International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-5, June 2019

ATC Evaluation and Maximization by Optimal Sizing & Location of TCSC using Grey Wolf Optimization

Anubha Gautam, Parsh Ram Sahrma, Yogendra Kumar

Abstract: ***Deregulation of power system provided the consumers more economical rates of electricity, but this also resulted in congestion of the power system due to participation of private utilities and increase in population. To remove congestion in the power system cost free and non cost free methods are used. Incorporation of FACTS devices, which is one of the cost free method, has proven a great efficiency in reducing system congestion. This paper demonstrates the novel method of incorporating FACTS device (TCSC) in the standard IEEE 30 Bus system with the help of Grey Wolf Optimisation which not only finds the location of device but also tunes the device so as to minimise power system losses and on the other hand increases the Available transfer capability (ATC) of the system above mentioned, by using ACPTDF, as the sensitivity factor. The utility of GWO is illustrated in this paper on standard IEEE 30 bus system and is demonstrated with the help of suitable table and figures.***

Index Terms**:** ***—Available Transfer Capability, ACPTDF, Deregulated Power System,FACTS, GWO, TCSC***

I. INTRODUCTION

Open access of power transmission is beirng a critical issue in most of the nations under deregulation of power industry. Deregulation in power system has brought a competition in power generation industries.Sharing of power in interconnected systems has increased the reliability of the system. But with increased power transactions due to utilization of interconnected systems, congestion came into existance resulted in transmission lines hitting voltage and thermal limits [1]

The power transfer capacity that is offered by the interconnected power system for further power utilization in commercial activities above already committed uses is termed as Available Transfer Capability (ATC). ATC can be represented as:

ATC=TTC-TRM-ETC-CBM

In the above expression, ETC is the existing transmission Commitment which is the summation of current transmission commitment among different areas.

Manuscript published on 30 June 2019.
***** Correspondence Author (s)
Anubha Gautam, Electrical Engineering,J C Bose UST, Faridabad. India
Parsh Ram Sharma, Electrical Engineering,J C Bose UST, Faridabad. India
Yogendra Kumar, Electrical Engineering, MANIT, Bhopal, India

Total Transfer Capability (TTC) can be well explained as the power transferred in the interconnected power network reliably. Whereas taking care of all the selected set of outlined pre-and post-possibility framework conditions. Transmission reliability Margin (TRM) is termed as the transfer capability required securing transmission in the interconnected system inspite of being subjected to a number of uncertain critical conditions during network operation.Capacity benefit Margin (CBM) is that quantity of power transfer capability which is reserved by serving entities at the load end, which ensures the approach to generation within generation reliability limits from interconnected systems [1]. Another term related with ATC is recallability,which in turn is the entitlement of the service provider to terminate the power supply for any reason including economic loss which is within the provision of contract. Non recallability can be defined as the right of service provider to interrupt the services only if there is a compromise with reliability of supply [1].Thus ,Recallable ATC = [TTC-TRM-Recallable transmission -Non recallable transmission with CBM]and similarly, Non Recallable ATC= [TTC-TRM-Non recallable Reserve with CBM]. Calculation of ATC is one of the method to find congestion and to relieve any system form it.An evolutionary programwas given for enhancing the power transmitting capacity of power system in dergulated environment [2]Further the algorithm was used to define the location & tuning of the FACTS devices and also for the estimation of real power generated at the sending end. The method also calculates voltages at sending end with real power demand at the load end in the power system.FACTS devices such as SSSC & UPFC being very versatile devices can be incorporated in the power system as these modifies the real and reactive power equations to enhance power flow in a powersystem with system security as a constraint[3].UPFC with the help of two synchronised voltage source converters can be connected in series & parallel through transformers to enhance system security[4-5].The results prove that when a particular FACTS device is tuned and placed optimally,with the help of evolutionary programming, it helps to reduce system losses and increases the available transfer capability i.e. ATC of the system[2]. If existing transmission system is being used to the possible extent, then the transmission system owners and customers can receive increased services at reduced costs [6]. To enhance the ATC, numerous changes are to be done in the generator terminal voltage and power output.

ATC at any time is dependenton the thermal limits , voltage and stability issues. Different power market participants, to ascertain the ATC valueand to make their contribution in industrial power markets , depend upon the data related to total system load value and its distribution ,together with the limits levied on the power network [7]. Inspite of being long process , Security constrained OPF (SCOPF) used steady state analysis approach to solve the OPF constrained by system steady state security[8,9].Due to long time consuming process of SCOPF, it was replaced by Transfer Based SCOPF for calculation of ATC in deregulated environment , which also included the assessment of TRM & CBM values.[10].

II. RELATED WORKS

G.C.Ejebe et al [11], explained a method of ATC formulation to explain the effects of reactive power flows, voltage striking the defined limits and thermal loading effects. A continuation power flow (CPF) approach was quite fast in calculating ATC for successive power transfer for processing large number of contingencies.Proposed methodutilizelinear incremental power flow approximation considering line thermal limits only.Mohamed Shaban et al used sequential programming method for calculating the optimized value of TTC and hence ATC was calculated to maximise the summation of generated power and demand at the load end[12] Ashwani Kumar, S.C. Srivastava and S.N. Singh calculated dynamic ATC by applying Hopf bifurcation limits and saddle node bifurcation & voltage limits was utilized for calculating static ATC[13]Luo X. Patton A. D. and Singh C. used Quickprop Algorithm for training neural network using optimal power flow. Generator and load status were considered as input to the neural network and transfer capability were set as the output.The method gave a quick solution when applied to calculate multiarea power transfer capability of power system[14]Ying Yi Hong proposed a strategy for ATC estimation utilizing multi layered feed forward system in [15]. In this paper, the crossover rule segment investigation organize is utilized to remove the basic transport data for free framework administrator (ISO). K. Selvi et al proposed GA for calculating TTC. Power transaction between two specified areas was calculated within the system constraints using global optimal search [16]

