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Application of Evolutionary Programming for the Placement of TCSC and UPFC for Minimisation of Transmission Losses and Improvement of Voltage Profile

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ABSTRACT

Flexible AC Transmission System (FACTS) devices are used in to improve stability and loadability of transmission networks as well as minimise losses . Types of FACTS that are normally used are Thyristor Controller Series Compensator (TCSC) and Unified Power Flow Controller (UPFC) which is to control power flow and stability of the power system at a certain location. The TCSC is suitable because it can be installed in a long transmission line system while UPFC can solve any reactive power problems. The objective of this study is to minimise total power losses and to improve the voltage profile by using FACTS devices in the transmission system. This paper proposes a static voltage stability index (SVSI) to determine the size and placement of TCSC and the Evolutionary Programming (EP) technique. The results of the transmission line losses and voltage profile using TCSC and UPFC are compared in order to demonstrate which FACTS device can produce better results. The IEEE 14 bus system is used in this study to validate the findings.

Keywords: Evolutionary Programming (EP), Thyristor Controlled Series Compensator (TCSC), Unified Power Flow Controller (UPFC), Flexible AC Transmission System (FACTS), Static Voltage Stability Index (SVSI)

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INTRODUCTION

Industry and consumer demand for power is increasing load requirement and can cause an overload in the transmission system leading to voltage collapse. Building a new transmission line (Abdullah, Musirin, & Othman, 2010a) or to decreasing power losses by injecting the Flexible AC Transmission System (FACTS) devices into the systems can resolve this problem. However, building another transmission line to solve the problem is complicated and not cost efficient. Therefore, FACTS is one of the devices used to solve the problem using an existing transmission line. The FACTS is a powerful electronic device used to control power flow in the power system. The FACTS device is capable of managing the network efficiently and it can be used to improve voltage stability, stability and transient stabilities of complex power systems.

Voltage stability can be divided into fast voltage stability index (FVSI), static voltage stability index, (SVSI), voltage stability index (VSI), and line stability index (LQP) (Abedelatti et al., 2015; Stoenescu et al., 2009). Voltage stability is a very important parameter to save the system from voltage collapse. Reducing or adding reactive power load before reaching the point of voltage collapse is one of the methods to preserve the system (Lakkireddy et al., 2015). Power losses will increase if reactive power is high. The rapid increase in power demand leads to instability in the system to result in contingency and outage. It will cause an overloading of the transmission line and affect quality of power (Shah & Prajapati, Jan-June 2015). In order to maintain voltage stability, FACTS devices are used in power systems to control the power flow in certain lines and improve security of transmission lines. The TCSC is one of the suitable types of FACTS that is smooth and flexible to control line impedance with fast responses (Abdullah et al., 2010a). To perform sensitivity analysis and ranking process, it depends on the real power flow index sensitivity and reduction of total system reactive power losses to find a suitable location to install the FACTS (Tlijani, Guesmi, Abdallah, & Ouali, 2012). The UPFC has its own unique features because it can combine all parameters of power flow, voltage, line impedance and phase angle (Kumar & Reddy, 2014).

The aim of this project is to minimise transmission line losses and ensure static voltage stability. This project proposed TCSC and UPFC as the FACTS device to control the power flow, voltage stability and power losses in the system. The TCSC can control the long transmission line (Rajaram, Reka, & Murali, 2010) reactance at high speed condition (Nishida, Hirabayashi, & Iwamoto, 2006). The UPFC can solve reactive power problems. Before installing the FACTS devices, the optimal location and the sizing of FACTS must be identified. The EP techniques are used to optimise the fitness which can be represented by using mathematical equations. It will find the best location to inject the FACTS, sizing of the FACTS, the value of power losses and minimum voltage profile after injecting TCSC and UPFC respectively. The IEEE-14 bus system is applied as the test system in order to install the FACTS devices.

