NOVEL SENSITIVITY INDICES BASED OPTIMAL LOCATION OF TCSC CONTROLLERS IN INDIAN GRID SYSTEM

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Abstract: *:This paper proposes a methodology to determine the location of Thyristor Controlled Series Compensator (TCSC) for secured power flow in the grid system using Novel Sensitivity indices. Three different Novel Sensitivity Indices are formulated based on Availability Based Tariff (ABT), Renewable Energy Integration (REI), Power Purchase (PP), Peak /off-peak (POP), Seasonal Demand (SD), Demand Growth (DG), Change in Capacity (CC), Open Access Customer (OA) and Generation Mix (GM). A methodology for finding the novel sensitivity indices of all the lines and selection of optimal location for placing TCSC for secured power flow in grid system is also presented. The Constriction factor based particle swarm optimization (PSO) algorithm is utilized for finding the settings of the TCSC to be placed on the line selected based on the novel sensitivity indices. To show the validity of the proposed methodology, simulations are carried out for a practical Indian Grid system. The result indicates the importance of considering the proposed novel sensitivity indices in deciding the location of TCSC.*

Keywords: *Thyristor Controlled Series Compensator (TCSC), Availability Based Tariff (ABT), Renewable Energy Integration (REI), Seasonal Demand (SD), Generation Mix (GM), Particle Swarm Optimization (PSO)*

I. Introduction

The delivery of power to the load centre from the generating stations needs systematic development and optimum utilization of power transmission infrastructure. The development of new power transmission network faces limitation from environmental aspects, right of way and cost problems applicable to both integrated and re-structured power utilities. However the optimum utilization of existing transmission infrastructure by means of cost effective and readily implementable measures like series compensation at suitable locations has become an imminent challenge in the context of deregulation and Open access, which is under implementation in India. To handle the task of power system operation, the transmission Infrastructure adequacy has become crucial factor because of demand-supply gap, multiple companies from State/Central/Private and cost of power.

The increasing Transmission capability along the existing routes and making optimum utilization of existing transmission infrastructure through upgradation is an attractive alternative to build new capacity. FACTS controllers are the right choice in increasing the utilization of transmission line to the thermal limit by modifying the line reactance. FACTS controllers [1] include Thyristor Controlled series compensators (TCSC), Static Var Compensators (SVC), Thyristor Controlled Phase Angle Regulator (TCPAR), Static Compensators (STATCOM), Unified Power Flow Controllers (UPFC) etc.

The line overloads can be eliminated or alleviated using TCSC which can reroute the power by modifying the reactance of the network thereby overloading can be avoided in the overloaded system and utilization increased in other part of the system. However, the line getting overloaded more frequently in a realistic scenario is to be determined correctly so as to modify the reactance of the line by optimally placing TCSCs. Thus it is essential to know the realistic power flow in all the lines.

In general, the power flow in the lines varies with changes in demand. The point of injection and point of drawl of open access(OA) customers, varying supply of power after utilization by captive power plants (CPPs) and infirm renewable energy integrations introduces more changes in power flow. The independent system operator's decision to meet grid discipline mechanism and practices followed to avoid grid disturbance introduces changes in the power flow as well. The practical issues like Inter State Transmission System (ISTS) constraints, islanding scheme, peak and off peak management with energy storage options, meeting loss reduction target etc., also brings more changes in the power flow. Therefore it is important to analyze the impact of CPPs, OA customers, ISOs decisions and practical issues while deciding the optimal location for placing TCSCs to eliminate or alleviate line overloads.

A lot of work has been done in the FACTS placement in power system by earlier researchers. In [2], achieving secured optimal power flow under normal and contingency conditions by placing TCSCs at appropriate location by finding Thermal Capacity Index and Contingency Capacity Index are proposed with optimization model using linear programming. The severity of overloading of the system is minimized by optimally placing TCSCs based on Real power flow sensitivity index with respect to the parameter of TCSC and the settings of TCSCs are arrived using genetic algorithm have been discussed in [3].

