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Differential Evaluation based Power flow control by using TCSC and split TCSC

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***Abstract* - The power system gets more stressed due to increasing loads and the need to transfer power over long transmission lines increases. The obvious and most effective measure to increase transmission capability is to build a new transmission line. However, this is a time-consuming solution as well as an expensive one. If voltage limits or voltage stability are the determining factors for the transfer capability, additional sources of reactive power can be installed at critical location in order to smoothen the voltage profile and to increase the power flow of transmission line.**

In literature, transmission line capacity was increased by using Thyristor Controlled Series Capacitor (TCSC) and micro tuning of line reactance by implementing split TCSC in place of single TCSC due to large change in TCSC reactance nearby resonance region. Loss sensitivity method is used for optimal placement of single TCSC and split TCSC. In proposed method, Differential Evaluation (DE) Optimization technique is used for placement of TCSC and split TCSC and its mathematical model was also studied. Power flow and power loss variation using TCSC and split TCSC is examined. The IEEE-14 bus system is used as a case study in MATLAB programming software.

***Key words*: Differential Evaluation (DE), Single TCSC and Split TCSC.**

I. INTRODUCTION

Electric power systems around the world are all of different sizes; each having its own generation, mix transmission structure and load capacity. Nevertheless, all of them share similar construction and operating principles, with four main elements becoming, at first sight, more visible, namely generating units, transmission lines, transformers and loads. Control and protection equipment have a vital function to play and they also constitute essential elements of the electric power system. From a dynamic view point, generating units and loads are the most important elements of the electric power system. In developing countries, there is unpredictable increase in power demand commercially and industrially, thereby providing quality and procure power to the consumers become a difficult task. Due to this increase in power demand, power transmission system has to maintain reliability and security during transmission of power. The rise in demand can be met by construction of additional transmission lines to provide more power. But construction of new transmission lines in addition is not a economical thing due to cost included in erecting towers, insulators and conductors. Using fixed capacitors which provide fixed series compensation is a economic technique compared to construction of additional transmission lines which was first used in USA. With the advent of power electronics smooth variation of compensation came in to existence instead of fixed series compensation. FACTS controllers narrow the gap between the non-controlled and the controlled power system mode of operation, by providing additional degrees of freedom to control power flows and voltages at key locations of the network. Key objectives of the technology are to increase transmission capacity allowing secure loading of the transmission lines up to their thermal capacities to enable better utilization of available generation and to contain outages from spreading to wider areas.

Among Flexible AC Transmission system (FACTS) devices, the Thyristor Controlled Series Capacitor (TCSC) device reduces the transmission line reactance. The reduced value of transmission line reactance enhances the active power flow in the transmission line and may be loaded up to thermal limits without incurring more loss in the line. These features of TCSC device enhance the transmission system to transfer the desired power at right line [1]. Many TCSC projects are installed worldwide and are operational .The Slatt TCSC project is unique in the sense that has Six TCSC modules connected in series. Application of multiple TCSC has given the idea of splitting the degree of compensation (k) which has benefits of power flow improvement and thus application of split TCSC is used in the transmission line over single TCSC. Mohan Mathur and Varma[2] presented that the reactance vs. current (X–I) capability curves for multi modules of TCSC reveals feasible combination of tuning multi TCSC providing micro tuning of net reactance in the line[3]. From the single TCSC reactance characteristic curve it is observed that small change in reactance with increase in

firing angle of TCSC thyristors but near resonance region each step of a firing angle makes a huge elapse of reactance. Hence proper tuning of reactance is not possible.
In literature, with the help of Single TCSC and Split TCSC transmission line capacity was increased. With Split TCSC they achieved fine power flow and Loss sensitivity method is used for the optimal placement of Split TCSC [3]. In the proposed method Differential Evaluation is used to place the Single and Split TCSC.

II. OPERATION OF SINGLE AND SPLIT TCSC

A. Operation of Single TCSC

It consists of series capacitor and thyristor controlled reactor (TCR) connected in parallel and TCR is controlled by firing angle∝ and its structure is taken from [3].The reactance characteristics of a TCSC device drawn between effective reactance of TCSC and firing angle ∝ and limitation angles as shown in [3]. The effective reactance 'X_{TCSC} (α)' of TCSC operates in three regions are inductive, capacitive and resonance.

B. Operation of Split TCSC

By using single TCSC it is difficult to utilize the full range of reactance, that's why split TCSC comes into picture [3]. It's structure is shown in below Fig.1. The TCSC has four normal modes of operation such as blocking mode, bypass mode, venirer inductive mode and vernier capacitive mode and additionally one more mode is possible which is known as cutoff mode. By making any one TCSC in cutoff mode, other can be tuned.