III. FACTS DEVICE AND ITS APPLICATION

In an interconnected power system, the ability of system to transfer the power reliably and securely among different associated areas is constrained by its thermal & voltage limits. But with use of FACTS devices the reliability of power transfer is enhanced due to their rapid action on system changes[17]. FACTS technology improves the way,transmission system operates with regards to thermal, voltage, and stability constraints. From the perspective of steady state system power flow, circuits do not normally share power in proportion to their ratings, and in most situations, voltage profile cannot be smooth. Therefore, ATC values are always limited ultimately by heavily loaded circuits and/or nodes with relatively low voltage. As stated in [18], FACTS devices reallocate power flows and regulate nodal voltages by utilizing circuit reactance, voltage magnitude and phase angle as the controlling parameters. In addition, due to the physical constraints on circuit impedance and phase angle of nodal voltage, most high voltage transmission lines are operating far below their thermal rating [19]. The thermal Limits of the transmission line were elevated by FACTS devices by controlling line reactance and voltage phase angles. The intense use of FACTS devices was ensured to work on the same power system network without changing the basic framework and making FACTS device cost effective [20]. Right off the bat, the ongoing improvement in high power gadgets has made these gadgets practical. Also, expanded stacking of intensity framework under the reregulation of intensity industry rouse the utilization of intensity stream control as exceptionally financially savvy methods for dispatching indicated control exchanges [21]. The ideal area of FACTS gadgets has to be determined due to their significant capital costs [22]. This paper deals with an algorithm, GWO, which focuses on the utilization of sensitivity factor, ACPTDF, for searching the optimal location and sizing of TCSC following the system constraints for reducing power losses and enhancing the ATC in the pre-founded framework of power system.

IV. ATC CALCULATION

ATC is the power transfer capacity that is offered by the interconnected power system for further power utilization commercial activities above already committed [31] With increasing demand, present power system is working under strained voltage and thermal limits. Thus ATC actually is the capability of system to transfer power from an unstrained system to a strained system through pre existing frame work. Sensitivity factor approach for determination of ATC is simple and faster than other approaches of ATC calculation. This sensitivity factor is termed as Power Transfer Distribution Factor (PTDF) whichcorrelates actual power flow and amount of transferred between two buses involved. The AC Power Transfer Distribution factor (ACPTDF) is sensitivity factor which is utilized to find the change in system parameters with the change in power transaction under steady state and contingency conditions [31].The PTDF (Power Transfer Distribution Factors) measures the sensitivity of line real power flows to a real power transfer (Manikandan et al. 2008). PTDF of line *i-j* for bilateral transaction between seller bus *m and a buyer bus n* is given as [23]

$$ACPTDF_{ij,m} = \Delta P_{ij} / P_{mn} \quad (1)$$

Where, P_{mn} is the transacted power flow between seller bus *m* and buyer bus *n*.

$$\Delta P_{ij} = \left[\frac{\partial P_{ij}}{\partial V_i}\right]\Delta V_i + \left[\frac{\partial P_{ij}}{\partial V_i}\right]\Delta V_j + \left[\frac{\partial P_{ij}}{\partial \delta_i}\right]\Delta\delta_i + \left[\frac{\partial P_{ij}}{\partial \delta_i}\right]\Delta\delta_j \quad (2)$$

Equation (2) may be return as

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

$$\Delta P_{ij} = \left[\frac{\partial P_{ij}}{\partial \delta_2} \cdots \frac{\partial P_{ij}}{\partial \delta_n} \frac{\partial P_{ij}}{\partial V_2} \cdots \frac{\partial P_{ij}}{\partial V_n} \right] * \begin{bmatrix} \partial\delta_2 \\ . \\ . \\ \partial\delta_n \\ \partial V_2 \\ . \\ . \\ \partial V_n \end{bmatrix} \quad (3)$$

$$\Delta P_{ij} = \left[\frac{\partial P_{ij}}{\partial \delta_2} \cdots \frac{\partial P_{ij}}{\partial \delta_n} \frac{\partial P_{ij}}{\partial V_2} \cdots \frac{\partial P_{ij}}{\partial V_n} \right] * \begin{bmatrix} J1 & J2 \\ J3 & J4 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ . \\ . \\ +Pt \\ 0 \\ . \\ . \\ -Pt \\ 0 \end{bmatrix} \quad (4)$$

The power transfer of line *i-j* in the system due to transaction *m-n* is given as

$$T_{ij,mn} = \begin{cases} \dfrac{(P_{ij}^{\max} - P_{ij}^{0})}{PTDF_{ij,mn}}; & PTDF_{ij,mn} > 0 \\ \alpha(\inf inite)\ ; & PTDF_{ij,mn} = 0 \\ \dfrac{(-P_{ij}^{\max} - P_{ij}^{0})}{PTDF_{ij,mn}}; & PTDF_{ij,mn} < 0 \end{cases} \quad (5)$$

Where

P_{ij}^{max} Represents active power flow limit of a line *i-j*.

P_{ij}^{0} Represents base case power flow in line *i-j*.

PTDFij, mnis the Power Transfer Distribution Factor for linei-j regarding exchange between transport m and n.

$$ATC_{mn} = \min\left\{T_{ij,mn}\right\}, ij \in N_L \ (6)$$

Here, *NL* depicts total number of lines.

V. OPTIMAL POWER FLOW PROBLEM

A. Control Variables[24]

- Control factors which have an expense: Active power produced by thermal generating units P_i^G
- Control factors that don't have an expense: Magnitude of voltage at the generating units V_i^G

Tap ratio of the transformers t_{ij}

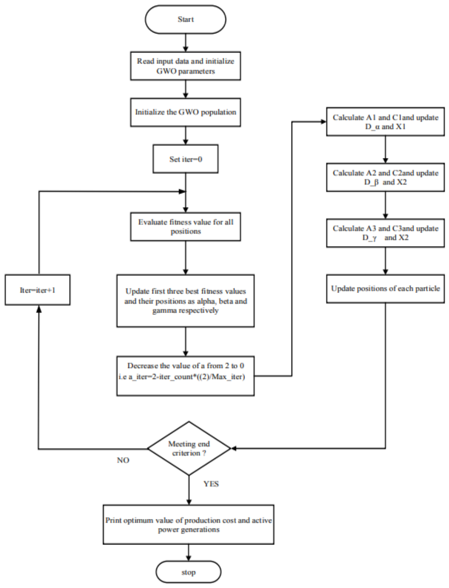

Fig.1 Flow Chart for GWO Algorithm[26]

B. Objective functions

- Maximize the ATC

$$\boldsymbol{ATC_{pq}} = \boldsymbol{mi}\{\boldsymbol{T_{ij,pq}}\};\ \boldsymbol{ij}\in\boldsymbol{nl}(7)$$

- Minimize Total power loss :

$$TPL = \sum_{k=1}^{nl} g_k (V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)) \quad (8)$$

C. Equality constraints

- Power balance at each node bus, i.e. power flow equations.

$$a)\ \boldsymbol{Pgi - Pdi - Pi(Vi, \delta i) = 0}$$
$$b)\ \boldsymbol{Qgi - Qdi - Qi(Vi, \delta i) = 0}$$

WherePgi&Qgi are active & reactive power generations at i_{th}bus, Pdi&Qdi are active & reactive power demand at i_{th}bus. Here Vi&δi are the voltage and its corresponding angle at i_{th}bus.

