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Effect of SVC installation on loss and voltage in power system congestion management

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ABSTRACT

In this paper, a new hybrid optimization technique is proposed namely Adaptive Embedded Clonal Evolutionary Programming (AECEP). This idea comes from the combination part of the clone in an Artificial Immune System (AIS) and then combined with Evolutionary Programming (EP). This technique was implemented to determine the optimal sizing of Flexible AC Transmission Systems (FACTS) devices. This study focused on the ability of Static Var Compensator (SVC) is used for the optimal operation of the power system as well as in reducing congestion in power system. In order to determine the location of SVC, the previous study has been done using pre-developed voltage stability index, Fast Voltage Stability Index (FVSI). Congested lines or buses will be identified based on the highest FVSI value for the purpose of SVC placement. The optimizations were conducted for the SVC sizing under single contingency, where SVC was modeled in steady state analysis. The objective function of this study is to minimize the power loss and improve the voltage profile along with the reduction of congestion with the SVC installation in the system. Validation on the IEEE 30 Bus RTS and IEEE 118 Bus RTS revealed that the proposed technique managed to reduce congestion in power system.

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1. INTRODUCTION

Congestion problem is one of the important issues in power system as its occurrence may lead to unstable condition and affects our daily activities. Important events such as increase in power demand, construction of new lineages of transmission lines; unscheduled power flow in lines can cause congestion in the transmission network and increase of transmission loss. Application of artificial intelligence in managing congestion has indicated the importance of artificial intelligence effectiveness in addressing many power system problems. Some studies have concentrated on maximising social and individual welfare as reported in [1-4]. This issue has been also discussed in detail in [5] which relates to reactive power issue, while the solution for congestion in deregulated environments. On the other side, a promising idea has been rapidly developed over the last two decades for controlling the power flow in transmission lines with the application of FACTS devices. Congestion management has been addressed in several studies as reported in [6-8]. The relationship to transient stability is very obvious, where congestion management was performed to enhance the transient stability. On the other hand, placement of TCSC is also crucial to improve system stability. One important approach to manage the congestion is the implementation of sensitivity analysis based on the transmission line susceptance. Index-based analysis [9-11] has also been addressed to manage the congestion. Other than that, SVC application has also been discussed in [12-14], which can be closely relevant to congestion management. Through the installation of FACTS devices, congestion problem can also be solved.

In order to improves voltage profile, reduce the power loss and improve both the steady state and dynamic performance of the system, reactive compensation on weak nodes has been the effective control measure [15]. In addition to that, FACTS devices are designed to control various parameters in transmission circuits. In [16], the optimal location of FACTS devices revealed a reliable study, where the devices parameters optimization is an effective way to deal with congestion management. Similarly, the Thyristor-Controlled Series-Compensated (TCSC) devices are optimized for congestion management under the non-smooth fuel cost function and penalty cost of emission as discussed in [17]. For this purpose, it is considered that the objective function of the proposed optimal power flow (OPF) problem is minimizing the fuel and emission penalty cost of generators. A hybrid method that is the combination of the bacterial foraging (BF) algorithm with Nelder–Mead (NM) method (BF- NM) is employed to solve the OPF problems. The optimal location of the TCSC devices are then determined for congestion management. On the other hand, the Harmony Search Algorithm (HSA) has been applied to optimal location of SVC in order to improve the power system voltage stability [18]. This can be a good idea for congestion management studies.

This paper presents effect of SVC installation on loss and voltage in power system congestion management. In this paper, a pre-developed index, namely Fast Voltage Stabiliy Index (FVSI) is used as a benchmark to identify the congested lines. This index was developed by Ismail Musirin *et. al* [19] which aims to indicate voltage stability condition in power system, when an excessive load was imposed on the power system network. In addition, voltage collapse can be identified when the index is approaching 1.000 or unity. Subsequently, to get the optimal sizing of SVC, the AECEP optimization technique was implemented to achieve the objective function of this study. The rest of the paper is organized as follows: Section 2 describes the voltage stability index for placement of SVC, optimal setting of SVC and Adaptive Embedded Clonal Evolutionary Programming (AECEP). Numerical results along with some observations are presented in section 3. Finally, the major contributions and conclusions of the paper are summarized in section 4.