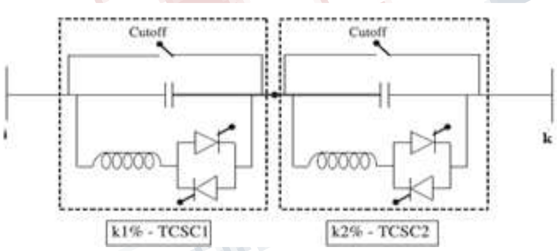

Fig.1: Schematic diagram of Split TCSC.
Modeling of single TCSC and Split TCSC with Newton Raphson Power Flow Analysis (NRPFA) is in [3, 4].

III. OPTIMAL PLACEMENT OF TCSC WITH DIFFERNTIAL EVALUATION (DE)

Differential evaluation is an effective, simple, fast, robust, inherently parallel, and has few control parameters need little tuning. It can be used to minimize non-linear, non-continuous, non-differentiable space functions, also it can work with noisy, flat, multi-dimensional, and time dependent objective functions and constraint optimization in conjunction with penalty functions [5]. Similar to other evaluation algorithms techniques, differential evaluation is a heuristic, population-based optimization method that uses a population of points to search for a global minimum of a function over continuous search space. The main steps of de involve intialisation, mutation, crossover and selection [6]. Step by step procedure of de is shown in the fig.2.

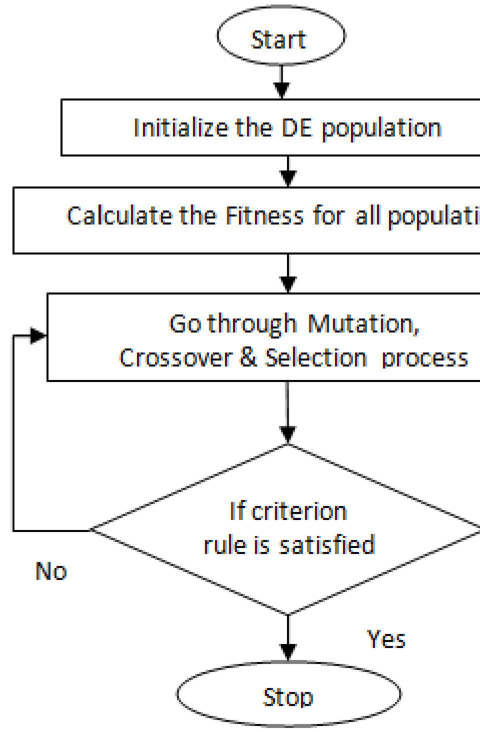

Fig.2: Flow chart of Differential Evaluation

IV. MATHEMATICAL MODELING OF DIFFERENTIAL EVALUATION

The main objective of this work is to determine the optimal location and the optimal parameter setting of the single TCSC and split TCSC in the power network to minimize the loss of the power system and to improve the power flow of the line is:

$$\min F = \sum_{k=1}^{ntl} P_{LK} \tag{1}$$

Subject to the following equality constraints

$$P_{gi} - P_{di} - \sum_{j=1}^{N} V_i V_j Y_{ij} (\vec{x}_{tcsc}) \cos(\delta_{ij} + \gamma_{ij} - \gamma_i) = 0 \tag{2}$$

and

$$Q_{gi} - Q_{di} - \sum_{j=1}^{N} V_i V_j Y_{ij} (\vec{x}_{t\,csc}) \sin(\delta_{ij} + \gamma_j - \gamma_i) = 0 \quad (3)$$

and following inequality constraints

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad \forall i \in N_G \quad (4)$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \qquad \forall i \in N_G \quad (5)$$

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad \forall i \in N \quad (6)$$

$$\delta_{ij}^{\min} \le \delta_i \le \delta_{ij}^{\max} \qquad \forall i \in N \quad (7)$$

$$x_{t\,csc}^{\min} \le x_{t\,csc} \le x_{t\,csc}^{\max} \quad (8)$$

$$\alpha^{\min} \le \alpha \le \alpha^{\max} \quad (9)$$

The step by step DE algorithm for the optimal placement of TCSC and split TCSC is as follows.

Step I. Initialize power flow data, and DE related parameters such as the size of population (NP), the maximum number of iteration or generation $(G_{\max})$, the number of variables to be optimized.

Step II. Randomly generate the initial population of NP. Considering the variables that should be optimized (i.e., the location and the parameter setting of TCSC).

Step III. Evaluate the fitness for each individual in the population according to the objective function in equation (1).

