ATC Enhancement for Optimal Placement of FACTS using Artificial Intelligence (AI) Technique

[1]Manisha Agarwal and [2]Aziz Ahmed

[1]M.Tech
AL-FALAH School of Engineering and Technology
Faridabad

[2]HOD
Department of Electrical Engineering
AL-FALAH School of Engineering and Technology
Faridabad

Abstract

The available transfer capability is one of the most important processes, used to identify the transfer of power between two areas without crossing the security constraints. To improve the available transfer capability between two areas, FACTS controllers are connected in the system. The major problem here is identifying the optimal location for fixing FACTS controller and the amount of voltage and angle to be injected in the system. By considering the aforementioned drawback, here a hybrid technique is proposed to identify the optimal location for fixing FACTS controller and the amount of voltage & angle to be injected in the system. The hybrid technique includes neural network and genetic algorithm. Here, neural network is used to identify the optimal location for fixing FACTS controller in the system and genetic algorithm is used to determine the amount of voltage and angle to be injected in the system. By using this hybrid technique, the available transfer capability between the areas is improved as well as the power loss in the system is reduced. The result shows the performance of the proposed method in improving the ATC and reducing the total power losses in the system.

Key words: *ATC, FACTS, SSSC, neural network, genetic algorithm.*

1. Introduction

Transfer capability of a power system signifies how much inter-area power transfer can be increased without system security encroachments [2]. Transmission lines contain several physical limits due to thermal capacity, stability, and voltage [1]. Optimization methods have been widely used in conventional power system to solve numerous problems such as market clearing mechanism, bidding decision, and ATC computation [7].

The Available Transfer Capability (ATC) denotes the unexploited transfer capabilities of a transmission network for the transfer of power for further commercial activity, in addition to already committed usage [3]. More precisely, ATC is considered as Total Transfer Capability (TTC) less than Transmission Reliability Margin (TRM), sum of existing transmission commitments (which includes retail customer service) and Capacity Benefit Margin (CBM) and assuming the other components related to ATC are zero for simplicity [4].

Total transfer capability refers to a gauge of the transfer capability residual in the physical transmission network for further commercial activity in addition to previously committed uses [5]. Using FACTS devices, the power system performance and stability can be improved [8].

Flexible Alternating Current Transmission System (FACTS) is an auspicious technology, which can boost the transmission capacity of the ac lines and can control the power flow over a certain transmission lines [9]. Also, FACTS devices are competent in controlling the voltage magnitude, phase angle, and circuit reactance [6]. The power flow arrangements as well as the reactive power flow in the transmission lines are controlled by means of FACTS technology, such as Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), and Unified Power Flow Controller (UPFC) [13]. UPFC is one of the most adaptable and intricate FACTS devices, combining the features of the STATCOM and SSSC [10].

2. Related Works

Some of the recent works related to ATC enhancement with FACTS controllers are discussed below.

Rani *et al.* [11] have proposed a genetic algorithm based technique to identify the best location for fixing FACTS devices for improving the Available Transfer Capability (ATC) of power transactions between source and sink areas in the deregulated power system. Here, two types of FACTS have been simulated: Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC) for improving the ATC of the interconnected power system. A Repeated Power Flow with FACTS devices including ATC has been employed to compute the best possible ATC value within real and reactive power generation limits, line thermal limits, and voltage limits.

Venkaiah *et al*. [12] have proposed a Static Security based ATC computation for real-time applications by means of three artificial intelligent techniques: Back Propagation Algorithm (BPA), Radial Basis Function (RBF) Neural Network, and Adaptive Neuro Fuzzy Inference System (ANFIS). These three diverse intelligent techniques have been tested on IEEE 24-bus Reliability Test System (RTS) and 75-bus Practical System for the base case and critical line outage cases for various transactions.

Umapathy *et al*. [13] have presented an application of probabilistic distribution based interval arithmetic approach to compute the ATC in a power network in terms of confidence intervals. The interval arithmetic approach allows integration of the uncertainty in the input parameters and offers strict bounds for the solution. Here, the deviation of the real power load has been represented as a Gaussian distribution function. Moreover, the proposed technique has been tested and validated on IEEE 14 bus test system.