A comprehensive survey of incorporation of FACTS controllers such as TCSC, SVC, SSSC, STATCOM, UPFC and IPFC devices for power flow control is presented in [4].Multiple SVC with a view to minimize load voltage magnitude deviations and network losses using Particle Swarm Optimization (PSO) algorithm is proposed in [5]. An assessment of techno-economic merits of placement of TCSCs and SVCs in a transmission network to facilitate wind power integration has been made in [6]

In [7] Contingency Severity Index is used to rank the branches to optimally locate the FACTS controllers for multiple contingencies with the objective of minimizing the severity of overloading. In [8], it has been reported that introduction of FACTS devices in a right location increases the loadability or decreases the losses of the system. In (9), a method to determine the optimal location of TCSC has been suggested based on real power performance index and reduction of total system reactive power loss.

The problem of placing SVC to provide the maximum transfer capability for all possible generation mixes is investigated in [10].An investigation is made in [11] to allocate FACTS under system fluctuations due to demand and renewable generation. The optimal location of FACTS devices to improve system loadability with minimum cost of installation of FACTS devices through application of PSO is dealt in [12].

The optimal location TCSCs to maximize the social welfare with minimizing the TCSC installation cost for enhancing the market trading capability through Sequential optimization technique in the deregulated power sector has been presented in [13,14]. The recommended percentage of series compensation in lines to alleviate congestion is explained in [15]. The impact of TCSC on spot prices and congestion is studied and revealed that TCSC helped to reduce congestion and losses and reduces the locational marginal price (LMPs) at the previously congested line in [16]. The performances of fixed compensator, SVC and STATCOM are compared in voltage profile improvement of IEEE 34 bus radial distribution system and the optimal placement of compensating devices is found using voltage sensitivity and loss sensitivity factors in [17].The critical buses and line segments to place FACTS controllers in the system has been proposed in [18] through an extended voltage phasor approach.

Although much work has been done to place FACTS controllers in the transmission system, the effect of Availability Based Tariff (ABT)[19] mechanism on power drawl, impact of Open Access Customers on capacity constraints, flexibility to purchase power and effect of capacity addition and significance of seasonal demand variations during peak and off peak hours which are influencing the power flow have not been addressed in detail for placing TCSCs. In view of the inadequacy of the existing methods to take care of these practical issues within the selection of optimal location of TCSC, this paper proposes the concept of placement of TCSC in the power transmission system to eliminate or alleviate the line overloads using novel sensitivity indices

The salient features of the proposed approach includes developing realistic generation mix schedules for meeting the seasonal demand, formulation of three different novel sensitivity indices based on ABT, Renewable Energy integration, power purchase and OA customers duly taking care of Peak/off-peak hour demand, system peak/off-peak demand, demand growth rate and change in capacity & configuration.

The main objective of this paper is to determine the TCSC location for secured power flow in the grid system using novel sensitivity indices which takes care of vital factors deciding the realistic power flow in the grid system. The Constriction factor based PSO is utilized for finding the settings of the TCSC to be placed on the line selected based on the novel sensitivity indices The proposed approach has been extensively analyzed and tested on practical Indian Grid system consisting of 36 Bus at 230 KV and 400 KV level supplying power to a metro city in India.

The paper is organized as follows: Section 2 speaks about the problem formulation explaining the concepts of novel sensitivity indices. Section 3 presents the methodology for finding the novel sensitivity indices and determination of best location and setting for TCSCs. Section 4 deals with the test system and simulation results and Section 5 concludes the proposed work and gives direction for future expansion.

2. Problem formulation

This section describes the vital factors influencing the loading of transmission lines, formulating realistic generation mix schedules and formulation and application of three different novel sensitivity indices to decide the location of TCSCs for secured power flow in the grid system.

2.1 Vital Factors influencing the Transmission Line loading

Factor-1: Availability Based Tariff (ABT) grid discipline: To encourage generators to generate more during peak load hours and curtail generation adequately during off peak hours on one hand and discouraging power utilities from overdrawing on the other hand ABT has been introduced. The utilities draw power from the central generating stations(CGS) based on their allocation under ABT grid discipline mechanism. However over drawl from the grid is violation of statutory provisions by the Utilities which is happening in India [20] during peak demand apart from over drawl to avail cheaper power when the frequency is high. This clearly necessitates the study of sensitivity of a transmission line loading for additional drawl from the grid either during demand changes or cheaper power availability under ABT.

Factor-2: Integration of Renewable Energy*:* The Wind Energy Generators(WEG) generates maximum during season and is evacuated to distant load centers after local consumption based on the transmission corridor availability and demand. According to the Indian Electricity Grid Code (IEGC) [21], System operator, shall make all efforts to evacuate the available solar and wind power and treat as a must-run station. However System operator may instruct the solar / wind generator to back down generation on consideration of grid security. Thus the sensitivity of the transmission line loading for Wind Energy Integration into the grid has to be studied.