Thyristor Controlled Static Compensator (TCSC) modelling

The TCSC is represented as a capacitive or inductive compensation. It is injected in series to a line (terminal) and allow alteration in impedance of the transmission path of the power flow by increasing or decreasing the value of reactance in line branch, XLI which is the reactance of transmission line where the TCSC is located (Abdullah, Musirin, & Othman, 2010b). The constraint limit for TCSC is given by equation (1) (Abdullah et al., 2010b).

$$(-0.8 \times X_L) \leq X_{TC} \quad (1)$$

Unified Power Flow Controller (UPFC) Modelling

The UPFC is a combination of TCSC and SVC devices. The TCSC devices are installed in the transmission line while SVC is installed at the bus. The SVC can operate as inductive and capacitive compensation. It is controlled by bus voltage absorbing or injecting reactive power. The constraint limit for UPFC is given by equation (2) and (3) (Abdullah et al., 2010b).

$$(-0.8 \times X_L) \leq X_{TCSC} \leq 0.2 \times X_L \qquad (2)$$

$$(-0.8 \times X_L) \leq X_{TCSC} \leq 0.2 \times X_L \qquad (3)$$

FACTS PLACEMENT

The first step is to determine the location of the TCSC and UPFC devices. They are installed at the weakest bus or heavily loaded in the system to reduce the losses (Abdullah et al., 2010a). The SVSI method is used in this study to determine the placement of the FACTS devices. The index shows the level of stability of each transmission line. The line that gives the value of SVSI nearest or equal to 1 indicate that the line is instable. The FACTS are installed on the instability transmission line. The SVSI are derived from the power flow between two buses, bus *i* and bus *j*. The SVSI mathematical formulation is given as below by equation (4).

$$SVSI_{ji} = \frac{\sqrt[2]{(X_{ji}{}^2 + R_{ji}{}^2)(P_{ji}{}^2 + Q_{ji}{}^2)}}{\left| |V_i|^2 - 2\,(X_{ji})(Q_{ji}) - 2\,(R_{ji})(P_{ji}) \right|} \qquad (4)$$

METHODOLOGY

The first step is to determine the location of the TCSC and UPFC devices. They are installed at the weakest bus or heavily loaded in the system to reduce the losses. They SVSI method is used in this study to determine the placement of the FACTS devices. The index shows the level of stability of each transmission line. The line that gives the value of SVSI nearest or equal to 1 indicates that the line is unstable. If value of SVSI less than 1, the system is stable. After determining a suitable location, EP technique is used in the system to optimise the fitness.

Static Voltage Stability Index (SVSI)

The following steps are used determine the SVSI value for TCSC installation:

a) Perform the load flow programme using the Newton Raphson iterative technique.

b) Calculate value of SVSI for every line in the system at the base condition by using equation (2).

c) Set the loading factor. Then, perform the load flow and re-calculate the new SVSI.

d) Increase the reactive power demand. Repeat steps b) and c) for the increased reactive power demand. This process will stop if the load flow solution diverges.

e) Collect and sort the SVSI in descending order.

f) Repeat steps c) until e) for another load bus.
g) Extract the maximum reactive power demand for the highest value of SVSI for every load bus.
h) Sort the maximum loadability (demand) obtained in step g) in ascending order. The smallest maximum loadability (demand) is ranked the highest and it is the weakest in the system.

Once the SVSI has been identified, then the placement of the TCSC and UPFC is based on the SVSI results.

Evolutionary Programming (EP)

The EP technique is used in the system to optimise the fitness, represented using mathematical equations. The EP consists of initialisation, fitness, mutation, combination, selection, new generation and convergence test. The following steps are followed to optimise EP.

a) Set loading factor to stress the system or increase the load demand. Calculate SVSI to define the weakest bus as a location to install the FACTS (TCSC and UPFC).

b) Initialization: Set random initial population. In this study, it sets the random number by referring IEEE-14 bus system. The random number is depending on the location and how many FACTS devices have to be installed into the system. In this system, it just selects one location and has one random number to install the FACTS device.

c) Fitness: It is to optimize objective function. In this study, it uses two times of fitness. The first is after installation and second is after mutation. In this fitness, it calculates losses, voltage minimum, voltage index, maximum, minimum and average to display in mutation.

d) Mutation: Generate new population (offspring) to select individual parents using Gaussian elimination method. Each element of the individual parent can be calculated using equation (5) and (6).