An application of complex valued neural network for ATC calculations with and without contingencies have been introduced by Chary *et al.* [14]. Here, a 9 bus test system has been used to evaluate the performance. The objective function is to increase the load on certain source and sink nodes. Also, the voltage limits of the buses and the line losses have been well considered in this proposed technique.

A unified optimization approach has been proposed by Jayashree *et al*. [15] for computing Available Transfer Capability (ATC) and performing Congestion Management (CM) in a deregulated power system handling both pool and bilateral transactions. Here, a power injection model has been employed for Unified Power Flow Controller (UPFC), DC load flow model for power network, and repeated linear programming method for optimization. The DC model enforces the line operating limits in MW. A computer package has been developed and the efficacy of the proposed unified technique has been validated on 4 bus and an IEEE 30 bus systems.

3. ATC Enhancement using FACTS Controller

Available transfer capability is used in power system to identify the ability of power flow between two areas for different system conditions. One of the techniques used to improve the available transfer capability of the transmission line is connecting FACTS controllers in the system. The major problem in connecting FACTS controller in the system is identifying the optimal location for fixing FACTS controllers and also computing the amount of voltage and angle to be injected in the system. By considering the abovementioned drawback, here we proposed a hybrid technique to identify the optimal location for fixing FACTS controller and also to determine the amount of voltage & angle to be injected in the system. The hybrid technique includes neural network and genetic algorithm. Here, neural network is used to find the best possible location for fixing FACTS controller in the system and genetic algorithm is used to compute the voltage and angle injecting values. The FACTS controller used here is SSSC. Initially, we see about the mathematical model used for injecting real and reactive power using SSSC.

3.1. SSSC Mathematical Model

The SSSC type of FACTS controller is used in our method and its mathematical model is given in equations 1, 2, 3 & 4.

$$\Delta P_i = G^{new} * V_i^2 + (V_i * V_{inj} * Y^{new} * \cos(\delta_i - \delta_k - \delta_{inj})) - (V_i * V_k * Y^{new} * \cos(\delta_i - \delta_k - \delta_{inj})) \quad (1)$$

$$\Delta Q_i = -B^{new} * V_i^2 + (V_i * V_{inj} * Y^{new} * \sin(\delta_i - \delta_k - \delta_{inj})) - V_i * V_k * Y^{new} * \sin(\delta_i - \delta_k - \delta_{inj}) \quad (2)$$

$$\Delta P_k = G^{new} * V_k^2 - (V_k * V_{inj} * Y^{new} * \cos(\delta_k - \delta_i - \delta_{inj})) - (V_i * V_k * Y^{new} * \cos(\delta_k - \delta_i - \delta_{inj})) \quad (3)$$

$$\Delta Q_k = -B^{new} * V_k^2 + (V_k * V_{inj} * Y^{new} * \sin(\delta_k - \delta_i - \delta_{inj})) - V_k * V_i * Y^{new} * \sin(\delta_k - \delta_i - \delta_{inj}) \quad (4)$$

where, ΔP_i, ΔP_k, ΔQ_i, ΔQ_k are the real and reactive injecting powers from and to bus respectively, I_q is the transformer reactive current, V_{inj} and δ_{inj} are the injecting voltage and angle respectively, $G^{new} = gik + G$, $B^{new} = bik + B$, and $Y^{new} = yik + Y$.

3.2. Identifying Optimal Location for Fixing SSSC Using Neural Network

Generally, neural network consists of two stages namely, training and testing. In training stage, neural network is trained based on the input and output data. While in the testing stage, an optimal location will obtain for the given input.

3.2.1. Training Neural Network

Neural network structure consists of three layers: input, hidden, and output layer. In the proposed method, input & output layers consist of two variables respectively and hidden layer consists of n variables. The structure of neural network used in the proposed method is shown in Fig 1.

