International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 20 (2017) pp. 10269-10275

Enhancement of ATC with FACTS device using Firefly Algorithm

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Abstract

Electrical power system in all part of the world and particularly in India is stressed. Demand of electrical power is increasing day by day makes this stress. The transmission lines erected in electrical power system is rigid and not easy to modify. The quality of transferring electrical power is based on the real and reactive power supply and margin availability in transmission lines. Available Transfer Capacity (ATC) is the limit margin of real power that can be transferred to the load center from the supply. The maximum ATC limit for the particular transmission line is fixed and it is not enough to cater the need of customer demand. Flexible AC Transmission System (FACTS) devices may used to enhance this transferring limit. These FACTS devices are classified into series, parallel and hybrid devices. In this research work one such series FACTS device Thyristor Controlled Series Capacitor (TCSC) is used to enhance this ATC. The performance of FACTS device is better when its location and size is optimized. For this Firefly Algorithm is used for optimizing the location and size of TCSC.

Keywords: Available Transfer Capability (ATC), TCSC, Firefly Algorithm (FA), FACTS, congestion, reactive power optimization.

INTRODUCTION

Transmission lines are stressed due to ever increasing electrical loads makes the transmission congestion [1], [11]. To relive this congestion ATC is calculated. A good method for improving ATC is including FACTS device into the power system [2]. The Flexible AC Transmission Systems (FACTS) devices have become the indispensible entities in the field of electrical power transmission and appropriate utilization. FACTS devices may give required reactive power, voltage control, and phase angle control for the improvement of transmission and over all power system performance. There are many FACTS devices such as SVC, TCSC, STATCOM, SSSC and UPFC. Of the family of FACTS devices is the UPFC that is capable of multi parameter governance. It is combination of two FACTS devices Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC). In this research paper TCSC is used since it is connected in series to the transmission line and gives better ATC.

Intelligent Algorithms are used to solve complex discontinuous engineering problems. ATC is one such complex engineering problem and solved by intelligent algorithm. The older intelligent algorithms are Genetic Algorithm (GA), Anastasios G. Bakirtzis et al. [3] used Enhanced Genetic Algorithm (EGA) to solve power system problem, which is Binary coded GA. Number of bits in the chromosome is reduced to enhance the performance of the algorithm. The nature of DE is minimization of optimization problem which helps to optimize power system problem. Vaisakh & Srinivas [4] used DE algorithm to solve power system problem. Generator real power except slack bus, generator voltage magnitudes, transformer tap settings are considered as control variables and converted into vector of DE algorithm. Wilensky & Reisman [5] explain fireflies natural behaviour of flashing lights which synchronous with other fireflies and converge to same rhythm. Xin-She Yang, et al. [6] used firefly algorithm to solve non-convex valve point loaded economic dispatch. ATC calculated based on line flow and the line flow limits [7]. ATC become more complex when renewable energy sources are included in the power system [8-9]. ATC become complex when deregulation is introduced in the power system [10]. Apart from overloading, contingency in power system may also create congestion [12]. Sensitivity factor of all generators pertain to the congestion of transmission line is required for generator rescheduling [13]. In this paper firefly algorithm is used solve ATC

THYRISTOR-CONTROLLED SERIES CAPACITOR (TCSC)

Series capacitors offer certain major advantages over their shunt counterparts. With series capacitors, the reactive power increases as the square of line current, whereas with Shunt capacitors, the reactive power is generated proportional to the square of bus voltage.

The variable series compensation used to

1. enhanced base-power flow and loadability of the series-compensated line;
2. additional losses in the compensated line from the enhanced power flow; and
3. increased responsiveness of power flow in the series-compensated line from the outage of other lines in the system

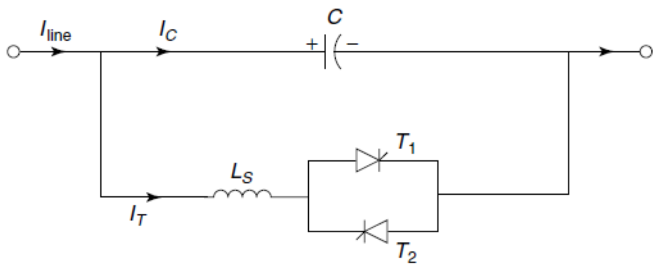

Figure 1: TCSC model

The basic conceptual TCSC module comprises a series capacitor, C, in parallel with a thyristor-controlled reactor, L_S, as shown in Figure 1.

