Transmission Line Congestion Management Using Hybrid Fish-Bee Algorithm with Unified Power Flow Controller

P. Valsalal, S. Thangalakshmi

Abstract—There is a widespread changeover in the electrical power industry universally from old-style monopolistic outline towards a horizontally distributed competitive structure to come across the demand of rising consumption. When the transmission lines of derestricted system are incapable to oblige the entire service needs, the lines are overloaded or congested. The governor between customer and power producer is nominated as Independent System Operator (ISO) to lessen the congestion without obstructing transmission line restrictions. Among the existing approaches for congestion management, the frequently used approaches are reorganizing the generation and load curbing. There is a boundary for reorganizing the generators, and further loads may not be supplemented with the prevailing resources unless more private power producers are added in the system by considerably raising the cost. Hence, congestion is relaxed by appropriate Flexible AC Transmission Systems (FACTS) devices which boost the existing transfer capacity of transmission lines. The FACTs device, namely, Unified Power Flow Controller (UPFC) is preferred, and the correct placement of UPFC is more vital and should be positioned in the highly congested line. Hence, the weak line is identified by using power flow performance index with the new objective function with proposed hybrid Fish – Bee algorithm. Further, the location of UPFC at appropriate line reduces the branch loading and minimizes the voltage deviation. The power transfer capacity of lines is determined with and without UPFC in the identified congested line of IEEE 30 bus structure and the simulated results are compared with prevailing algorithms. It is observed that the transfer capacity of existing line is increased with the presented algorithm and thus alleviating the congestion.

Keywords—Available line transfer capability, congestion management, FACTS device, hybrid fish-bee algorithm, ISO, UPFC.

I. Introduction

THE electric power industry is deregulated with healthy competition in the market to expand the customer benefits by efficient management and application of technical novelties. The generation and distribution of power are carried out by many entities in a horizontally distributed deregulated power system. Generating companies (Gencos) will try to maximize their profit by selling all the generated power, whereas Distribution companies (Discos) will tend to buy power at cheaper cost. Transmission system still being a

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natural monopoly plays a key role in maintaining healthy competition through open access. The transmission network of electric power system should be strengthened to adapt the new changes in electricity market as well as to serve the changing requirements of the grid.

The ISO is one of the entities of the deregulated power system, matches the supply and demand by forecasting load, coordinating transmission capacity, planning and maintaining the reliability of grid without getting involved in market competition. ISO approves a proposed transaction after analyzing the feasibility of transaction of a particular bid with respect to system operating conditions. Most of the times, the transmission network is unable to oblige the entire service requests in a deregulated environment. This leads to overloading of one or more transmission lines, and the system is said to be congested.

Most of the modern approaches for congestion management employ Optimal Power Flow (OPF) based schemes. They either use reorganizing of generators or improving the line capacity. The application of generator reorganizing beyond a particular point increases the congestion management cost heavily. Hence, the line transfer capacity is improved with the help of FACTS devices to mitigate congestion.

There are various algorithms and FACTS devices reported in literature. The optimal location of Thyristor Controlled Series Compensation (TCSC) is discussed in [1] using min-cut algorithm to relieve line congestion in restructured environment based on benefit index. The allocation of TCSC and DG Unit in appropriate places is designed to relieve congestion [2]. A new methodology for congestion relief by locating UPFC and IPFC using a hybrid meta-heuristic approach is suggested [3]. The optimal sizing of a SVC based on PSO has been described [4]. For optimal location of TCSC, a parameter λ, the quotient of the resonant frequency and the network frequency is used [5]. An effective location of TCSC for power system congestion management by reducing total reactive power loss in the system and load curtailment is suggested [6]. A multi-objective PSO is employed to find Pareto solutions of secure congestion management [7]. A hybrid Cat-Firefly algorithm with TCSC and SVC is proposed to alleviate the congestion [8]. Locational Marginal Price congestion controlling by means of enriched STF-LODF is suggested [9]. Singh and Verma [10] presented the use of cost-free technique for discharging congestion. A congestion management scheme via ideal location of TCSC in deregulated power systems through Mixed Integer Nonlinear

Programming (MINLP) is offered [11]. A technique for congestion controlling with the help of UPFC in a competent market is developed by considering bid functions as linear [12]. The objective of the present work is to manage congestion in deregulated power systems using FACTS devices.