Factor-3: Power Purchase*:* Purchase of power through Power Trading Companies and Power Exchanges [22-23] are the most common thing in the Power Utilities to meet the increasing demand and shortage of power due to outage of plants. Thus the sensitivity of a transmission line loading to trade power has to be assessed.

Factor-4: **Daily Peak and off peak demand:** The demand requirement may vary depending on the time of the day. The load centers, peak and off - peak demand would reflect the transmission infrastructure to be made available to meet the demand condition. Hence the analysis of the sensitivity of the transmission line loading to Peak and off peak demand is significant.

Factor-5: Varying seasonal demand: The demand at various load centers varies with different seasons. In India, five different seasons, viz, April to June, July to September ,October & November, December to February and March are specified in the regulations for Transmission Pricing Strategy and accordingly the representative dates are considered[24]. Thus the transmission infrastructure requirements to meet the seasonal demand have to be taken care while studying the sensitivity of the transmission line loading.

Factor-6: Future Projected demand for the plan period: The demand of the load center has to be projected for the plan period and accordingly to meet the demand growth, the infrastructure adequacy have to be assessed and the sensitivity of a transmission line loading to meet the demand growth has to be evaluated.

Factor-7: Change in capacity of generation and transmission system configuration: The capacity of old power plants may be de-rated to lower value after long service or increased to higher value after renovation and modernization. Similarly the additional generation due to expansion of the existing power plants or creation of newer power plants with associated power evacuation system in the study area in addition to wind energy integration or power purchase has to be critically analyzed. Thus the change in capacity of generation and its transmission system configuration have to be taken into account along with present demand and projected demand while evaluating the sensitivity of the transmission line loading.

Factor-8: Accommodating Open Access Customers*:* The non-discriminatory provision for the use of transmission lines by any licensee or consumer under the Open Access policy which creates competition in power market. The point of injection and point of drawl of open access customers for the specified period is to be taken into account to evaluate the sensitivity of the transmission line loading.

2.2 Realistic Generation Mix based on the vital factors

In practice, multiple generating agencies are feeding the Indian grid. The following different generation mix schedules based on (i)CGS as slack (ii)maximum utilization of CGS under ABT high frequency conditions (iii) over drawl from CGS to meet the shortage during emergency along with wind generation integration are formulated for conducting power flow studies with system peak and off peak demand conditions.

GM Schedule-1

$$\sum_{i=1}^{n} D_i = \left[\lambda_S \ (C_1) + \ \lambda_{AQ} \ \sum_{g=2}^{n}(C_g)\right] + \lambda_{FG} \sum_{g=1}^{n}(S_g) + \lambda_{FG} \sum_{g=1}^{n}(P_g) \qquad (1)$$

GM Schedule -2

$$\sum_{i=1}^{n} D_i = \left[\lambda_{ODABTHF} \ (C_1) + \ \lambda_{AQ} \ \sum_{g=2}^{n}(C_g)\right] + \lambda_{FG} \sum_{g=1}^{n}(S_g) + \lambda_{RG} \sum_{g=1}^{n}(P_g) \qquad (2)$$

GM Schedule -3

$$\sum_{i=1}^{n} D_i = \left[\lambda_{ODUSS}\ (C_1) + \lambda_{AQ} \sum_{g=2}^{n} (C_g)\right] + \lambda_{RG} \sum_{g=1}^{n} (S_g) + \lambda_{FG} \sum_{g=1}^{n} (P_g) \quad (3)$$

GM Schedule -4

$$\sum_{i=1}^{n} D_i = \left[\lambda_S(C_1) + \lambda_{AQ} \sum_{g=2}^{n} (C_g)\right] + \lambda_{FG} \sum_{g=1}^{n} (S_g) + \lambda_{FG} \sum_{g=1}^{n} (P_g) + \lambda_{WG} \sum_{g=1}^{n} (W_g) \quad (4)$$

GM Schedule -5

$$\sum_{i=1}^{n} D_i = \left[\lambda_{ODABTHF}\ (C_1) + \lambda_{AQ} \sum_{g=2}^{n} (C_g)\right] + \lambda_{FG/RG} \sum_{g=1}^{n} (S_g) + \lambda_{RG} \sum_{g=1}^{n} (P_g) + \lambda_{WG} \sum_{g=1}^{n} (W_g) \quad (5)$$

