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Optimal Location and Rating of Thyristor Controlled Series Capacitor for Enhancement of Voltage Stability using Fast Voltage Stability Index (FVSI) Approach

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ABSTRACT

In an electric power system network, the continuous demand has caused it to be heavily loaded leading to voltage instability. This phenomenon has also led to voltage profile depreciation below the acceptable secure limit. The significance and use of Flexible AC Transmission System devices and capacitor placement is in order to alleviate the voltage profile decay problem. This paper presents an application of Bacterial Foraging algorithm in optimizing the rating of Thyristor Controlled Series Capacitor for voltage profile improvement, minimization of losses and voltage stability enhancement. Voltage stability level of the system is defined based on the Fast Voltage Stability Index (FVSI) approach. The IEEE 14 bus system is used as a test system in order to demonstrate the height of applicability and efficiency of the proposed system. The test result shows that the location of TCSC improves the voltage profile of the system and also minimizes the transmission line losses.

Keywords

Bacterial Foraging (BF) Algorithm, Fast Voltage Stability Index (FVSI), Flexible AC Transmission System (FACTS), Multi-Objective function, Thyristor Controlled Series Capacitor (TCSC).

1. INTRODUCTION

Most large power system blackouts, which occurred worldwide over the last twenty years, are caused by heavily stressed system with large amount of real and reactive power demand and low voltage condition. When the voltages at the system buses are low, the losses will also be increased. This study is devoted to develop a technique for improving the voltage and minimizing the losses and hence eliminate voltage instability in a power system [1]. Static Var Compensator (SVC), Thyristor Controlled Phase Shifting Transformer (TCPST) and Thyristor Controlled Series Capacitor (TCSC) etc., can maintain voltage profile in the power systems and, therefore, can control the active power through a transmission line [11].

Many advantages in power system operation and planning can be immediately realized by regulating the power flows and simultaneously supporting the bus voltages. Such advantages include the minimization of system losses, elimination of line overloads and low voltage profiles. F.G.Bagriyanik et al [4] proposed a technique for power loss minimization based on Genetic Algorithm using TCSC. R.Benabid et.al [5] proposed an application of NSPSO for solving the optimal location and size of SVC and TCSC that can help for voltage stability enhancement. This paper proposes a method for finding the optimal rating of Thyristor Controlled Series Capacitor (TCSC) using Bacterial Foraging algorithm in order to minimize the loss, voltage profile improvement and voltage stability enhancement. The voltage stability assessment is analyzed using Fast Voltage Stability Index (FVSI) approach. FVSI gives a scalar number to each line of the system. This index ranges from zero (no load system) to one (voltage collapse). Thus critical line will be the line with the highest FVSI value and the load bus connected in the line will be vulnerable bus in the system [14]-[15]. This paper uses minimization of FVSI of the system as one of the objectives of the optimization problem.

The Bacterial Foraging algorithm is a computational intelligence based technique that is not largely affected by the size and nonlinearity of the problem. The bacterial foraging algorithm can converge to the optimal solution in many problems where most analytical methods fail to converge. A load flow program written in MATLAB using bacterial foraging technique was used to compute power flow. The test results show that the location and sizing of the TCSC identified by the proposed technique improves voltage level of the system and also minimize the transmission losses. For practical and economic considerations, the number of TCSC units is limited to one [13]. Here TCSC is connected in between buses 5 and 6 (line 18) in IEEE 14- bus system.

This paper is organized as follows: Model of TCSC is given in section 2. Problem Formulation is given in section 3. Bacterial Foraging algorithm for proposed method is given in section 4. Results and discussion are given in section 5, the conclusion is drawn in section 6.

2. MODEL OF THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

Thyristor Controlled Series Capacitor (TCSC) is a series compensation component which consists of capacitor bank shunted by Thyristor Controlled Reactor (TCR). The basic idea behind power flow control with TCSC is to decrease or increase the overall effective impedance of the transmission line, by adding a capacitive or inductive reactance correspondingly. The TCSC is modeled as a variable impedance, where the equivalent reactance of the line $\mathrm{X_{ij}}$ is defined as

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

where, X_{line} is the transmission line reactance, and X_{TCSC} is the TCSC reactance.

The level of the applied compensation of the TCSC usually varies between 20% inductive reactance and 80% capacitive reactance [5].

3. PROBLEM FORMULATION

The objective function of this paper is to find the optimal location and rating of TCSC which minimizes the line losses, voltage deviation and FVSI. This is mathematically stated as [8] - [9], [12], [14]:

Minimize

$$\mathrm{F} = [\mathrm{f}_1, \mathrm{f}_2, \mathrm{f}_3\,] \qquad (2)$$

The first term f_1 represents real power loss as [8], [12]

$$f_1 = \sum_{k \in Nl} g_k (V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij}) = P_{loss}{}^{l} \qquad (3)$$

The second term f_2 represents the total voltage deviation (VD) of all load buses from desired value of 1 p.u.

