Global Journal of Pure and Applied Mathematics.
ISSN 0973-1768 Volume 11, Number 6 (2015), pp. 4447-4456

http://www.ripublication.com

Evaluation Of Total Transfer Capability Using Firefly Algorithm

A. Ahamed Jeelani Basha and M. Anitha

Assistant Professor, Associate Professor, Department of Electrical Engineering,
FEAT, Annamalai University Annamalai Nagar-608002, Tamilnadu, India.
E-mail: ahamedjeelani_basha@yahoo.in E-mail: vishanitha@yahoo.com

Abstract

The calculation of Total Transfer Capability (TTC) is one of the critical and major task in the deregulated power market. Firefly (FF) algorithm is used to solve the Optimal Power Flow (OPF) based approach for TTC calculation incorporating various system constraints. The real power output of generators in source area and real power load in sink area can be adjusted to obtain the maximum transfer capability. The calculation of TTC can be made more accurate by incorporating the Transmission Reliability Margin (TRM) by considering the single and multiline outages. The proposed method is demonstrated on 4-bus system and a practical Indian utility 62 bus system. Various case studies were carried out on those test systems with and without TRM and the results are compared with published results. It is found that FF algorithm gives better solution for the TTC problem.

Keywords: Deregulation, firefly algorithm, optimal power flow, total transfer capability, transmission reliability margin.

1. Introduction

With the restructuring of electric power industry, total transfer capability (TTC) becomes an important concern of system operator. It is defined as the amount of electric power that can be transferred from one area (source) to another (sink) area without violating system constraints [1]. Transmission reliability margin (TRM) is incorporated to calculate the TTC value to make it more accurate, which is the amount of transfer capability necessary to protect the interconnected network against outages and overloading. Therefore, TTC computation involves the determination of three main concepts which have been reported in literature [2]. TTC is mathematically defined as the sum of TRM, ATC, the Existing Transmission Commitments (ETC) and the Capacity Benefit Margin (CBM). TTC can be calculated by various mathematical methods and algorithms such as Continuation Power Flow (CPF) method, Repetitive Power Flow (RPF) method, Linear ATC method (LATC) and Optimal Power Flow (OPF) based method.

The CPF method traces the power flow solution curve, starting at a base load, leading to the steady state voltage stability limit or the critical maximum loading point of power systems [3]. This method can overcome the singularity of the Jacobian matrix near the saddle-node bifurcation point, or the critical point. RPF method repeatedly solves the conventional power flow equations to obtain the maximum transfer capability. In both CPF and RPF methods, common loading factor for a specific cluster of generators and loads are employed. This might lead to conservative TTC value since the optimal distribution of generation and loading are ignored [4].

In LATC method, transfer capabilities of the system are calculated by PTDFs and are based on approximated linear incremental power flows. Even though this method is fast and easy, it ignores voltage and reactive power effects on the system. Hence in case of a stressed system with deficit of reactive power and voltage control, this method gives unacceptable errors [5]. OPF has been a powerful tool under very active development for over many years. A number of conventional optimization methods such as linear programming, mixed integer programming, interior point method and non-linear programming exist to solve OPF problems [6]. The convergence of conventional methods depends upon the convexity of the problem. But OPF problem is generally non linear and non convex in nature. Hence many stochastic methods like Genetic Algorithms (GA) [7], Evolutionary Programming (EP) [8], Simulated Annealing (SA) [9], Tabu search [10] have been proposed in the literature to solve OPF problems. Rajathy *et al.*, Employed DE as an optimization tool to solve TTC problem in deregulated market [11]. For calculating the TTC to considerations, main conditions, assumptions and framework is them presented [12].

This paper present the calculation of OPF based TTC problem by using firefly algorithm. The value of TTC can be made more accurate by considering transmission reliability margin in which single and multiline outages are considered. The proposed TTC problem is formulated as an optimization problem with many operational constraints. The proposed method has been implemented and tested on 4-bus system and a practical Indian utility 62 bus system. From the results of various case studies in both the test systems, the algorithm has been validated by comparing the results with previously published method.