D. Inequality constraints

a) Generated active power limits: $p_{Gi}^{Min} \leq p_{Gi} \leq p_{Gi}^{Max}$
b) Generated reactive power limits: $Q_{Gi}^{Min} \leq Q_{Gi} \leq Q_{Gi}^{Max}$
c) Upper and lower voltage limits: $\boldsymbol{Vimin} \leq \boldsymbol{Vi} \leq \boldsymbol{Vimax}$

d) TCSC reactance limits in pu: $-\boldsymbol{0.8XL} \leq \boldsymbol{X_{tcsc}} \leq \boldsymbol{0.2X_L}$

e) Transformer TAP setting limits $\boldsymbol{T_{imin}} \leq \boldsymbol{T_i} \leq \boldsymbol{T_{imax}}$

Voltage limits at each node of the network are taken between 0.90 p.u. to 1.05 p.u., while generator terminal voltage is limited between 0.95 p.u. to 1.50 p.u. as per standards.

VI. GREYWOLF OPTIMIZATION ALGORITHM

The GWO mimics the hunting behavior and the social hierarchy of grey wolves. In addition to well organisedsocial hirarchae, well planned pack hunting is another significant social action of grey wolves.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

The main segments of GWO are encircling, hunting and attacking the prey. When applying GWO algorithm, we consideralpha (α) wolf atthe position with best fitness value and consequently second and third best ones are beta (β) and gamma (g). These 3 wolves guides different wolves throughout searching. Once the prey is positioned, the grey wolfs encircle it and tease it till it is tired and become stationary at a position. This encircling can be mathematically represented as below [26]

$$\vec{D}=|\vec{C}*\vec{X}\_prey\ (t)-\vec{X}\_GW\ (t)|$$
$$\vec{X}\_GW\ (t+1)=\vec{X}\_prey\ (t)-\vec{A}*\vec{D}$$

Where t indicates current position, $\vec{X}$ is the position vector of the prey, $\vec{X}$_GW represents a position vector of grey wolf, and A & C are coefficient vectors and calculated as follows.

$$\vec{A}=2\vec{a}*\vec{r}_1-\vec{a}$$
$$\vec{C}=2*\vec{r}_2$$

Here a is reduced from 2 to 0 through the span of emphases and $\vec{r}_1$, $\vec{r}_2$ are random values between 0 and 1.

As the equationsrepresenting the system and its output are non-linear and the solution can't be realized easily so search behavior of Grey wolf is simulated mathematically to locate the position of prey (solution). First three positions of wolf are considered to have best fitness values as Alpha, Beta & gamma so these are sorted and position of other wolfs are updated with respect to the alpha, beta & gamma wolfs and are are often developed mathematically as follows.

$$\vec{X}_1=\vec{X}\_\alpha(t)-\vec{A}_1*\vec{D}\_\alpha$$
$$\vec{X}_2=\vec{X}\_\beta(t)-\vec{A}_1*\vec{D}\_\beta$$
$$\vec{X}_3=\vec{X}\_\gamma(t)-\vec{A}_1*\vec{D}\_\gamma$$

Where $\vec{D}\_\alpha$ $\vec{D}\_\beta$ $\vec{D}\_\gamma$ are defined as

$$\vec{D}\_\alpha=|C*\vec{X}\_\alpha(t)-\vec{X}_{GW}(t)|$$
$$\vec{D}\_\beta=|C*\vec{X}\_\beta(t)-\vec{X}_{GW}(t)|$$
$$\vec{D}\_\gamma=|C*\vec{X}\_\gamma(t)-\vec{X}_{GW}(t)|$$

The average of algebraic sum of three positions of wolves gives us the best position of grey wolf

$$X_{GW}(t+1)=\frac{\vec{X}_1+\vec{X}_2+\vec{X}_3}{3}$$

Algorithm for Grey Wolf optimization can be written as :

Step1: Read input data and initialize GWO parameters(a, A, C)

Step2: Initialize population of grey wolfs (n=100)

Step 3: Initialize iter count, t=0

Step 4: Evaluate fitness value for all wolfs and update first three positions as a (alpha), b (beta) & g (gamma) respectively

Step 5: Decrease the value of a from 2 to 0 as per the relation:

$$a(iter)=2*iter\_count(\frac{2}{Max\ Iter})$$

Step6: Calculate new values of A & C for updating the position vector of a , b & g (i.e D a D b & D g)

Step 7: Update position of each solution

Step 8: if position is same end, else increase iteration count to t=t+1and go to Step 4.

VII. POWER FLOW MODELING OF TCSC

Thyristor controlled series compensator (TCSC) device is a series compensator to control the power flow by compensating the reactance of line. Each capacitive and inductive reactance is done by proper selection of capacitor and inductor values of the TCSC device which is completed through reactance equation.

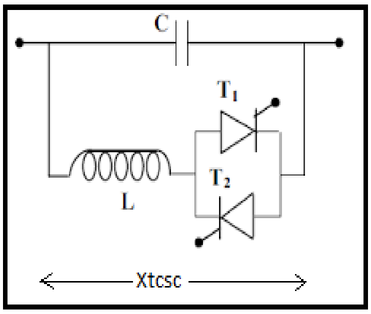

Fig.2 A schematic diagram of TCSC device

Using power injection model of TCSC[30].

