Study of Interline Power Flow Controller in Congestion management of power system with Flower Pollination Algorithm

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***Abstract*—Inter line Power Flow Controller (IPFC) is one of the converter based latest FACTS controllers. In this paper, the appropriateness of IPFC in congestion management of power system is studied. The main challenging objective of the FACTS controllers is maximizing the usage of the existing system instead of constructing a new one. However, in several practical operating conditions this approach leads to congestion, which further collapse the entire system. Hence, investigation of IPFC in congestion management becomes an area of research interest. For that, an IEEE 30-bus system considered as a test system in MATLAB environment. A relatively latest natural inspired algorithm known as Flower Pollination Algorithm (FPA) estimates the optimal place and size of the IPFC. It mimics the flowering plants reproduction system. For the case study, three practical scenarios like those that overloading, line outage and generator outage are taking into account and adequate results obtained.**

Keywords— Congestion management, DLUF, FACTS, Flower pollination algorithm, IPFC, LUF

I. Introduction

Integration of FACTS devices in power system is one kind of powerful solution to deregulation problems and maximizes the utilization of existing system. Such over powering sometimes leads to congestion in the transmission lines, which further aggravated and collapse the entire system. This can be anticipated by using the latest series converter based FACTS controller, Inter line Power Flow Controller (IPFC). In this paper, the congestion management of IEEE 30- bus test power system with the aid of IPFC is studied by means of MATLAB software. A relatively latest natural inspired algorithm, which mimics the flowering plants reproduction, is presented.

In 1998, Gyugi proposed the IPFC and its specialty is not only its multi functionality but also its controllability of multi transmission lines in a substation [1]. Instead of reactive power compensation with huge AC capacitor bank and bulk reactor it is possible to control the real power flow in specific corridor through controlling the converter operation merely controlling the converter switching pattern. The controllable converter output voltage is injected into the transmission lines using properly designed series transformer [2].

The IPFC is a series – series device connected any two lines, normally over flow in one line is diverted into another low utilized line. IPFC uses two converters to do this operation. The required amount of real power exchange among the lines is optimized by FPA. New method of identify underutilized line is DLUF used to find location of IPFC. Sub program for DLUF calculation is developed to identify the location of IPFC and the main program is developed to find optimal size of IPFC for all three scenarios.

Section I summarizes the basic concepts, operating principle of IPFC and the need of congestion management. Section II is explored the problem formulation and the required constrains. In section III the implementation of flower pollination algorithm is presented. In the proposed simulation, the three possible scenarios (1) over loading, (2) line outage and (3) generator outage are given and discussed in section IV. The mentioned three scenarios are frequently occurred practical problems and causing congestion in the power system. In section V the proven results at different operating conditions are given. The conclusions spotlights on the appropriateness of IPFC in congestion management given in section VI.

II. Problem Formulation and DLUF

A. Disparity Line Utilization Factor

Enough research works are available in modeling and controlling of IPFC [3-6]. The main objective of the problem is to find out the optimal location of IPFC to relive the congestion occurred in the system. This paper rather than modeling, emphasize into the formulation of multi objective function with the aid of Disparity Line Utilization Factor (DLUF). Line Utilization Factor (LUF) is used to identify the most congested line in the system. However, IPFC required minimum two lines and hence LUF alone insufficient in finding optimal place for IPFC. The DLUF is the difference between the percentages of Mega Volt Ampere utilization of each line connected to the same bus and higher the value meant higher the congestion. The optimal location of the IPFC based on the higher value of DLUF.

$$\mathrm{DLUF}_{(ij)-(ik)} = \left|\frac{\mathrm{MVA}_{(ij)} - \mathrm{MVA}_{(ik)}}{\mathrm{MVA}_{maxij}}\right| \tag{1}$$

where; $\mathrm{DLUF}_{(ij)-(ik)}$- Disparity line utilization factor of transmission line set i-j and i-k connected to bus i and bus j,

MVA_{ij} -Actual MVA rating of transmission line connected between bus i and bus j,

MVA_{ik} -Actual MVA rating of transmission line connected between bus i and bus k,

MVA_{maxij} -Maximum MVA rating of transmission line connected between bus i and bus j.