2. RESEARCH METHOD

This section presents the implementation of FVSI as a voltage stability indicator, followed by the description of SVC placement, the proposed AECEPO technique and other important algorithms.

2.1. Voltage Stability for Placement of SVC

Due to environment and economic constraints, effective power system must to operate close to their admissible limits. The security level of a power system can be estimated by the operator through the implementation of artificial intelligence approach; which can give knowledge to the power system operators o the status of the power system network. In this paper, the Fast Voltage Stability Index (FVSI) has been decided for giving the dependable positioning rundown to a power system administrator. Algorithm for congested lines identification while the maximum loadability is given in Figure 1. FVSI was broadly actualized as a rule concerning voltage stability and checking because of its reliance on reactive power rather than real power. Being proposed by I. Musirin [20], dependability of FVSI in voltage stability appraisal has been legitimized in [21], [22] where the record was connected for weak cluster identification, most extreme loadability and reactive power planning. FVSI of l-th line is given in (1). Where Z_l is the line impedance, X_l is the line reactance, V_s is the sending end voltage and Q_r is the line receiving end reactive power. It must to be noticed that for a regular power system that is free from voltage breakdown risk, FVSI must be not as much as unity. This index is important in order to identify which lines are congested.

$$FVSI = \frac{4Z_l^2 Q_r}{V_s^2 X_l} \tag{1}$$

2.2. Adaptive Embedded Clonal Evolutionary Programming (AECEP)

The AECEP advantage is that the calculation time short and fast operation. EP can reduce computation time to reach the optimal solution. AECEP has proven to be superior in terms of fast computational time, especially in solving power system optimally in most cases in the study. Ref [13] reported that the number of iterations result of the AECEP usually short at less than 10 iterations. However, the EP also has disadvantages such as inability to reach a settlement as appropriate. It is called as nearly optimal. Similarly, the technique AIS. This is due to inherit traits AIS and EP. The only difference between AIS and the EP is that, AIS undergoes the process of cloning without fusion, while the EP only has the combination process but does not have cloning process.

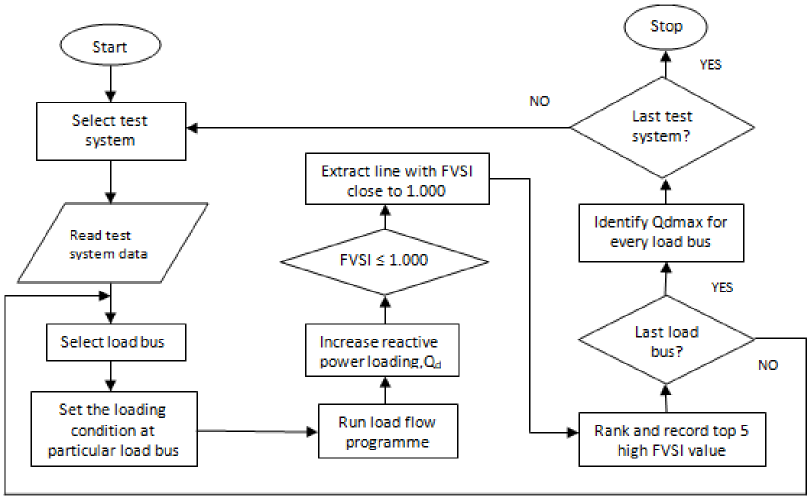

Figure 1. Flowchart of congested line identification when the maximum loadability

2.3. Algorithm of AECEP for location and sizing of SVC

In this study, AECEP is implemented to minimize the power losses in the system; while monitoring voltage at all buses in the system to be within the acceptable limit. The algorithm for AECEP is explained as follows:

Step 1: Initialization: In this process, random numbers are generated using the uniformly distribution random number of SVC. These candidates are also known as parents. The random number is denoted as *x*. The general equation for *x* is given as follows:

$$Parent, X_{nk} = \begin{bmatrix} X_{11} & \cdots & X_{1,2k} \\ \vdots & \cdots & \vdots \\ X_{n1} & \cdots & X_{n,2k} \end{bmatrix} \tag{2}$$

Matrix size = *n x 2k* where ; *n* = population number is 20; *k* = number of control variables. The population size is normally chosen between 10 to 20. Based on the experience and past researches [20], 20 is the suitable population size to achieve optimal solution.

