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Congestion management of System by optimal placement of TCSC inacontingency condition

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With the restructuring in the Indian Power Sector, the power sector management have been going through major transformation in the generation, transmission and distribution areas. To meet the load demand it's still a huge challenges. Due to contingency line constraints are violated, which leads to congestion, thus threatening the overall security of the interconnected system. TCSC is used to relieve the congestion in the system. In this paper, TCSC placement in an N-1 Contingency case is located through the PSO by forming the weighting function considering system index in a6 bus system and 14 bus system using MATPOWER tool.

Keywords: TCSC, PSO, Congestion, Contingency, MATPOWER

Introduction

In a real-time, ideal condition for the power sector management is to achieve the balance between generation and the load demand without violating the system constraints. However, with the urbanization and industrialization, load consumption is increasing every day. Indian power sector went through a major transformation with delicensing in the GENCOS, TRANSCO, DISCOMS through the Electricity act 2003. Though now the power sector is changed through from the conventional vertically integrated power sector to deregulated power sector[1]. Now with restructured power systems, a more private player is participating in the generation sector. In India, the power sector is still taken as a social service rather than the market commodity and which provide leverage to the load side; thus, the distribution sector is the suffer from heavy financial losses.

With restructured power systems, many players are selling the power to the grid without maintaining the power quality. Also, the power agreement in India is still a long term agreement between the buyer and the seller. Open access for exchange is a small fraction of this.

With increasing load demand, buyers are withdrawing more than there allocated capacity through threatening the network. Overloading, branch outage, generation outage or equipment failure leads to congestion in a system. Congestion is the condition when the power flows in a branch more than the Actual transfer capacity (ATC).

Congestion violates voltage constraints, stability and the higher thermal capacity of the line[2]. If congestion is not relieved timely than it may further causes disturbances and thus blackout the whole

region[3]. Congestion problem is easily solved by establishing a new transmission line butconstructing a new transmission line take year to be operation and Cost nearly crore of the rupee. Also, with the rising environmental problem, evacuating new land in urban areas is done through generation rescheduling, FACTS devices, nodal pricing, zonal pricing and market splitting. FACTS devices are used to relieve the congestion, thus ensuring the system constraints and stability. TCSC is series of FACTS devices used to relieve the congestion also it mitigating the sub-synchronous resonance[4].

Installed Capacity in India by sector-wise and by different sources which are contributing to the grid to meet the load demand is shown in table 1 and table 2 respectively[5].

Table 1. Total Installed Capacity (July/2020) as per Central Electricity Authority (CEA) in India

Sector	MW	Total Percentage
Central Sector	94,027	25.3%
State Sector	103,652	27.9%
Private Sector	174,298	46.9%
Total	3,71,977	

Thyristor-controlled series capacitor (TCSC)

TCSC is formed through a Capacitor shunted by a Thyristor -Controlled Reactor (TCR) to provide reactive support to the line. TCSC is placed in series with the transmission line[6].The main consideration for TCSC is as it's immune to sub-synchronous resonance, better control, line current harmonics with TCSC is lower than the ambient system harmonics, dynamic stability, compensation of reactive power, increasing the active power flow. TCSC has two operating ranges; one is inductive for is huge challenges. Congestion management $0<\alpha<\alpha_{Llimit}$ andcapacitive for $\alpha_{Climit}<\alpha<90$ degree.

Table 2. Generation Capacity by different sources in India

Fuel	Generation in MW	Total Percentage
Total Thermal (Coal, Lignite, Gas, Diesel)	2,31,456	62.2%
Coal	1,99,595	53.7%
Lignite	6,360	1.7%
Gas	24,992	6.7%
Diesel	510	0.1%
Hydro	45,699	12.3%
Nuclear	6,780	1.8%
Renewable EnergySources	88,042	23.7%
Total	371,977	

Series reactance is generally known as TCSC whose reactance limit is lie as[7] :

$$-0.8x_{line}< x_c<0.7x_{line}$$

Where, $X_{line}$is branch reactance and X_{TCSC} reactance of the TCSC.

Congestion in a system

Load flow is solved using optimal power flow in a 6-bus system and 14 bus system for the base case. Outage in generators or transmission line, overloads causes Congestion in a system. In this paper, N-1 contingency is created arbitrarily through outage of one transmission line[8].MATPOWER code run the optimal power flow for 6-bus system and 14-bus system. In this paper, the congestion is created through branch outage.

System Weighting function

The objective in this paper is to locate the TCSC in a congested line while maintaining thermal constraints and power flow constraints in the transmission network. A fitness function is formed for the PSO by considering the system index.