II. FACTS DEVICES

Based on network connection, FACTS controllers are broadly classified as series controllers, shunt controllers, combined series-series controllers, and combined series-shunt controllers. The series-shunt controllers are a combination of separate shunt and series controllers which are controlled in a coordinated manner. The shunt part of the controller injects current into the system while series part of the controller injects voltage in the line. The real power can be exchanged between the series and shunt controllers via a DC link when controlled in a unified manner. UPFC is one such controller coming under the category of series-shunt controllers. The control variables like line impedance, transmission voltage, and phase angle can be controlled simultaneously with the help of UPFC to regulate the active and reactive power in the transmission line very easily. Hence, UPFC is chosen from among various FACTS devices for further analysis.

A. UPFC

The basic construction of UPFC includes two power electronic converters which are connected through a common DC link. The roles of power converters are to exchange the real and reactive between UPFC and line with the help of common DC link. Hence, proper isolation has to be provided to match the voltage levels between power system and power electronic converters. This is accomplished by using two transformers. The series converter is connected in series with the transmission line and generates a voltage whose magnitude and phase angle can be adjusted. Thus, it ensures required real and reactive power in the transmission line. The shunt converter provides the real power requirement of a series converter. Therefore, the real and reactive power in the transmission line can be controlled and regulated with the help of UPFC. The general structure and equivalent circuit of UPFC are shown in Fig. 1.
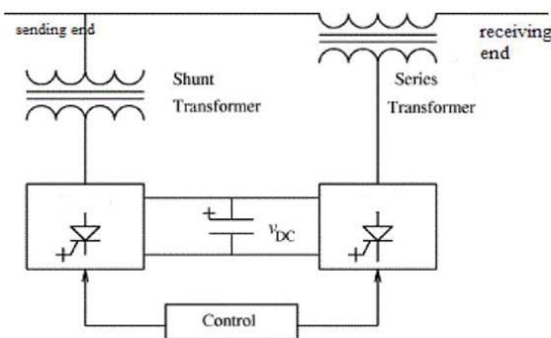
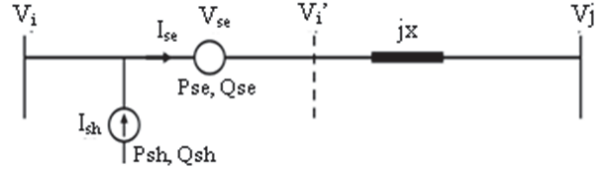

Fig. 1 (a) Structure of UPFC

Fig. 1 (b) Equivalent circuit of UPFC

The term x_s describes the reactance seen from the terminals of series transformer and is given by

$$x_s = x_k r_{max}^2 \left(\frac{S_B}{S_S}\right) \tag{1}$$

where, x_k denotes the series transformer reactance, r_{max} is the maximum per unit value of injected voltage magnitude, S_B is the system base power, and S_S is the nominal rating power of the series converter. The series connected voltage source is modeled by an ideal series voltage (V_{se}) with controllable magnitude (r) and phase angle (γ), which is given by:

$$V_{se} = rV_k e^{j\gamma} \tag{2a}$$

subject to:

$$0 \leq r \leq r_{max} \tag{2b}$$

$$0 \leq \gamma \leq 2\pi \tag{2c}$$

Since optimal locations of FACTS devices are paramount in minimizing congestion, a new objective function is proposed to find the optimal location of UPFC controller for congestion management by improving the line transfer capability.

III. EXISTING ALGORITHMS

There are many algorithms; namely, Particle Swarm Optimization (PSO), Artificial Bee Colony Optimization (ABCO) and Fish School Optimization (FSO). PSO is a derivative-free algorithm. The calculation is very simple and is less dependent of a set of initial points than the other optimization techniques. But, the regulation speed and direction is less accurate because of partial optimism and cannot be applied for the problems of scattering and optimization. Even though ABCO is a high performance optimizer which is very easy to understand and implement, it is slow to converge and sometimes trapped in a local optimal solution. Though FSO shows better results for searching in high dimensional and unstructured spaces, it fails to keep the balance of exploration and exploitation, which reduces the searching speed to find the best result. So, a hybrid algorithm combining the ABCO and FSO algorithms is proposed to minimize the limitations of individual algorithms for locating the UPFC.