In addition to this optimal location, the size of the IPFC is required to minimize the capital investment of the system.

$$\text{Min } F = \min (w_1 f_1 + w_2 f_2) \tag{2}$$

Where, w_1, w_2 are weight factors and f_1, f_2 are objective functions. The two objective functions are the size of IPFC and fuel cost for power generation respectively.

B. Minimization of Converter size

IPFC has two series converters commonly a voltage source converter (VSC) whose size has to minimized, for the minimization IPFC size.

$$f_1(x) = \min (PQ_1^2 + PQ_2^2) \tag{3}$$

Where PQ are real and reactive power of the VSC, which indirectly denote the size of the IPFC.

$$PQ_1^2 + PQ_2^2 = \left(V_{se_{ij}} \left(\frac{\overline{V_i - V_{se_{ij}} - V_j}}{Z_{ij}} \right) \right)^2 + \left(V_{se_{ik}} \left(\frac{\overline{V_i - V_{se_{ik}} - V_k}}{Z_{ik}} \right) \right)^2 \tag{4}$$

C. Minimization of Fuel cost

In this paper, quadratic cost function is considered. After relieving congestion, the generating cost has to minimize. This forms the second objective of the problem under consideration.

$$f_2 = \sum_{i=1}^{ng} \alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2 \tag{5}$$

In equation [5] P_G is the real power generation and α, β, γ are cost coefficients of the generator.

D. Equality Constraints

Real (PG) and reactive (QG) power generated must be equal to sum of their respective load (PD,QD) and losses (PL,QL). The real power balance equation stated by the equation [6] and reactive power balance equation stated in the equation [7] form the equality constraint of the problem

$$\sum_{i=1}^{ng} P_{Gi} = P_D + P_L \tag{6}$$

$$\sum_{i=1}^{ng} Q_{Gi} = Q_D + Q_L \tag{7}$$

E. Inequality Constraints

Inequality constraints mainly based on the physical limit of the real power and reactive power as given in the equations [8] and [9] respectively. Further, the reliable quality of electric power generation mainly depends on the voltage tolerance limit, which forms another inequality constraint as equation [10]. In general, the transmission lines designed to use for its maximum power handling capacity and hence the maximum power transfer cannot be violate. Similarly, the maximum size of the IPFC could not be violated its maximum limit which form inequality constraints equation [11] and [12].

$$P_{Gi(\min)} \le P_{Gi} \le P_{Gi(\max)} \text{ fori=1 to nbus} \tag{8}$$

$$Q_{Gi(\min)} \le Q_{Gi} \le Q_{Gi(\max)} \text{ fori=1 to ng} \tag{9}$$

$$V_{i(\min)} \le V_i \le V_{i(\max)} \text{ fori=1 to nbus} \tag{10}$$

$$S_i \le S_{i(\max)} \text{ fori=1to nbr} \tag{11}$$

$$PQ_i \le PQ_{i(\max)} \text{ fori=1to nVSC} \tag{12}$$

Where, min and max indicates minimum and maximum limits of the control and dependent variables. 'nbus' is the number of bus, 'ng' is number of generator, 'nbr' is number of branch and 'nVSC' is number of voltage source converter. PG and QG are real and reactive power generation. V is the voltage magnitude; S is the complex power (MVA) flow in the transmission line. PQ is the capacity of VSC.

III. Flower Pollination Algorithm

It is a nature-inspired algorithm and mimics the flowering plants reproduction system. Plants survive for billions and billions of years by using this pollination process, hence it should be one of the best processes to get best outcome. The valid assumption made for the FPA are, pollinator (insects) used to visit the species of same flower. Pollinators obey levy flight movement. A flower underwent either global or local pollination. Switching probability decides the pollination type for the flower. Global pollination is takes place between the flower and the best flower (global flower) in the species.

