Performance Evaluation of Reactive Power Compensation of TCSC and SVC on Voltage Profile Enhancement and Power System Loss Minimization Using Firefly Algorithm

Olakunle Elijah Olabode, Oluwasegun Dayo Ayantunji, Victor Uchenna Nwagbara

Abstract--FACTS devices are alternative means of controlling active and reactive power loss with a view to lower system loss, enhanced system voltage profile, increased transfer capability and improvedsteady state and dynamic performance of power system. The optimal placement, locations and sizes of these devices influence its performance on the grid. This paper presentsperformance evaluation of reactive power compensation of TCSC and SVC on voltage profile enhancement and power system loss minimization using Firefly Algorithm. The results of the analysis showed that with the system reinforced with TCSC, the total system loss reduced from 13.3674MW to 13.2890MW which is about 0.586% reduction. Also the reduction in active power loss with the optimal location of SVCs is 13.2400MW which amount to 0.95 % reduction. An appreciable voltage enhancement occurred at bus 4, 5, 10 and 14 as a result of system reinforcement with TCSCs and SVCs. In all SVC gives better result than TCSC in term of active power reduction and voltage profile enhancement.

Index Terms: Active Power Loss, Firefly Algorithm, Reactive PowerCompensation, SVC, TCSC, Voltage Profile Enhancement

1.0 INTRODUCTION

Effective management of reactive compensation on weak nodes is one of the major challenges in power sector industry and this is largely due to ever-increasing demand for electricity, the environmental constraints in expansion of transmission networks and transmission open access in a restructured power market [1, 2]. Adequate reactive compensation on power system enhances voltage profile, minimizes power loss and it as well improves steady state and dynamic performance of power system [4].

The progressive advancement in the field of power electronics paved way for emergent of FACTS devices whose technologies solely depend on power electronic Devices[1, 4].FACTS devices are solid-state converters endowed with the ability to rapidly and smoothly inject or absorb reactive power by controlling the firing delay angles of thyristors (Valves). With these, it is possible to control the phase angle, the voltage magnitude at chosen buses and /or line impedances of a transmission system [1, 5].

FACTS devices most frequently find in literature for these functions are Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (STATCOM), Unified Power Flow Controller (UPFC) and Interlink Power Flow Controller (IPFC) [6-8]. These FACTS controllers are classified as Series (TCSC and SSSC), Shunt (SVC and STATCOM) and combined Series-Shunt (UPFC) devices based on their existence in the system [9, 10].

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In the recent time, swarm intelligence, population based optimization algorithms are widely employed by researchers in finding the optimal sizes of these devices while load flow techniques still remain the potential tool for finding the exact location for sitting of these devices [11]. Power system loss minimization and voltage profile enhancement has been attempted by quite a number of researchers using these population based algorithms which includes Genetic Algorithm (GA) [12], Particle Swarm Optimization (PSO) [13], Hybrid Binary Genetic Algorithm and Particle Swarm Optimization [14],Bacterial Swarming Algorithm (BSA) [15] and Firefly Algorithm (FA) [16] among others.

In the last one decade, Dr. Xin-She Yang brings to birth firefly algorithm (FA) at Cambridge University, the algorithms was modeled to mimic the inherent flashing characteristics of fireflies [17]. It is one of the newest members of metaheuristic, nature-inspired, optimization algorithms having many similarities with Particle Swarm Optimization (PSO), Artificial Bee Colony optimization (ABC) and Bacterial Foraging Algorithms (BFA) except that it is relatively easier both in concept and implementation and this make this algorithm superior in performance relative to others when it comes to solving complex optimization problems [16, 18-19].

In this paper, the researchers carried outperformance evaluation of reactive power compensation of TCSC and SVC on voltage profile enhancement and power system loss minimization using Firefly Algorithm. The proposed approach identifies the optimal location and the parameters of TCSC and SVC, the depth of loss minimized and the extent of voltage profile enhancement was used as the performance metric. One-line diagram of IEEE 14-bus system used as test system is as shown in Figure 1 below, basically it interconnects five generator buses, nine load buses and twenty transmission lines.

