Improvement of Available Transfer Capability in a deregulated power system using Firefly Algorithm based optimal placement of TCSC and SVC devices

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Abstract - **In this paper the use of Thyristor Controlled Series Compensator (TCSC) and Static Var Compensator (SVC) to enhance Available Transfer Capability (ATC) of power transactions between a specific power-seller and a power-buyer in a deregulated power system. The principle of TCSC device is to compensate the inductive voltage drop in the line by an inserted capacitive voltage or in other words to reduce the effective reactance of the transmission line to enhance ATC in the network. SVC devices have the capability to afford fast-acting reactive power compensation on electrical systems. SVC can be installed at any appropriate point in the system for ATC enhancement with increased transfer capability and reduced total losses while sustaining a smooth voltage profile under different network conditions. The goal of the optimization is to find the best location and parameters of TCSC and SVC devices using Firefly Algorithm for maximizing ATC and minimizing power losses. The effectiveness of the proposed method is proved using IEEE-30 bus system without and with TCSC and SVC for the selected transactions. The simulation results show that the introduction of TCSC and SVC devices in a right location could enhance ATC, reduction of total losses and improving the line congestion as compared to that of the system without TCSC and SVC devices.**

Keywords —Available Transfer Capability, Firefly Algorithm, Thyristor Controlled Series Compensator, Static Var Compensator and AC Power Transfer Distribution Factors

I. INTRODUCTION

Transmission lines are stressed due to ever-increasing electrical loads makes the transmission congestion [1]. To relieve 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 indispensable 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 overall power system performance [3]. A series FACTS device, such as, a Thyristor Controlled Series Compensator (TCSC), is capable of continuously varying the impedance so as to control the power flow could enhance ATC [4, 5]. SVC works as a shunt connected variable reactor or capacitor that compensates for the reactive power required in a transmission network and keeps bus voltage magnitude within its limit. An SVC with a thyristor-controlled compensator is used to increase the reliability, dynamic stability, and power transmission capability of a power interconnector and reduce congestion with a high degree of wind power. The SVC significantly increased the power transfer capability of transmission lines and effectively increased the real power and network [6].

Many methods have been suggested to calculate the ATC. The methods differ on the basis of the power flow model being employed, the system aspects considered, the compelling limits under consideration and few other factors. The sensitivity based methods are fast in ATC determination which are based on the power flow sensitivity and are proposed by many authors for fast computation of ATC [7, 8]. Linear sensitivity factors are employed for the fast calculation. These factors give the approximate change in line flows for changes in generation of the system. Linear sensitivity factors uses DC Power Transfer Distribution Factors (DCPTDFs) and Line Outage Power Transfer Distribution Factors (LOPTDFs) derived from DC load flow. DCPTDFs are easy to calculate and giving fast computations. But less accurate as in DC power flow voltage and reactive power effects are not considered. More accurate PTDFs can be calculated using AC power

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flow model. Line power flows are simply function of the voltages and angles at its terminal buses. So PTDF is a function of these voltage and angle sensitivities. AC Power Transfer Distribution Factors (ACPTDFs) are also proposed for ATC determination [9]. ACPTDFs are derived around the base operating point using full AC Load Flow analysis. In ACPTDF based methods, reactive power limits and voltage limits are also considered and therefore more accurate with less computation complexity. In this study the assessment of ATC using AC Power transfer distribution factors (ACPTDFs) based approach has been used for single and simultaneous transactions using power transfer sensitivity and jacobian calculated using N-R method. A newly developed firefly algorithm [10] is used to optimize location and size of TCSC/SVC the control variables, real power generation, and positions 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. Simulation results reveal the effectiveness of the firefly algorithm method in IEEE 30 bus system without and with TCSC/SVC.