The global pollination takes place by changing the flower pollen gamete with global flower by the pollinator. Equation [13] gives this global pollination.

$$F_i^{k+1} = F_i^k + \gamma L(\lambda)(F_i^k - F_g^k) \tag{13}$$

Where, F_i^{k+1} is the ith flower for k+1 iteration, F_i^k is the ith flower for kth iteration, γ is constant, $L(\lambda)$ is the levy flight movement, F_g^k is the global flower of kth iteration [8].

Local pollination assumed, to takes place between same species of flowers but not with global flower as given the equation (14).

$$F_i^{k+1} = F_i^k + \varepsilon(F_m^k - F_n^k) \tag{14}$$

Where, F_i^{k+1} is the ith flower for k+1 iteration, F_i^k, F_m^k, F_n^k are ith , mth and nth flowers respectively for the kth iteration, ε is the constant.

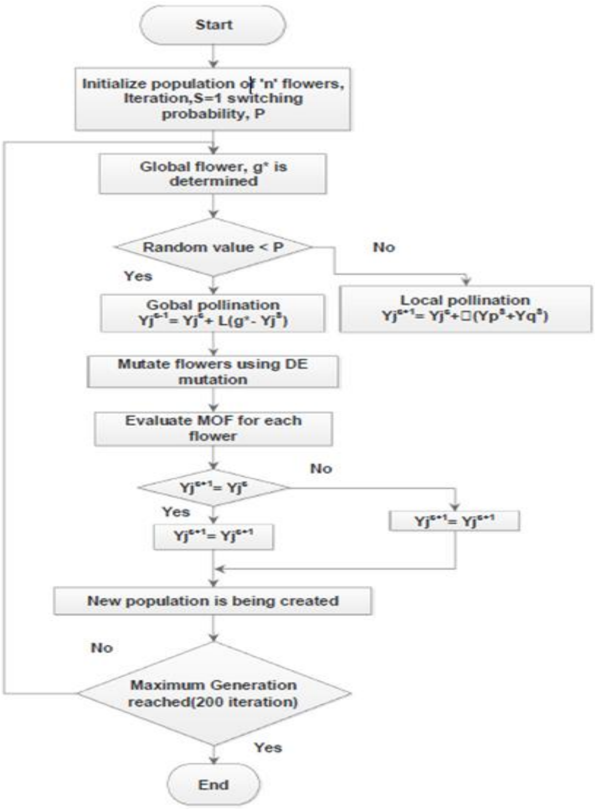

Fig. 1.Flow chart of FPA algorithm

IV. CASE STUDY AND RESULTS

In the proposed simulation 3 scenarios (1) over loading, (2) line outage and (3) generator outage are considered. The mentionedthree scenarios are frequently occurred practical problems and causing congestion in the power system. Fig.1 shows the single line diagram of standard IEEE test 30 bus system [6,7]. The detail of this test system is given in the table I.

A. Scenarios 1: Overload

In power system major congestion occurred due to overload. Over load cannot be avoid but congestion due to overload may avoid to some extent. In this simulation, the IPFC connected between the congestion line and its corresponding alternate line. Real power flow in the congested line is divert into alternate line by IPFC and relives congestion.

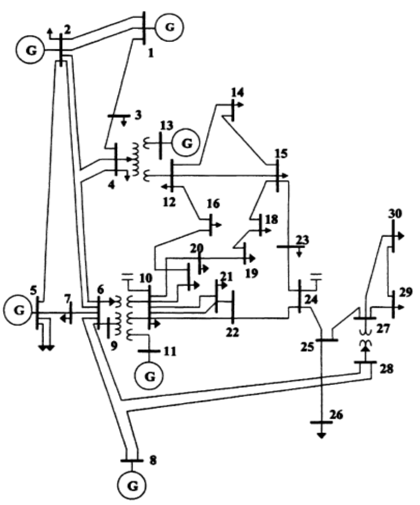

Fig. 2.Line diagram of IEEE test 30 bus system

S. No.	CLP	ALP	LUF Of CLP	LUF Of ALP	DLUF
1	9-4	2-9	1.08122	0.397051	0.684169
2		8- 9		0.181866	0.899355
3		**9-10**		**0.053807**	**1.027410**
4		9-11		0.211485	0.869735
5		9-12		0.154349	0.926871
6		4-28		0.126078	0.955142
7		9-28		0.590699	0.490522