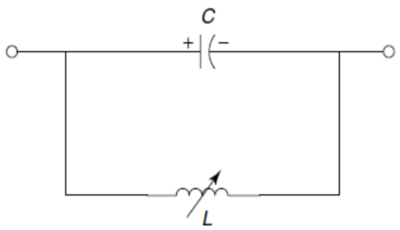

Figure 2: TCSC equivalent model

The above figure shows the equivalent circuit of TCSC, A simple understanding of TCSC functioning can be obtained by analyzing the behavior of a variable inductor connected in parallel with an FC, as shown in above Figure 2. The equivalent impedance, Zeq, of this LC combination is expressed as

$$Z_{eq} = (j\frac{1}{\omega C}) \parallel (j\omega L) = -j\frac{1}{\omega C - \omega L} \quad (1)$$

Firefly algorithm

Firefly algorithm (FA) mimics firefly's intelligent technique to find optimal solution for engineering problems. For optimization flashing light is formulated based on objective function. Brightest firefly is the most optimal solution for the problem under consideration. A firefly is set of control variables of the problem considered. Brightness of the firefly is calculated by evaluating the objective function to be optimized. This algorithm may used for maximization or minimization problem. FA has idealization as compared to natural firefly, they are

- Firefly is unisex and attracted by another firefly in spite of sex
- Firefly moves towards brightest if no brighter one then firefly moves randomly in solution space
- Brightness of firefly is affected by problem nature

General form FA optimization is a maximization of objective function subjected to constraints. FA moves fireflies towards global optimal solution spot through iteration by iteration. A firefly is a set of control variable and its light intensity is objective function or fitness value of the firefly. The process of FA are create or initialize fireflies, find brightness of firefly, move each firefly towards brightest one, find global brightest to give optimal solution. General form of FA optimization is maximize objective function, subjected to equality function and inequality function as given below,

$$\text{Minimize } ATC_{ij} = \min(P_{ij,lm}^{\max}) \quad (2)$$

$$\text{Subject to: } g(|V|, \delta) = 0 \quad (3)$$

$$X_{min} \leq X \leq X_{max} \quad (4)$$

Where,

C_t is total generating cost in $/hr

g(|V|, δ) is power flow balance equation

X is a set of control variable

X_{min}, X_{max} are minimum and maximum value of control variable

Firefly Based Reactive Power Allocation

To optimize location and size of TCSC the control variables, real power generation, and position are considered. The limits on these control variables form prime constraints in addition to power balance condition. Actual values of these control variables are used to form a firefly. These fireflies form population and initialized randomly from the solution space and then evolution is carried out using its brightness and distance from brightest firefly.

Encoding

Encoding is the process of converting set of control variables in location of TCSC into firefly for optimization. Ability of FA is to operate on floating point and mixed integer makes ease of encoding. Final iteration of FA gives global bright firefly which is the optimal solution of location of TCSC. For the evolution and better convergence fitness function is most important as follows.

Fitness Function

An appropriate fitness function (brightness) is vital for evolution and convergence of FA. It is a location of TCSC objective functions and penalty functions if any. FA evaluates brightness for each firefly in the population. Objective function value for a firefly is called brightness of the firefly. FA makes a firefly to move towards brighter firefly in the population. Distance moved and brightness of each firefly is calculated and best firefly (global best) is calculated in the iteration. Improvement in solution is achieved iteration by iteration and final iteration provides global best optimal solution to LOCATION OF TCSC.