II. Available Transfer Capability

Available transfer capability (ATC) is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above committed uses [4]. ATC can be expressed as:

$$ATC = TTC - ETC - CBM - TRM \tag{1}$$

Total Transfer Capability (TTC) is defined as the amount of electric power that can be transferred over the interconnected transmission network in reliable manner with all the uncertainties and contingencies considered. Existing Transmission Commitments (ETC) is defined as the amount of transmission transfer capability which is required for committed transactions. Capacity Benefit Margin (CBM) is defined as the amount of transmission transfer capability reserved by load serving entities to ensure that the interconnected systems do meet generation reliability requirements. Transmission Reliability Margin (TRM) is defined as the amount of transmission transfer capability necessary to ensure that the interconnected transmission network is secure under a reasonable range of uncertainties in system conditions. As the Power system is stochastic in nature the Independent System Operator (ISO) has to continuously monitor and update ATC after every transaction. ATC at base case, between bus *m* and bus *n* using line flow limit (thermal limit) criterion is mathematically formulated using ACPTDF (or) PTDF as

$$ATC_{mn} = \min(T_{ij,mn}), ij \in N_L \tag{2}$$

$T_{ij,mn}$ - denotes the transfer limit values for each line in the system. It is given by

$$\begin{cases} \frac{(P_{ij}^{max} - P_{ij}^{0})}{PTDF_{ij,mn}}; & PTDF_{ij,mn} > 0 \\ \frac{(-P_{ij}^{max} - P_{ij}^{0})}{PTDF_{ij,mn}}; & PTDF_{ij,mn} < 0 \\ \infty; & PTDF_{i,mn} = 0 \end{cases} \tag{3}$$

where P_{ij}^{max} , P_{ij}^{0} are maximum power flow limit in MW and base case power flow of a line between bus *i* and *j*.

III. Static Modeling of FACTS devices

The power flow equations of the line connected between bus i and bus j having series impedance $r_{ij} + jx_{ij}$ and without any FACTS devices are given by

$$P_{ij} = V_i^2 g_{ij} - V_i V_j (g_{ij} \cos\delta_{ij} + b_{ij} \sin\delta_{ij}) \tag{4}$$

$$Q_{ij} = -V_i^2 (b_{ij} + B_{sh}) - V_i V_j (g_{ij} \sin\delta_{ij} - b_{ij} \cos\delta_{ij}) \tag{5}$$

Where V_i, V_j are the magnitudes voltage at bus-i and bus-j, δ_{ij} is the angle difference between bus-i and bus-j and $g_{ij} = \frac{r_{ij}}{r_{ij}^2 + x_{ij}^2}$, $b_{ij} = \frac{-x_{ij}}{r_{ij}^2 + x_{ij}^2}$

Similarly the active power (P_{ji}) and reactive power (Q_{ji}) flow from bus-j and bus-i in the line given by

$$P_{ji} = V_j^2 g_{ij} - V_i V_j (g_{ij} \cos\delta_{ij} - b_{ij} \sin\delta_{ij}) \tag{6}$$

$$Q_{ji} = -V_j^2 (b_{ij} + B_{sh}) + V_i V_j (g_{ij} \sin\delta_{ij} + b_{ij} \cos\delta_{ij}) \tag{7}$$

3.1 Power flow control of TCSC

The power flow control of TCSC is to decrease or increase series impedance of the lines by adding a capacitive or inductive reactance. Fig.1 shows a transmission line with one TCSC connected between bus-i and bus-j.

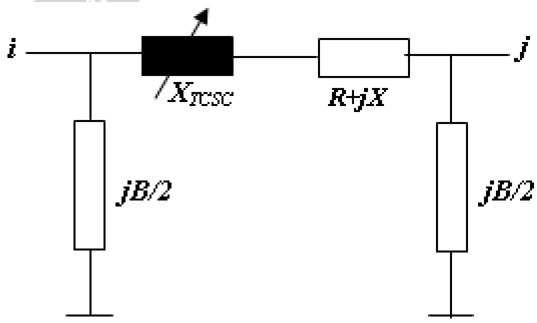

Fig.1 Equivalent circuit of TCSC

The reactance of the line with TCSC is given by

$$x_{ij} = x_{line} + x_{TCSC} \tag{8}$$

$$x_{TCSC} = \gamma_{TCSC} * x_{line} \tag{9}$$

Where, X_{line} is the reactance of the transmission line and γ_{TCSC} is the compensation factor of TCSC. The level of applied compensation of the TCSC usually varies between 20% inductive and 80% capacitive [4]. The real and reactive power flow from bus-i to bus-j and bus-j to bus-i in the line given by Eqn (4) to (7) with modified g_{ij} and b_{ij} as given by

$$g_{ij} = \frac{r_{ij}}{r_{ij}^2 + (x_{ij} - x_{TCSC})^2} \tag{10}$$

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$$b_{ij} = \frac{-(x_{ij} - x_{TCSC})}{r_{ij}^2 + (x_{ij} - x_{TCSC})^2} \qquad (11)$$

3.2 Power flow control of SVC

In practice, a SVC can be considered as a variable reactance whose reactance can be varied by varying the firing angle of the TCR. The SVC susceptance (Bsvc) can be controlled to operate the SVC in either inductive or capacitive mode, within the limits of operation. The equivalent circuit of SVC is shown in Fig 2.