TABLE I. DETAIL OF TEST SYSTEM

S.No	Description	Value
1	Base MVA	100
2	Number of bus	30
3	Number of generator	6
4	Number of transmission line	41
5	Real power load demand (MW)	283.4
6	Reactive power load demand (MVAR)	126.2

The test case loads are 283.4 Mw and 126.2 Mvar and it is works good without violating any constraints. In this scenario, it is assume that the loads are increase by 25%. Due to this over loads, the transmission line number 10 is congested. The power rating of the line is 42 MVA but the MVA flow due to over load is 55.7666 MVA causes congestion. The alternate path of power flow is identifying using LUF as given in the table II.

Table III gives LUF (Line Utilization Factor) of the congested line and its alternate lines that are connected either bus number 9 or 4. IPFC may connect any one of these alternate line to relive the congestion. The location of IPFC connection is the line that has maximum DLUF (Difference in LUF).

TABLEII. CONGESTED LINE DETAIL

TABLEIII. LUF AND DLUF OF ALTERNATE LINES

Congested line No	The line connected between the buses	MVA limit of the line	Actual MVA Flow	Overflow MVA
10	9 – 4	42	55.7666	13.7666

In the table, alternate path connected between buses 9-10 because its utilization is less and has maximum DLUF.Line-10 between 9-4 is congested and the alternate path having less LUF is Line-9 connected between buses 9-10, is considered for IPFC installation. Hence, IPFC of 30 MW; is installed in these Line-10 and Line-9. If IPFC connected, then Congestion relived and summarized in the table IV.

TABLEIV. RESULTS OF IPFC CONNECTION

S. No.	CLP	ALP	LUF Of CLP	LUF Of ALP	DLUF
1	9-4	2-9	1.33594	0.519984	0.807791
2		8-9		0.226467	1.10131
3		**9-10**		**0.080832**	**1.24694**
4		9-11		0.19872	1.12905
5		9-12		0.189202	1.13857
6		4-28		0.185437	1.14234
7		9-28		0.678661	0.649114

TABLEV. FPA OPTIMIZATION RESULT

IPFC connection	Congested Line		LUF	Alternate Line		LUF	DLUF	Loss (MW)	Gen. Cost ($/hr)
	No.	Between		No.	Between				
Before	10	9-4	1.27721	9	9-10	0.0808324	1.19637	12.1254	1108.85
After			**0.99869**			0.0894745	**0.90921**	**11.9257**	**1107.35**

After IPFC connection, congestion in the line is relived andLUF become less than 1. LUF of alternate line is slightly increases, DLUF between these lines is reduced, loss is reduced and generation cost is reduced. This fixed value of IPFC is not better way and hence FPA optimization is used and the optimized result is given in the table V. Compare to fixed value of IPFC, FPA optimization gives better loss and generation cost.

TABLE VI. CONGESTED LINE DETAIL

Method	IPFC (MW)	Loss (MW)	Gen. Cost ($/hr)
Before IPFC	-	12.1254	1108.85
Fixed IPFC	30	11.9257	1107.35
FPA optimize	38.541	**11.2136**	**1106.74**

B.Scenarios 2: Line outage

Line outage is one of the common problems faced by the electric power suppliers. Since the path of power flow is disturbed, the power has to take another path to reach its load demand. This change of path due to line outage causes congestion. IPFC may use to relive this type of congestion and provide better control and operation. In this scenario line no. 6 connected between buses 2 and 9, is asserted as outage. Due to this, line no. 10 is congesting as given in the table VI.

TABLE VII. RESULTS OF IPFC CONNECTION

Congested line No	The line connected between the buses	MVA limit of the line	Actual MVA Flow	Overflow MVA
10	9 – 4	42	42.3697	0.36997

To relive the congestion the power flow path has to change using IPFC. To find the location of this IPFC LUF of all alternated lines for the congested line is calculated and given in the table VII.