Step IV. Create a new population by:

Mutation: randomly choose three different vectors from the current population and generate a trial vector by:

$$\underline{V} = \underline{X}_{r1,G} + F.(\underline{X}_{r2,G} - \underline{X}_{r3,G}) \quad (10)$$

Crossover: For each $\underline{X}_{i,G}$ to get new vector $u_{i,G}$ use:

$$u_{j,G} = \begin{cases} V_{j,G} & for\, j = \langle n \rangle_D, \langle n+1 \rangle_D, \ldots, \langle n+L-1 \rangle_D \\ (X_{i,G})_j & for\ all\ \ other\ \ j \in [0, D-1] \end{cases} \quad (11)$$

Selection: For each $\underline{X}_i$, G and corresponding $u_{i,G}$ to select vectors for the next generation, $G = G + 1$. Use:

$$X_{i,(G+1)} = \begin{cases} u_{i,(G+1)} & if \quad f(u_{i,(G+1)}) \le f(X_{i,G}) \\ X_{i,G} & otherwise \end{cases} \quad (12)$$

Step V. Stop the process and print the best individual (optimal location and optimal parameter setting of TCSC) if the stopping criterion is satisfied, else go back to step IV.

V. RESULTS & ANALYSIS

Differential Evaluation Procedure Is Used To Find Optimal Placement Of Tcsc And Split Tcsc And Ieee 14 Bus System Is Used As A Case Study**.**

The below Fig.3 shows the single line diagram of IEEE 14 bus system. In that 5 generators and 20 transmission lines with 14 buses.

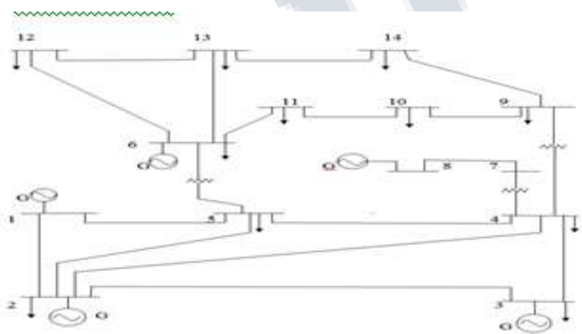

Fig.3: Single line diagram of IEEE 14 bus system.

From the analysis of Differential Evaluation the optimal placement of TCSC is on 20th line between 13 and 14 buses. The below Fig.4 shows the reactance characteristics for single TCSC and this curve is plotted against number of firing points (0-91). In resonance region i.e., from 137° to 148° reactance compensation is not possible by using single TCSC. But in critical region i.e., nearer to resonance, change in reactance starts increasing and gives maximum difference ΔX of 3.1782% hence, fine tuning is not possible. This difficulty is override by using split TCSC for same degree of compensation k.

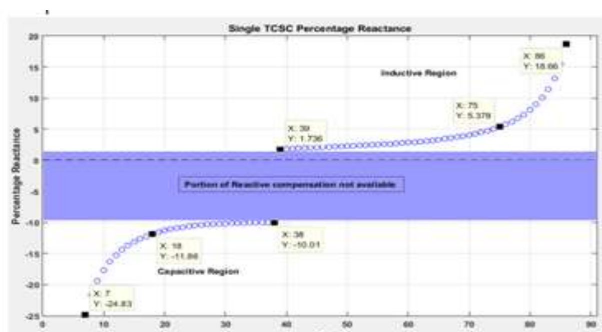

Fig.4: Single TCSC reactance characteristic curve in percentage for IEEE 14-bus system.

The below Fig.5 Shows the Split reactance characteristics curve for k_1 = 2% and k_2 = 8% of compensations with respect to '7444' firing points. The split TCSC reactance can vary from 18.66% to -24.83% for the same resonance region limitation as shown in Fig.4.

Fig.6 shows the percentage real power transfer on 20th transmission line with single TCSC installed in IEEE 14 bus system. Real power transfer without TCSC in line no. 20 (i.e., between bus numbers 13 and 14) is 1.6692 MW in base case NRPFA. Installing single TCSC on optimally selected 20th line makes the transmission line flexible to transfer real power from 94.41% to 99.46% on inductive side and 103.2% to 108.13% on capacitive side; but tuning of power between 99.46% and 103.2% does not exist.