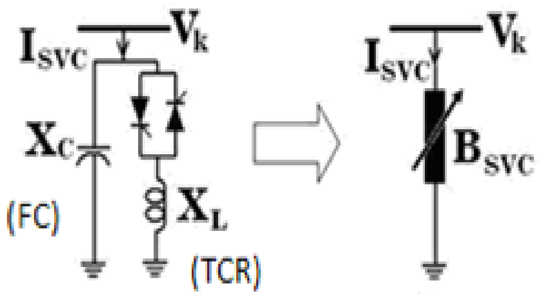

Fig.2 Equivalent circuit of a SVC

A line connecting two buses *i* and *k* in any given power system network and the voltage drop between the bus-*i* and bus-*k* is expressed as

$$V_d = V_i - V_k \qquad (12)$$

Assuming that the SVC is installed at bus-k, Eqn (12) becomes:

$$V_d = V_i - V_{SVC} \qquad (13)$$

$$V_d = V_i - \sqrt{\frac{Q_{SVC}\ X_L\ X_C}{X_C - X_L}} \qquad (14)$$

From Eqn (14), it can be understood that if the voltage at bus- i is kept constant, then by regulating the voltage at bus-k at or near the base voltage, the voltage is stabilized and the voltage drop minimized. Eqn (14) gives an appropriate control of this equivalent reactance permitting voltage magnitude regulation at the SVC point of connection. The SVC will inject or absorb reactive power (Q_{SVC}) at a selected bus. It injects reactive power into the system if $Q_{SVC}<0$ and absorbs reactive power from the system if $Q_{SVC}>0$. Operating range of SVC is normally ±100MVAr.

IV. Problem Formulation

The objective is to maximize the ATC, when a transaction is taking place between a seller bus (m) and buyer bus (n). The objective function to be maximized is given by

$$J = Max\ (ATC_{mn}) \qquad (15)$$

It is subjected to the following equality, in-equality and practical constraints.

$$P_{Gi} - P_{Di} - \sum_{j=1}^{nb} V_i V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \qquad (16)$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{nb} V_i V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \qquad (17)$$

where P_{Gi}, Q_{Gi} are the real and reactive power generations at ith bus, P_{Di}, Q_{Di} are the real and reactive power demands at ith bus, $Y_{ij}\ \theta_{ij}$ are the bus admittance magnitude and its angle between ith and jth buses, δ_i, δ_j are voltage angles of bus i and bus j respectively nb, n_g is the total number of buses and generator

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \quad for\ i = 1,2 \ldots\ldots n_g \qquad (18)$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \quad for\ i = 1,2 \ldots\ldots n_g \qquad (19)$$

$$V_b^{min} \le V_b \le V_b^{max} \quad for\ i = 1,2 \ldots\ldots n_b \qquad (20)$$

The constraints on the TCSC and SVC devices are

$$-0.8x_{line} \le x_{TCSC} \le 0.2x_{line}\ p.u. \qquad (21)$$

$$-100\ MVAR \le Q_{SVC} \le 100\ MVAR \qquad (22)$$

Where, X_{TCSC} Is the reactance added to the line by placing TCSC, X_{Line} is the reactance of the line where TCSC is located. To prevent overcompensation, TCSC reactance is chosen between -0.8 X_{line} to 0.2 X_{Line}. Q_{SVC} is the reactive power injected at the bus by placing SVC. The constraints on the Installation Cost of the corresponding FACTS devices are given by,

$$IC = C * S * 1000 \qquad (23)$$

where *IC* denotes optimal installation cost of FACTS devices in US$. *C* represents cost of installation of FACTS devices in US $ /KVAR. The cost of installation of TCSC and SVC are taken from Siemens data base. The cost of installation of various FACTS devices are given by the following equations:

$$C_{TCSC} = 0.0015S^2 - 0.713S + 153.75US\$/KVAR \qquad (24)$$

$$C_{SVC} = 0.0003S^2 - 0.3051S + 127.38\ US\$/MVAR \qquad (25)$$

Where S is the operating range of TCSC devices in MVAr and it is given by

$$S = |Q_1| - |Q_2| \qquad (26)$$

Where Q_2 is the reactive power flow in the line after installing FACTS device in MVAr and Q_1 represents reactive power flow in the line before installing FACTS device in MVAR.

