The Sensitivity Index and the Differential Evolution Technique Applications on the Determination of FACTS Placement

Bongkoj Sookananta

Faculty of Engineering, Ubon Ratchathani University, Warinchamrap, Ubonratchathani 34190

Tel : 0-4535-3326 E-mail: bongkojs@googlemail.com

Abstract

This paper presents techniques for the determination of FACTS device placement. Two kinds of techniques are presented. The first one is the use of sensitivity index. In this paper, the estimation of network performance index sensitivity with respect to the FACTS parameter is proposed as the calculation technique is improved for easier implementation in practical. The second one is the heuristic optimization technique. The applications of the Differential Evolution (DE) and the Genetic Algorithm (GA) are presented as the application of the DE on the optimal FACTS problem is new and that of the GA is widely used. Therefore, consideration of the GA application in this paper is aimed for performance comparison with the DE and the sensitivity index. All considered techniques are tested and the results show the advantages of the Differential Evolution technique over the other selected techniques. Therefore, it is good alternative for implementation on the determination of FACTS allocation.

Keywords: FACTS placement, differential evolution, genetic algorithm, sensitivity index, network performance index

1. Introduction

At present, electricity industries in many countries, especially developed ones are changing from old monopoly models to something closer to a privatized industry. Each part of the electric power system is operated separately. Transmission line utilization has increased substantially due to the marketing of power from non-government-owned power plants [1]. This dramatic increase in power trading activity has the potential to cause transmission congestion. Increasing transmission capability on present sites and making maximum use of existing transmission systems through upgrades is an attractive alternative and the use of the flexible AC transmission system (FACTS) controller is one of interesting options [2].

The Flexible AC Transmission System (FACTS) devices have been well-known for their capability to manage the power flow in the electric power system for over decades. From the first introduction, they have been implemented in many sites around the world for different purpose details [3] such as regulation of power flows in prescribed transmission routes, prevention of cascading outages by contributing to emergency control and damping of severe oscillations.

Due to their relatively high cost of investment, the process of installation project is considerably important, especially in the determination of type, location and rating of the equipment. The investment cost of the devices and recommendations for the FACTS installation project can be found in [4]. Therefore, research area in the optimal location and sizing of the FACTS device, known as the optimal FACTS problem, is widely developing. The optimal type of the device determination is sometimes included in the optimal FACTS problem but is mostly predetermined by using the knowledge base of the system operator on the considered network. In this paper, the optimal location and sizing of the device are taken into account and the type of the FACTS device is assumed to be pre-assigned.

In general, a technique for the determination of the optimal FACTS placement is proposed based on device application. For the application on damping system oscillation, the device is allocated for the best controllability and the indices derived from the system transfer function are usually utilized to determine the optimal location of the device on a considered system [5]. Although the dynamic operation is important characteristic of the devices, it is not considered in this paper as the static operation of the devices can also give equally benefit in terms of economic aspect.

Deployment of the devices for better system steady-state performance can be planned associated alternatively with various techniques. Some techniques use the sensitivity index relating change in considered system performance value with respect to the device parameter to increase this considered system performance [6, 7]. Voltage stability index is also used to determine the device placement for improvement of the system voltage stability [8]. At the later development when the heuristic optimization techniques are well-known and widely used to solve many problems in variety of subjects including economics and engineering. The heuristic optimization techniques such as Genetic Algorithm (GA) [9] are implemented in the FACTS placement problem due to its flexibility and easy implementation with alternatively various considered factors.

This paper utilizes a heuristic optimization technique named Differential Evolution (DE) to determine the optimal placement of FACTS device. This technique is rarely applied to the FACTS placement problem. The multi-objective DE application to the problem is found in [10]. The objective is to gain benefit of steady state system operation i.e. to obtain the least cost of generation under regulated system or power pool electricity market operation. Alternative objectives for the power exchange or mixed power exchange and bilateral transaction electricity market are to maximize the social welfare or to maximize the available transfer capability of a considered transaction. The losses of electric power transmission are also common considering factor [11]. To easier understanding of the techniques proposed in this paper, the most simple and common objective, the least cost of generation, is applied.