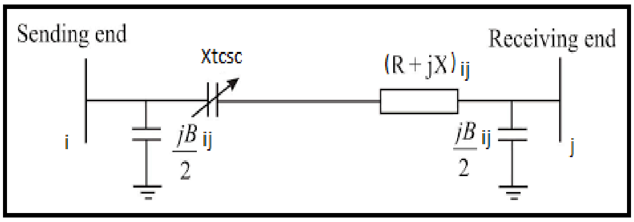

Fig.3 Equivalent circuit of TCSC connected in Line

$$\Delta Y_{ij}=y_{ij}^{'}-y_{ij}=(G_{ij}^{'}+jB_{ij}^{'})-(G_{ij}+B_{ij})\ \ (9)$$
$$G_{ij}{'}+jB_{ij}{'}\ G_{ij}+B_{ij}=\frac{1}{Y_{ij}}(10)$$
$$G_{ij}=\frac{r_{ij}}{r_{ij}^2+x_{ij}^2}\&B_{ij}=\frac{-x_{ij}}{r_{ij}^2+x_{ij}^2}(11)$$

By using equation (10) the Y bus matrix is modified which in turn modifies the elements of Jacobian matrix used in NR method. This modification changes the estimation of dynamic and receptive power streams in the line which can be well described by the power flow equations with modified admittances as:

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

$$P_{ij(tCSC)} = V_i^2 G_{ij}^{'} - V_i V_j [G_{ij}^{'} \mathrm{Cos}(\delta_{ij}) - B_{ij}^{'} \mathrm{Sin}(\delta_{ij})] \quad (12)$$

For power loss minimization objective ,FACTS devices are tested for different locations available within system with the help of GWO algorithm which tests the power loss results in different locations and then sorting the best location & optimized value of FACT device , where power loss is minimum. After getting this location further ATC calculation is done by an assumption that FACT device is already being installed at a particular location .

VIII. METHODOLOGY APPLIED

The objective function constitutes of two objectives:

Obj= W_a X (Maximization of ATC)+ W_b X (Minimization of TPL)

Total weight factors= $W_a + W_b = 1$

MATLAB software is used for the following programming.

A) For ATC maximization

Without TCSC

1. Optimal power flows are obtained by GWO
2. NR with OPF is applied to get the line flows.
3. Transaction is created and NR with OPF is again applied to get the new Line flows
4. With the help of line flows obtained with and without transactions. change in Active line flows are calculated.
5. With change in Active line flows and transaction created (ie 1MW) ACPTDF values are calculated.
6. The ACPTDF calculated are used to evaluate the ATC for a particular Transaction for nearest bus and for farthest bus.

With TCSC

1. The optimal power flows are obtained by GWO
2. Optimal location and sizing of TCSC is obtained with GWO with the objective of ATCmaximization
3. NR with OPF is applied to get the line flows with TCSC
4. Transaction is created and NR with OPF is again applied to get the new Line flows
5. With the help of line flows obtained with and without transaction, change in Active line flows are calculated.
4. With change in Active line flows and transaction created (i.e 1MW) ACPTDF values are calculated.
5. The ACPTDF calculated are used to evaluate the ATC for a particular Transaction for nearest bus and for farthest bus.

B) Minimization of Total power loss (TPL)

The same process is applied for Minimization of power loss but with an objective to minimize TPL only. It can be seen that the value of ATC is also decreased with the reduction of TPL.

ACPTDF calculated using equation (1) , can be demonstrated as shown in table 1.

Table no 1: Calculation of ACPTDF

Line No	ACPTDF VALUES (Bilateral Transactions -Sender to Buyer Bus)	
	2 to 5	2 to 26
1	-0.0491	-0.1499
2	0.1071	0.2286
3	0.1359	0.3077
4	0.1032	0.2194
5	0.6312	0.1709
6	0.1852	0.3763
7	0.2180	0.3091
8	-0.3981	0.1627
9	0.4114	-0.1679
10	-0.0004	0.1019
11	-0.0088	0.2054
12	-0.0051	0.1174
13	0.0000	0.0000
14	-0.0088	0.2054
15	0.0165	0.2072
16	0.0000	0.0000
17	0.0020	0.0295
18	0.0081	0.1184
19	0.0064	0.0592
20	0.0019	0.0290
21	0.0064	0.0585
22	0.0030	0.0187
23	0.0030	0.0185
24	0.0030	0.0184
25	-0.0030	-0.0187
26	-0.0063	-0.0583
27	-0.0048	0.1438
28	0.0002	0.2561
29	-0.0048	0.1418
30	0.0069	0.1261
31	0.0002	0.2537
32	0.0020	0.2667
33	0.0023	0.5146
34	0.0000	1.0220
35	0.0023	-0.5090
36	-0.0023	0.5129
37	0.0000	0.0002
38	0.0000	0.0002
39	0.0000	0.0001
40	-0.0004	0.1028
41	-0.0019	0.4123

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

Table no 2: OPF result comparison between GWO and Firefly Algorithm

OPF Results Comparison for Transaction 2-26				
Without Device				
Control Variables	For ATC Maximization		For TPL Minimisation	
	GWO	FA [31]	GWO	FA [31]
PG_1 (MW)	118.9856	119.9812	118.9856	119.3438
PG_2 (MW)	54.28698	63.6613	53.75598	74.2959
PG_5 (MW)	27.94923	31.8922	27.94923	28.2397
PG_8 (MW)	35	23.7808	35	17.7711
PG_{11} (MW)	25.70227	26.3744	25.70227	21.9291
PG_{13}(MW)	28.48362	24.2911	28.48362	26.7144
Total Generation (MW)	290.4077	289.981	289.8767	288.294
ATC (MW)	12.1845	7.4715	12.18	7.4315
TPL(MW)	7.01	6.1819	6.493	4.8941

It can be well depicted from table no 2 that GWO algorithm gives better OPF results even without applying FACTS devices when compared with other evolutionary programming methods.

IX. RESULTS & DISCUSSIONS

The proposed calculation is tested on standard IEEE 30 bus system with 41 transmission lines [29] for two cases. At the start, ATC values in IEEE 30 bus system is calculated using ACPTDF with respect to all the five generators connected at bus number 2, 5, 8, 11 & 13. The bus at which generator is connected is seller bus while the load buses are considered as buyer buses. The results for all possible transactions are obtained and elaborated as below:

Fig.4 shows the variation of ATC value with the generator at bus no 2 for all the possible transactions. Here bus number 2 is considered as seller bus while all the load buses are taken as buyer bus. It is clearly shown in Fig.4 that ATC is maximum, (116.5 MW), between buses 2 and 5. Also the least value of ATC is obtained as 12.18 MW between buses 2 to 26.

Fig.5 gives the ATC distribution due to the generator at bus no 5. From the graph it can be deduced that maximum ATC (184.56 MW) is between buses 5 to 2 whereas minimum ATC (12.26 MW) is obtained between buses 5 to 26.