V. Optimal Allocation of FACTS devices using Firefly Algorithm (FA)

To optimize the location and size of TCSC/SVC 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 the brightest firefly. Encoding is the process of converting set of control variables in location of TCSC/SVC 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/SVC. For the evolution and better convergence fitness function is most important as follows. An appropriate fitness function (brightness) is vital for evolution and convergence of FA. It is a location of TCSC/SVC objective functions and penalty

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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/SVC. 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 eqn (27)..

$$\beta = \beta_o exp(-\gamma r^2) \qquad (27)$$

Where, β is attractiveness of a firefly, β_0 is initial attractiveness, γ is absorption coefficient and r is distance between fireflies. Distance between fireflies i and j is calculated using Cartesian distance as given below the eqn (28)

$$r_{ij} = \|X_i - X_j\| = \sqrt{\sum_{k=1}^{d}(X_{i,k} - X_{j,k})^2} \qquad (28)$$

In 2-dimensional solution space the distance between i and j fireflies may calculated as follows the eqn (29)

$$r_{ij} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2} \qquad (29)$$

Movement of i^{th} firefly towards jth brighter firefly is based attractiveness and distance between them as given below

$$X_i^{k+1} = X_i^k + \beta_o * \exp(-\gamma r^2) * (X_j^k - X_i^k) + \alpha * \varepsilon_i^k \qquad (30)$$

Where the left side first term is initial position of ith firefly, second term gives attractiveness towards j^{th} firefly and third term introduce random movement in i^{th} firefly. Initial attractiveness β_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. 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. FA algorithm for solving location of TCSC is given below

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

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 eqn (30)

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.

VI. Simulation Results and Observations

This section presents the details of the simulation done on IEEE 30 bus system without and with SVC/TCSC devices for ATC calculation under normal operating condition. The optimal location and size of SVC and TCSC devices are obtained using Firefly Algorithm. The system data are in a per-unit system and taken from [4] and the base MVA value is taken to be 100 MVA. In the IEEE-30 bus system consists of six generators and forty one lines are considered. For this system, the total active power demand is 283.4MW and there are six generators connected at buses 1, 2, 5, 8, 11, 13, and two shunt compensators connected at buses 10 and 24 and four tap changing transformers connected between buses 6–9, 6–10, 4–12 and 27–28. Here, the transactions with generators connected at buses 2, 5, 8, 11 and 13 are treated as seller buses and the load buses are treated as buyer buses. Generators at buses 8, 11 and 13 are considered in area 1, while the remaining generators at buses 1, 2 and 5 are considered in area 2. The tie-line existing between the two areas and transaction is carried out between area 1 and area 2. Three inequality constraints are considered in these studies: the voltage limit, line thermal limit and reactive power generation limit. In OPF problem, ATC is considered as an objective. The ATC has been determined using ACPTDFs based on the line flow limit under normal and line outage conditions. The method runs for each increment of the transaction over its base value until any of the line flows or the bus voltages hits the limiting value. Transaction is carried out between area 1 and area 2 and the voltage magnitude limit of each bus is assumed to be between 0.95p.u. and 1.05p.u. The optimal location and size of TCSC/SVC devices are obtained using Firefly Algorithm for maximizing ATC for the selected bilateral, multilateral and area wise transactions. Installation cost of TCSC/SVC devices has also been calculated for each transaction with reference to ATC value and cost of installation. The simulations have been carried out on a 2.40 GHz Dual Core, Intel Pentium system in a MATLAB 2010a environment.