2. Problem Formulation

The *TTC* computation problem has been formulated as an optimization problem:

$$Max\ F = \sum_{i=1}^{ND\_SNK} P_{Di} \tag{1}$$

$$P_{Gi} - P_{Di} - \sum_{k}^{N} V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{2}$$

$$Q_{Gi} - Q_{Di} - \sum_{k}^{N} V_i V_j Y_{ij} \sin(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{3}$$

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad i = 1,2, \dots \dots, NG \tag{4}$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \quad i = 1,2, \dots \dots, NG \tag{5}$$

$V_i^{min} \leq V_i \leq V_i^{max} \quad i = 1,2,\dots\dots\dots,N$ (6)

$|S_{Li}| \leq S_{Li}^{max} \quad i = 1,2,\dots\dots\dots,NL$ (7)

Where

F is the total load of load buses in a sink area.

P_{Gi} and Q_{Gi} are the real and reactive power generation at bus i.

P_{Di} and Q_{Di} are the real and reactive load at bus i,

V_i and V_j are the voltage magnitudes at bus i and j respectively.

Y_{ij} and θ_{ij} are the magnitude and angle of element,

δ_i and δ_j are the voltage angles of bus i and j.

P_{Gi}^{min} and P_{Gi}^{max} are the lower and upper limits of real power generation at bus i

Q_{Gi}^{min} and Q_{Gi}^{max} are the lower and upper limit of reactive power generation at limits of voltage magnitude at bus$i$.

$|S_{Li}|$ is the i^{th} line or transformer loading and

S_{Li}^{max} is the i^{th} line or transformer-loading limit.

N is the total number of buses,

NG is the number of generators,

NL is the number of branches

ND_SNK is the number of load buses in sink area.

The base case power flows in the transmission lines is changed by varying the generation in the source area and the load in drop area simultaneously. Such action continues until the contingency causes the violation of any one of the system limits such as thermal limit, voltage limit and stability limit. The minimum quantity of power transmitted among all the contingencies under any one of this violation, it is found that TTC representing the power transaction which is given as

$TTC = \text{Min}(TTC_0, TTC_K)$ (8)

where

TTC_0 = maximum amount of power transfer without contingency constraints,

TTC_K = maximum amount of power transfer under the contingency K.

3. Firefly Algorithm

The firefly algorithm was developed by Xin-She Yang [13] in 2008. It is a meta-heuristic optimization algorithm, inspired by the flashing behaviour of fireflies. The primary purpose for a firefly's flash is to act as a signal to attract other fireflies. There exist three idealized rules based on the major flashing characteristics of fireflies [14]. These are the following: (1) All fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex. (2) The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not a brighter or more attractive firefly than a particular one, it will then move randomly. (3) The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. For maximization problems, the light intensity is proportional to the value of the objective function.

3.1. Attractiveness

In the firefly algorithm, the form of attractiveness function β(*r*) of a firefly is described as a monotonically decreasing function as given by the following function:

$$\beta(r) = \beta_0 \exp(-\gamma r^m)\text{, with } m \geq 1 \qquad (9)$$

Where,

r = distance between any two fireflies

β_0 = initial attractiveness at r = 0

γ = light absorption coefficient, which controls the light intensity.

3.2. Distance

The distance between any two fireflies *i* and *j* at x_i and x_j, respectively, is determined using the following equation:

$$r_{ij} = \left\| x_i - x_j \right\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \qquad (10)$$

Where $x_{i,k}$ is the k^{th} component of the spatial coordinate x_i of the i^{th} firefly and *d* is the number of dimensions we have, for d = 2, we have

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \qquad (11)$$

3.3. Movement

The movement of a firefly *i* towards a more attractive (brighter) firefly *j* is determined by the following equation:

$$x_{i+1} = x_i + \beta_0 \exp(-\gamma r_{ij}^2)(x_j - x_i) + \alpha(rand - 0.5) \qquad (12)$$

Where the first term is the current position of a firefly, the second term is used for considering a firefly’s attractiveness to light intensity seen by adjacent fireflies and the third term is the random movement of a firefly in case there are not any brighter ones.

4. Results and Discussion

The FF algorithm is proposed to solve TTC problem. The 4-bus system and 62-bus Indian utility system are used to illustrate the effectiveness of the proposed algorithm. TTC can be made more accurate by considering transmission reliability margin (TRM) with single and multiline outages. Transactions between different control areas are investigated. To illustrate the validity of the proposed algorithm, the results of the 4-bus system are compared with that of previously published work.

FF algorithm parameters are as follows: γ = 1.0, α =0.5, β_0 = 0.2, number of fireflies are taken as 100 and 100 total generations are considered. Simulation studies are carried out on Intel core 2 Duo (1.8GHz) processor in MATLAB environment.