Step 2: Fitness computation and cloning process. Fitness computation is conducted to perform the optimization. In this study, losses equation in power system is the fitness which needs to be minimized. This can be referred to as the objective function as presented in equation (8). The total losses are computed by running the load flow process.

Step 3: Cloning process. On the other hand, cloning process is a process to duplicate the parents. The cloned population:

$$\tau_{nmk} = \begin{bmatrix} X_{11} & \cdots & X_{1k}X_{1,k+1} & \cdots & X_{1,2k} \\ \vdots & \cdots & \cdots \quad \cdots & \cdots & \vdots \\ X_{n1} & \cdots & X_{nk}X_{n,1+k} & \cdots & X_{n,2k} \\ X_{21} & \cdots & X_{2k}X_{2,k+1} & \cdots & X_{2,2k} \\ \vdots & \cdots & \cdots \quad \cdots & \cdots & \vdots \\ X_{n1} & \cdots & X_{nk}X_{n,k+1} & \cdots & X_{n,2k} \end{bmatrix} \begin{matrix} m \\ \\ m \end{matrix} \tag{3}$$

Matrix size of cloned population: *mn* x *2k* where : *n* = population number m = cloning number k = number of control variables.

Step 4: Adaptive mutation. Mutation is a process to produce offspring (children). Offsprings are bred based on the Gaussian Mutation operator. A search step, is responsible for the adaptive process, where this value can be rabdomly generated (0,1).

Step 5: Fitness 2 computation. In this phase, fitness values are recalculated using the offsprings. To ensure the mutation process works well, there must be changes of fitness values at this stage as compared with the Fitness 1 calculation.

Step 6: Combination. Combination is a process to connect the whole population and population after the cloned process in cascade form. From the parent population, A1 and offspring population A2, the combined population can be write as C as in equation (4).

$$C = \begin{bmatrix} \frac{A_1}{A_2} \end{bmatrix} \quad (4)$$

Step 7: Tournament Selection. Tournament selection is a process to prescribe the candidates for the next iteration. If the cloning multiplier m is 10, therefore F1 and F2 will have (20x10) = 200 individuals. Only 20 best members or individuals are prescribed from this population. There are many techniques for the selection process such as pair wise comparison, elitism and roulette wheel. Any suitable technique can be adopted for this purpose. But in this study, pair wise comparison is used.

Step 8: Stopping Criterion. The stopping criterion for AECEP is determined by evaluating the difference between the maximum fitness or minimum fitness which is supposed to be less than $\mathcal{E}$. $\mathcal{E}$ is the accuracy level set in the beginning of optimization process. The typical value is 0.0001. The general equation can be given by:

$$\Delta f = f_{max} - f_{min} \leq 0.0001 \quad (5)$$

If Δf does not achieve the desire $\mathcal{E}$ value, the optimization process will repeat.

2.4. Optimal Setting of SVC

The SVC can operate either in capacitive or in inductive mode. While it may be function either to inject or to absorb reactive power from the bus where it is connected. The voltage can be improved in static and dynamic condition hence reduces the active power loss. Figure 2 shows the variable susceptance model of SVC. The SVC model used in this study is based on representation the shunt controller as variable susceptance; the following simplified equations describe the susceptance SVC model [23].