GM Schedule -6

$$\sum_{i=1}^{n} D_i = \left[\lambda_{ODSS}\ (C_1) + \lambda_{AQ} \sum_{g=2}^{n} (C_g)\right] + \lambda_{RG} \sum_{g=1}^{n} (S_g) + \lambda_{FG} \sum_{g=1}^{n} (P_g) + \lambda_{WG} \sum_{g=1}^{n} (W_g) \quad (6)$$

where

C_1 - Central Generation -slack,
C_g - Central Generation
S_g - State generation
P_g - Private generation includes OA injection
W_g - Wind Integration in Renewable Energy
D_i - Demand includes OA drawls and losses
λ_{FG} - Coefficient of full generation = 1
$0 \leq \lambda_{RG} < 1$ - Coefficient of reduced generation
$\lambda_{ODABTHF} > 1$ - Coefficient of over drawl during ABT high frequency
$\lambda_{ODSS} > 1$ - Coefficient of over drawl during shortage from State

2.3 Formulation of Novel Sensitivity Indices

(a) SD Sensitivity Index

The peak and off peak demand of all load buses for five different seasons are taken to formulate Seasonal Demand Sensitivity Index.

SD Sensitivity Index is expressed as

$$SI_{SD} = \left(\frac{P_{SD}}{P_{MW\ Limit}} - 1\right) \quad (7)$$

where P_{SD} is the line Power flow in the transmission lines for peak and off peak demands of all load buses during five different seasons and $P_{MW\ Limit}$ is the thermal loading limit of the line.

(b) GM Sensitivity Index

Generation Mix Sensitivity index is arrived based on different Generation Mix strategies without renewable energy integration for System peak and off peak demand conditions.

The GM Sensitivity Index is expressed as

$$SI_{GM} = \left(\frac{P_{GM}}{P_{MW\ Limit}} - 1\right) \quad (8)$$

where P_{GM} is the line Power flow during different generation mix with system peak and off peak demand.

(c) REI Sensitivity Index

Renewable Energy Integration Sensitivity index is formulated using the three different generation mix strategies with renewable energy integration for peak and off peak demand pertaining to wind season.

The REI Sensitivity Index is expressed as

$$SI_{REI} = \left(\frac{P_{REI}}{P_{MW\ Limit}} - 1\right) \quad (9)$$

where P_{REI} is the line power flow during different generation mix strategies with renewable energy integration for peak and off peak demand pertaining to wind season.

2.4 Optimal Placement of TCSCs based on Novel Sensitivity Indices

Three different novel sensitivity Indices have to be arrived for all the lines. Positive sensitivity index indicate overloading of the line. The value of positive sensitivity indices and number of occurrences of positive sensitivity indices are to be noted for all the positive sensitivity lines. Ranking of lines to place TCSCs to be done based on the value of positive sensitivity indices and number of occurrences of positive Sensitivity Indices. The line with highest values of positive sensitivity index and more number of occurrences of positive Sensitivity Indices ranks first for locating TCSC and the same order the second, third TCSC may be placed till the removal of all the overloads.

2.5 Objective function for optimal Settings of TCSCs

After selection of lines for placement of TCSCs, the setting of the TCSCs have been found out using constriction factor based PSO with the objective of removing or minimizing the overloads in the system. The objective function has been solved with TCSC constraints along with power balance constraint. The TCSC has been chosen for this work because of its advantage in smooth and flexible control of power flow.

Objective function = Minimise $\left[\sum_{j=1}^{n} \mathbf{OVL}_j \right]$ (10)

$$OVL = \begin{cases} 0 & ; \text{ if } P_{pq} \leq P_{pq}^{max} \\ P_{pq} - P_{pq}^{max} & ; \text{ if } P_{pq} > P_{pq}^{max} \end{cases} \quad (11)$$

where

OVL : Overload value of a line in MW
P_{pq} : Real Power flow between buses p and q
P_{pq}^{max} : Thermal limit for the line between buses p and q

TCSC Constraint:

$$-0.5X_L < X_{TCSC} < 0.5X_L \quad (12)$$

Here X_L indicate the reactance of the transmission line in per unit, whereas X_{TCSC} refers reactance of TCSC to be incorporated in the transmission line in per unit

Power Balance Constraint

To solve the optimization problem, power balance equation are taken as equality constraints. The power balance equation is given by

$$\sum P_G = \sum P_D + P_L \quad (13)$$

where

$\sum P_G$ – Total Power Generation

$\sum P_D$ – Total Power Demand

P_L – Losses In transmission network

3. Methodology

Power flow study for a plan period of three years has been proposed as Base Case, Case -1 and Case2 to identify the line getting overloaded in all the three years thereby avoiding redundant incorporation of TCSC controller. Lines with Positive Sensitivity Indices in all the above case studies are considered for placement of TCSCs.