Attractiveness

Firefly moves towards more attractiveness. This attractiveness of considered firefly with others is calculated using the function. This attractiveness is decreases with increase in distance between fireflies. Main reasons for reduction in attractiveness are absorption factors in nature are implemented by using absorption coefficient. This function is monotonically decreasing function given below the equation 5.

$$\beta = \beta_0 \exp(-\gamma\, r^2) \tag{5}$$

where,

β is attractiveness of a firefly

$\beta_0$is initial attractiveness

γ is absorption coefficient

r is distance between fireflies

Distance

Distance between fireflies i and j is calculated using Cartesian distance as given below the equation 6

$$r_{ij} = \| x_i - x_j \| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \tag{6}$$

In 2-dimensional solution space the distance between i and j fireflies may calculated as follows the equation 7

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{7}$$

Movement

Movement of i[th] firefly towards j[th] brighter firefly is based attractiveness and distance between them as given below

$$x_i^{k+1} = x_i^k + \beta_{0*}\exp(-\gamma\, r^2) * (x_j^k - x_i^k) + \alpha * \varepsilon_i^k \tag{8}$$

Where the left side first term is initial position of i[th] firefly, second term gives attractiveness towards j[th] firefly and third term introduce random movement in i[th] firefly. Initial attractiveness $\beta_0$is taken as 1.0; absorption coefficient γ is taken as 0.9. Randomising coefficient α rang in between 0 and 1, in this work it is taken as 0.2; ε_i is randomization vector ranges from 0 to 0.5.

Stopping Criteria

Fireflies moves randomly and try to attract towards brighter firefly. FA improves problems' solution iteration by iteration and the iteration has to be stopped either the problem is converged or iteration reached its maximum value. Stopping of iteration is important to provide solution for time complexity. In this research work maximum number of 200 iterations is considered as stopping criteria.

ALGORITHM

FA algorithm for solving location of TCSC is given below

Step 1: Firefly is a set of control variables in location of TCSC

Step 2: Initialize fireflies in the population within solution space

Step 3: Location of TCSC objective function is used to find brightness of firefly

Step 4: Attractiveness of firefly with other fireflies is calculated

Step 5: Distance between fireflies is calculated

Step 6: firefly i is moved towards firefly j using equation 8

Step 7: Rank the fireflies and find the current global best

Step 8: Repeat step 4 to step 7 till stopping criterion is satisfied

Step 9: Print the result after stopping criterion is satisfied.

Problem Formulation

ATC is the available margin that can be utilized to transfer real power in the particular transmission line. It is the difference between Total Transfer Capacity (TTC) and actual power transmission as given below.

ATC = TTC – Actual power flow (9)

$$ATC_{ij} = \min(P_{ij,lm}^{\max}) \quad (10)$$

$$P_{ij,lm}^{\max} = \frac{P_{lm}^{\max} - P_{lm}^{0}}{PTDF_{lm.ij}} \quad (11)$$

$$PTDF_{lm,ij} = \frac{X_{li} - X_{mi} - X_{lj} + X_{mj}}{X_{lm}} \quad (12)$$

$P_{ij,lm}^{\max}$ is the maximum real power that can be transferred from i^{th} to j^{th} bus. $PTDF_{lm,ij}$ is called Power Transfer Distribution Factor used to find ATC.

Simulation Result

To validate the developed algorithm, IEEE 30 bus system is considered. It has 30 buses and 41 transmission lines. ATC calculated for the stressed system is given in the table 1. In this line number 11 connected between buses 6-8 has no ATC margin. TTC power is considered from the line data and actual power flow is calculated using NR power flow.