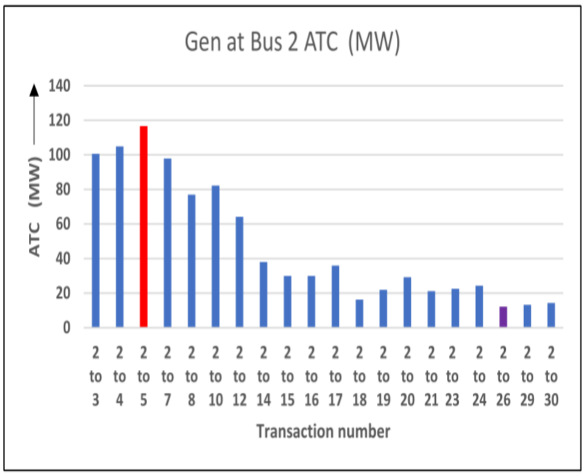

Fig.4 Variation of ATC values for all transaction with Gen-2

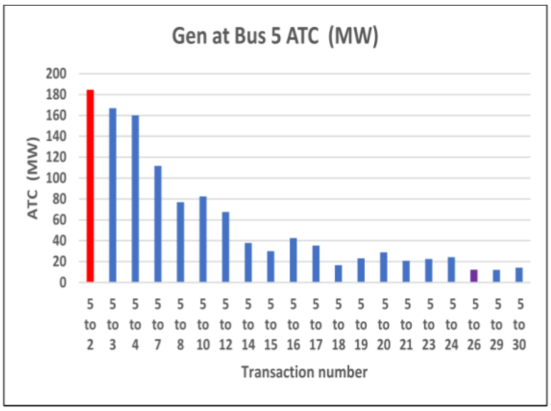

Fig.5 Variation of ATC values for all transaction with Gen-5

Fig.6 indicates the effect of generator on bus no 8 on ATC values in IEEE 30 bus network. The line between the buses 8 & 12 is having maximum ATC of 70.41 MW and the line between buses 8 & 26 has minimum ATC value of 12.18 MW.

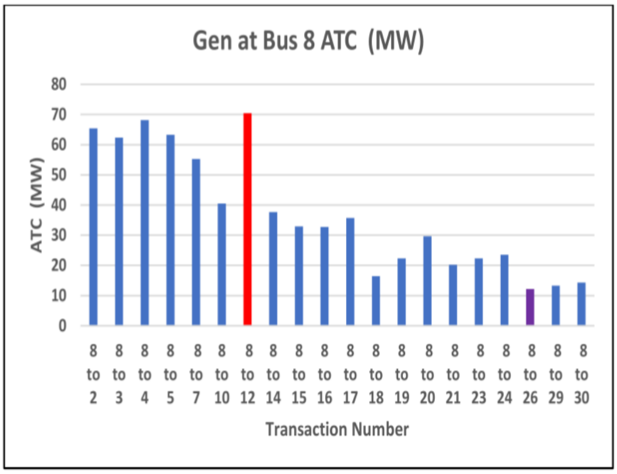

Fig.6 Variation of ATC values for all transaction due toGen-8

Further fig.7 depicts the ATC distribution in different lines. When generator is placed at bus number 11. The graph shows max ATC in the line between buses 11 & 16 which equals to 37.77 MW while least ATC (6.09 MW) is in the line between the buses 11 & 26.

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)*

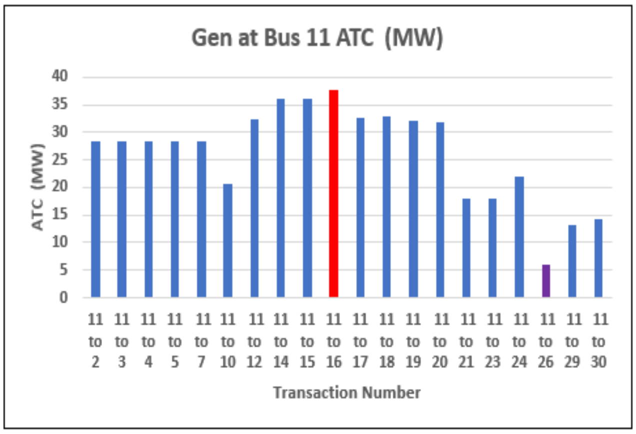

Fig.7 Variation of ATC values for all transaction due toGen-11

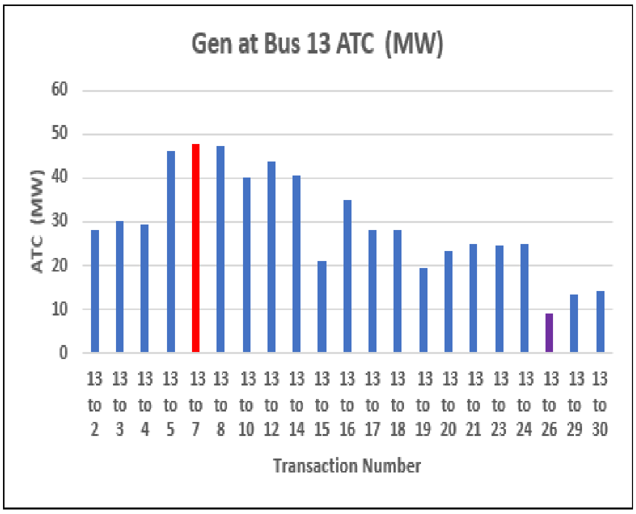

Fig.8 Variation of ATC values for all transaction due toGen-13

Also Fig.8 gives the ATC distribution in IEEE 30 bus system due to generator at bus no 13. The graph shows maximum ATC of 34.67 MW between buses 13 & 7 while minimum ATC valuing to 8.89 MW can be seen between buses 13& 26.

From Fig.4 to Fig.8 it can be identified that maximum value of ATC is observed for the transactions where the generator is connected very nearer to the buyer bus, while ATC is minimum when the generator is connected very far away.

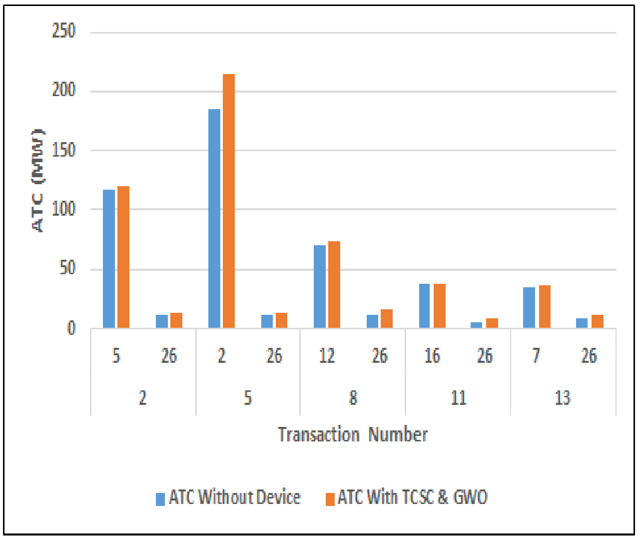

Fig.9 ATC values with TCSC- GWO and without TCSC

Case I: Maximization of ATC

Table no 3 shows the results when the program runs for the objective of maximizing ATC between the buses under transaction with GWO.