A single type FACTS device such as TCSC and SVC is installed in the test system to study the effectiveness of the

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devices in enhancing ATC for different bilateral and multilateral transactions. The test system results for different bilateral and multilateral transactions under normal operating conditions using proposed approach are given in Table 1 and Table 2. In bilateral transactions, seven transactions between a seller bus in source area and buyer bus in sink area such as (5-30, 13-27, 5-20, 2-10, 11-27, 8-30, 8-30 and 2-23) and multilateral transactions, three transactions between a seller bus in source area and buyer bus in sink area such as (5, 8, 11- 27, 30 and 8, 13 – 27, 20 and 2, 8, 13 - 23, 27) are considered. In this study, ATC enhancement is obtained with optimal location and sizing of TCSC/SVC devices by applying Firefly Algorithm technique. Installation cost of these TCSC/SVC devices has also been calculated for each transaction with reference to ATC value.

From Table1 and 2, consider a bilateral transaction from bus 13 to bus 27, the optimal location of TCSC is connected between buses 27 to 29. The optimal size (reactance) of TCSC is -0.1925 p.u and negative sign indicates that TCSC operates in capacitive mode. By considering SVC device, the optimal location of SVC is connected at bus 28 and rating of the SVC is 43.75 Mvar and negative sign indicate that SVC injects reactive power into the system. ATC value is 44.83 MW without installing FACTS devices, whereas after installing either TCSC or SVC, the ATC value is increased to 47.81 MW and 45.27 MW respectively without violating system constraints. From the Table 2 and Fig.3 shows that ATC is increased with use of TCSC or SVC for different transactions. The results also show that TCSC could enhance ATC much higher than SVC. From the Fig 4 it can clear that the active power losses is 14.78 MW without placing FACTS devices , but it is reduced to 11.25 MW after placing SVC and also reduced 9.64 MW by placing TCSC. Moreover the reactive power loss is 5.647 MVAR without placing TCSC/ SVC devices but it is reduced to 4.11 MVAR and 3.54 MVAR by placing TCSC and SVC devices respectively is shown in Fig 5. The corresponding optimum cost of installation of TCSC devices and SVC devices is 1.02 x10^6 US $ and is 1.21 x10^6 US $ respectively is also shown in Table 1. The real power loss and installation cost are reduced with use of TCSC but reactive power loss is more as compared with SVC. The different bilateral transactions and multilateral transactions results are shown in Table 1 and 2 and Fig 3-5.

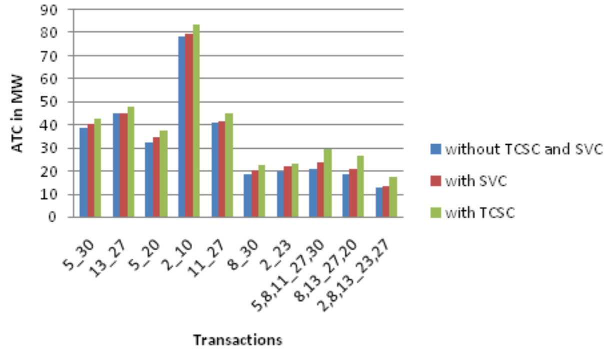

Fig.3 ATC enhancement for IEEE-30 bus system without and with TCSC/SVC devices

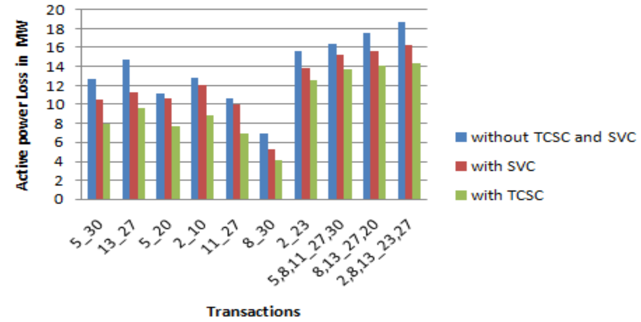

Fig.4 Active Power Loss for IEEE-30 bus system without and with TCSC/SVC devices

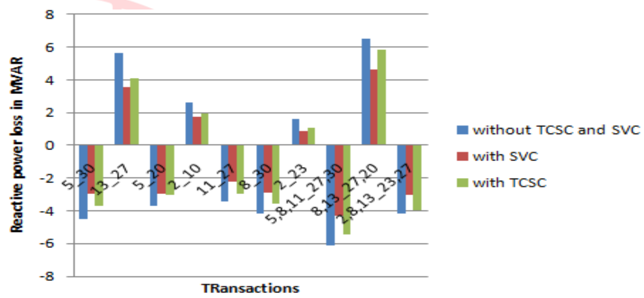

Fig.5 Reactive Power Loss for IEEE-30 bus system without and with TCSC/SVC devices