4.1. 4-Bus System

The 4-bus test system consists of 2 generator buses, 3 load buses, 7 transmission lines. The system data including transmission line parameters, real & reactive power load, generator real & reactive power limits are given in [12]. The system voltage lower and upper limits are taken as 0.95 and 1.05 p.u respectively.

The TTC computation problem has been formulated as an optimization problem. The main objective is to maximize the TTC of the system considering the necessary system constraints like generator limit violation, line overload or bus voltage violation. Six different case studies are used to illustrate the TTC calculation of 4 bus test system using FF algorithm. In these cases, transaction of power is carried out from bus 2 to 1, bus 2 to 4, bus 3 to 1, bus 3 to 4, bus 2 to 3 and bus 3 to 2. TTC is calculated using FF algorithm for all the cases with and without TRM and the results are listed in Table 1. The table also shows the limiting condition in each case as well as TTC values of previously published work for comparison [12].

Using the proposed algorithm, TTC in all the six case studies is found to be 55.03 MW, 72.03 MW, 62.03 MW, 93.05 MW, 62.31 MW and 35.13 MW without any contingencies in the system. Next TTC values are computed in all the six case studies with TRM. In these cases, the outage of transmission line which gives the minimum TTC value is considered as the most critical line. Among all the case studies, in case 6, the outage of transmission line 3-4 is the most critical line as it gives the least value of TTC and is found to be 20.03 MW.

Table 1. TTC values with and without TRM-4 bus system

Case studies	Power Transfer		With / Without TRM	TTC (MW)		Limiting condition
	From bus	To bus		(Mohamed Shaaban et al.)[12]	FFA	
Case 1	2	1	Normal	51.4	55.03	G2 limit
			Outage 1-3	**45.2**	**46.97**	**1-2**
			Outage 2-4	53.4	55.97	1-3
			Outage 2-3	63.2	63.5	V_1
Case 2	2	4	Normal	67.8	72.03	G2 limit
			Outage 2-3	93.6	95.07	3-4
			Outage 3-4	**46.7**	**48.16**	$\mathbf{V_1}$
			Outage 1-2	74.2	80.17	V_1
Case 3	3	1	Normal	59.8	62.03	G3 limit
			Outage 2-4	54.8	60.01	V_1
			Outage 1-2	**57.7**	**59.1**	**1-3**
			Outage 3-4	61.8	62.95	V_1
Case 4	3	4	Normal	90.2	93.05	G3 limit
			Outage 1-3	94.6	95.17	V_1
			Outage 2-4	**90**	**91.92**	**1-3**
			Outage 1-2	92.2	98.3	2-4

Case 5	2	3	Normal	56	62.31	G2 limit
			Outage 1-3	57.4	60.17	1-2
			Outage 1-2	**55.8**	**56.93**	**1-3**
			Outage 2-4	55.8	58.95	V_1
Case 6	3	2	Normal	31.5	35.13	G3 limit
			Outage 1-3	54.8	60.01	3-4
			Outage 3-4	**18.6**	**20.03**	**1-3**
			Outage 1-2	30.8	40.02	V_1

From the table 1, it is inferred that obtained TTC values using FF algorithm is better than that of previously published work. This shows the capability of the FF algorithm to give better TTC results which enable the system operator to enhance the better utilization of the available transmission network. The convergence characteristics of firefly algorithm for the most critical line (3-4) in case 6 are shown in Figure 1.