Table no 3: Consolidated results for ATC maximization

Bus		OPF WITHOUT TCSC			OPF WITH TCSC		
SB	**BB**	**ATC (MW)**	**TPL (MW)**	**TQL (MVAR)**	**ATC MW)**	**TPL (MW)**	**TQL (MVAR)**
2	**5**	116.65	7.01	30.5	120.75	7.13	28.33
	26	12.18	7.01	30.3	13.18	7.13	28.15
5	**2**	184.56	7.03	30.1	215.13	7.45	29.78
	26	12.26	7.09	30.7	13.45	7.19	28.48
8	**12**	70.41	7.04	30.4	74.046	7.17	28.26
	26	12.18	7.08	30.8	16.57	7.21	28.52
11	**16**	37.77	7.11	30.6	38.08	7.24	28.39
	26	6.09	7.01	31.3	8.01	7.78	29.24
13	**7**	34.67	7.05	29.6	36.89	7.69	27.56
	26	8.89	7.08	30.5	11.46	7.97	28.95

The ATC values obtained between 2-26, 5-26, 8-26, 11-26 & 13-26 are12.18 MW, 12.26 MW, 12.18 MW, 6.09 MW & 8.89 MW respectively which are much higher than the values obtained from other EP,Firefly algorithm [31] as shown in figure10, which shows that TCSC when optimised with GWO for position and value gives better results as compared to other FACTS devices.

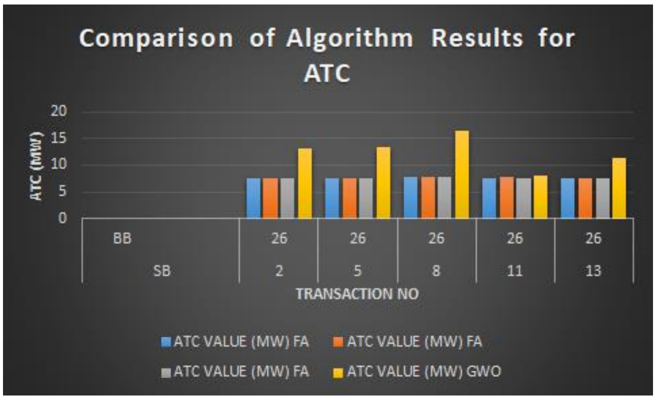

Fig.10 Comparison of ATC values with TCSC- GWO and firefly algorithm [31]

From the above transactions maximum and minimum values of ATC due to seller bus is calculated and is further used in OPF for the enhancement of the same.

The algorithm was applied on IEEE 30 bus system for the purpose of enhancing ATC esteem by finding the ideal area and size of TCSC using Grey Wolf Optimization. Table no 3 gives the results of ATC maximization with the TCSC. The results are obtained by applying OPF and then applying TCSC in the system are graphically represented in fig.9.

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication (BEIESP)

In table 3 SB is the seller bus and BB is buyer bus. Whereas TPL is total active power loss and TQL is total reactive power loss .The location and size of TCSC is searched at the locations such that the ATC value is maximized. The search algorithm works efficiently to locate the device location and its size to maximize the objective function. Additionally total reactive power loss is decreased as compare to the base case due to specific allocation and sizing of TCSC with GWO. The results also show that with the increment in ATC value the total active power losses are increased due to increase of power transfer capability. It is observed that thepercentage increase of ATC with GWO is much higher than those obtained by other EP. From fig.11 it can be seen that ATC between far away buses and generator bus is increased as compared to other EP used previously. ATC value in transaction 2 – 26 is increased from 12.18 to 13.18 which are 8.2%.

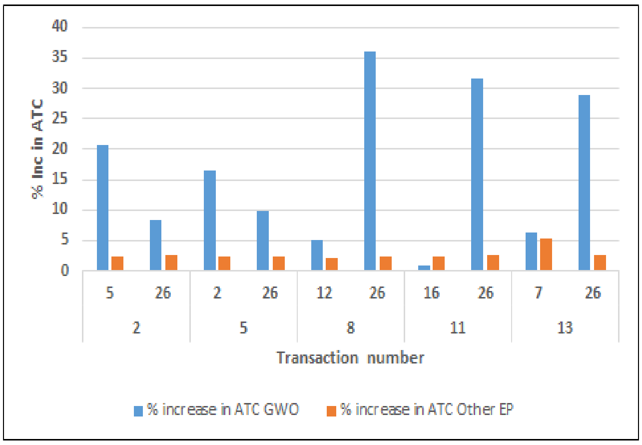

Fig.11Comparison of % Increment in ATC

MW and similarly between 5-26 the percentage increase in ATC is 9.7% , between 8-26 it is 36.04% , whilein 11-26 transaction it is increased by 31% and between 13-26 this increment is approximately 29%. These increments in ATC values as magnitude and as percentage are far much better than the values obtained by other EP [31].

Case II: Minimization of Total Active power loss

Table no 4: Consolidated results for PL minimization

Bus		Load Flow OPF			Load Flow OPF-TCSC		
SB	BB	ATC (MW)	TPL (MW)	TQL (MVAR)	ATC MW)	TPL (MW)	TQL (MVAR)
2	5	116.6	7.01	30.0	90.67	5.06	28.56
	26	12.18	7.01	30.3	8.34	5.61	29.23
5	2	184.56	7.03	30.1	165.67	5.89	29.67
	26	12.26	7.09	30.7	9.45	5.63	31.67
8	12	70.41	7.04	30.4	45.89	5.32	26.89
	26	12.18	7.08	30.8	7.54	5.12	24.78
11	16	37.77	7.11	30.6	32.78	5.32	32.78
	26	6.09	7.01	31.3	6.03	4.32	45.89
13	7	34.67	7.05	29.6	32.43	5.67	27.54
	26	8.89	7.08	30.5	9.54	6.03	31.67

Table no.4 shows the consolidated results when objective is to reduce the active power losses. It is observed from the table that active power losses are reduced when compared to the losses in ATC maximization. Here ATC value is reduced due to reduction in active power losses. Again, in this case also reactive power loss is reduced because of the optimized TCSC location.Fig.12 shows the variation of Active power loss without and with TCSC GWO.