$$I_{SVC} = jB_{SVC}V \quad (6)$$

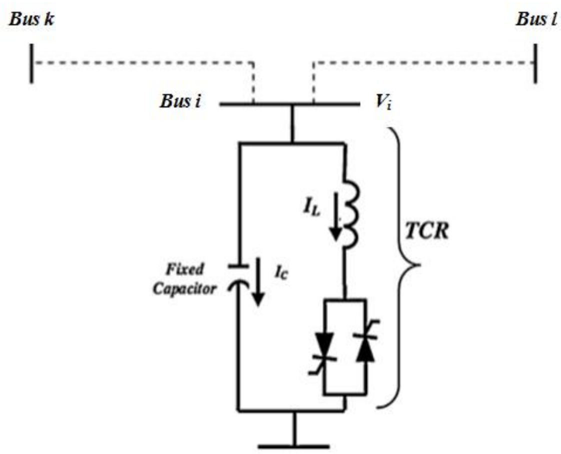

Figure 2. Basic circuit schema of SVC

The reactive power Q_i^{SVC} exchanged with the bus I can be expressed as:

$$Q_i^{SVC} = B_i^{SVC}.V_i^{SVC} \quad (7)$$

2.5. Objective function

The objective of this study is to minimize the active power loss. The mathematical equation is given by;

$$F = P_{Loss} = min \sum_{n=1} I^2 R \quad (8)$$

2.6. FACTS Devices Constraints

Parameters of shunt FACTS devices must be restricted within their limits.

$$Q_{SVC}^{min} \leq Q_{SVC} \leq Q_{SVC}^{max} \quad (9)$$

Where , Q_{svc} is the reactive power injected at SVC placed bus in MVar.

2.7. Power Balance Constraints

While solving the optimization problem, power balance equations are taken as equality constraints. The power balance equations are given by,

$$\sum P_{Gen} = \sum P_{Demand} + P_{Loss} \quad (10)$$

Where,

P_{Gen} - power generation
P_{Demand} - power demand
P_{Loss} - power loss in the transmission system

2.8. Voltage Stability Constraints

Limits on the buses voltage magnitude;

$$V_{bus}^{min} \leq V_{bus} \leq V_{bus}^{max} \quad (11)$$

3. RESULTS AND ANALYSIS

This section presents the results and discussion of the study. Loss minimization and voltage profile improvement are the main concerns in this study. Tests were conducted on the IEEE 30-Bus RTS.

3.1. Loss Minimization

The results for the effect of the SVC installation to relieve the congestion problem in the power system are discussed in detail in this section. The first objective of this study is to minimize the power losses. Table 1 tabulates the results of sizing of SVC when particular loaded buses in the IEEE 30-Bus RTS were reactively loaded. As discussed in section 2.1, the congested line is determined from the highest ranking list regardless of FVSI values. Hence, for the purpose of simplicity the lines connected to a particular load bus in their ranking list are selected for SVC placement. For example, if Bus 3 is listed in the ranking list, any line connected to this bus can be selected for SVC placement. From the first column, 5 loaded buses with the highest maximum permissible load are chosen to identify their congested lines or buses. The percentage of loss minimization is achieved at highest, 69.69% when the maximum loading is up to 350.9 MVar. The SVC was installed at bus 7 with optimal size of 198.21MVar. For instant, while SVC was installed at bus 11 which maximum loading is 182MVar at loaded bus 10, the percentage of loss minimization also shown the good result; 24.34% with optimal size of 196.40MVar. Congested lines or buses with the corresponding optimal size of SVC for other cases can be referred to the same table.

To illustrate the efficiency of the proposed technique for power system congestion management, IEEE 118 Bus RTS is also used as a large test system as tabulated in Table 2. From the table, the installation of SVC at bus 62 is optimal for reducing the power loss and congestion relief. It can be observed from the highest percentage of loss; 10.50% when the optimal size of SVC is 467.34MVar. The second highest percentage of loss minimization is 3.94% when SVC was installed at bus 85 with optimal size; 296.09MVar.