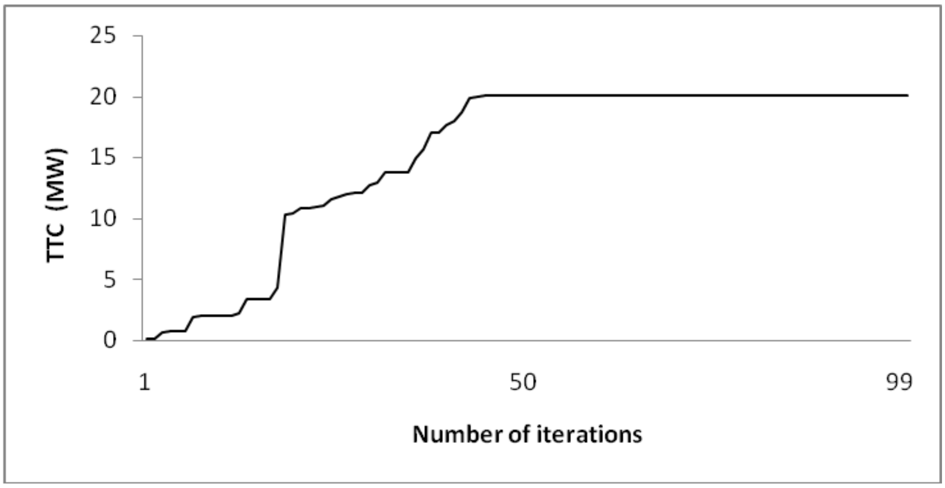

Figure 1. Convergence characteristics of FF algorithm-4 bus system

4.2. 62 Bus Indian Utility System

The test system consists of 19 generator buses and 89 transmission lines, 11 tap changing transformers with load demand of 2908 MW. The system is separated into three areas with six generators in area 1 and area 3 respectively, whereas area 2 has seven generators. The network topology and the data for the Indian utility 62 bus system are available in [15].

4.2.1. Power transfer from area 2 to 1:

TTC is determined by varying the total generation of area 2 and total load of area 1 randomly from base case value. The base case load of area 1 is increased and their details are given in Table 2. From the table 2, it is found that the generation of area 2 reaches its maximum limit when the load of area 1 is 1765.84 MW. The convergence characteristics of firefly algorithm are shown in Figure. 2.

Table 2 Load details in area 1

Load bus numbers	38	39	42	43	44	53	55	62	**Total (MW)**
Base case load (MW)	166	30	30	25	109	248	94	93	**795**
Increased Load using FFA (MW)	300	78.64	88.52	99.98	300	500	199.8	198.9	**1765.84**

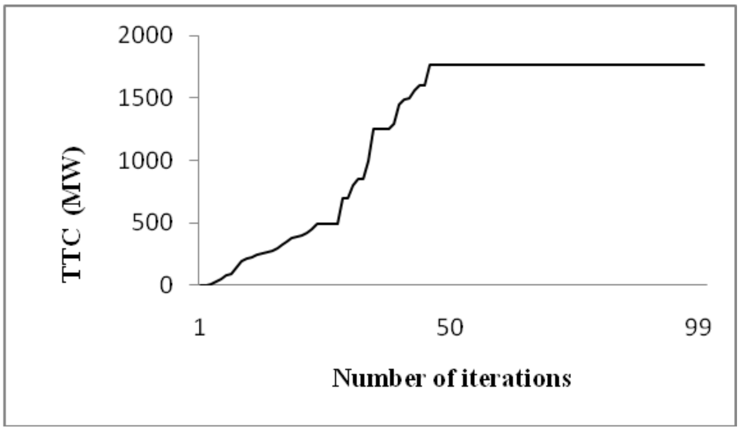

Figure 2. Convergence characteristics of FF algorithm-62 bus system

To reveal the impact of line outages on TTC calculation, transmission reliability margin is included. In this case, tie-line (55-58) between area 2 and area 1, transmission lines (42-44), (12-20) of area 1 and area 2 are made out of service individually and simultaneously. The value of TTC calculated in all the four cases is given in Table 3. From the table 3, it is observed that the most critical line is found to be the tie-line (55-58) as its outage yields the lowest value of TTC and is found to be 1672.52 MW. When this critical line is made out of service, the line connected between buses (1-2) gets overloaded. All the line flows along with their limits corresponding to critical line outage are shown in Figure 3.

Table 3. TTC values with TRM during transaction from area 2-1

Cases	TTC (*MW*) FFA	Limiting condition
Normal	1765.84	Gen area 2
55-58	**1672.52**	**1-2**
42-44	1727.04	12-13
12-20	1801.15	7-8
55-58, 42-44, 12-20	1680.82	49-50