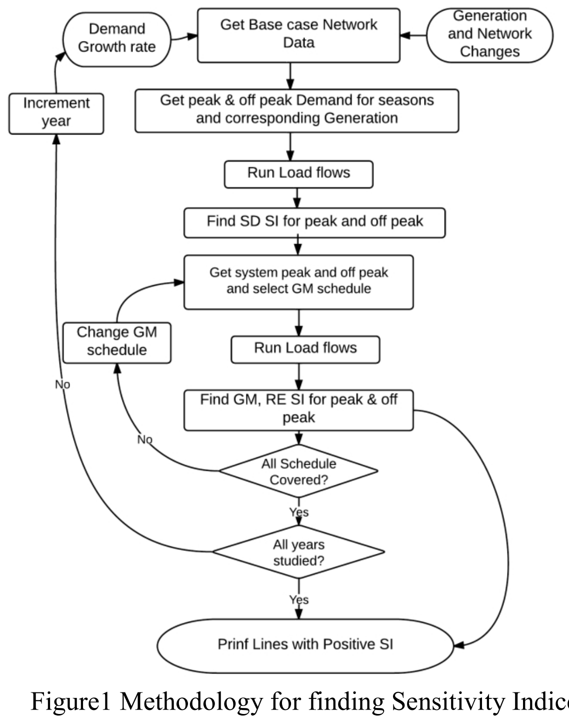

Figure1 Methodology for finding Sensitivity Indices

Figure-1 depicts the methodology for finding the novel sensitivity indices. The computation steps involved in finding the novel sensitivity indices for all the lines in the system is presented below

3.1 Computational steps

Step 1 : Calculate SI_{SD} from base case results for peak and off peak demand of all load buses for five different seasons.

Step-2 : Calculate SI_{GM} from base case results for GM Schedule I, II and III with system peak and off peak demand.

Step-3 : Calculate SI_{REI} from base case results for generation Schedule IV,V and VI with peak and off peak demand pertaining to wind season.

Step-4 : Calculate SI_{SD} , SI_{GM} and SI_{REI} from case-1 results based on projected demand without capacity addition and network augmentation.

Step-5: Calculate SI_{SD} , SI_{GM} and SI_{REI} from case-2 results based on projected demand with capacity addition and network augmentation

3.2 Constriction factor based PSO and its implementation

PSO is a population based self adaptive, stochastic optimization technique [9,14]. PSO is developed through simulation of bird flocking in two dimensional spaces.

The following equations are utilized in computing the position and velocities in the x-y plane.

$$V_i(k+1) = \varphi \{V_i(k) + c_1 * rand_1 \; (P_{besti} - S_i(k)) + c_2 * rand_2 * (G_{besti} - S_i(k))\} \quad (14)$$

$$S_i(k+1) = S_i(k) + V_i(k+1) \quad (15)$$

where

$V_i(k)$ = velocity of particle i at the k^h iteration

$V_i(k+1)$ = velocity of particle i at k+1 th iteration

φ =Constriction factor, which is function of c_1 and c_2

$$\varphi = \frac{2}{\left| 2 - c + \sqrt{c^2 - 4c} \right|} \quad (16)$$

$rand_1$ = Random number between 0 and 1

$rand_2$ = Random number between 0 and 1

$P_{best\,i}$ = Best position of i^{th} particle

$G_{best\,i}$ = Best position among the Particles (group best)

$S_i(k)$ = Position of particle i at k^{th} iteration

The velocity of the particle is modified by using the equation (15).

The Value of constriction factor is taken as 0.786 to enable quick convergence. The weighing factors C_1 and C_2 are taken as 2.The population of 20 and number of iterations 10 are considered in the computing process.

Calculation of fitness function:

Fitness function = (OVL) (17)

Algorithm :

Step 1: Line data, bus data, No.of TCSC devices and number of iteration is entered.