The sensitivity of network Performance Index (PI) with respect to the FACTS parameter as presented in [7] is utilized in this paper for determination of optimal placement of FACTS device and the technique for estimation of the index is proposed for convenience implementation in practical. The performance of the sensitivity index and the DE applications on the FACTS placement problem for test network is compared with the GA.

2. Background

This section provides useful information of the FACTS device and selected techniques for the determination of the devices. The information of FACTS devices is provided for only the TCSC which is chosen as the representation of FACTS device in the numerical example given in the later section. However, the techniques are not limited for only the TCSC. The selected techniques are the use of sensitivity index, the DE and the GA.

2.1 Thyristor-Controlled Series Capacitor (TCSC)

The TCSC is a series compensator device. The purpose of the device is to decrease the overall effective series transmission impedance between two buses. It could be explained that when the series compensating capacitor is installed, its impedance cancels a portion of the actual line reactance and thereby the effective transmission impedance is reduced as if the line was physically shortened.

The configuration of a typical TCSC from a steady-state perspective consists of the fixed capacitor with a thyristor-controlled reactor [12] as shown in Figure 1.

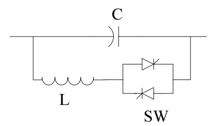

Figure 1 TCSC configuration

The total equivalent impedance of the compensator, x_{TCSC} is a function of the capacitive, inductive reactances and the firing angle of thyristor valves. For simplicity, the compensation of TCSC for line connecting bus i to bus j is represented as shown in Figure 2. Calculation in this paper utilizes the expression of TCSC compensation in terms of percentage of line reactance.

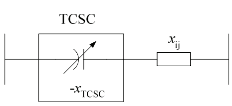

Figure 2 Steady-state equivalent of TCSC

The control limits on the thyristor firing angle are converted and simply represented by line compensation limits in a function of the original uncompensated reactance. To avoid over-compensation, the maximum capacitive compensation is 70 percent of line reactance and the maximum inductive compensation is 20 percent of line reactance. The limit is treated as constraint for the system operation and the TCSC allocation optimization technique.

2.2 Use of sensitivity index

This method is one of the most popular techniques available for the optimal FACTS placement determination. An index relates the change of two considered values. Implementation of the sensitivity index to the FACTS placement problem usually uses the relation of change in the values indicate power system performance or benefit with respect to the change in FACTS device parameter. In this paper, the index called a real power line flow Performance Index (PI) and the subsequent sensitivity factor proposed in [7] are selected for FACTS allocation problem application.

The PI can be used to indicate the severity of system loading and is expressed as

$$PI = \sum_{m=1}^{N_l} \frac{w_m}{2n} \left(\frac{P_m}{P_m^{\max}} \right)^{2n} \tag{1}$$

where P_m is the real power flow through line m

$P_m^{\max}$ is the thermal limit of line m

n is an exponent used to adjust the index value to avoid the masking effect in the contingency

w_m is the weighting coefficient used to reflect the importance of lines

As in this paper, the TCSC is utilized as a representation of the FACTS devices in the numerical study, the sensitivity index relating line loading and TCSC parameters is considered. It is determined using the partial differentiation of PI with respect to the change of FACTS parameter as follows.

$$\frac{\partial PI}{\partial x_k} = \sum_{m=1}^{N_l} w_m P_m^3 \left(\frac{1}{P_{lm}^{\max}} \right)^4 \frac{\partial P_m}{\partial x_k} \tag{2}$$

where x_k is the FACTS device parameter.

Further derivation of equation (2) in terms of power injections is used to calculate the sensitivity index for indicating the optimal TCSC allocation. The sensitivity of PI with respect to a shunt-controller can be found in [7]. The exact calculation sensitivity PI can be performed by using the following equations [7].

