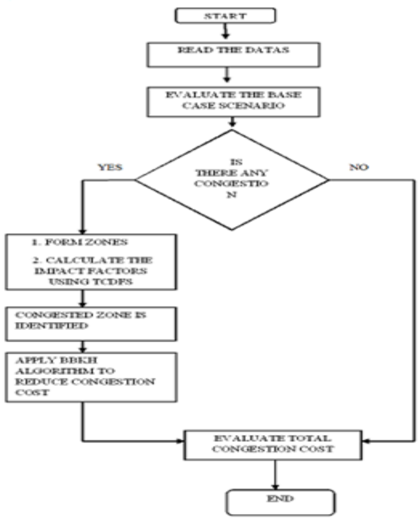

Figure 1. Flowchart for zonal congestion management

VI. Market Analysis

In the zonal congestion management the market flow method plays a vital role. The market flow is used to calculate the native and transfer impact[3]. Market flow is widely used by ISOs/RTOs(independent system operator/regional transmission organization) in the congestion management process[6]. Market flow means the amount of energy flows (or parallel flows) on a specified flowgate or facility as a result of dispatching the generating resources serving market load within a market-based operating entity's market[3],[20]. Market flows play a major role in the transmission congestion management process for the market entities. Market flow reduces all generation/load to account for the RTO imports and exports.

The market flow is used to calculate native impact and transfer impact by separating the generator output into native portion and transfer portion, separately [3]. The native portion N_i is the CA's generation serving the CA's native load and the transfer portion (or generation surplus) T_i corresponds to the CA's generation serving other CAs' load within the market area. They are defined as

Native portion is given by:

$$N_i = \min(\hat{P}_i, \hat{L}_i) \tag{12}$$

Transfer portion is given by:

$$T_i = \begin{cases} \hat{P}_i - \hat{L}_i, if \hat{P}_i > \hat{L}_i \\ 0, if \hat{P}_i \le \hat{L}_i \end{cases} \tag{13}$$

VII. Differential evolution Krill Herd Migration Algorithm

Differential evolution krill herd (DEKH) is a meta-heuristic algorithm that is used to minimize congestion cost . At first DEKH was introduced by Gai-Ge Wang for optimization [21],[24]. But in this scenario DEKH is implemented for congestion management. The steps are given below:

A. Algorithm Steps:

Step 1: Initialization:

The number of particles are initialized randomly.

The generators are denoted as particles. Here six particles are chosen.

Step 2: Evaluating the population and declaration of position:

The number of krills chosen here are 40.

The positions are declared by

$$\frac{dX_i}{dt} = N_i + F_i + D_i \tag{14}$$

- Movement affected by other krill N_i.
- Foraging action F_i.
- Physical diffusion D_i.

Step 3: Fitness evaluation:

The fitness function can be evaluated by:

The movement affected by other krill N_i is given by

$$N_i^{new} = N^{\max}\alpha_i + w_n N_i^{old} \tag{15}$$

and N^{max}, w_n and N_i^{old} are the maximum speed, the inertia weight, the last motion, respectively.

The foraging action can be given as

$$F_i = V_f \beta_i + w_f F_i^{old} \tag{16}$$

and V_f is the foraging speed, w_f is the inertia weight. F_i^{old} is the last one. The maximum diffusion can be given by

$$D_i = D^{\max}\delta \tag{17}$$

Where D^{max} is the maximum diffusion speed, and δ is the random directional vector. Herein, the position in KH from t to $t + \Delta t$ to is formulated as follows:

$$X_i(t+\Delta t) = X_i(t) + \Delta t \frac{dX_i}{dt} \tag{18}$$

Most importantly, note that Δt is an important parameter and should be regulated in terms of the special real-life problem . The reason is that, to some extent, this parameter can be treated as a scale factor of the speed and features the variations of the global best attraction , and its value is of vital importance in determining the speed of the convergence and how the KH works. But it does not have a fast convergence for the better convergence and global search combination of hybrid differential evolution (HDE) operator is used which is modified as DEKH algorithm

Step 4: Hybrid differential evolution operator:

Here, in order to further enhance the exploitation of KH, a more focused hybrid mutation operator performing local search, called hybrid differential evolution (HDE) operator, is incorporated into the KH to form a novel differential evolution KH(DEKH)method. This more focused local search technique can make the population not converge prematurely. The greedy selection strategy is used in this operator. In other words, the newly generated krill replace the previous one only when its fitness is better than before. Therefore, in this way, the HDE operator works better than mutation. It provides the better search by inserting two operators

- Mutation operator.
- Crossover operator

Step 5: Finding the fitness value*:*

By repeating the 2 to 4 the fitness value (X_{best}) is calculated. From that the globally best (G_{best}) is calculated.