Table 1: ATC before FACTS device connection

Line No	Line between buses	TTC	Actual Flow	ATC
1	1-2	130	17.3	112.7
2	1-3	130	5.21	124.79
3	2-4	65	1.96	63.04
4	2-5	130	29.5	100.5
5	2-6	65	2.84	62.16
6	3-4	130	2.61	127.39
7	4-6	90	10.1	79.9
8	4-12	65	11.2	53.8
9	5-7	70	23.9	46.1
10	6-7	130	42.3	87.7
11	**6-8**	**32**	**32**	0
12	6-9	65	25.4	39.6
13	6-10	32	3.26	28.74
14	6-28	32	3.4	28.6
15	8-28	32	9.83	22.17
16	9-11	65	57.1	7.9
17	9-10	65	41	24
18	10-20	32	9.95	22.05
19	10-17	32	9.2	22.8
20	10-21	32	18.4	13.6
21	10-22	32	8.93	23.07
22	12-13	65	59.4	5.6
23	12-14	32	8.38	23.62
24	12-15	32	21	11
25	12-16	32	9.26	22.74
26	14-15	16	2.28	13.72
27	15-18	16	6.7	9.3
28	15-23	16	8.39	7.61
29	16-17	16	6.23	9.77
30	18-19	16	3.6	12.4
31	19-20	32	7.51	24.49
32	21-22	32	6.02	25.98
33	22-24	16	9.84	6.16
34	23-24	16	6.62	9.38
35	24-25	16	6.4	9.6
36	25-26	16	4.27	11.73
37	25-27	16	2.28	13.72
38	27-29	16	6.43	9.57
39	27-30	16	7.3	8.7
40	28-27	65	12.7	52.3
41	29-30	16	3.76	12.24

To get ATC margin and to stabilize the system FACTS device TCSC is conned in the line number 11 which improves the ATC as given in the table 2.

Table 2: After FACTS device connection

Line No	Line between buses	TTC	Actual Flow	ATC
1	1-2	130	17.3	112.7
2	1-3	130	5.21	124.79
3	2-4	65	1.96	63.04
4	2-5	130	29.5	100.5
5	2-6	65	2.84	62.16
6	3-4	130	2.61	127.39
7	4-6	90	10.1	79.9
8	4-12	65	11.2	53.8
9	5-7	70	23.9	46.1
10	6-7	130	42.3	87.7
11	**6-8**	**32**	**25**	7.0
12	6-9	65	25.4	39.6
13	6-10	32	3.26	28.74
14	6-28	32	3.4	28.6
15	8-28	32	9.83	22.17
16	9-11	65	57.1	7.9
17	9-10	65	41	24
18	10-20	32	9.95	22.05
19	10-17	32	9.2	22.8
20	10-21	32	18.4	13.6
21	10-22	32	8.93	23.07
22	12-13	65	59.4	5.6
23	12-14	32	8.38	23.62
24	12-15	32	21	11
25	12-16	32	9.26	22.74
26	14-15	16	2.28	13.72
27	15-18	16	6.7	9.3
28	15-23	16	8.39	7.61
29	16-17	16	6.23	9.77
30	18-19	16	3.6	12.4
31	19-20	32	7.51	24.49
32	21-22	32	6.02	25.98
33	22-24	16	9.84	6.16
34	23-24	16	6.62	9.38
35	24-25	16	6.4	9.6
36	25-26	16	4.27	11.73
37	25-27	16	2.28	13.72
38	27-29	16	6.43	9.57
39	27-30	16	7.3	8.7
40	28-27	65	12.7	52.3
41	29-30	16	3.76	12.24

To find the size of connected FACTS device TCSC, the algorithm firefly is used and it gives the size of TCSC is 7 MW. Hence the TCSC connected in the line number 11 with the capacity of 7 MW will enhance the ATC.

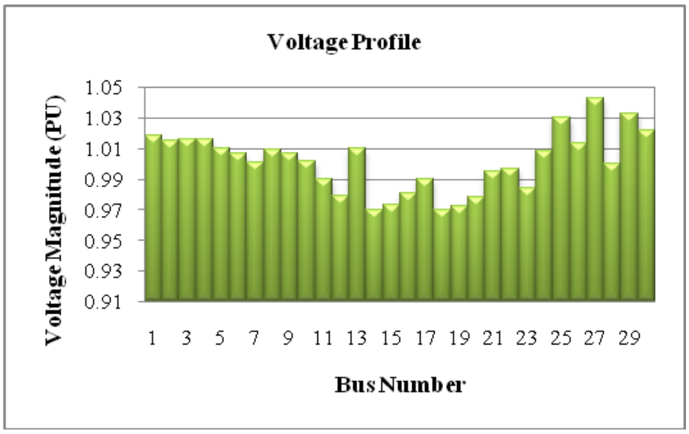

Figure 3: Voltage profile of IEEE 30 bus system

After the ATC adjustment due to connection of TCSC the voltage in all 30 buses are updated and it is within the tolerance value as shown in the figure 3