$$\frac{\partial P_m}{\partial x_k} = \begin{cases} \left(S_{ml} \frac{\partial P_i}{\partial x_k} + S_{mj} \frac{\partial P_j}{\partial x_k} \right) & for\ m \neq k \\ \left(S_{ml} \frac{\partial P_i}{\partial x_k} + S_{mj} \frac{\partial P_j}{\partial x_k} \right) + \frac{\partial P_j}{\partial x_k} & for\ m = k \end{cases} \quad (3)$$

$$\left.\frac{\partial P_i}{\partial x_k}\right|_{x_k \to 0} = (V_i^2 - V_i V_j \cos\delta_{ij}) \left.\frac{\partial \Delta G_{ij}}{\partial x_k}\right|_{x_k \to 0} - V_i V_j \sin\delta_{ij}) \left.\frac{\partial \Delta B_{ij}}{\partial x_k}\right|_{x_k \to 0} \quad (4)$$

$$\left.\frac{\partial P_j}{\partial x_k}\right|_{x_k \to 0} = (V_j^2 - V_i V_j \cos\delta_{ij}) \left.\frac{\partial \Delta G_{ij}}{\partial x_k}\right|_{x_k \to 0} + V_i V_j \sin\delta_{ij}) \left.\frac{\partial \Delta B_{ij}}{\partial x_k}\right|_{x_k \to 0} \quad (5)$$

where S_{ml} is the ml^{th} element of matrix S which relates line flow with power injections

$$\left.\frac{\partial \Delta G_{ij}}{\partial x_k}\right|_{x_k \to 0} = 2G_{ij}B_{ij} \text{ and } \left.\frac{\partial \Delta B_{ij}}{\partial x_k}\right|_{x_k \to 0} = B_{ij}^2 - G_{ij}^2$$

For simplicity, in this paper the sensitivity index is determined by the change of PI with respect to the change of percentage compensation from the device. For the forth order performance index (n = 2) and equal line importance (w_m = 1 for all lines), it is expressed by the following formula.

$$SI_{PI} = \sum_{m=1}^{N_l} P_m^3 \left(\frac{1}{P_m^{\max}} \right)^4 \frac{\Delta P_m}{\Delta x_{\%}} \quad (6)$$

where SI_{PI} is the sensitivity index of PI and

ΔP_m is the change of power flow in line m due to small change of percentage compensation Δx% from TCSC

The PI will be small when all the lines are within their limits and reach a high value when there are overloads. Therefore, the device should be placed in the line having most negative sensitivity index as this results in reduction of PI and thus decreation of congestion.

The estimation of the PI sensitivity index by using equation (6) can easily be obtained using additional calculation of the results from an available power flow simulator. Therefore, complex mathematical calculation can be avoided.

To observe the change of power flow due to a very small change of the FACTS device compensation, the compensation of 1% from the TCSC is used to calculate the PI sensitivity index in this paper.

By using the sensitivity index to indicate the place where the TCSC is best improving line loading, the SI_{PI} for every branch of the system (candidates of TCSC placement) is calculated. All of them are compared to each other and the most negative value is of interest as corresponding branch is the optimal allocation of TCSC. By installing TCSC on this branch, the available room for additional power flow is increased for cheap dispatch. This is subsequently in saving cost of generation.

2.3 Differential Evolution (DE) technique

DE is the later development evolutionary optimization technique. The key procedures for the good performance of this method are a scheme for generating trial parameter vectors and the weighted difference between two population vectors to a third vector. The algorithm of the DE can be found in [13]. It is given as follows.

Step 1: Initialise a set of population members randomly

Step 2: Evaluate the fitness (objective value) for each population member and record the best fitness and member

Step 3: Shuffle the population into a number different sets to make the differential variations of the whole population

Step 4: From the populations in *Step 3*, select one to be 'base vector' population and determine the 'weighted difference' population from other two sets of population, then add the base vector and weighted difference vector together to obtain the 'mutant population'

Step 5: Crossover operation between the initial population and the mutant population by randomly replacing the initial population with the mutant population at the crossover probability

Step 6: Evaluate fitness of the mutant vectors, compare with that of the initial population and replace some of population members by the better vectors obtained from *Step 5*

Step 7: Record the best member found so far

Step 8: Repeat *Step 2* to *Step 7* until one of the stopping criteria is met. The criterion is either the maximum number of generations or the target value of the best fitness. The solution to the problem is the recorded member from *Step7*

In this paper, it is applied with the step size of 0.5 and crossover of 0.8. The stopping condition for the DE searching process is met when the difference of the best solutions found in every 20 generations are not greater than 0.1. Fitness of the trials is the total generation cost of a considered power system. It is calculated by the MATPOWER simulator [14].