TABLE VIII. LUF AND DLUF OF ALTERNATE LINES

IPFC connection	Congested Line		LUF	Alternate Line		LUF	DLUF	Loss (MW)	Gen. Cost ($/hr)
	No.	Between		No.	Between				
Before	10	9-4	1.0088	9	9-10	0.07568	0.9331	7.32906	945.795
After			**0.8390**			0.07646	0.7625	**7.24135**	**945.629**

Line-9 connected between buses 9 and 10 has low LUF and high DLUF is chosen for IPFC connection. Then IPFC of fixed size 30 MW is connected between line 10 (between 9-4) and line 9 (between 9-10). After this IPFC connection the congestion is relived, loss is reduced and generation cost is reduced as given in the table VIII.This IPFC size may optimize to get better result, hence FPA is used to optimize the size of IPFC. The FPA optimized results is given in the table 9. The size of IPFC is reduced as compared to fixed size, loss is reduced and generation cost is reduced for this optimal size of IPFC.

TABLEIX. FPA OPTIMIZATION RESULT

S. No.	CLP	ALP	LUF Of CLP	LUF Of ALP	DLUF
1	9-4	8- 9	1.0088	0.2494	0.759341
2		**9-10**		**0.0756**	**0.933118**
3		9-11		0.2099	0.798892
4		9-12		0.1508	0.857912
5		4-28		0.1314	0.877361

C.Scenarios 3: Generator outage

Generator outage is another problem faced by the electric power suppliers. As a generator is outage, generation of other generators need to increase to satisfy the load demand. This makes the power flow in certain transmission line, is congested. IPFC may use to relive this type of congestion and provide better control and operation. In this scenario generator4 is outage and causes line no. 10 congesting as given in the table X.

TABLEX. LUF AND DLUF OF ALTERNATE LINES

Method	IPFC (MW)	Loss (MW)	Gen. Cost ($/hr)
Before IPFC	-	7.32906	945.795
Fixed IPFC	30	7.24135	945.629
FPA optimize	**21.5712**	**7.21648**	**944.483**

TABLEXI. CONGESTED LINE DETAIL

Congested line No	The line connected between the buses	MVA limit of the line	Actual MVA Flow	Overflow MVA
10	9 – 4	42	45.4112	3.4112

To relive the congestion the power flow path has to change using IPFC. To find the location of this IPFC LUF of all alternated lines for the congested line is calculated and given in the table XI.Line-9 connected between buses 9 and 10 has low LUF and high DLUF is chosen for IPFC connection. Then IPFC of fixed size 30 MW is connected between line 10 (between 9-4) and line 9 (between 9-10). After this IPFC connection the congestion is relived, loss is reduced and generation cost is reduced as given in the table XII.

This IPFC size may optimize to get better result, hence FPA is used to optimize the size of IPFC. The FPA optimized results are given in the table XII. As compared to fixed size, loss and generation cost is reduced for optimal size of IPFC.

TABLE XII. FPA OPTIMIZATION RESULT

Method	IPFC (MW)	Loss (MW)	Gen. Cost ($/hr)
Before IPFC	-	7.4429	941.24
Fixed IPFC	30	7.2925	940.89
FPA optimize	**20.9945**	**7.1321**	**940.67**

V. CONCLUSION

A novel flower pollination algorithm (FPA), is used to find the size and location of IPFC based on DLUF. Congestion is the problem of overloading the transmission line. This congestion may occur due to any one of three scenarios, overloading, line outage and generator outage. Overloading and line outage are quit common and frequent causes for the congestion. This congestion is effectively relived by using the hybrid FACTS device IPFC. The developed program uses standard IEEE test case 30-bus system for the implementation. From these THREE scenarios, the most vulnerable line is 10th line and the alternate line path is 9th line. Hence locating IPFC between these lines is the best choice. Maximum size of 40MW capacity IPFC is the best size in this location and FPA algorithm gives the optimal real power injection based on the congestion. IPFC may tune to inject real power as suggested by FPA. FPA works well for all types of congestion as discussed above. It identifies the congestion based on LUF and finds the location based on DLUF also suggests the optimal size of IPFC. In future, the appropriateness of IPFC is going to test with higher order test system.

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