Figure 2 shows the flow chart of DEKH algorithm.

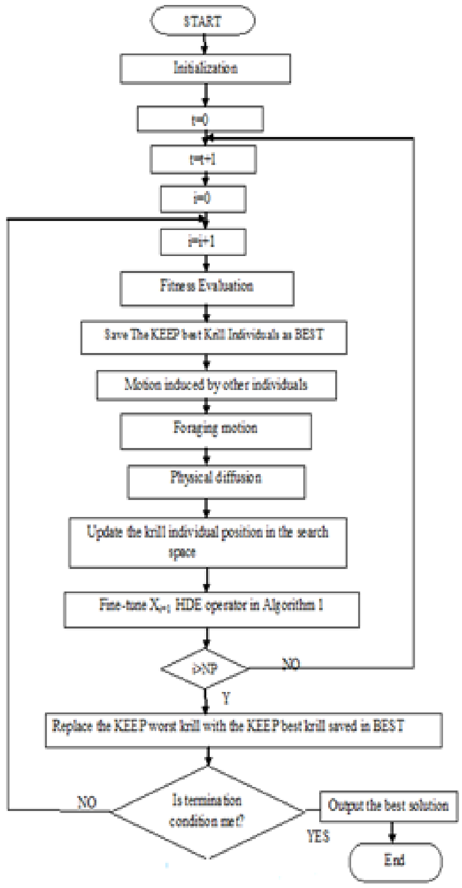

Figure 2. Flowchart for DEKH algorithm

VIII. SYSTEM STUDIES

The DEKH algorithm has been illustrated on a 30-bus system. For this system, the congestion zones based on the real and reactive power flow sensitivity indexes are shown. The 30-bus system has been divided into three zones with zone 1 as the most sensitive zone. It has been assumed that RTO selects generators G2,G5, and G11 from the most sensitive zone 1 to participate in the congestion management based on their qualifying bids in an open market. The DEKH parameters are given in the table 1. The generator sensitivity factors are given in the table 2. The real and reactive power values are clearly shown in table 3. The figure.3,4 shows the change in real and reactive power generation. The DEKH convergence is shown in figure.5.

TABLE 1. DEKH PARAMETERS

Control variables	6 generators
Number of krills	40
Foraging velocity V_f	0.02
Physical diffusion D_i	0.005
Movement affected by other krill N_i	0.01
Mutation FW	0.1
Cross over constant CR	0.4

From the graphs, shown in the Figure.5 It is evident that computation time and congestion costs are less in the DEKH algorithm. In the Figure.3 and Figure.4 it is shown that the change in both real and reactive powers.

The table 2 shows the sensitivity factors of each generator. Here there are six generators are to be rescheduled. The generator which has high sensitivity will be reschedule at first. The impact factors of each zone are shown in table 4.

TABLE 2 .GENERATOR SENSITIVITY FACTORS

GENERATORS	GSF
G1	349.180767
G2	314.603117
G5	181.584327
G8	616.486803
G11	651.811006
G13	588.067936

TABLE 3. PTCDFS AND QTCDFS

BUS	PTCDF	QTCDF	BUS	PTCDF	QTCDF
1	**-0.026512**	**0.033474**	16	0.007439	0.010395
2	**-0.001144**	**0.037479**	17	-0.026703	0.004959
3	0.012207	0.001049	18	0.011253	0.004768
4	**-0.036621**	0.030327	19	-0.020027	0.039196
5	**-0.021172**	**-0.038815**	20	-0.020599	-0.028419
6	-0.003815	0.030327	21	0.007629	0.018311
7	-0.010872	-0.026989	22	-0.005150	-0.011253
8	**0.017929**	**-0.001907**	23	0.005913	0.035381
9	-0.001717	-0.012016	24	0.009727	0.038910
10	0.023460	0.067520	25	-0.005341	0.011063
11	**-0.022125**	**-0.017166**	26	0.000763	-0.004482
12	-0.008392	0.003719	27	-0.013924	0.045013
13	**0.006294**	**0.018883**	28	-0.005913	-0.036430
14	-0.012779	0.022602	29	-0.005341	0.041866
15	-0.033188	0.011730	30	-0.000763	0.022125

TABLE 4. IMPACT VALUES

ZONES	L_i	P_i	NATIVE (MW)	TRANSFER (MW)
1	189.20	253.39	189.20	64.19
2	226.50	254.39	226.50	27.89
3	0.00	85.79	0.00	85.79