Table 1. Installation of SVC in IEEE 30 Bus RTS for Loss Minimization

Loaded Buses	Q_{dmax} (MW)	SVC Location (Bus)	Range of SVC Size	SVC Size (MVaR)	Pre Loss (MW)	Post Loss (MW)	Loss Reduction (%)
3	351.2	3	10-20	28.69	68.81	57.12	16.99
		4	10-20	28.69	68.81	63.47	7.75
4	391.6	4	10-20	28.69	48.65	43.74	10.09
		12	10-20	28.69	48.65	47.05	3.29
7	350.9	5	0-400	380.50	82.14	71.69	12.72
		7	0-200	198.21	82.14	24.90	**69.69**
10	182	9	10-20	28.69	28.39	26.21	7.68
		11	0-200	196.40	28.39	21.48	24.34
12	187.5	12	10-20	28.69	22.02	20.87	5.35
		13	0-200	199.89	22.05	18.04	18.19

Table 2. Installation of SVC in IEEE 118 Bus RTS for Loss Minimization

Loaded Buses	Q_{dmax} (MW)	SVC Location (Bus)	Range of SVC Size	SVC Size (MVaR)	Pre Loss (MW)	Post Loss (MW)	Loss Reduction (%)
3	339	3	10-20	28.69	153.54	150.63	1.90
		5	10-20	28.69	153.54	153.04	0.33
41	327	41	10-20	28.69	158.48	154.07	2.78
		42	0-200	166.17	158.48	157.85	0.40
67	418	62	0-500	**467.34**	204.00	182.59	**10.50**
		67	10-20	28.69	204.00	184.34	9.64
75	517	75	10-20	28.69	169.95	166.67	1.87
		77	10-20	28.69	169.95	169.71	0.14
83	310	83	10-20	29.82	167.43	162.08	3.20
		85	0-300	**296.09**	167.43	160.84	**3.94**

3.2. Voltage Improvement

Figure 3 and 4 present the results of voltage profile when SVC was installed on particular congested buses in IEEE 30-Bus RTS and IEEE 118-Bus RTS respectively. From the results, it is shown that SVC installation exhibit better performance as compared to without the SVC installation. With the SVC installation, the voltage profile increases better to 0.90 p.u until 1.05 p.u using AECEP technique for both test system.

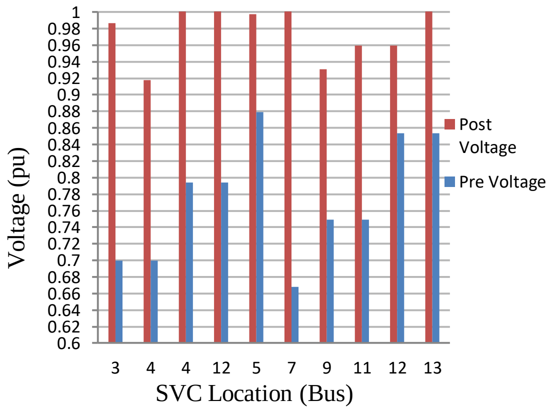

Figure 3. The effect of SVC installation on voltage profile in IEEE 30 Bus RTS

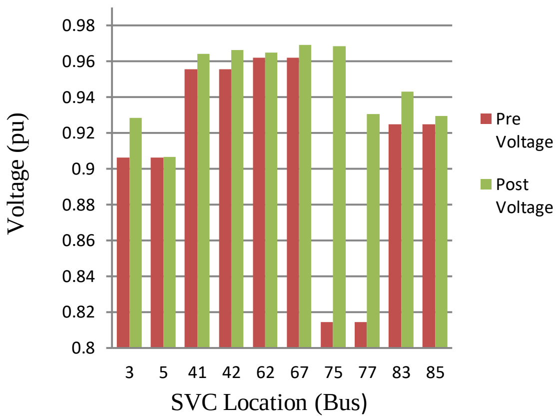

Figure 4. The effect of SVC installation on voltage profile in IEEE 118 Bus RTS

4. CONCLUSION

This paper presents two techniques in order to solve the congestion problem. Firstly, the pre developed index, namely FVSI is used to identify the congested buses to install the SVC. Second, using the AECEP technique to determine the optimal size of SVC for loss minimization with voltage profile improvement. As the conclusion, the power loss minimization and voltage profile improvement are performing well when the SVC installation is implemented as congested buses with optimal size. Obviously, the system is under stressed or congested conditions need to be relieved by some means such as FACTS devices. Installation of FACTS devices at suitable locations can relive the system much from stress conditions; reduced line losses and also help the system to maintain an acceptable voltage profile in the load buses.

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