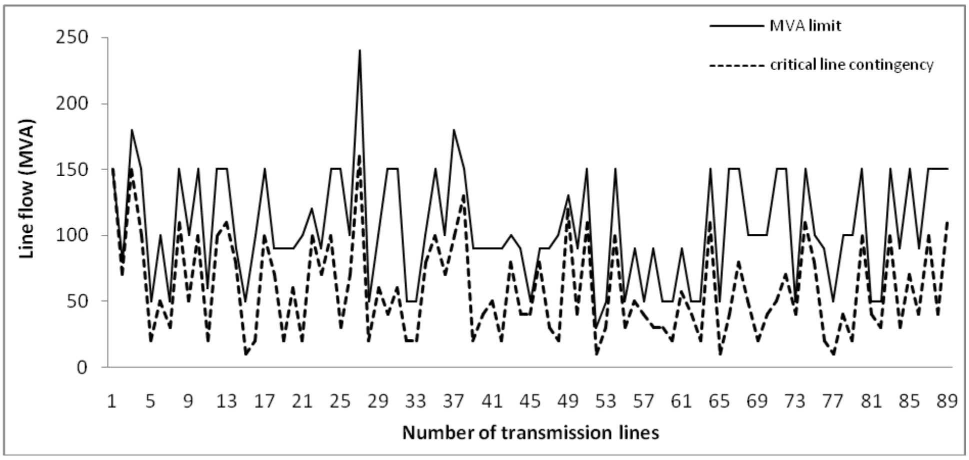

Figure 3. Line flows during critical line outage (55-58)

4.2.2 Power transfer from area 2 to 3:

In this case study, the transfer capability is computed by FF algorithm in which the transaction of power from area 2 (source) to area 3 (sink) is considered. In this case, the load of area 3 is varied randomly and the generation of area 2 is also varied simultaneously. It is found that the value of TTC for this transaction is 2275.21 MW. The real power load of all the load buses in area 3 before and after the transaction is depicted in Figure 4.

Next the impact of single line and multiline outages in computation of TTC is studied in this transaction. The single line outages are simulated on tie-line (20-23), (13-17), (14-16) and also multiline outage are carried out in lines (56-57), (20-23), (14-16). The obtained results are given in Table 4. From the simulation results, it is clear that the most critical line (13-17) gives minimum TTC value. During the outage of critical line, the transmission line between the buses 27 & 29 gets overloaded and is clearly shown in Figure 5.

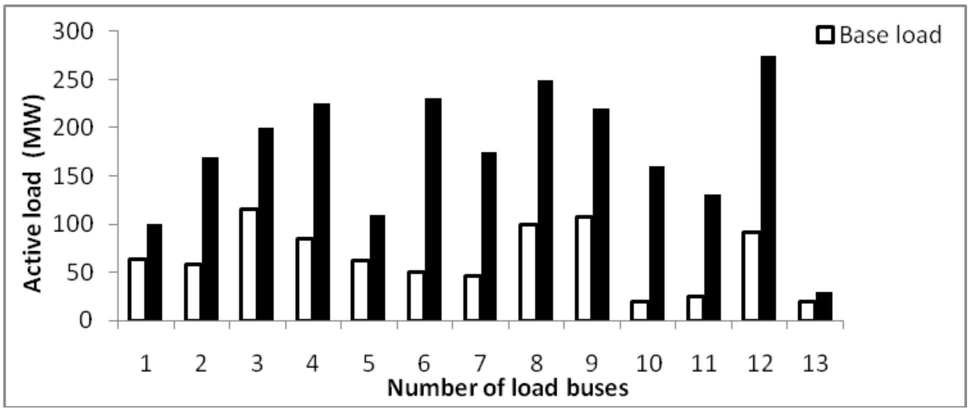

Figure 4. Real power load in area 3

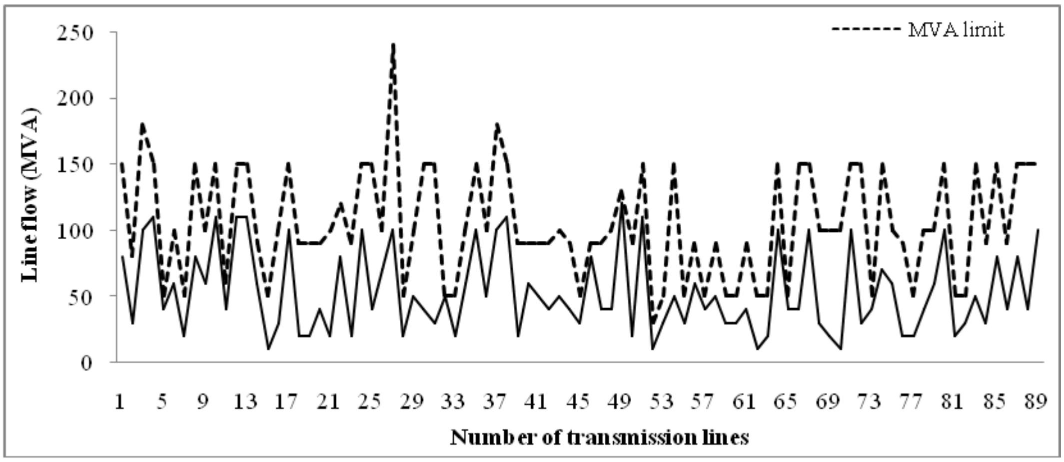

Figure 5. Line flows during critical line outage (13-17)