2.0 MATHEMATICAL MODEL OF THYRISTOR CONTROLLED COMPENSATOR (TCSC)

TCSC a series-type reactive power support usually connected in series with the transmission line with the aim of decreasing or increasing the overall lines effective series transmission impedance either by injecting a capacitive or inductive reactance accordingly.

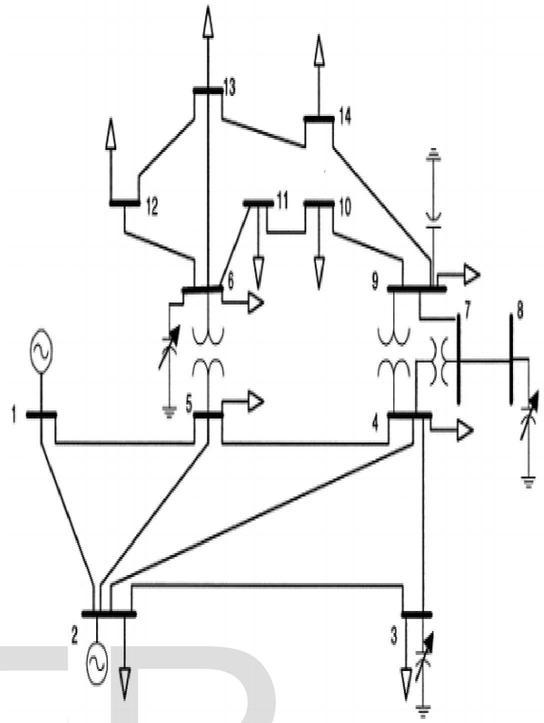

Figure 1: One-line diagram of IEEE 14 bus system

TCSC reactance is within the range of $-0.8X_{line} \le X_{TCSC} \le 0.2_{line}$ to keep the size minimum in a bid to reduce the cost of TCSC to be incorporated into the power system.

The TCSC modelled by the reactance X_{TCSC} is expressed as follows;

$$X_{ij} = X_{line} + X_{TCSC} \tag{1}$$

$$X_{TCSC} = \gamma_{TCSC} X_{line} \tag{2}$$

The variable series compensator expressed in transfer admittance matrix form is as follows;

$$\begin{bmatrix} \Delta I_i \\ \Delta I_j \end{bmatrix} = \begin{bmatrix} jB_{ii} & jB_{ij} \\ jB_{ji} & jB_{jj} \end{bmatrix} \begin{bmatrix} V_i \\ V_j \end{bmatrix} \tag{3}$$

For inductive operation we have;

$$B_{ii} = B_{jj} = -\frac{1}{X_{TCSC}} \tag{4a}$$

$$B_{ij} = B_{ji} = \frac{1}{X_{TCSC}} \tag{4b}$$

The incremental change in the reactance is given as;

$$\Delta X_{TCSC} = X_{TCSC}^{(i)} - X_{TCSC}^{(i-1)} \quad (5)$$

At each iteration run, the reactance (X_{TCSC}) is updated thus;

$$X_{TCSC}^{(i)} = X_{TCSC}^{(i-1)} + \left(\frac{\Delta X_{TCSC}}{X_{TCSC}}\right)^{(i)} (X)_{TCSC}^{(i-1)} \quad (6)$$

2.1 MATHEMATICAL MODEL OF STATIC VAR COMPENSATOR (SVC)

SVC is a shunt-type variable reactive power support usually connected to a bus in a power system either to inject or absorb reactive power with the aim of raising or lowering the voltage magnitude at that bus within a specified value. The reactive power generation of SVC for this work is confined within the range of $-50MVAR \le Q_{SVC} \le 50MVAR$ to keep the size minimum so as to reduce the cost of SVC to be incorporated into the power system.