In multilateral transactions between a seller buses in source area and buyer buses in sink area such as (5, 8, 11- 27, 30 and 8, 13 - 27, 20 and 2, 8, 13 - 23, 27) with maximize the ATC is considered. From Table 1 shows a multilateral transaction from buses 8, 13 to buses 27, 20 is consider. In this case the ATC value is 18.63 MW without installing FACTS devices, whereas after installing either TCSC or SVC, the ATC value is increased to 26.72 MW and 20.7 MW respectively without violating system constraints. The active power losses is 17.61 MW without placing FACTS devices , but it is reduced to 14.07 MW after placing TCSC and optimal location of TCSC is connected between bus 22 to bus 24. The optimal size (reactance) of TCSC is -0.0887 p.u and negative sign indicates that TCSC operates in capacitive mode and the corresponding cost of installation of TCSC devices is 0.71 x10^6 US $. The active power loss is also reduced 15.63 MW by considering SVC device is connected at bus 18 and rating of the SVC is – 19.35 MVAR and negative sign indicate that SVC injects reactive power into the system and the corresponding

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installation cost of TCSC devices is 0.97 x10^6 US $. Moreover the reactive power loss is 6.534 MVAR without placing TCSC/ SVC devices but it is reduced to 5.818 MVAR and 4.671 MVAR by placing TCSC and SVC devices respectively. The corresponding different multilateral transactions results are shown in Table 1 and 2. From the Table 1, 2 and Fig 3-5, it can be clear that ATC values are increased for all possible transactions and power losses is reduced after placing FACTS devices in right location. The results also show that TCSC could enhance ATC much higher than SVC. The active power loss and installation cost is reduced with use of TCSC device but reactive power loss is more as compare with SVC

Table.1 Optimal parameters of SVC and TCSC devices for IEEE-30 bus system for selected bilateral and multilateral transactions

Transactions	Control parameters of SVC devices with enhancement of ATC			Control parameters of TCSC devices with enhancement of ATC		
	Location (at bus)	Size in MVAR	Cost (US $) x$10^8$	Location (line)	Size in X_{TCSC} (p.u)	Cost (US $) x$10^8$
5 - 30	Bus -30	59.43	1.25	Bus (16-12)	-0.1181	0.82
13 - 27	Bus -28	43.75	1.21	Bus (27-29)	-0.1925	1.02
5 - 20	Bus -18	-13.11	0.81	Bus (15-18)	-0.1121	0.93
2 - 10	Bus -6	82.74	1.76	Bus (16-17)	-0.2162	1.17
11 - 27	Bus -22	-8.245	0.68	Bus (6-28)	-0.0541	0.68
8 - 30	Bus -15	-24.57	1.01	Bus (27-30)	-0.2696	1.78
2 - 23	Bus -23	-9.815	0.75	Bus (15-23)	-0.1262	1.02
5, 8, 11- 27, 30	Bus -16	-21.45	1.05	Bus (22-21)	-0.0921	0.78
8, 13 – 27, 20	Bus -18	-19.35	0.97	Bus (22-24)	-0.0887	0.71
2, 8, 13 - 23, 27	Bus -23	-14.36	0.83	Bus (15-23)	-0.0901	0.73

Table 2 Results for IEEE-30 bus system under normal operating conditions for selected bilateral and multilateral transactions

Transactions	ATC in MW			Active power loss in MW			Reactive power loss in MVAr		
	without FACTS	with SVC	with TCSC	without FACTS	with SVC	with TCSC	without FACTS	with SVC	with TCSC
5 - 30	38.74	40.28	42.65	12.64	10.47	7.962	-4.521	-2.942	-3.693
13 - 27	44.83	45.27	47.81	14.78	11.25	9.641	5.647	3.547	4.117
5 - 20	32.54	34.72	37.62	11.11	10.64	7.708	-3.689	-2.978	-3.012
2 - 10	78.71	79.35	83.46	12.79	12.04	8.811	2.612	1.778	1.978
11 - 27	40.89	41.54	44.78	10.68	9.978	6.923	-3.422	-2.217	-2.942
8 - 30	18.52	20.26	22.61	6.921	5.237	4.126	-4.178	-2.879	-3.587
2 - 23	19.54	21.73	23.01	15.62	13.91	12.62	1.612	0.879	1.078
5, 8, 11- 27, 30	20.54	23.78	29.54	16.42	15.24	13.78	-6.128	-4.278	-5.478
8, 13 – 27, 20	18.63	20.57	26.72	17.61	15.63	14.07	6.534	4.671	5.818
2, 8, 13 - 23, 27	12.84	13.08	17.54	18.67	16.28	14.32	-4.137	-3.047	-3.978