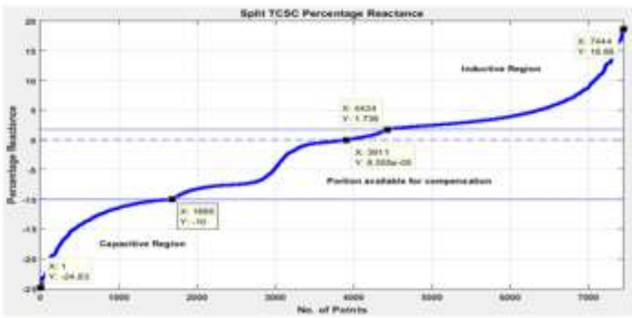

Fig.5: Split TCSC reactance characteristic curve in percentage for IEEE 14-bus system

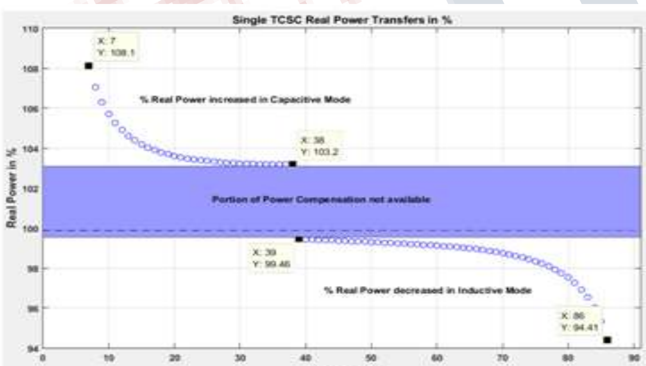

Fig.6: Real Power transfer variation in line 20 with single TCSC for IEEE 14-bus system.

Fig.7 shows that a split TCSC in place of single TCSC for the same degree of compensation (10%) makes the transmission line more flexible and alters power flow in wide range tuning i.e., power between 99.46% and 103.2% .

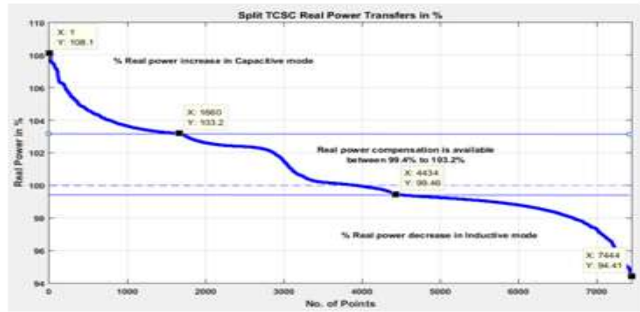

Fig.7: Real power transfer variation in line 20 with split TCSC for IEEE 14-bus system.

Below Fig.8 Shows the power loss curve by providing single TCSC. In this figure the power loss in 20th transmission line is 0.0009 MVA under base case NRPFA. With TCSC, losses increased from 100.9% to 108.9% in inductive mode and are decreased from 94.32% to 84.55% in capacitive mode.

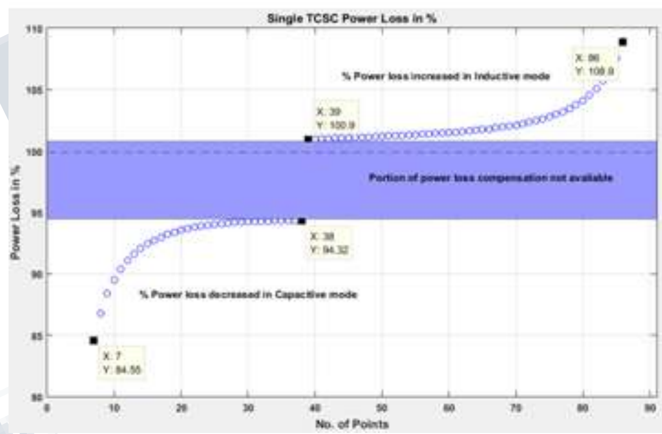

Fig.8: Power loss variation in line 20 with single TCSC for IEEE 14-bus system.

From the Fig.9 it is clear that Implementing split TCSC makes the transmission line power loss to vary at fine rate including portion 94.32 to 100.9%. This is not possible through single TCSC shown as highlighted portion in Fig.8.

Fig.10 shows the voltage profile is analyzed that bus13 and bus 14 are within permissible limits ±5% on both inductive and capacitive mode operations for the case of without TCSC, with TCSC and split TCSC for IEEE 14 bus system.