The transfer admittance equation for the variable shunt compensator is given as;

$$I_{SVC} = jB_{SVC}V_i \quad (7)$$

The reactive power injected by SVC at bus i is given as;

$$Q_{SVC} = Q_i = -V_i^2 B_{SVC} \quad (8)$$

The linearized equation representing the total susceptanceB_{SVC} as state variable is given as;

$$\begin{bmatrix} \Delta P_i \\ \Delta Q_i \end{bmatrix}^k = \begin{bmatrix} 0 & 0 \\ 0 & \frac{\partial Q_i}{\partial B_{SVC}} \end{bmatrix}^k \begin{bmatrix} \Delta \theta_i \\ \Delta B_{SVC} \end{bmatrix}^k \quad (9)$$

At the end of iteration(k), the variable shunt susceptance B_{SVC} is updated as;

$$B_{SVc}^{k+1} = B_{SVC}^k + \Delta B_{SVC}^k \quad (10)$$

It should be noted that this changing susceptance stands for the total SVC susceptance needed to maintain the nodal voltage magnitude at the specified value.

2.2 MATHEMATICAL MODEL OF FIREFLY ALGORITHM

The firefly algorithm being one of the newest members of nature inspired, meta-heuristic is based on three idealized rules as detailed in [16]. The light intensity of m^{th} firefly is given as;

$$I_m = Fitness(x_m) \quad (11)$$

The attractiveness function of a firefly is represented by the equation (12) below;

$$\beta_{(r)} = B_{(0)} \times e^{(-\gamma r^m)} \qquad m \ge 1 \quad (12)$$

The distance between any two fireflies is represented *by* r, $B_{(0)}$is the initial attractiveness at r=0, and γ is an absorption coefficient which controls the decrease of the light intensity.

The distance (r) between m^{th} *and* n^{th} fireflies is given as;

$$r_{m,n=}|x_m - x_n| = \sqrt{\sum_{v=1}^{d}(x_{m,v} - x_{n,v})^2} \quad (13)$$

The movement of a firefly (m) when is attracted by a brighter firefly$(n)$is as expressed by the equation;

$$xi = x_i + \beta_o * e^{(-\gamma r_{m,n}^2)} * (x_m - x_n) + \alpha * \left(rand\left(-\frac{1}{2}\right)\right) \quad (14)$$

Where $x_i$the current is position of a firefly, $\beta_o * e^{(-\gamma r_{m,n}^2)} * (x_m - x_n)$ is the firefly's attractiveness to light intensity seen by adjacent fireflies and $\alpha * \left(rand\left(-\frac{1}{2}\right)\right)$ is the random movement of a firefly in case there are no any brighter ones.

3.0 PROBLEM FORMULATION

With the proposed algorithm, SVCs and TCSCs are installed at appropriate locations in the test system independently with the aim of minimizing the real power losses and raising the voltage at defective buses within the acceptable range without any special attention on the installation cost.

3.1 OBJECTIVE FUNCTION

The mathematical model that minimized real power loss is defined as;

$$Min\ P_{loss} = \sum_{i=1}^{n} G_i\left(V_i^2 + V_j^2 - 2V_iV_j \cos\delta_{i,j}\right) \quad (15)$$

3.2 SYSTEM CONSTRAINTS

The equalityconstraints are the power balanced equations given as;

$$P_{Gi} - P_{Di} = P_i(V, \delta) \quad (16)$$

$$Q_{Gi} - Q_{Di} = Q_i(V, \delta) \quad (17)$$

The inequality constraints are the limitation imposed on the system and SVC and TCSC limits;

Voltage constraints on the generator (PQ) - bus is given by the equation (18);

$$V_{min}^i \le V_i \le V_{max}^i \quad (18)$$

The reactive power generation limit on the load (PV)-bus is thus;

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \qquad (19)$$

By transforming the power loss function of equation (15) and the voltage constraints of equation (18), we obtain the light intensity of FA thus;

$$Max. I_m = \frac{1}{1+\left(P_{loss} + \sum_{i\in\varphi}\left(V_i - V_i^{limit}\right)^2\right)} \qquad (20)$$