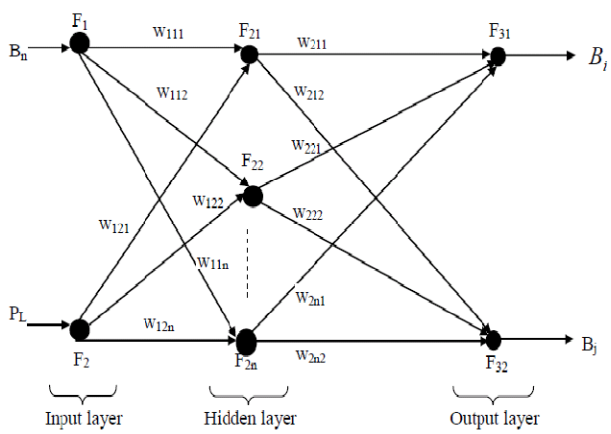

Fig .1. Structure of neural network used in the proposed method

The power loss and possible bus connections are given as input to the neural network and the output we obtained is optimal location for fixing SSSC in the system. By considering this condition, neural network is trained. For training the neural network, back propagation algorithm is used. After the completion of training process, neural network is ready for practical application. In the testing stage, if we give the power loss and possible bus connections to the network, it gives the optimal location for fixing SSSC in the system. The next process is computing voltage and angle injecting values using genetic algorithm.

3.3. Computing Voltage and Angle Injecting Values Using GA

Genetic algorithm is one of the most salient evolutionary algorithms, often used for optimization process. Here, GA is used to compute the voltage and angle injecting values. Normally, GA consists of five stages namely, generation of initial chromosomes, fitness function, crossover operation, mutation operation, and termination.

3.3.1. Generation of Initial Chromosome

The initial step in genetic algorithm is initializing the chromosome. Number of genes used here is two they are, voltage and angle injecting values. Each gene is generated based on a certain limit. After the generation of initial chromosome, the next step is to compute the fitness function.

3.3.2. Fitness Function

Fitness function is used to find the optimum chromosome generated in the above stage. In the proposed method, total power loss is considered as the fitness function. The fitness function is computed for all the initial chromosomes and then ordered based on the low power loss.

3.3.3. Crossover Operation

The next process after calculating the fitness function is crossover. In crossover operation, a new set of chromosomes are generated from the above chromosomes based on the crossover rate. Subsequently, fitness function is applied for the new set of chromosomes generated and then ordered based on the low power loss.

3.3.4. Mutation Operation

Here, mutation operation is applied to the above chromosomes. The mutation operation is performed based on the mutation rate by arbitrarily selecting the genes in the chromosome. The next step after the completion of mutation operation is termination.

3.3.5. Termination

In this stage, the best chromosome i.e., voltage and angle injecting values is selected based on the fitness function. The above process is repeated until it reaches the maximum number of iterations. After completing the process, a best set of chromosome is obtained based on power loss reduction.

By connecting SSSC in optimal location identified in section 3.2 and injecting voltage & angle values computed in section 3.3, the power flow in the system is improved as well as the power loss in the system is reduced. Next, we compute the available transfer capability of the system.

3.4. Computing Available Transfer Capability

Computing the available transfer capability of the system is the most important process. Here, available transfer capability is computed using two different methods: linear static method and reactive method [16]. Initially, we see about the linear static method.

3.4.1. Linear Static Method

The change in the line flow ($line\ i - j$) due to a transfer of bus $(s - b)$ is given as,

$$\rho_{ij,T} = \frac{\partial P_{ij}}{\partial P} \quad (5)$$

$$\Delta P_{ij} = \rho_{ij} \to T \Delta P_s \quad (6)$$

where, ΔP_s is the amount of power transferred from slack bus to any other bus.

The power flow for different transfer limit is given as,

$$\Delta P_s^{ij} = \frac{P_{ij}^{\max} - P_{ij}^{o}}{\rho\, ij, i \to b}, \rho\, ij, i \to b > 0 \quad (7)$$

$$\Delta P_s^{ij} = \frac{-P_{ij}^{\max} - P_{ij}^{o}}{\rho\, ij, i \to b}, \rho\, ij, i \to b < 0 \quad (8)$$

where, $P_{ij}^{\max}$ is the positive line flow limit and P_{ij}^{0} is the initial positive line flow.