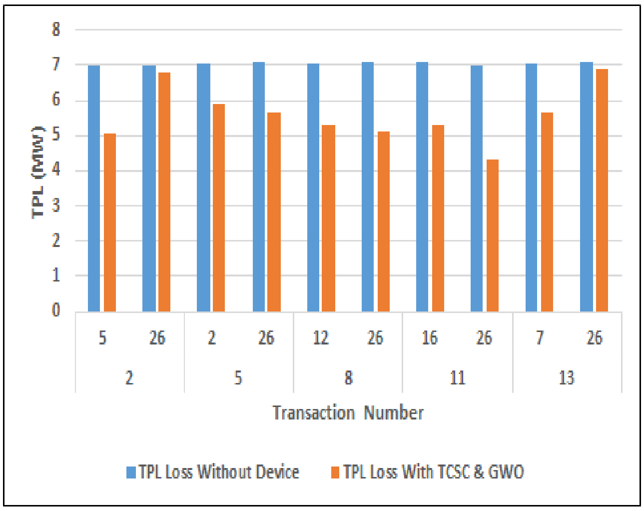

Fig.12 TPL values with TCSC- GWO and without TCSC

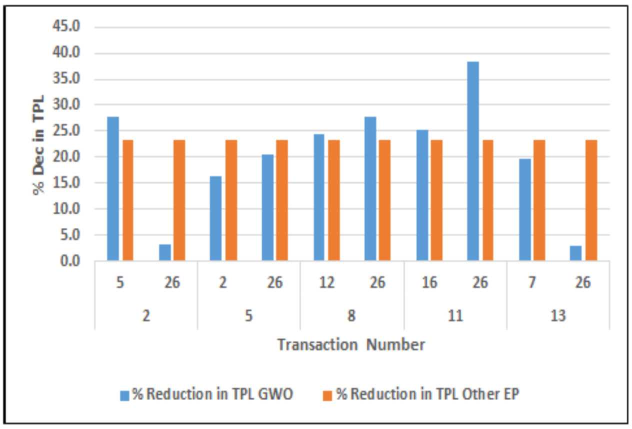

Fig.13comparison of % Decrement in TPL

Fig.13 shows the relative comparison of percentage TPL reduction when using GWO and with other EP [31]. It can be well established that the percentage reduction of TPL when considering OPF with and without TCSC using GWO is higher in most of the transactions as compared to other current EP methods.

Table no 5 Optimised Location and Sizing of TCSC by GWO

SB	BB	For ATC Maximization		For TPL Minimization	
		TCSC Loc	TCSC Size	TCSC Loc	TCSC Size
2	5	12	-0.6977	6	-0.6024
	26	19	0.2676	9	0.3052
5	2	2	0.1091	35	0.2677
	26	8	-0.576	17	0.4912
8	12	16	-0.0724	21	-0.1838

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

	26	38	-0.3927	36	-0.5804
11	16	6	0.3439	6	0.6197
	26	19	0.6907	38	0.3093
13	7	26	-0.6112	26	-0.2724
	26	5	0.2479	5	0.3052

Table no 5 illustrates the optimised size and location of TCSC using GWO.

X. CONCLUSION

For maintaining the efficient and economical electricity trades and operations, it is very essesntial to meet with the requirements of expanding power system. With the increase in the transactions in power industry, the system is working near its thermal and voltage limits. To rectify this problem either the expansion of system is required or the current system may be utilised optimally up to its maximum capacity. Thus different methodologies are worked out for enhancing ATC of system using FACTS devices. Based on the versatile control capabilities of TCSC its applicability is tested technically to enhance the ATC of standard IEEE 30 Bus system, under transmission limitations. ATC is calculated for bilateral transaction by using ACPTDF as sensitivity factor. The location and parameter setting of TCSC is carried out with the help of GWO, to fulfil the objective of increasing ATC and decreasing power losses sticking with the voltage & thermal stability contraints.GWObeing very simple to apply with better efficiency as compared to other optimisation methods such as firefly algorithm due to a guiding agent (α wolf)in the technique. Moreover this optimisation technique never gets stuck in local minima so is very reliable and fast. The results obtained for ATC maximisation for far end bilateral transactions are much better then those obtained by firefly algorithm.

Finally it can be summed up that application of TCSC in the given test system has given better results for ATC maximisation and power loss minimisation using ACPTDF as sensitivity factor. TCSC being tuned and placed with the help of GWO to achieve the objective of the paper using the pre existing network in deregulated environment without expanding it.