2.4 Genetic Algorithm (GA) technique

GA is one of the most often chosen among the heuristic optimization techniques. It has widely been applied to solve the FACTS allocation problem [9]. Similarly to other evolutionary optimization techniques, it consists of seven components which are chromosome representation, population, fitness evaluation, selection, mating/crossover, mutation and convergence. Feature and algorithm of the GA can be found in [15].

In this paper, the binary GA is applied and the algorithm of the GA is given as follows.

Step 1: Initialise a set of trial solutions randomly

Step 2: Encode the trial solutions into chromosomes and a group or set of chromosomes represents a population

Step 3: Evaluate the fitness (in this paper, it is an objective value) for each population member

Step 4: Rank the population members by their fitness

Step 5: The first typical number of chromosomes are kept as parents while the rest are discarded

Step 6: Create new offspring by selection and mating procedures

Step 7: replace the discarded chromosomes by the new offspring

Step 8: Repeat *Step 3* and *Step 7* for the new set of population members until one of the stopping criteria is met. The criterion is either the maximum number of generations or the target value of the best fitness. The solution to the problem is the best one of kept members from *Step5*

In this paper, the GA is applied with population of 40, roulette wheel selection, crossover of 0.5 and mutation of 0.01. The stopping condition for the GA searching process is met when the difference of the best solutions found in every 20 generations are not greater than 0.1. Fitness of the trials is the total generation cost of a considered power system. It is calculated by the MATPOWER simulator [14].

3. Problem formulation

This section presents the problem formulation used for the heuristic optimization application (the DE and the GA). The optimal location of the TCSC is determined to obtain the minimum cost of generation. The objective of the problem can be expressed as follows.

$$\text{Min.} \quad f = C_G(P) \tag{7}$$

This is subject to power balance, generation output limits, line thermal limits, voltage limits and the FACTS compensation limits. The constraints of the problem are now given as follows.

$$\text{S.t.} \quad G_T = D_T + L_T \tag{8}$$

$$MVA_{ij} \le MVA_{ij}^{\max} \tag{9}$$

$$G_i^{\min} \le G_i \le G_i^{\max} \tag{10}$$

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{11}$$

$$0.3x_{ij} \le x_{ij} - x_{TCSC} \le 1.2x_{ij} \tag{12}$$

where

G_T is the total generation

D_T is the total demand

L_T is the total losses

C_G is the cost of electricity generation

P is the active power generation

G_i is the power output of generation at bus i

$G_i^{\min}$ is the minimum power output of generation at bus i

$G_i^{\max}$ is the maximum power output of generation at bus i

MVA_{ij} is the apparent power flowing along line ij

$MVA_{ij}^{\max}$ is the maximum allowable transaction amount from bus i to bus j

V_i is the bus voltage at bus i

$V_i^{\min}$ and $V_i^{\max}$ are the minimum and the maximum voltage at bus i

x_{TCSC} is the TCSC reactance

x_{ij} is the line reactance

The problem can be considered as 2 sub-problems. Firstly, the optimal FACTS placement problem is solved by heuristic optimization technique. It seeks for better trial solutions of TCSC location when the simulation proceeds. Secondly, each trial solution representation to the transmission network is then included in the power flow model and the optimal power flow problem is solved by using the MATPOWER simulator. In other words, the power flow simulator is a tool for handling the problem constraints, determining the optimal dispatch and flows, and calculating and feeding the fitness of each trial back into the optimization procedure. Note that in this paper the fitness is calculated from the objective function of the problem. However, the fitness can be in the different form of the objective of the problem.

4. Numerical studies and results

There are 2 parts of the numerical studies in this section. The first part (subsection *A*) is to study the proposed estimation of the PI sensitivity index. The second part (subsection *B*) is to study the application of the sensitivity index and the DE technique to the optimal FACTS placement problem.

4.1 The estimation of the PI sensitivity index

In this subsection, the 5-bus test system in [7] is considered as the corresponding sensitivity index presented in [7] is used to compare with the estimated value of sensitivity index obtained in this paper. The network consists of 3 generators, 2 loads and 6 branches as shown in Figure 3.