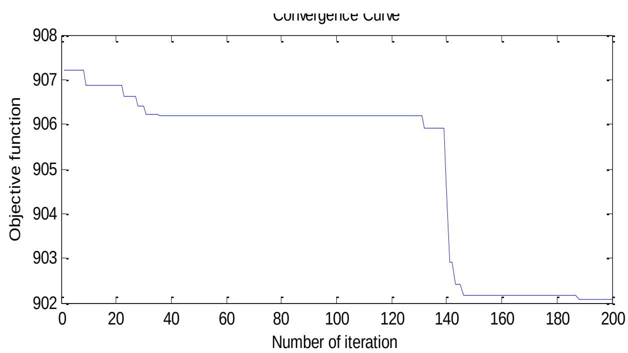

Figure 4: Firefly convergence curve for ATC

Stopping criterion for firefly algorithm is considered as 200 iterations and the convergence curve for ATC is given in the figure 4.

The 6 generators in the system have its own minimum and maximum limits hence the generation of individual generator should satisfy this condition. The firefly algorithm gives the best generation pattern as given in the figure 5.

This power system has 4 transformers and its tap position along with its minimum and maximum limit is given in the figure 6

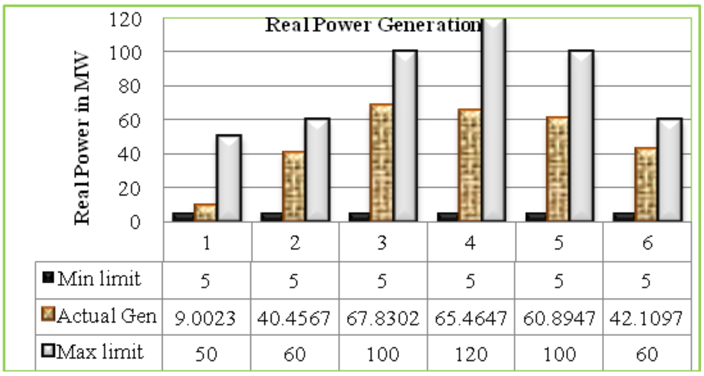

Figure 5: Real power generation for ATC

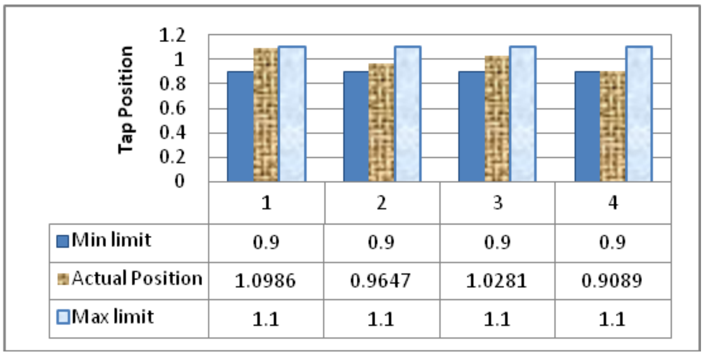

Figure 6: Transformer tap positions

CONCLUSION

In this research work to evaluate the ATC, IEEE 30 bus is considered. It has 41 transmission lines. Among these 11^{th} line is more stressed and has no available or ATC margin. To improve the ATC limit FACTS device TCSC is connected in the line and its size is determined by the intelligent algorithm Firefly. After connecting TCSC the ATC margin is improved by 7 MW. Firefly algorithm mimics the social behavior of the insect firefly to find the best optimal values. In this research work the objective is to improve the ATC margin in the stressed line. TCSC is series connected FACTS device injects real power to enhance the real power limit in the stressed line. This work may extend for multiple FACTS device connection in the power system to get better ATC.

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