REFERENCES

1. Gupta, KS Verma HO. "Enhancement of Available Transfer Capability by the use of UPFC in Open Power Market."*National Power Systems Conference, NPSC* December 2002
2. OngsakulWeerakorn, JirapongPeerapol. Optimal allocation of FACTS devices to enhance total transfer capability using evolutionary programming. In: *IEEE int symposium on circuits and systems, ISCAS*, vol. 5; 2005. p. 4175–8.
3. Acha E, Fuerte-Esquivel CR, Amirez-Perez H, Angeles-Camacho C. FACTS – modelling and simulation in power networks. *John Wiley & Sons;* 2004.
4. Gyugyi L, Rietman TR, Edris A, Schauder CD, Torgerson DR, Williams SL. The unified power flow controller: a new approach to power transmission control. *IEEE Trans Power Deliv 1995;10 (2):1085–97.*
5. Arabi A, Kundur P. "A versatile FACTS device model for power flow and stability simulation", *IEEE Trans PWRS* 1996;11,4:1944–50.
6. Gerbex Stephane, Cherkaoui Rachid, Germond Alain J. "Optimal location of multi-type FACTS devices in a power system by means of genetic algorithms*", IEEE Trans Power Syst* 2001;16(3):537–44.
7. Sauer PW. "Technical challenges of computing available transfer capability (ATC) in electric power systems",*Proceedings of 30th annual Hawaii international conference on system science;* 1997.
8. Kim BH. A study on the convergency property of the auxiliary problem principle. *J ElectrEngTechnol*2006;1(4):455–60.
9. Hur D, Park JK, Kim BH. "An efficient methodology for security assessment of power systems based on distributed optimal power flow",*Eur Trans Electr Power* 2003;13(3):161–5.
10. Ou Y, Singh C. "Assessment of available transfer capability and margins",*IEEE Trans Power Syst*2002;17(2):463–8.
11. Ejebe, G. C., Tong, J., Waight, J.G. and et al. "Available Transfer Capability Calculations", *IEEE Transactions on Power Systems,* Vol. 13(4), pp. 1521-6, November 1998.
12. Mohamed, S., Yixin, Ni, Felix, F. W., "Transfer Capability Computations in Deregulated power systems," *Proceedings of the 33rd Hawaii International Conference on System Sciences,* – 2000.
13. Kumar, A., Srivastava, S. C., and Singh S. N., "Available Transfer Capability Assessment in a Competitive Electricity Market Using a Bifurcation Approach", *IEE Proc. on Generation, Transmission and Distribution, vol.* 151, No. 2, pp. 133 – 140, March 2004.
14. Luo, X., Patton, A. D., and Singh, C., "Real Power Transfer Capability Calculations Using Multi Layer Feed Forward Neural Network", *IEEE Transactions on Power Systems,* 15(2): 903-908, May 2000.
15. Ying-Yi Hong , and Chien-Yang Hsiao, "On-Line ATC estimator using hybrid principal component analysis network", *Journal of the Chinese Institute of Engineers,* Vol. 30, No. 5, pp. 781-789, 2007.
16. Selvi, K., Ramaraj, N., Bhavani, M., "Total Transfer Capability Evaluation using Genetic Algorithms" *IE(I) Journal – EL,* Vol. 88, pp. 60-64, June 2007.
17. Y. Xiao, Y. H. Song, and Y. Z. Sun, "Available Transfer Capability Enhancement Using FACTS Devices," *Proceedings of the 2000 IEEWPWS Summer Meeting, Seattle,* July 2000, vol. I, pp. 508-515.
18. L. Gyugyi, Flexible AC Transmission Systems (FACTS), Y. H. Song and A. T. Johns, Eds., 1999, *Inst. Elect. Eng. Power and Energy Series 30, ch. I.*
19. N. G. Hingorani and L. Gyugyi, "Understanding FACTS, concepts and technology of flexible ac transmission systems",*NewYork: IEEE,* 2000.
20. G.D.Galiana et a1. ,"Assessment and control of the impact of FACTS devices on power system performance ", *IEEE Trans on power System* , Vol.ll ,No4,Nov.1996,pp.193l-1936.
21. E. Larsen , N. Miller, S. Nilsson and S.lindgren, "Benefits of GTO-Based compensation systems for electric utility applications -, *IEEE Trans on power Delivery* Vol 7,No. 4,October 1992,pp.2056- 2064.
22. K.S. Verma , S.N. Singh and H.O. Gupta , .' Facts Devices Location For Enhancement of TTC", *Roorkee - 247667 India.*
23. Bavithra, K., S. Charles Raja, and P. Venkatesh. "Optimal Setting of FACTS Devices using Particle Swarm Optimization for ATC Enhancement in Deregulated Power System." *IFAC-PapersOnLine*49.1 (2016): 450-455.
24. Daniel Kirschen "New Formulations of the Optimal Power Flow Problem", *University of Washington.*
25. Mirjalili, Seyedali, Seyed Mohammad Mirjalili, and Andrew Lewis. "Grey wolf optimizer." *Advances in engineering software* 69 (2014): 46-61.
26. Teeparthi, Kiran, and DM ViNod Kumar. "Grey wolf optimization algorithm based dynamic security constrained optimal power flow." *Power Systems Conference (NPSC),* 2016 National. IEEE, 2016.
27. Kadia, J. V., and J. G. Jamnani. "Modelling and analysis of TCSC controller for enhancement of transmission network." *International Journal of Emerging Technology and Advanced Engineering* 2.3 (2012).
28. Agrawal, Rahul, S. K. Bharadwaj, and D. P. Kothari. "Population based evolutionary optimization techniques for optimal allocation and sizing of Thyristor Controlled Series Capacitor." *Journal of Electrical Systems and Information Technology (2018).*
29. IEEE 30 Bus system http://www.ee.washington.edu/research/pstca/pf30/pg_tca30bus.htm
30. Tabatabaei, N.M., Aghajani, G., Boushehri, N.S. and Shoarinejad, S., 2011. Optimal location of FACTS devices using adaptive particle swarm optimization mixed with simulated annealing",*International Journal on Technical and Physical Problems of Engineering (IJTPE),* 7, pp.60-70.
31. M.VenkateswraRao, S .Sivangaraju, ChintalapudiV.Suresh "Available transfer capability evaluation and enhancement using various FACTS controllers: Special focus on system security", *Ain Shams Engineering Journal,* 2015

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

AUTHORS PROFILE

Anubha Gautam was born in 1978 in India. She obtained her Bachelor of Engineering from Oriental Institute of Science & Technology, Bhopal, India in 2001. She obtained Masters of Technology (Heavy electrical Equipment) form Maulana Azad National Institute of Technology, Bhopal in 2007. She is currently pursuing PhD in Electrical Engineering Department from YMCA university of Science Technology, Faridabad. She has an experience of 15 years in teaching. Her Area of interest are Power system, Power electronics and Electrical Machines.

P R Sharma was born in 1966 in India. He received his degree of Bachelor of Engineering from Punjab University in 1988 and degree of Masters of Technology in Electrical Engineering (Power System) from Regional Engineering College Kurukshetra in 1990. He received his PhD Degree from MD University, Rohtak in 2005. He started his career from industry. He has vast experience in teaching and industry. Currently he is working as Professor in Electrical Engineering department in YMCA University of Science and Technology, Faridabad. His area of interest is “Optimal location & Coordination control of FACTS devices in Power System”.

Yogendra Kumar was born in 1965 in India. He received his Bachelor of Science (Electrical) and completed Masters of Technology (Heavy Electrical Engineering). He pursued his PhD in Electrical Engineering from Indian Institute of Technology, Roorkee, India. He is at present employed in MANIT, Bhopal, India as Head of Department in Electrical Engineering guiding a number of PhD scholars. Apart from academic responsibilities he is also bearing administrative responsibilities. He is indulged in research in various fields of Electrical Engineering . His favourite field in Electrical Engineering like Power system, Heavy Electrical Machines