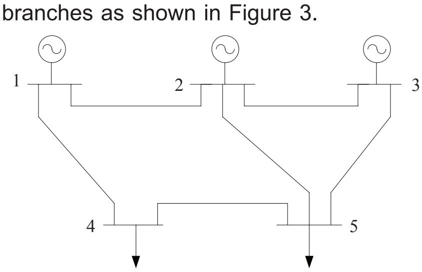

Figure 3 Five-bus system [5]

Each of two transmission lines connected buses 1-2 and 3-5 is of impedance 0.0258 +j0.0866 pu and the rest lines are of impedance 0.0129+j0.0483 pu. The MVA base and all MW limits are 100. The maximum MW capacity of the generators 1 and 2 are 100 and 200 with cost function of $6P_1 + 0.06P_1^2$ and $3P_2 + 0.03P_2^2$. To consider only the optimal dispatch under pool or regulated environment, the demand at bus 4 and bus 5 are set to 170+j20 and 80+j20 MVA respectively. The generator 3 delivers 85 MW. This is slightly change from the original network in [7] operated under the mixed power pool/bilateral contract with the willingness-to-pay to avoid curtailment.

By using equation (6), the PI sensitivity index of the network is estimated and presented in Table 1. The exact value of the PI sensitivity index computed in [7] for the same test system under slightly different system operation is also shown in Table 1 for comparison.

Table 1 Sensitivity Index of 5-Bus Test System (Fig.3)

Branch	From bus	To bus	Estimated Index	Index [5]
1	1	2	-0.0004	-0.778
2	1	4	-0.0004	-1.667
3	2	3	0.0002	1.017
4	2	5	0.0016	4.974
5	3	5	-0.0011	-2.221
6	4	5	0.0005	1.664

From Table 1, the exact values of all indices are much different from the estimated values. However, the quality of the values should be considered regarding to the application and the interpretation of these indices is based on the comparison of each value with the others in the set. The application of the SI to the optimal FACTS allocation problem is performed to obtain the most suitable place for TCSC installation with the corresponding most negative SI. For this numerical example, the most negative SI for both set of indices belong to branch 5 connecting bus 3 and bus 5. Therefore, the estimated value of index is well applicable.

4.2 The SI and the DE applications on the optimal FACTS allocation

In this section, numerical studies on the application of the DE, the GA and the use of sensitivity index to FACTS allocation problem are performed on 3 different size, standard test system; the 5-bus system, the IEEE 24 bus RTS and the 118-bus test system.

4.2.1 Case study 1

The 5-bus network details and data can be found in [16]. The network consists of 7 branches and 3 generators as shown in Figure 4. The total network demand is 150 MW. It is assumed that the system has no resistive reactance and reactive power consumption. Therefore, the DC power flow model is suitable for utilization to solve the power flow of this test system.

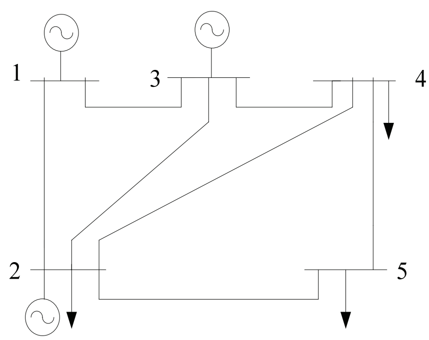

Figure 4 Five-bus system [16]

By using the sensitivity index as given in equation (6), the change of line flow due to 1% change of TCSC compensation is determined. The PI sensitivity index is calculated and given in Table 2.

Table 2 Sensitivity Index of 5-Bus System (Fig.4)

Branch	From bus	To bus	Index
1	1	2	-1.96E-05
2	1	3	2.31E-05
3	2	3	3.04E-08
4	2	4	0.0135
5	2	5	-0.0113
6	3	4	3.63E-05
7	4	5	0.0271

With this calculation, the TCSC should be placed at branch having most negative index. Therefore, branch 5 connected bus 2 and bus 5 is the most suitable. However, this technique can be used to determine only the optimal location of the FACTS devices. It cannot provide the solution for the optimal sizing of the device. Therefore, the method to handle with this issue is still required. In order to compare with the solutions from the GA and the DE, the size of the device presented in Table 3 is a trial value, assigned manually.

By using the DE and GA, both optimal sizing and location of the TCSC can be determined. The optimal location of the device is given in branch number and the optimal sizing is given in compensation percentage.