Table 4. TTC values with TRM during transaction from area 2-3

Cases	TTC (MW) FFA	Limiting condition
Normal	2275.21	Gen area 2
13-17	**2029.23**	**27-29**
14-16	2303.94	32-33
20-23	2299.12	4-15
56-57, 20-23,14-16	2105.66	60-12

5. Conclusion

In this paper**,** the formulation and implementation of the OPF-based TTC calculation for different test systems using FF algorithm is detailed. The real power output of generators in source area and real power load in drop area are adjusted to obtain the maximum TTC. The proposed method is very effective and capable of giving optimal solution to maximize the transfer capability of the test systems with and without TRM. The result shows good convergence characteristics in determining TTC between different areas. The obtained results validate the superiority of the proposed FF algorithm compared to other methods.

References

[1] North American Electric Reliability Council (NERC), 1995, “Transfer Capability Definitions and Determination,” NERC Report.

[2] Dobson, Greene, S., Rajaraman, R., DeMarco, C.L., Alvarado, F.L., and Zimmerman, R., 2001, “Electric Power Transfer Capability-Concepts, Applications, Sensitivity and Uncertainty,” Power Systems Engineering Research Center publication, Cornell University, pp.01-34.

[3] Ejebe, G.C., Tong, J., Waight, J. G., Frame, J. G., Wang, X. and Tinney, W. F., 1998, “Available transfer capability calculation,” IEEE Trans. on Power Syst., 13(4), pp.1521-1527.
[4] Gravener, M.H. and Nwankpa, C., 1999, “Available transfer capability and first order sensitivity,” IEEE Trans. on Power Syst., 14(2), pp.512-518.
[5] Ejebe, G.C., Waight, J.G., Manuel, S. N. and Tinney, W. F., 2000, “Fast Calculation of linear available transfer capability,” IEEE Trans. on Power Syst., 15(3), pp.112-116.
[6] Dai, Y., McCalley, J.D. and Vimal, V., 2000, “Simplification expansion and enhancement of direct interior point algorithm for power system maximum loadability,” IEEE Trans. on Power Syst., 15(3), pp.1014-1021.
[7] Bakirtzis, A.G., Biskas, P.N., Zoumas, C.E. and Petridis, V., 2002, “Optimal power flow by enhanced genetic algorithm,” IEEE Trans. on Power Syst., 17(2), pp.229-236.
[8] Yuryevich, J., and Wong, K. P., 1999, “Evolutionary programming based optimal power flow algorithm,” IEEE Trans. on Power Syst., 14(4), pp.1245-1250.
[9] Roa-Sepulveda, C.A. and Lazo, B.J., 2003, “A solution to the optimal power flow using simulated annealing,” Electric. Power and Energy Syst., 25(1), pp. 47-57.
[10] Abido, M.A., 2002, “Optimal Power Flow using Tabu Search Algorithm,” Elect. Power Comp. and Syst., 30(5), pp.469-483.
[11] Rajathy, R., Gnanadass, R., Manivannan, K. and Harish Kumar, 2010, “Differential Evolution based method for Total Transfer Capability Evaluation,” Int. J of Eng., Sci. and Tech., 2(5), pp.81-91.
[12] Mohamed Shaaban, Yixin Ni, Hongwei Dai and Felix F. Wu, 1998, “Considerations in Calculating Total Transfer Capability,” Proc. International Conference On Power System Tech., 2, pp.1356-1360.
[13] Yang, X.S., 2008, “Nature-Inspired meta-heuristic algorithms,” Luniver Press, Beckington, UK.
[14] Yang, X.S., 2010, “Firefly Algorithm, Stochastic test Functions and Design Optimisation,” Int. J of Bio-Inspired Comput., 2(2), pp.78-84.
[15] Gnanadass, R., Narayana Prasad Padhy and Manivannan, K., 2004, “Assessment of Available Transfer Capability for Practical Power Systems with Combined Economic Emission Dispatch,” Elect. Power Syst. Res., 69(2), pp. 267-276.