The available transfer capability for bus $(s - b)$ is computed by using the equation (9).

$$ATC_{s \to b} = \min \{\Delta P_s^{ij}\ \ for\ all\ lines\ (i - j)\} \quad (9)$$

The above equations of linear method are used to compute the available transfer capability.

3.4.2. Reactive Method

The maximum complex power flow is obtained using equation 16 & 17.

$$P_{jk}{}^{*} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (10)$$

$$Q_{jk}{}^{*} = \sqrt{(S_{jk}{}^{\max})^2 - P_{jk}{}^{*}} \quad (11)$$

where, $a = P_{jk\Theta}{}^2 + Q_{jk\Theta}{}^2$

$$b = -P_{jk\Theta}((S_{jk}{}^{\max})^2 - m^2)$$

$$c = \frac{1}{4}\left((S_{jk}{}^{\max})^2 - m^2\right) - P_{jk\Theta}\left(S_{jk}{}^{\max}\right)^2 \left(S_{jk}{}^{\max}\right)^2$$

$$\left(S_{jk}{}^{\max}\right)^2 = P_{ij}^2 + Q_{ij}^2$$

The power flow for different transfer limit is given as,

$$\Delta P_s^{ij} = \frac{P_{ij}{}^{*} - P_{ij}^{0}}{\rho\, ij, i \to b}, \rho\, ij, i \to b > 0 \quad (12)$$

$$\Delta P_s^{ij} = \frac{-P_{ij}{}^{*} - P_{ij}^{0}}{\rho\, ij, i \to b}, \rho\, ij, i \to b < 0 \quad (13)$$

The available transfer capability for bus $(s - b)$ is computed by using the equation (14).

$$ATC_{s \to b} = \min \left\{\Delta P_s^{ij}\ \ for\ all\ lines\ (i - j)\right\} \quad (14)$$

By using the above equations, the available transfer capability between the lines are computed.

4. Result and Discussions

The proposed technique is implemented in MATLAB 7.10 B and it is tested using IEEE 30 bus system, which is shown in Fig 1.

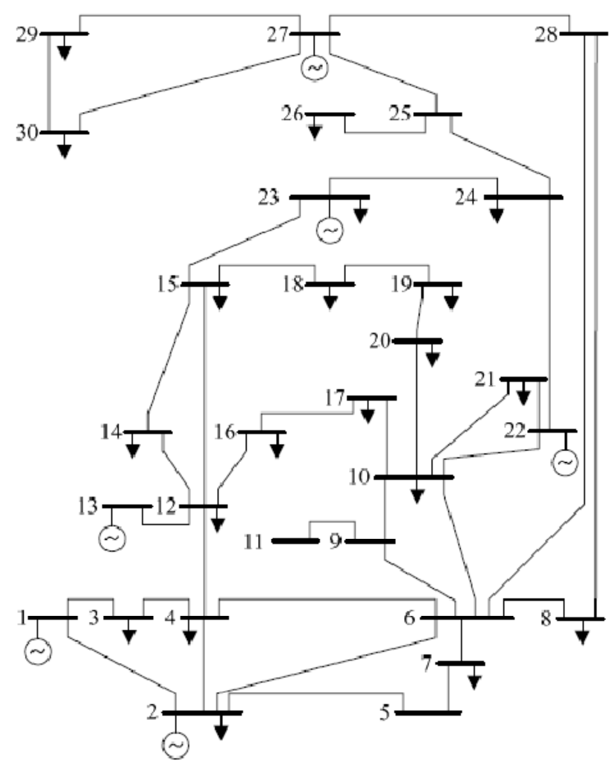

Fig. 2 IEEE 30 bus system

In the above shown test bus system, bus 1 is considered as slack bus and buses 2, 13, 22, 23, & 27 are considered as generator bus. All other buses in the test system are load bus and the base MVA is 100. Next, we see about the ATC results obtained using the proposed method and conventional method without UPFC.