IV. PROPOSED HYBRID FISH – BEE ALGORITHM

The proposed hybrid Fish–Bee algorithm accelerates the search for finding the optimum solution. It employs parallel

technique for hybridization in which the search by individual algorithms is performed simultaneously. It selects the specified number of best individuals from each system after exchanging many user defined iterations. Generally, individuals having larger fitness value are selected. Thus, the proposed algorithm parallelizes the two algorithms such that the local behavior of ABCO and global search of FSO are effectively used to find the optimal solution.

The basic steps of hybrid Fish – Bee algorithm are:
– Step 1: Create initial random solution
– Step 2: Evaluate fitness and select best solutions
– Step 3: Divide population between the two algorithms.
– Step 4: Start FSO and ABCO algorithm
– Step 5: Fish plans to move position to find food and Bees plans to move position to find better food.

– Step 6: Fish movement is based on searching of food or following another fish for finding the food's position.
– Step 7: Once food search is over, a movement policy based on weighted local search is chosen.
– Step 8: Similarly, bee movement is based on computing internal and external irregularities.
– Step 9: Once searching process is over, a movement policy based on weighted local search is chosen.
– Step 10: Recombine both solutions
– Step 11: Check whether the objective is met
– Step 12: Iterate the process

The proposed algorithm is used for finding the location of UPFC employ in the proposed objective function. Fig. 2 shows the flowchart to derive the optimal location of UPFC.
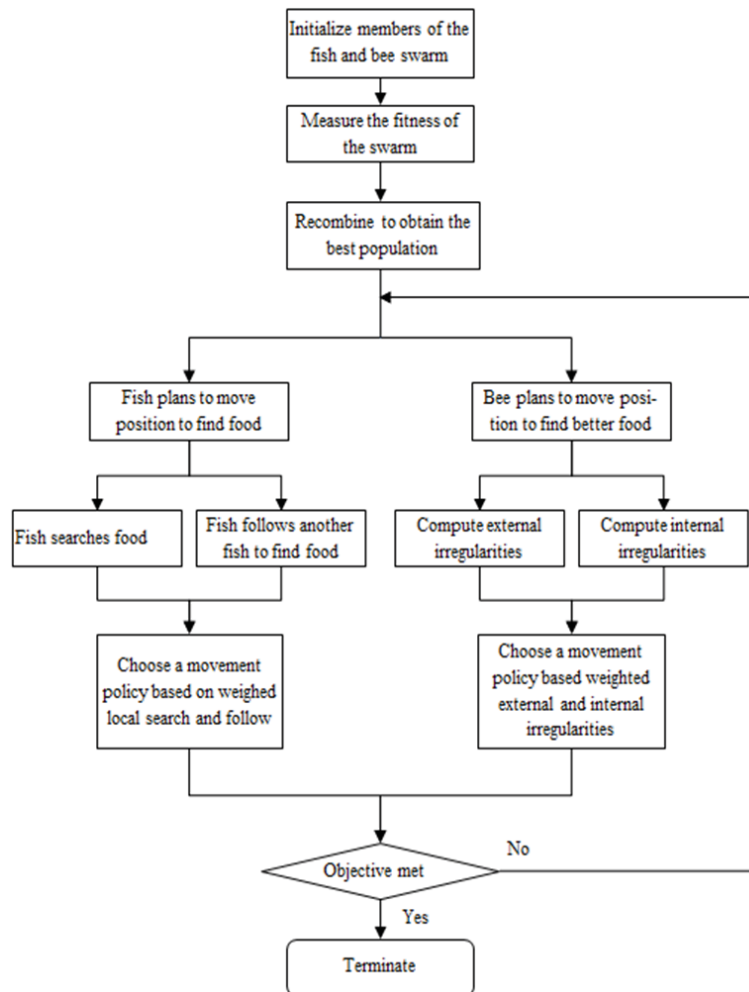

Fig. 2 Flow chart to derive the optimal location of UPFC

For implementing the objective function with the proposed algorithm, identification of a highly congested line is necessary. Hence, a factor to determine the severity of transmission line congestion is used to identify the most congested line. The system loading severity under normal and contingency cases is explained by a real power flow performance index.