Voltage Deviation Index

Voltage profile of a system must be within the limit[9].

$$V_{index} = \frac{(V_r - V_n)}{V_r} \qquad (1)$$

V_r=voltage after outage (slack bus)

V_n: voltage after each iteration

Minimum voltage deviation index of the TCSC is the main objective in the equation as mentioned above.

Loss Parameter index

Here , Total losses is calculated in term of MVA[10].

$$S_l = P_l + jQ_l \qquad (2)$$

$$S_{index} = \frac{S_{ln}}{S_{lb}} \qquad (3)$$

Where,

S_l=P+jQ

S_{ln}=New losses

S_{lb}= base losses

Minimum loss parameter index of the TCSC is the main objective in the equation as mentioned above.

Reliability

To find out system reliability, the most important performance index used is Reliability. Energy not transferred to the network is considered as Energy not served. Failure in the substation results in Energy not served (ENS)[11].

ENS to the user through the equation is given in equation (4).

$$\text{ENS}=\alpha d \sum_{k=1}^{N} \lambda_k \,|I_{kp}|\, {*}V_{rated} \qquad (4)$$

In the above equation, the peak load current of the branch is denoted by I_{kp} ,the rate of failure for the k^th^ branch or line is denoted by λ_k and V_{rated} signifies the rated voltage of the system. The load factor and duration of repairing are denoted by and, respectively.

In equation (7), the system reliability is given by:

$$R = \left(1-\frac{\text{ENS}}{\text{PD}}\right) \qquad (5)$$

Where, R is reliability, energy not served is ENS and the total load demand is PD.

The aim is to increase Reliability to the maximum level.

Single Objective Weighting Function

$$= 0.5V_{index} + 0.3S_{index} + 0.2R^{-} \qquad (6)$$

Where

f is single objective weighting function

All the above objective function is used in a single objective weighting function to make the fitness function needed for PSO. The highest weighting factor is considered for the voltage deviation, then loss index. The primary objective is to keep the fitness function for the optimal location of TCSC in a 14 bus system at a minimum level.

Particle Swarm optimization (PSO)

PSO is inspired by the social behaviors of the bird's swarm. In 1995, PSO was developed by the Kennedy and Eberhart to solve non-linear problems.

PSO is an optimization technique based on the movement of the swarms.PSO uses the same optimization technique as used by the bird to search for food in a particular area. In a search space, through fitness function fitness values are evaluated and accordingly, particles velocity and position is updated. In a search space, every particle adjusts it is flying based on its own and others flying experience. Pbest is the local best, obtained so far by a particular particle and Gbest is the global best or overall best, obtained so far by any particles which are associated with the fitness solution.[12]

The particles and velocity updates is shown in equation 7 and 8, respectively.

$$v_{ik} = w * v_{ik} + c_1 * \text{rand} * (P_{bi} - s_{ik}) + c_2 * \text{rand} * (G_{bi} - s_{ik}) \quad (7)$$

$$s_{ik} = s_{ik} + v_{ik+1} \quad (8)$$

Where,

v_{ik} denote velocity of particle i at k th iteration

v_{ik+1}denote particle i velocity at (k+1)th iteration, denote inertia weight, c_1=c_2= Learning factor, s_{ik}denote Current position of particle i at kth iteration, s_{ik+1}denote Current position of particle i at (k+1)th iteration, P_{bi} denote particlei best position, G_{bi} denote global best position.

Results and Discussion

Optimal load flow is used to obtain in the 6 bus system and 14 bus system. Then N-1 Contingency is created by the outage of branch 5. Then the PSO technique is to get the optimal location of TCSC by forming a fitness function. The fitness function is formed through the multiple system index considering the losses, voltage deviation profile, reliability. Each of the indexes is provided with a weighting factor according to the system preference.

Case 1: TCSC in a 6 Bus System

In a6 bus system, the optimal location of TCSC in the base case is at branch 8 (in-between bus 3 and bus 5). With TCSC, voltage profile is improved significantly at bus 5. Voltage profile for the base case and with TCSC is shown in figure 1.

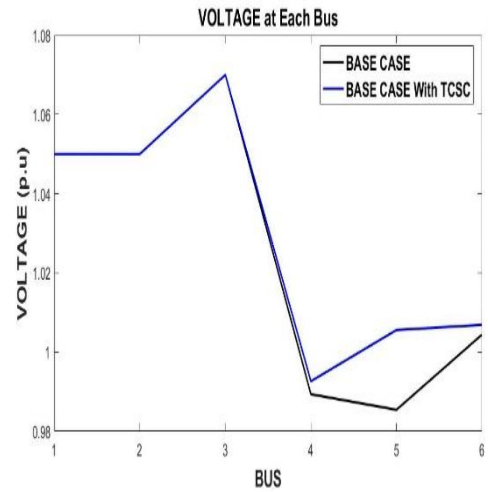

Fig. 1. Voltage at each bus in base case and with TCSC in 6 bus system

By using TCSC the active power in a branch is increased by a more significant margin in a 6 bus system, as shown in figure 2.