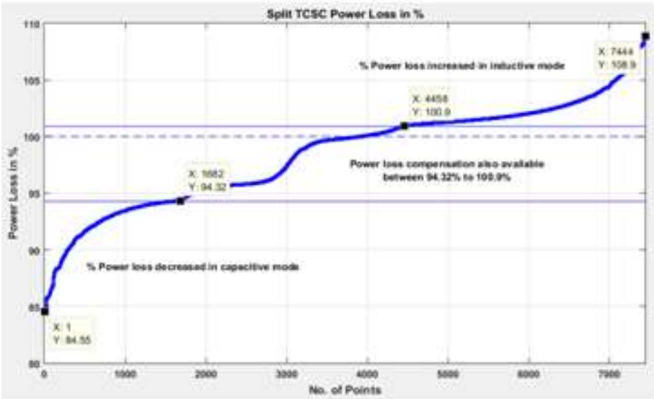

Fig.9: Power loss variation in line 20 with split TCSC for IEEE 14-bus system

Thus fine variation in reactance change, power loss, and transfers the power at any fine increment or decrement of dynamic load.

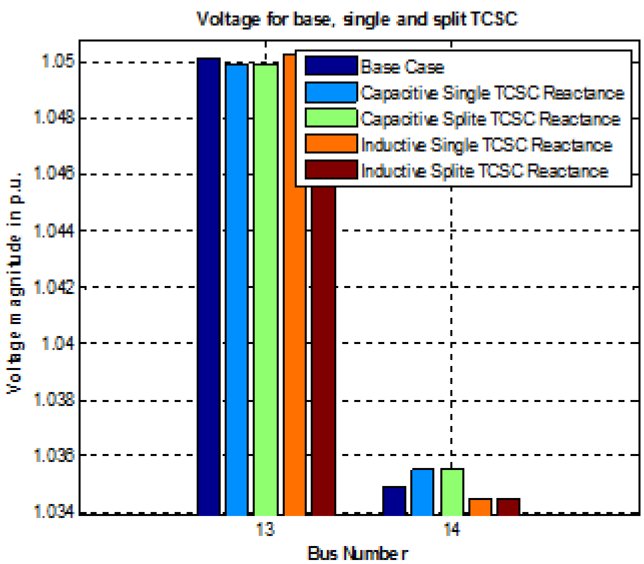

Fig.10: Magnitude of voltages at each bus with single and split TCSC for IEEE 14-bus system.

Table I shows the minimum and maximum change in the reactance, real power and power losses for single and split TCSC compensations. Table II shows that change in real power by using single and split TCSC.

Table I. Minimum and maximum ΔX, ΔP and ΔS_L for IEEE 14-bus system

Type	Degree of compensation (%)	$18.66 < \%X < -24.83$		$94.41 < \%P < 108.13$		$84.55 < \%S_L < 108.86$	
		$\%\Delta X_{min}$	$\%\Delta X_{max}$	$\%\Delta P_{min}$	$\%\Delta P_{max}$	$\%\Delta S_{Lmin}$	$\%\Delta S_{Lmax}$
Single TCSC	10	0.0090	3.1782	0.0029	1.0804	0.0054	1.5650
Split TCSC	1:9	6.1651e-08	0.3932	1.8956e-08	0.1342	3.1426e-08	0.2766
	2:8	**3.5785e-09**	**0.3810**	**1.0990e-09**	**0.1305**	**2.9234e-09**	**0.2710**
	3:7	2.8428e-07	0.2285	8.5297e-08	0.0706	1.3740e-07	0.1397
	4:6	1.6407e-07	0.3533	5.1615e-08	0.1166	8.6969e-08	0.2423
	5:5	0	0.3083	0	0.0900	0	0.1799

Table II. Test results of IEEE 14 bus system

Parameter	Base NRPFA	With Single TCSC (%)	With Split TCSC (%)
Power Flow	1.6692 MW	94.41 - 99.46 103.18 - 108.13	94.41 - 108.13
Max ΔP	-	1.0804	0.1305

VI. CONCLUSIONS

1. This paper presents Differential Evaluation method for the placement of single TCSC and split TCSC in IEEE 14 bus system.
2. By using Differential Evaluation method optimal placement for single TCSC and split TCSC is at line 20 in IEEE 14 bus system, where as in case of Loss sensitivity method it is at line 19. It is also observed that real power compensation is achieved between 99.4% to 103.2% by using single TCSC real power compensation is not available during resonance region.
3. From Table II it is also observed that change in power is decreases i.e., 0.1305% by split TCSC where compared to single TCSC i.e., 1.0804% with this it is proved that by using DE method change in power decreases when compared with Loss sensitivity method i.e., 0.2424% by using split TCSC when compared to single TCSC i.e., 1.2051.
4. Hence, fine control of power in transmission line is observed by fine tuning of line reactance in terms of micro ohms by split TCSC when compared to single TCSC, which is shown in Fig. 4 and Fig. 5.

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BIOGRAPHY

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