Table 3 The optimal Location of TCSC for 5-Bus System

Technique	Location /size	Generation cost ($)	Computational time (second)
Sensitivity index	Branch 2-5, 55%	1581.26	0.3
DE	Branch 3-4, 63.10%	1580.80	11.79
GA	Branch 3-4, 64.80%	1580.75	40.70

By using the DC power flow model, the cost of generation is $1583.86 at the optimal power dispatch of the base case (network without TCSC). From Table 2, the optimal location of the TCSC for the 5-bus system obtained from the GA and the DE is branch 6 connected bus 3 to bus 4. The lowest value of generation cost is obtained from the DE, $1580.75, but is only $0.05 different from that obtained from the GA. However, in this case the DE has 4 times less computational time than the GA. The use of sensitivity index method gives the fastest computational time. However, note that it is not included the time for determination of the optimal sizing of the device.

In [17], the optimal location of 75% compensation TCSC for this 5-bus test system is found to be branch 2-5 at which the total cost of generation is $1582.2. However, in this paper the best manually trial is found at the 55% compensation of the TCSC on branch 5 with corresponding cost of generation $1581.26. This value is better than that presented in [17]. This supports the idea that the associated method for determination of the sizing of the device is required. Therefore, the DE application is the most interesting option in this case.

4.2.2 Case study 2

The IEEE 24 bus RTS details and data can be found in [18]. The network consists of 38 branches and 10 generators. The total loads are 2850 MW, 580 MVar. The power flow of this system is solved by using the AC power flow model. At the optimal power dispatch of the base case (network without TCSC), the cost of generation is $33444.84.

For this case study, both the optimal location and sizing of the TCSC obtained from the GA and the DE are presented in Table 4. With the use of sensitivity index technique, the optimal location of the device is selected based on the sensitivity of PI with respect to the device parameter as given in Table 5 and the best trial of sizing is taken as the optimal setting of the device. They are also given in Table 4.

Table 4 The optimal Location of TCSC for IEEE 24-Bus RTS

Technique	Location /size	Generation cost ($)	Computational time (second)
Sensitivity index	Branch 24, 40%	33443.47	12.4
DE	Branch 23, 46.11%	33417.27	142.4
GA	Branch 23, 44.89%	33417.26	162.8

From Table 4, the optimal placement of the TCSC on the IEEE 24-bus RTS obtained from the DE and the GA is branch 23 connecting bus 16 to bus 14. With different sizing, the cost of generation obtained from the GA is the lowest and lower than that obtained from the DE $0.01. In this case, the GA has 1.12 times longer computational time in comparison to the DE.

Table 5 Sensitivity Index of IEEE 24-Bus RTS

Branch	Index	Branch	Index
1	-2.24E-06	20	0.0000
2	1.34E-05	21	-0.0003
3	0.0002	22	-0.0002
4	-0.0001	23	0.0005
5	-0.0002	24	**-0.0004**
6	-0.0001	25	-0.0006
7	-0.0001	26	-0.0006
8	-1.05E-05	27	-0.0001
9	0.0001	28	0.0012
10	2.99E-05	29	-0.0001
11	3.71E-10	30	0.0002
12	0.0004	31	-3.06E-06
13	-0.0004	32	0.0001
14	0.0001	33	0.0001
15	0.0001	34	-3.75E-05
16	-0.0001	35	-3.75E-05
17	-0.0002	36	-7.48E-06
18	-1.74E-05	37	-7.48E-06
19	0.0002	38	7.14E-07

For this case, parallel branch 25 and branch 26 connecting bus 21 to bus 15 have the most negative index. By placing one TCSC, the parallel branches will be unbalance. Therefore, branch 24 connecting bus 16 to bus 15 with the second most negative sensitivity index is selected. It is found that with the TCSC on this branch, the cost of generation is $33443.47 which is higher than that on branch 23. Among all techniques, the use of sensitivity index has the shortest computational time which, however, does not include time for determination of the optimal sizing. Once again, the DE is the most interesting application among selected methods on the FACTS placement determination.

4.2.3 Case study 3

The IEEE 118-bus test system details and data can be found in [19]. The network consists of 186 branches and 54 generators. Total demand of the system is 4242 MW and 1438 MVar. The generation cost of the base case (the network without TCSC) is $129,660.68.