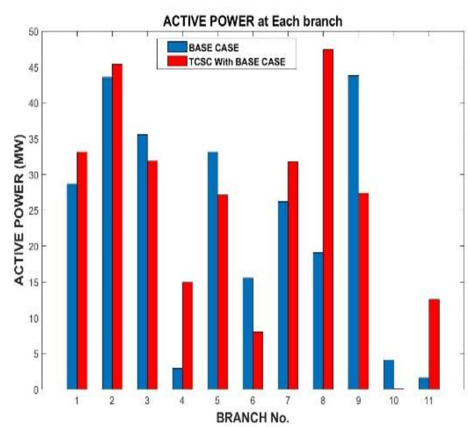

Fig. 2 Active power flow at each branch in base case and with TCSC in 6 bus system

Losses

Through the use of TCSC, the losses are reduced to a greater extend, as shown in the table 3.

Table 3. Loss in base case and after TCSC

Base Case (MVA)	Base Case with TCSC (MVA)
25.4166	24.0142

Case 2: 14-bus system

Voltage Profile

Voltage for the base case, N-1 Contingency case and with TCSC case is obtained and is shown in table 3. The deviation allowed for the voltage is 5% as per the Indian grid code. In the Contingency case, the voltage profile gets deviated and is at lower permissible limits, and with TCSC the voltage at respective buses get improved through are within the system constraints.

Table 4. Voltage Profile with Base Case , N-1 Case and with TCSC case

Bus No.	Base Case	Outage Case	TCSC Case
1	1.0600	1.0600	1.0600
2	1.0408	1.0439	1.0435
3	1.0156	1.0162	1.0149
4	1.0145	1.0110	1.0094
5	1.0164	1.0097	1.0116
6	1.0600	1.0600	1.0600
7	1.0463	1.0451	1.0444
8	1.0600	1.0600	1.0600
9	1.0437	1.0429	1.0424
10	1.0391	1.0385	1.0381
11	1.0460	1.0458	1.0456
12	1.0448	1.0447	1.0447
13	1.0399	1.0399	1.0398
14	1.0239	1.0234	1.0231

Losses

N-1 contingency leads to congestion occurs in the system, which results in line reach its thermal limits and flow of current reach to reach its limits, which amplify the losses. Reactive power compensation is done with TCSC, and it removes the congestion, hence reduce the loss of the system. This paper discusses that the cumulative losses of the system are the summation of individual losses for all branches and cumulative losses for all the cases is as given in table 4.

Table 5. Comparison of losses with Base Case , N-1 Case and with TCSC case

Base Case (MVA)	40.2470
Outage Case (MVA)	42.8136
TCSC Case (MVA)	41.5135

In an N-1 Contingency case, the losses are increased by 2.5666 MVA, and with TCSC in contingency case, the losses are reduced by 1.2991 MVA.TCSC is in the capacitive region, so the overall reactance of the branch decreases.

Reactive Power Flow

More difference in voltage between two buses lead to more reactive power. Due to outage, the whole active power and reactive power flow from different branches by optimal power flow method as the load consumption is same. The reactive power touches the upper limit in congested lines. A reactive power compensation in a branch is obtained with the help of TCSC.Reactive power for all the three cases in the respective branches is shown in the table 6.

The deterioration of N-1 outage of voltage profile leads to an increase in reactive power and reach up to its maximum extend. TCSC improved the voltage profile via reactive power compensation and contained it within its limit. The active power in the branch is increase by TCSC. Transmission line remains within the thermal limits with TCSC.

Table 6. Reactive Power Flow in the outage branch and in branch where TCSC is placed

	Reactive Power in Branch 5 (MVaR)	Reactive Power in Branch 2 (MVaR)
Base Case	1.5903	6.3651
Outage Case	Outage	8.3162
TCSC Case	Outage	6.7874

Conclusions

This paper discusses the PSO based approach, used to locate the optimal location of TCSC. The function is formulated as an optimization problem to minimize the voltage variations in a system using TCSC. The optimal location of TCSC considering the weighting function is found through the PSO. Reliability of the system is also considered for the formation of the weighting function. The result obtained is for a standard 14-bus system. PSO is used to obtain an optimal location on the branch. With the N-1 outage, voltage profile of the system is very worst and also the losses in the system were increased, thus threatening the security constraints of the system. The voltage profile is greatly improved, reliability of the system is improved, and also the losses are less as compared with the N-1 outage by optimally locating of TCSC.

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