$$x_{i+m,j} = x_{i,j} + N\left(0, \sigma_{i,j}^2\right) \tag{5}$$

$$\sigma_{i,j} = \beta \left(x_{j\,max} - x_{j\,min}\right)\left(\frac{f_i}{f_{max}}\right) \tag{6}$$

where

$x_{i+m,j}$ = Parents mutation (offspring)

$x_{i,j}$ = Parents

$N\left(0, \sigma_{i,j}^2\right)$ = Gaussian random variable with mean μ and variance

β = mutation scale, $0 < \beta < 1$

$x_{i,max}$ = maximum random number of every variable

$x_{i,min}$ = minimum random number of every variable

f_i = fitness for ith random number

f_{max} = maximum fitness

e) Mutate fitness 2. It is similar to step b).

f) Combination: Combine the offspring and parents, which are fitness 1 and fitness 2.

g) Selection: The selection is performed based on the combination process. Rank the process and select the best result. It is used as a survival to choose the next generation.

h) Convergence criterion: It is to determine the stopping criteria. It refers to the difference between maximum fitness and the minimum fitness of the objective function. It will converge if it approaches the stopping criteria. The stopping criteria can be calculated using equation (7).

$$fitness_{max} - fitness_{min} \leq 0.01 \quad (7)$$

RESULTS AND DISCUSSIONS

The IEEE14-bus test system is used as a case study. It consists of 20 interconnected lines, 1 slack bus, 9 load buses, 4 generator buses and 20 transformers tap changer. The base power is 100 MVA and the load bus 14 is selected to perform the test as it is the weakest bus. Two constrains were used in this system before performing the optimisations. The constrains are the total loss and must be less than *P_loss* and the voltage minimum after must be more than *V_set. P_loss* and *V_set* are total power loss and voltage set before injecting the TCSC and UPFC.

TCSC and UPFC as FACTS device

Table 1 shows the bus rank with base case SVSI to define the best location to install the TCSC. Results show that the highest value of voltage stability index is at bus 14, 0.802p.u. However, in this study, determining the most suitable location to install the FACTS depends on the lowest maximum loading because the best location is at the fastest location to diverge when injecting the load at the point. From Table 1, it shows that bus 14 is the lowest maximum loading and it will be the weakest bus and line 20 is heaviest line with a voltage stability value of 0.802p.u.

Table 1
Bus rank base SVSI for IEEE-14 bus system

Rank	Weak Bus	Heavily Line	Maximum loading (MVAR)	SVSI (p.u)
1	14	20	100	0.802
2	9	9	220	0.665
3	7	8	290	0.440
4	10	9	160	0.412
5	13	13	250	0.388
6	6	4	520	0.275
7	11	11	170	0.233
8	8	2	500	0.184
9	12	12	150	0.055

Based on the results in Table 2, Figure1 and Figure 2, the comparison of transmission line losses and voltage stability before and after injecting the TCSC is tabulated. Load demand is increased gradually to observe the best placement and sizing for FACTS because different load demand will have different location to inject FACTS depending on which line is the weakest using SVSI method. In this study, power losses decrease due to the increasing load demand from 80 to 100MVAR. From Table 2 and Figure 1, it shows the graph for transmission losses for TCSC and UPFC. At load demand 100MVAR, the transmission losses before injecting FACTS is 58.612MW. After injecting UPFC, transmission losses decrease to 27.504MW (53.07% losses) and after injecting TCSC, it reduces to 51.324MW, 12.43% lower than before installing FACTS. Therefore, it can be seen clearly that the transmission line losses can be reduced in a bigger percentage by installing UPFC compared with TCSC. Table 1 and Figure 2 show the graph for voltage stability for TCSC and UPFC. At loading of 100MVAR, the value of voltage stability before injecting the FACTS is 0.802 and after injecting the TCSC and UPFC, the voltage stability is 0.394 and 0.027p.u respectively. It shows that installing UPFC into IEEE-14 bus system makes it more stable compared with TCSC.