By using equation (6), the estimation of the PI sensitivity index can be calculated as shown in Figure 5.

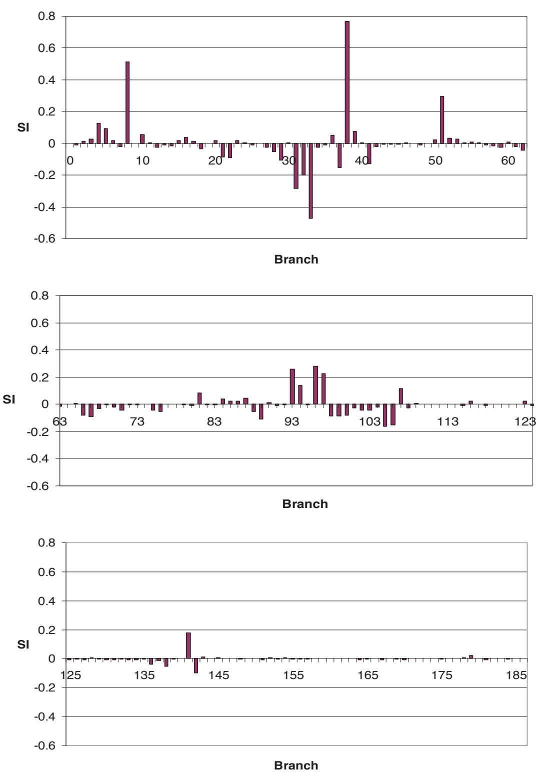

Figure 5 The PI sensitivity index of the IEEE-118 bus system

From the figure, the most negative index belongs to branch 33 connecting bus 25 to bus 27. Therefore, the optimal allocation of the TCSC determined by using the PI sensitivity index is branch 33. To comparison with the optimal location and sizing of the device obtained by the DE and the GA, the best manually trial value for sizing of the device on branch 33 is presented in Table 6. The optimal location and sizing of the device determined using the DE and the GA is also given in Table 6.

From Table 6, the optimal allocation of the TCSC on the IEEE-118 bus determined by using the DE and the GA are branch 51 and branch 96 respectively. Among three methods, the GA is fastest but it does not provide satisfactory solution. However, repeat of the GA can also give satisfactory solution. The smallest value of the objective is obtained from the DE. It is noticed that for large system the heuristic techniques are competitive with the use of estimated sensitivity index. In conclusion, the overall performance of the DE is better than that of the GA and the use of sensitivity index. Therefore, from this case study the DE is the most interesting technique for the optimal FACTS placement problem.

Table 6 The optimal Location of TCSC for IEEE 118-Bus

Technique	Location /size	Generation cost ($)	Computational time (second)
Sensitivity index	Branch 33, 50.82%	129657.09	5.3×10^4
DE	Branch 51, 39.37 %	129645.16	7×10^4
GA	Branch 96, 0.66%	129660.01	1.04×10^4

All cases are studied under typical loading conditions. Under difference loading condition of a considered network, optimal placement of FACTS device can be difference for the network. Since in practical the devices generally have large size and cannot be moved easily, they should be placed at the location that results in satisfactory benefit. More details of the influence of location on FACTS benefits can be found in [10].

5. Conclusions

This paper presents the applications of the PI sensitivity index and the Differential Evolution technique for determination of the FACTS devices. The estimation technique for the sensitivity index is proposed for easier implementation in practical. The result from estimation in this paper is compared with that from previous publication.

From case studies, it works well and can provide the same subsequent result for the optimal FACTS problem as the original calculation. The Genetic Algorithm technique which is the most widely used method in this area of application is utilized for better illustration of the SI and the DE performances. Among three techniques, the use of PI sensitivity index is fastest but it can give only the optimal allocation of the device and the determination technique for sizing of the device is then still required. However, it is possible that the use of PI sensitivity index technique could be used as pre-selection of feasible solutions. The DE and the GA can provide both optimal location and sizing of the devices but the DE is generally faster, specifically up to 4 times for some case. Therefore, the DE is the most interesting as it gives satisfactory solution and computational time for considered objective while the use of sensitivity index has limitation on optimal sizing determination.

6. References

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