The power system and optimal values of FA parameters is as shown in table one below;

Table 1: Power System and Optimal Values of FA Parameter

		Minimum	**Maximum**
Power System Variables	Voltage Magnitude (p.u)	0.950	1.500
	Q_{SVC}(MVAR)	-50	50
	X_{TCSC}(p.u)	-0.8	0.2
Firefly Algorithm Parameters	α (Randomness)	0.0	0.6
	β (Attractiveness)	0.4	1.0
	ɤ (Absorption)	0.1	1.0
	(d)No of dimension	0.0	0.2
	Population Size	30	50
	No of iterations	-	100

4.0 RESULTS AND DISCUSSION

This section shows the result of power flow calculations coded in MATLAB (R2013a, Version 8.1.0.64) on IEEE 14- bus system using the proposed FA for optimal placement of TCSC and SVC devices without any special consideration for the cost of installation. The objective is to compare the effectiveness of reactive power compensation of TCSC and SVC using transmission loss and voltage profile enhancement as performance metrics. Table 2 and Table 3 present the optimal location and parameters of TCSCs and SVCs respectively.

Table 2: The Optimal Location and Parameters of TCSCs

Proposed Approach	*Line Location of mth TCSC (L_m)*	γ_{TCSC}(*p.u*)
Firefly Algorithm	8	- 0.114
	15	-0.799
	17	- 0.790
	18	-0.666

Table 3: The Optimal Location and Parameters of SVCs

Proposed Approach	*Location (Bus No)*	$\boldsymbol{Q(MVAR)}$
Firefly Algorithm	4	11.101
	5	6.021
	10	9.780
	14	8.606

The effect of optimal placement TCSCs and SVCs on voltage profile enhancement of the system is presented in Table 4 and Table 5 below using the proposed approach. Places where significant improvements were observed were marked with yellow colour.

Table 4: Voltage Profile Enhancement with TCSC and SVC using Firefly Algorithm (FA)

Bus No	**Voltage Magnitude (p.u)**		
	Base Voltage	With TCSC	With SVC
1	1.060	1.060	1.060
2	1.045	1.045	1.045
3	1.010	1.010	1.010
4	0.967	0.976	1.001
5	0.974	0.984	1.041
6	1.070	1.070	1.070
7	1.035	1.035	1.035
8	1.090	1.090	1.090
9	0.973	0.973	0.973
10	0.974	0.986	1.027
11	1.035	1.035	1.035
12	1.046	1.046	1.046
13	1.017	1.017	1.017
14	0.951	0.958	1.045

The percentage voltage profile enhancement observed on the test case system is presented in the Table 5 below;

Table 5: % Voltage Profile Enhancement with TCSC and SVC using Firefly Algorithm (FA)

Bus No	**Voltage magnitude (p.u)**	
	% increase with TCSC	% increase with SVC
4	0.93	3.51
5	1.02	6.88
10	1.23	5.44

14	0.74	9.88

The effect of the system reinforced with SVCs and TCSCs bring about an appreciable reduction in the active power loss of the system and these are presented in table 6 below;

Table 6: Active Power Loss with the system reinforced with TCSCs and SVCs using Firefly Algorithm (FA)

	Base Case	**TCSC**	**SVC**
Active Power Loss (MW)	13.3674	13.2890	13.2400
Reduction in Active Power Loss (MW)	------	0.0784	0.1274
% Reduction in Active Power Loss	-----	0.59	0.95

A bar chart showing voltage profile enhancement capabilities of TCSC and SVC with the proposed techniques is presented in figure I below;