Table 2
Comparing results for total loss and SVSI of bus 14 before and after TCSC installation

Load Demand (MVAR)	Transmission Losses (MW)			% Δ Loss		SVSI (p.u)		
	Pre	Post TCSC	Post UPFC	TCSC	UPFC	Pre	Post TCSC	Post UPFC
80	41.722	41.134	27.523	1.41	34.03	0.529	0.382	0.027
85	44.491	43.374	27.463	2.51	38.27	0.584	0.416	0.056
90	47.902	45.871	27.512	4.24	42.57	0.645	0.346	0.031
95	52.394	48.448	27.512	7.53	47.49	0.718	0.373	0.044
100	58.612	51.324	27.504	12.43	53.07	0.802	0.394	0.027

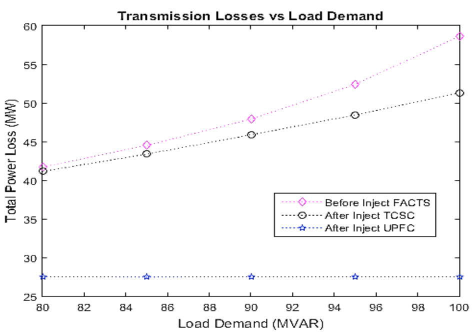

Figure 1. Comparison of transmission line losses for TCSC and UPFC

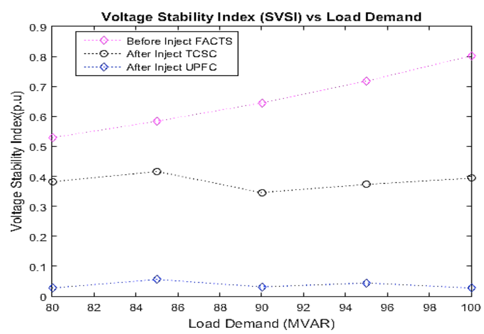

Figure 2. Comparison of Voltage Stability Index (SVSI) for TCSC and UPFC

Table 3 and Figure 3 show the voltage profile before and after installing the TCSC and UPFC. Voltage profile is increased after installing the TCSC in the system. After injecting the TCSC and UPFC, the minimum voltage is increased . Before injecting TCSC and UPFC, the value of minimum voltage is 0.7383V, at load demand, 80MVAR. The minimum voltage increase after injecting TCSC and UPFC is 0.7435V and 0.788 respectively. For the other loading condition, the voltage profile also increases after the installation of TCSC and UPFC. This shows that the installation of UPFC improves the voltage profile of the system.

Table 3
Voltage Profile at Bus 14

Load Demand (MVAR)	Voltage Profile (V)		
	Pre (TCSC and UPFC)	Post TCSC	Post UPFC
80	0.7383	0.7435	0.788
85	0.7146	0.7206	0.771
90	0.6879	0.6951	0.752
95	0.6551	0.6642	0.732
100	0.6149	0.6260	0.710

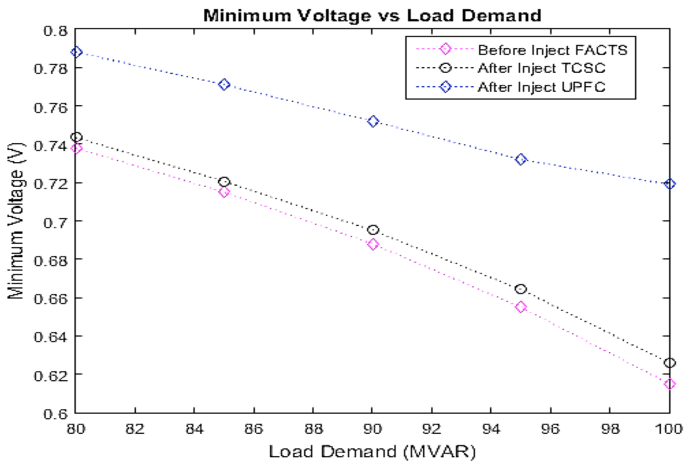

Figure 3. Comparison of Minimum Voltage for TCSC and UPFC

CONCLUSION

The FACTS is a powerful device that controls transmission line losses and improves minimum voltage. In this paper, the application of TCSC and UPFC by adopting the Evolutionary Programing to reduce transmission line losses and improve minimum voltage in the IEEE 14-bus system has been successfully performed. Results show that FACTS devices can improve minimum voltage and reduce power losses in the system. The UPFC shows much better performance compared with TCSC as it provides more stability and a faster response.

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