VII. CONCLUSION

This paper has introduced a Firefly Algorithm to ideally designate FACTS devices to upgrade ATC and limiting the power losses of the competitive electricity market which comprises of bilateral and multilateral exchanges. The recreation results enormously demonstrate that the proposed calculation has momentous heartiness in expanding the ATC. Furthermore, the result also shows the effectiveness of optimized the location, rated values and installation cost of FACTS devices. It is found out that the proposed method is able to find out the optimal location in less computational time and with relatively small number of iterations.The FACTS devices are put in this specific transmission line and the reactance esteem must be changed for the situation if TCSC is utilized and responsive power esteem must be changed if SVC is utilized. From the outcomes, it is demonstrated that introducing SVC as a FACTS devices will improve voltage profile and result in ATC upgrade, where as TCSC can improve ATC in both warm prevailing case and voltage overwhelming case. At long last, it obviously appears from the outcomes that TCSC is more compelling than SVC in improving ATC under both typical and possibility conditions.

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REFERENCES

[1] Kulmala, A., Alonso, M., Repo, S., Amaris, H., Moreno, A., Mehmedalic, J., & Al-Jassim, Z. (2017). Hierarchical and distributed control concept for distribution network congestion management. *IET Generation, Transmission & Distribution*, *11*(3), 665-675.

[2] Babu, T. G., & Srinivas, G. N. (2017). Enhancement of ATC with FACTS device using Firefly Algorithm.

 DOI : 10.18231/2454-9150.2019.0128 © 2019, IJREAM All Rights Reserved.

International Journal of Applied Engineering Research, *12*(20), 10269-10275.

[3] Albatsh, F. M., Mekhilef, S., Ahmad, S., Mokhlis, H., & Hassan, M. A. (2015). Enhancing power transfer capability through flexible AC transmission system devices: a review. *Frontiers of Information Technology & Electronic Engineering*, *16*(8), 658-678.

[4] Manikandan, B. V., Raja, S. C., & Venkatesh, P. (2011). Available transfer capability enhancement with FACTS devices in the deregulated electricity market. *Journal of Electrical Engineering & Technology*, *6*(1), 14-24.

[5] Magaji, N., & Mustafa, M. W. (2009). Optimal location of TCSC device for damping oscillations. *ARPN journal of Engineering and Applied Sciences*, *4*(3), 28-34.

[6] Sahadat, M. N., Al Masood, N., Hossain, M. S., Rashid, G., & Chowdhury, A. H. (2011, March). Real power transfer capability enhancement of transmission lines using SVC. In *2011 Asia-Pacific Power and Energy Engineering Conference*(pp. 1-4). IEEE.

[7] Wu, Y. K. (2007). A novel algorithm for ATC calculations and applications in deregulated electricity markets. *International Journal of Electrical Power & Energy Systems*, *29*(10), 810-821.

[8] Nair, V. K., Prakash, V. A., Kuruseelan, S., & Vaithilingam, C. (2017). ATC Evaluation In A Deregulated Power System. *Energy Procedia*, *117*, 216-223.

[9] Kumar, A., Srivastava, S. C., & Singh, S. N. (2004). Available transfer capability (ATC) determination in a competitive electricity market using AC distribution factors. *Electric Power Components and Systems*, *32*(9), 927-939.

[10] Yang, X. S., Hosseini, S. S. S., & Gandomi, A. H. (2012). Firefly algorithm for solving non-convex economic dispatch problems with valve loading effect. *Applied soft computing*, *12*(3), 1180-1186.

[11] Abdel-Rahman, M. H., Youssef, F. M., & Saber, A. A. (2006). New static var compensator control strategy and coordination with under-load tap changer. *IEEE Transactions on Power Delivery*, *21*(3), 1630-1635.

 DOI : 10.18231/2454-9150.2019.0128 © 2019, IJREAM All Rights Reserved.