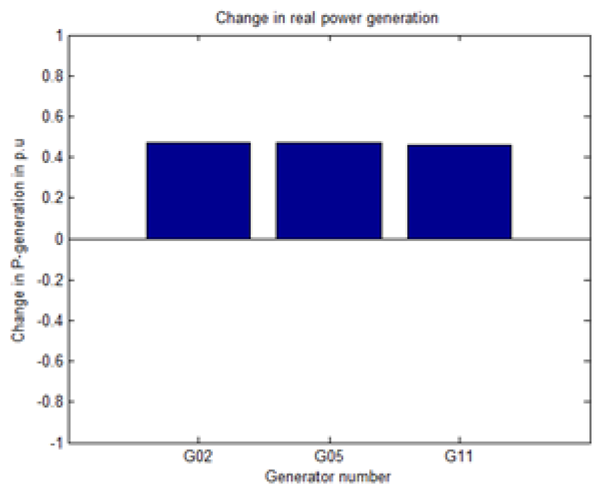

Figure 3. Change in P-generation

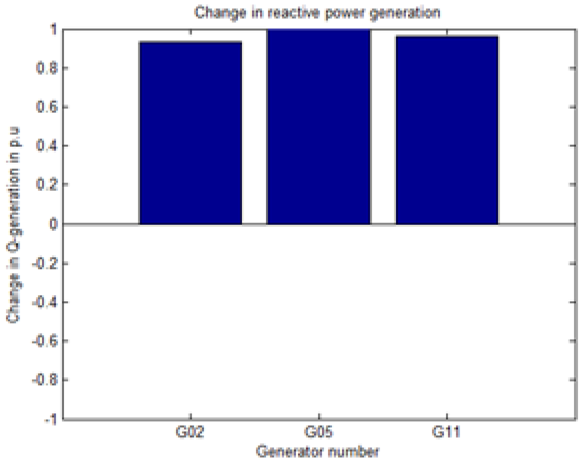

Figure 4. Change in Q-generation

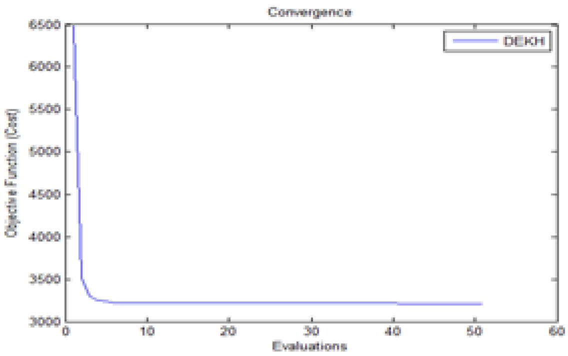

Figure 5. DEKH convergence

Congestion cost for 30-bus system is 6384.119871 Rs/hr. But after applying the DEKH algorithm the congestion cost is minimised as 3113.587629 Rs/hr. The table 6 shows the DEKH Convergence effectively in each zones.

TABLE 6 DEKH CONVERGENCE

Cost parameters	**DEKH**
ZONE 1	720.507380
ZONE 2	1633.445896
ZONE 3	758.283896
CONGESTION COST	3113.587629
MOST AFFECTED ZONE	2

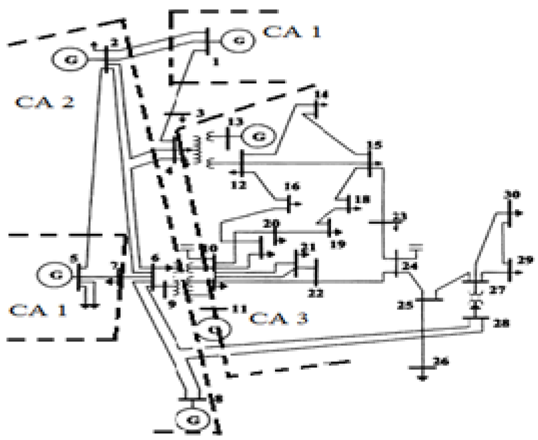

Figure 6. Zone formation for the 30-bus system

TABLE 7 RESCHEDULED GENERATORS IN EACH ZONE

CONTROL AREAS	**GENERATORS TAKING PART IN EACH ZONE**	**GENERATORS TO BE RESCHEDULED**
CA1	G5,G1	G5
CA2	G2,G8	G2
CA3	G11,G13	G11

The zonal formation has been shown in Figure 6 and the generators to be rescheduled in each zone have been shown in table 7.

CONCLUSION

In the present work the objective function has been solved using market analysis and DEKH algorithm. Market flow plays a major role in the interregional congestion management process for the market-based operating entities. Using the market flow the impact factors are calculated. The major contribution is, it utilizes both active and reactive power cost functions in the objective function, since the reactive power plays a vital role in the congestion relief at low congestion cost. The congestion cost is minimized by using DEKH algorithm comparing with other algorithms.

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