Step 2: Initial population of particles is created duly taking care of TCSC constraints.

Step 3: Evaluate the fitness function for the particles generated above.

Step 4: P_{best} and G_{best} for the individual particle and as a group is identified.

Step 5: The velocity is updated using (14) and new population is created using .(15)
Step 6: Check for number of iteration, if iteration limit is reached, go to step 7. Else go to step 3.
Step 7: Print G_{best} for TCSC setting.

4. Simulation Study

4.1 Test System

The power network of a metro City in India is considered for this study of optimal location of TCSC controllers. Figure-2 shows the practical 36 Bus system considered for this study. The network of 230 KV level and 400 KV level covering 22 Numbers 230/110 KV Substations of 3600 MVA, 4 Numbers 400/230-110 KV Substations of 1500 MVA, 2 major thermal stations of 1080 MW total capacity, about 500 MW of captive & independent power plants, about 1000 MW power from CGS and 500 MW power from WEGs are considered. The total demand in the study area is about 2700 MW. Based on the Electric Power Survey(EPS) report of Central Electricity Authority, New Delhi and historical data on load growth, the demand projection of 8 percent per annum is considered. Simulations are carried out in MATLAB.

The following cases are considered for conducting power flow studies

Base Case (Year 2011-12): Existing Network Condition.

Case-1 (Year 2012-13) : Base Case + 8%demand projection + without capacity addition in generation and transmission system

Case-2 (Year 2013-14): Case-1 + 8%demand projection + capacity addition in generation and transmission system

Base Case is considered to know the transmission line loading of the existing system. Case-1 is considered to analyze the impact of demand growth on transmission line loading in the next year presuming no generation capacity addition and transmission system augmentation to reflect the realistic scenario of Indian power system. Case-2 is considered to reveal the impact of demand growth with generation capacity addition and transmission system augmentation on transmission line loading in the successive year.

4.2. Analysis of Results

The sensitivity indices of SD, GM and REI are arrived for all the lines of the test system for base case, case-1 and case-2. The lines with positive index for the different sensitivity indices are listed in Table-1 to Table-3 for base case, case-1 and case-2 respectively.

Radial lines and power evacuation lines with positive sensitivity indices if any need not be considered for TCSC placement since the capacity of these lines must be augmented. On identifying the overloaded lines in all the three cases based on positive sensitivity indices, the lines are prioritized based on value of positive sensitivity indices and number of occurrences of positive Sensitivity Indices in each line. The line 6, 10, 15, 22 are identified with positive Sensitivity Indices. Among the above lines, line 6, 15 are having positive sensitivity Indices in all the three years depicted in figure-3. Further, lines are ranked based on the value of positive sensitivity indices and number of occurrences of positive Sensitivity Indices in each line in Table-4. Line-6 has highest values of positive sensitivity indices with more number of positive sensitivity indices when comparing with line-15. Thus the base case, case-1 and case-2 results has been compared.

Table-1: Positive SI for the Base case

Line No	Sensitivity Indices	SI_1	SI_2	SI_3	SI_4	SI_5
6	SD(Peak)	-	-	0.12	-	0.19
	GM(Peak)	0.37	0.25	-	NA	
	RE(Peak)	-	0.17	-		
	SD(Off Peak)	-	-	0.06	-	0.16
	GM (Off Peak)	0.12	-	-	NA	
	RE(Off Peak)	-	0.1	-		
15	GM(Peak)	0.26	0.1	-	NA	
	RE(Peak)	-	0.11	-		
	GM (Off Peak)	0.41	0.25	-		
	RE(Off Peak)	-	0.16	-		

Table-2: Positive SI for Case-1

Line No	Sensitivity Indices	SI_1	SI_2	SI_3	SI_4	SI_5
6	SD(Peak)	0.01	0.02	0.19	0.02	0.26
	GM(Peak)	0.44	0.32	-	NA	
	REI(Peak)	-	0.24	-		
	SD(Off peak)	-	-	0.04	-	0.13
	GM(Off peak)	0.14	0.01	-	NA	
	REI(Off peak)	0.1	-	-		
10	SD(Peak)	-	-	-	0.005	-
	SD(Off peak)	-	-	0.01	0.06	0.03
15	GM(Peak)	0.21	0.05	-	NA	
	REI(Peak)	-	0.05	-		
	GM(Off peak)	0.38	0.23			
	REI(Off peak)	-	0.14	-		
22	SD(Off peak)	0.32	0.31	0.4	0.26	0.42