Table 1 : ATC results

From bus	To bus	Conventional method without UPFC (p.u)		Proposed method with SSSC (p.u)	
		ΔP_{ij} $(linear)$	ΔP_{ij} $(reactive)$	ΔP_{ij} $(linear)$	ΔP_{ij} $(reactive)$
1	2	15.064	1.041	20.701	0.177
1	3	0.904	0.062	0.012	0
2	4	2.862	0.198	0.039	0
3	4	2.862	0.198	0.039	0
2	5	35.476	2.451	0.488	0.004
2	6	7.532	0.52	10.350	0.088
4	6	7.532	0.52	10.350	0.088
5	7	8.587	0.593	0.118	0.001
6	7	8.587	0.593	0.118	0.001
6	8	11.298	0.781	0.155	0.001
6	9	0.377	0.026	0.518	0.004
6	10	2.184	0.151	0.03	0
9	11	0.377	0.026	0.518	0.004
9	10	2.184	0.151	0.03	0
4	12	4.218	0.291	0.058	0
12	13	9.792	0.676	13.455	0.115
12	14	2.335	0.161	0.032	0
12	15	3.088	0.213	0.042	0
12	16	1.318	0.091	0.018	0
14	15	3.088	0.213	0.042	0
16	17	3.389	0.234	0.047	0
15	18	1.205	0.083	0.017	0
18	19	3.578	0.247	0.049	0
19	20	0.829	0.057	0.011	0
10	20	0.829	0.057	0.011	0
10	17	3.389	0.234	0.047	0
10	21	6.591	0.455	0.091	0.001
10	22	4.519	0.312	6.21	0.053
21	23	1.205	0.083	0.017	0
15	23	1.205	0.083	0.017	0
22	24	3.276	0.0226	0.045	0
23	24	3.276	0.0226	0.045	0
24	25	0.377	0.026	0.518	0.004
25	26	1.318	0.091	0.018	0
25	27	4.708	0.325	6.469	0.055
28	27	4.708	0.325	6.469	0.055
27	29	0.904	0.062	0.012	0
27	30	3.992	0.276	0.055	0
29	30	3.992	0.276	0.055	0
8	28	0.377	0.026	0.518	0.004
6	28	0.377	0.026	0.518	0.004

Table-1 shows the ATC results obtained using the proposed method and conventional method. The important parameters in ATC calculation are ΔP_{ij} linear and reactive. The best location identified for fixing SSSC in the system using proposed method is 7-6 and after connecting SSSC in the above obtained location, the amount of voltage and angle to be injected is obtained using the proposed method. Thus, the performance of the system is improved. The results of the proposed method are compared with the conventional method without SSSC. From the above table, it is clear that in most of the bus connections, the linear and reactive parameters ΔP_{ij} of proposed method are very low compared to conventional method. Due to the reduction of linear and reactive parameters ΔP_{ij} of proposed method, the ATC between the buses is increased. Next, we see about the total power losses in the system using conventional method and proposed method.

Table 2 : Total power loss comparison

	Power Loss (MW)
Without SSSC	10.56
Proposed method with SSSC	6.237

Table-2 shows the total power loss in the system using conventional method and proposed method. The proposed method not only increases the ATC in the system, but also reduces the total power losses in the system. The total power loss in the system using conventional method is 10.56 MW, and after connecting SSSC using proposed method, the total power loss gets reduced to 6.237 MW. From the above results, it is clear that the proposed method is capable of increasing the ATC and also reducing the total power loss in the system.

5. Conclusion

In this paper, the proposed technique was implemented in MATLAB and tested for IEEE 30 bus system. From the above results, it is clear that the proposed method improves the available transfer capability and also reduces the total power loss in the system. The ATC of the system was computed using linear method and reactive method. From the obtained results, it is obvious that in all possible connections, the ΔP_{ij} linear and reactive values were very low compared to conventional method. Due to the reduction of ΔP_{ij} linear and reactive values, the ATC in the lines was improved. The proposed method has also reduced the total power losses in the system. For conventional method, the total power loss occurred in the system was 10.56 MW whereas, the total power loss for proposed method was 6.26 MW. Finally, the proposed method has identified the optimal location for fixing SSSC and also the amount of voltage and angle to be injected in the system. Thus, the ATC in the lines was improved as well as the total power loss in the system was minimized.

References

[1] Manoj kumar dinkar and shishir dixit, "Available transfer capability determination using load flow methods",

International Journal of Power System Analysis, Vol. 1, No. 1, pp. 5-9, 2012.