V. POWER FLOW PERFORMANCE INDEX (PI)

Transmission line congestion occurs when voltage/thermal

limits are violated. Line outages or high load demands are the cause of congestion in the transmission network. The severity of the system loading under normal and contingency cases depends on real power line flow performance index [13]. The degree of congestion in a transmission line is determined by using power flow performance index, PI, which is mathematically expressed as:

$$PI = \sum_{all\ branches\ i} \left(\frac{P_{flow\ l}}{P_l^{max}}\right)^{2n} + \sum_{all\ branches\ i} \left(\frac{\Delta|E_i|}{\Delta|E_i|^{max}}\right)^{2m} \qquad (3)$$

where PI: Performance Index, $P_{flow\ l}$: Real power flow in the line, P_l^{max}: Maximum power limit, E_i: Transmission Line voltage and E_i^{max}: Maximum voltage limit.

After computing the PI values, a priority list is created for congestion analysis. The power flow is executed based on the priority list to identify the weak transmission line in which the actual MVA exceeds the acceptable limit. The PI value would be high during overloading or congestion. UPFC improves the power transfer capacity by properly adjusting its control parameters. Thus, the line with highest PI is the appropriate location for installing UPFC.

VI. PROPOSED OBJECTIVE FUNCTION

The costs related with congestion and voltage profile improvement are included in the objective function for congestion management using UPFC [14]. The main aim of congestion management is to relieve congestion by reducing branch loading, minimizing voltage deviation after load disturbance and to improve the transfer capacity of the line. This can be achieved by the use of UPFC in appropriate location. Hence, the objective function for finding the optimal location of UPFC includes all these factors. The objective function is represented as given by (4a):

$$Minimize\ f(g, h) \qquad (4a)$$

$$where, f(g, h) = \alpha \left[\frac{1}{Branch\ loading}\right]^2 + \beta \left[\frac{e^{(\Sigma_1^k V_{diff})^2}}{\sum_{n=1}^m (L_{nmax} - L_n)}\right] \qquad (4b)$$

where, L_n: Utilized line capacity, L_{nmax}: Maximum line capacity, V_{diff}: Difference from reference voltage, m: Number of transmission lines, k: Number of buses (All values in objective function are normalized).

Subject to the following conditions:
a. Total power generated - total load -total losses = 0
b. Line utilization is less than the line capacity
c. Voltage variation is minimal and is within the limits.
d. $\beta = 1 - \alpha$;

where, α is the weighting factor with respect to branch loading, and β is the weighting factor with respect to voltage deviation and line capacity.

The value of α and β are taken as 0.5 to ensure maximum transfer capacity. The appropriate location of UPFC is identified by using the proposed objective function employing the proposed hybrid Fish – Bee algorithm. An index namely, power transfer capacity index is defined to analyze the performance of UPFC.

A. Power Transfer Capacity Index

To ascertain the performance of UPFC, a power transfer capacity index which is the ratio of real power in the line to the maximum MW of the line is used and is measured by using (5) with and without UPFC.

$$Power\ transfer\ capacity\ Index = \frac{P}{P_{max}} \qquad (5)$$

where, P = Real power actually flowing in the line, P_{max} = the maximum real power flow limit of the line.

Maintaining power transfer capacity index value near to unity is an indication of transfer capability improvement.

VII. IDENTIFICATION OF LOCATION OF UPFC

The locations of UPFC are identified by using the proposed objective function for IEEE 30 bus test system with $\alpha = \beta = 0.5$ to improve the power transfer capability of the line. It is assumed that the rating of UPFC is given.

A. IEEE 30 Bus System

The test case of IEEE 30 Bus system is shown in Fig. 3. The location of FACTS devices is identified by using the existing and proposed algorithms for the selected line outage is tabulated in Table I. The power transfer capacity index with and without UPFC is tabulated in Table II.
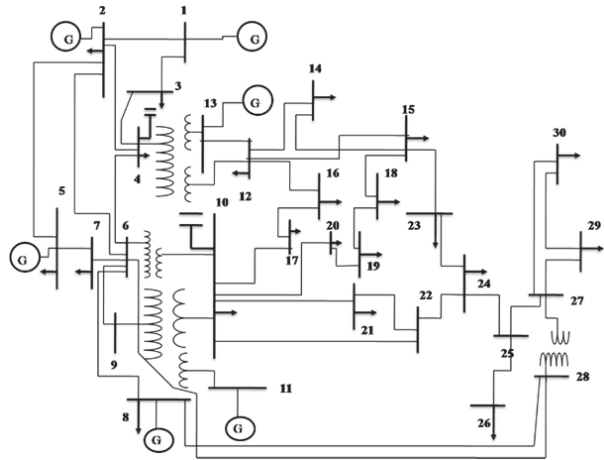
Fig. 3 IEEE 30 Bus system