Table-3: Positive SI for the Case-2

Line No	Sensitivity Indices	SI_1	SI_2	SI_3	SI_4	SI_5
6	SD(Peak)	-	-	0.13	-	0.23
	GM(Peak)	0.3	-	-	NA	
	REI(Peak)	-	0.02	-		
	SD(Off Peak)	-	-	-	-	0.08
15	GM(Peak)	0.14	-	-	NA	
	REI(Peak)	-	0.01	-		
	GM(Off peak)	0.32	0.17	-		
	REI(Off peak)	-	0.08	-		
22	SD(Off peak)	0.32	0.31	0.4	0.26	0.42
	GM(Off peak)	0.16	0.16	0.16	NA	
	REI(Off peak)	0.23	0.23	0.23		

Considering the above points for TCSC incorporation, the line 6 is the first preferred location. Line 15 is the second preferred location. Line-22 is the third best location. Thus based on the number of availability of TCSC controller, the location may be identified in the same way

Figure -3 : Overloaded Lines in all the year condition

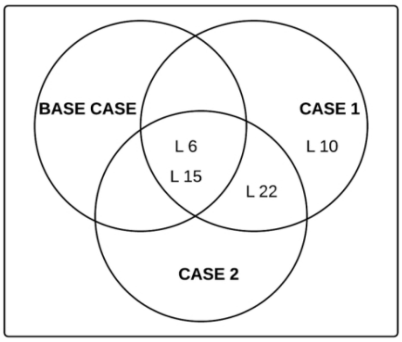

Table-4: Lines Priority for placement of TCSCs

Line No	Parameter	Base Case	Case1	Case2
6	No of Positive SI / Total SI	9/24	13/24	5/24
	Max. Positive SI value	0.37	0.44	0.3
15	No of Positive SI / Total SI	6/24	6/24	5/24
	Max. Positive SI value	0.41	0.38	0.32

. Figure-4 shows line flows with major impact after placement of TCSCs. Table-5 shows the TCSC values chosen to avoid overloading in the chosen 36 Bus Indian Grid System.

Fig.4. Comparison of Power flow in lines with TCSC and With and without TCSCs

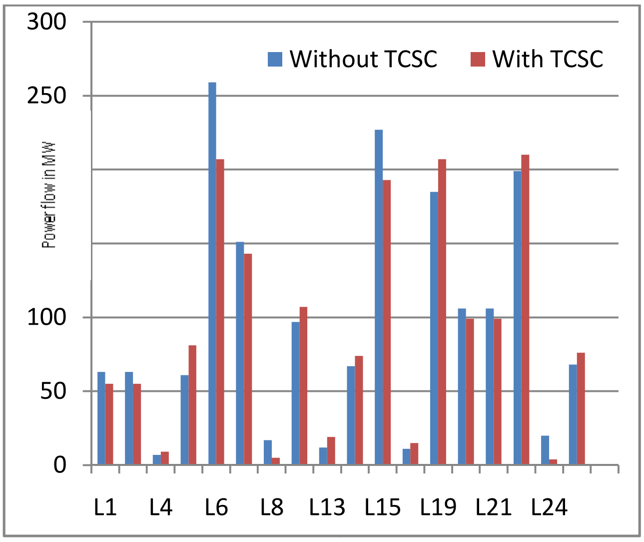

Table-5 TCSC values to minimize overload in 36 Bus Indian Grid System

Line No	Line X value in Ohm/KM	TCSC Value in Ohm/KM
6	0.4367	0.259
15	0.4367	0.0983

5. CONCLUSIONS

The Novel Sensitivity Indices have been proposed based on vital factors influencing the transmission line loading. The computation and application of novel sensitivity indices for optimal location of TCSC for secured power flow in the grid system have been presented systematically. The constriction factor based PSO is utilized for finding the settings of TCSC. The simulations are carried out for checking the validity of the proposed methodology using a practical Indian Grid system consisting of 36 Bus at 230 KV and 400 KV level supplying power to a metro City in India. The study results prove the significance and effectiveness of the proposed novel sensitivity indices in deciding the optimal location of TCSC for secured power flow in the grid system. The proposed approach can also be implemented for improving the voltage profile of the system using different FACTS controllers.

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Figure -2 : Indian Power Utility Network 36 Bus system