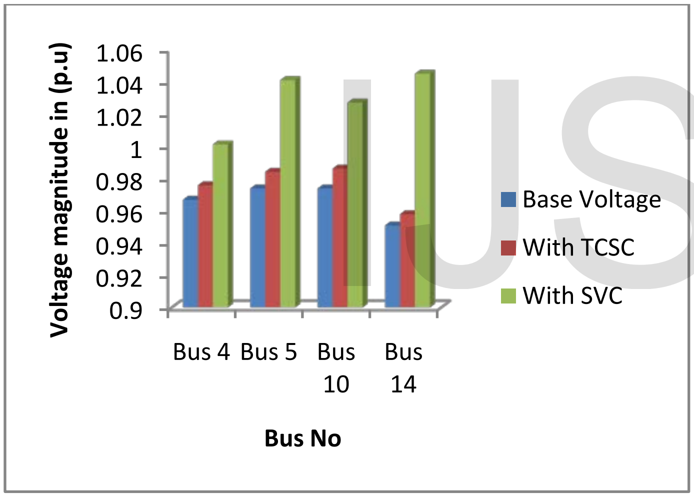

Figure 1: Comparison of Voltage Magnitude in (p.u)

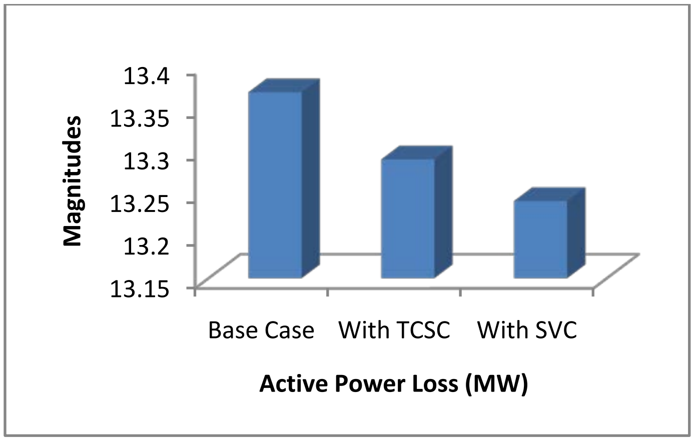

Figure 2: Comparison of Active Power Loss in (MW)

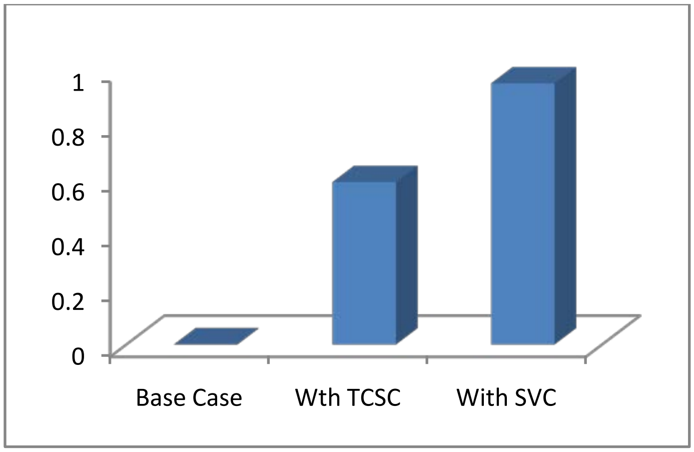

Figure 3: Comparison of Active Power Loss in % (MW)

5.0 CONCLUSION

Performance evaluation of reactive power compensation of TCSC and SVC on voltage profile enhancement and power system loss minimization using Firefly Algorithm was presented in this paper. The results of the analysis showed that with the system reinforced with TCSC, the total system loss reduced from 13.3674MW to 13.2890MW which is about 0.586% reduction. Also the reduction in active power loss with the optimal location of SVCs is 13.2400MW which amount to 0.95 % reduction.

It was also found that the identified location and parameters of both SVCs and TCSCs using Firefly algorithm raised the voltage magnitude of defective buses within acceptable limits. However, from the analysis above, application of SVCs were found to bring appreciable improvement in system's voltage profile in addition to significant reduction in total active power losses compared with what was observed when the system was reinforced with TCSCs.

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