TABLE I
LOCATION OF UPFC FOR CONGESTION MANAGEMENT – IEEE 30 BUS SYSTEMS

Tripped line	From Bus	To Bus	Identified Locations			
			Using Existing Algorithms			Using proposed Algorithm
			PSO	ABCO	FSO	
1	1	2	7	7	7	7
14	9	10	25	25	14	25
18	12	15	7	7	7	7
10	6	8	32	27	27	27

After analyzing the location of UPFC in IEEE 30 bus test

system, it is observed that the power transfer capability of both underutilized and overloaded lines is improved. This is validated with new objective function with proposed algorithm.

TABLE II
POWER TRANSFER CAPACITY INDEX – IEEE 30 BUS SYSTEM WITH LINE 1 OUTAGE

Line No	Line b/w buses	P/Pmax Without UPFC	P/Pmax with UPFC			
			Using Existing Algorithms			Using proposed Hybrid Fish-Bee (7)
			PSO (7)	ABCO (7)	FSO (7)	
2	1-3	1.74	1.38	1.32	1.28	1.09
3	2-4	1.54	1.22	1.16	1.13	1.07
6	3-4	1.72	1.43	1.36	1.32	1.09
4	2-5	1.38	1.18	1.12	1.09	1.05
5	2-6	1.36	1.22	1.15	1.12	1.08
7	4-6	1.21	0.98	1.06	1.03	0.99
9	5-7	1.24	1.01	0.95	1.02	0.98
10	6-7	0.32	0.36	0.39	0.37	0.44
11	6-8	0.87	0.93	1.00	1.06	1.02
12	6-9	0.92	0.98	1.05	1.02	0.98
13	6-10	0.98	1.04	0.97	1.06	1.01
16	9-10	0.96	1.02	0.95	1.03	0.99
8	4-12	0.88	0.93	1.00	1.10	1.06
21	12-13	0.91	0.96	1.03	0.99	1.02
22	12-14	0.94	0.99	1.06	1.02	0.98
23	12-15	0.98	1.04	0.97	1.02	0.97
24	14-15	0.88	0.93	1.01	0.98	1.03
27	16-17	0.78	0.82	0.89	0.95	1.04
25	15-18	0.67	0.70	0.76	0.81	0.85
28	18-19	0.84	0.88	0.95	1.01	0.97
29	19-20	0.54	0.61	0.66	0.69	0.76
18	10-20	0.96	1.00	1.08	1.05	1.01
17	10-17	0.94	0.98	1.05	1.01	0.97
19	10-21	0.91	0.96	1.03	1.00	1.09
20	10-22	0.36	0.37	0.4	0.42	0.46
30	21-22	0.92	0.96	1.03	0.99	1.04
26	15-23	0.93	0.96	1.03	0.99	1.08
31	22-24	0.94	0.97	1.04	1.00	1.04
32	23-24	0.87	0.9	0.98	1.05	1.01
33	24-25	0.92	0.95	1.03	1.00	1.07
34	25-26	0.96	0.99	1.07	1.04	1.00
35	25-27	0.89	0.92	1.00	1.07	1.03
36	27-28	0.90	0.93	1.00	1.06	1.02
37	27-29	0.48	0.49	0.53	0.56	0.59
38	27-30	0.63	0.65	0.70	0.73	0.80
39	29-30	0.89	0.91	0.98	1.07	1.02
15	8-28	1.27	0.96	1.03	1.00	1.05
14	6-28	0.94	0.96	1.03	1.00	1.00

VIII. CONCLUSION

UPFC has been selected as one of the best FACTS devices for enhancing the power transfer capability of transmission lines because of its ease of control. A new objective function is proposed for identifying the optimal location of UPFC. The power flow performance index (PI) is taken as reference for identifying the congested line. The optimal location of UPFC for IEEE 30 bus is identified by using the proposed hybrid Fish – Bee algorithm by making line outage and finding corresponding overloaded lines. The power transfer capacity index is computed by using the proposed hybrid Fish – Bee algorithm before and after placing UPFC, and the results are compared with PSO, ABCO, and FSO algorithms. From the results, it is observed that the power transfer capacity of line is improved effectively after placing UPFC in the proper location by using the proposed hybrid Fish – Bee Algorithm.

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