[2] K. Narasimha Rao, J. Amarnath and K. Arun Kumar, "Voltage Constrained Available Transfer Capability Enhancement With FACTS Devices ", ARPN Journal of Engineering and Applied Sciences, Vol. 2, No. 6, pp. 1-9, Dec 2007.

[3] J. Vara Prasad, I. Sai Ram and B. Jayababu, "Genetically Optimized FACTS Controllers for Available Transfer Capability Enhancement", International Journal of Computer Applications, Vol. 19, No.4, pp. 23-27, April 2011.

[4] Kiran Seelam, Surender Kumar Yellagoud and Veeranjaneyulu Puppala, "An Improved Evaluation Method for Available Transfer Capability by Incorporating the Reactive Power Flows", International Journal of Engineering Science and Technology, Vol. 2, No. 12, pp. 7572-757, 2010

[5] Venkatesan Chakkaravartthy and Mary Daniel, "Computation of Total Transfer Capability using Power Producer's Bidding in the Deregulated Environment", European Journal of Scientific Research, Vol.68 No. 2, pp. 172-181, 2012.

[6] K. Chandrasekar and N. V. Ramana, "Fast and Efficient Method to Assess and Enhance Total Transfer Capability in Presence of FACTS Device", International Journal of Advances in Engineering & Technology, Vol. 1, Issue 5, pp. 170-180, Nov 2011.

[7] Mohamed Shaaban, Yixin Ni and Felix F.Wu, "Transfer Capability Computations in Deregulated Power Systems", International Conference on System Sciences, pp. 1-5, 2000.

[8] K. Lokanadham, "Optimal Location of FACTS Devices in Power System by Genetic Algorithm", Global Journal of Researches in Engineering, Vol. 10, Issue. 1, pp. 25-30, Apr 2010.

[9] Hossein Farahmand, Masoud Rashidinejad and Ali Akbar GharaveisI, "A Combinatorial Approach of Real GA & Fuzzy to ATC Enhancement", Turk J Elec Engin, Vol. 1, No. 4, pp. 77- 88, 2007.

[10] S. Tara Kalyani and G. Tulasiram Das, "Simulation of Real and Reactive Power Flow Control with UPFC Connected to a Transmission Line", Journal of Theoretical and Applied Information Technology, pp. 16-22, 2008.

[11] K. Radha Rani, J. Amarnath, and S. Kamakshaiah, "Allocation Of FACTS Devices For ATC Enhancement using Genetic Algorithm", ARPN Journal of Engineering and Applied Sciences, Vol. 6, No. 2, pp.87-93, Feb 2011.

[12] Chintham Venkaiah and Dulla Mallesham Vinod Kumar, "Static Security Based Available Transfer Capability (ATC) Computation for Real-Time Power Markets", Serbian Journal Of Electrical Engineering, Vol. 7, No. 2, pp. 269-289, November 2010.

[13] Prabha Umapathy, C.Venkataseshaiah and M.Senthil Arumugam, "Assessment of Available Transfer Capability Incorporating Probabilistic Distribution of Load Using Interval Arithmetic Method", International Journal of Computer and Electrical Engineering, Vol. 2, No. 4, pp. 692-697, August, 2010.

[14] D. Venu Madhava Chary and J. Amarnath, "Computation of Available Transfer Capability Incorporating Effect of Reactive Power and Losses using Complex Neural Network", ARPN Journal of Engineering and Applied Sciences, Vol. 4, No. 8, pp. 45-50, Oct 2009.

[15] Ramasubramanian Jayashree and Mohammed Abdullah Khan, "A Unified Optimization Approach for the Enhancement of Available Transfer Capability and Congestion Management using Unified Power Flow Controller", Serbian Journal Of Electrical Engineering, Vol. 5, No. 2, pp. 305-324, Nov 2008.

[16] Ibraheem and Naresh Kumar Yada, "Implementation of FACTS Device for Enhancement of ATC Using PTDF", International Journal of Computer and Electrical Engineering, Vol. 3, No. 3, pp. 343-348, Jun 2011.