$$f_2 = VD = \sum_{k=1}^{N_{PQ}} (V_k - Vref_k)^2 \qquad (4)$$

The last term f_3 is the Fast Voltage Stability Index (FVSI) of the line ij and is given by [14]-[15]

$$\mathrm{f}_3 = \mathrm{FVSI}_{\mathrm{ij}} = \frac{4\mathrm{Z}^2\,\mathrm{Q}_{\mathrm{j}}}{\mathrm{V}_{\mathrm{i}}{}^2\,\mathrm{X}_{\mathrm{ij}}} \qquad (5)$$

Z = Line impedance

X_{ij} = Line reactance

Q_j = reactive power at the receiving end

V_i = sending end voltage

The minimization problem is subject to the following equality and inequality Constraints:

Load Flow Constraints:

$$P_i - V_i \sum_{j=1}^{Ng} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0, i = 1,2,\ldots\ldots N_B - 1 \qquad (6)$$

$$Q_i - V_i \sum V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) = 0, i = 1,2,\ldots.. N_{PQ} - 1 \qquad (7)$$

(ii) Voltage Constraints:

$$V_i^{\min} \le V_i \le V_i^{\max}; i \in N_B \qquad (8)$$

(iii) Reactive Power Generation Limit:

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}; i \in N_g \qquad (9)$$

(iv) Reactive Power Generation Limit of capacitor banks:

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max}; i \in N_c \qquad (10)$$

(v) Transformer tap setting limit:

$$t_k^{\min} \le t_k \le t_k^{\max}; k \in N_t \qquad (11)$$

(vi) Transmission line flow limit:

$$S_i \le S_i^{\max}; i \in N_l \qquad (12)$$

4. BACTERIAL FORAGING ALGORITHM FOR THE PROPOSED METHOD

Foraging theory is based on the assumption that animals search for nutrients which maximizes their energy intake (E) per unit time (T) spent for foraging [6]. The E.coli bacterium is probably the best understood micro organism. The bacterial foraging optimization (BFO) algorithm mimics how bacteria forage over a landscape of nutrients to perform parallel nongradient optimization. The Mutation in E.coli occurs at a rate of about 10-7 per gene, per generation and can affect its physiological aspects. The E.coli bacterium has the control system that enables it to search for food and avoid noxious substance. To find the minimum of $J(\theta), \theta \in R^p$ where there is no measurements or analytical description of the gradient $\nabla J(\theta)$. θ is the control variable (line reactance) ant it is a position of a bacterium and $J(\theta)$ represents the combined effects of attractants and repellents from the environment, for example $J(\theta)$<0, $J(\theta)$=0 and $J(\theta)$>0 representing that the bacterium at location θ is nutrient-rich, neutral and noxious environments respectively.

Let j be the index for the chemotactic step, k be the index for the reproduction step and l be the index of the elimination-dispersal event.

$$\text{Let } P(j,k,l) = \{\theta^i(j,k,l) i = 1,2,\ldots.S\} \qquad (13)$$

The equation (13) represents the position of each member in the population of the S bacteria, at the jth chemotactic step, K^{th} reproduction step and i^{th}elimination-dispersal event. Let N_c be the length of the life time of the bacteria as measured by the number of chemotactic steps taken during their life. Let $C(i)$>0, i =1,2,….S denotes a basic chemotactic step size, that is used to define the lengths of steps during runs. The control parameters of bacterial foraging algorithm are given in the Table 1.

Table 1. Control Parameters of the Bacterial Foraging Algorithm [6]

S.No	Parameters	Values
1	Number of bacteria ,S	50
2	Maximum number of steps, N_s	4
3	Number of chemotactic steps,N_c	100
4	Number of reproduction steps,N_{re}	4
5	Number of elimination-disperse steps, N_{ed}	2
6	Probability, P_{ed}	0.25
7	Size of the step, C(i)	0.1

5. RESULTS AND DISCUSSIONS

The program for the Bacterial Foraging based optimization algorithm used in this study was written in MATLAB 7.0 on Pentium IV, 3GHz 512 MB RAM processor and used to perform the optimization routines with IEEE 14-bus system. System data and results are based on 100 MVA and bus1 is the reference bus. The IEEE 14-bus system, which consists of five generator buses (bus 1 is slack bus 2, 3, 6 and 8 are PV buses), 9 load buses and 20 lines (4-7, 4-9 and 5-6) in which three lines are with the tap changing transformers. The line parameters and loads are taken from [12].In order to verify the presented models and illustrate the impacts of TCSC study; two cases for test systems are considered. Table 2 gives the control variables for the test system. The initial real power loss is 13.5100 MW for the Normal case (i.e. light load). For critical case, the initial real power loss is 60.2100 MW (Table IV).

Case 1: results of optimal power flow without TCSC and with one TCSC for the base case (i.e. light load).

Case 2: results of optimal power flow without TCSC and with one TCSC for the critical case (i.e. heavy load-whose loads and initial power generations are twice as those of case 1).

The aim of case-2 is minimized losses with optimal placement of TCSC in weakest line. For practical and economic considerations, the number of TCSC units is limited to one [13]. Based on highest FVSI values of test system, line18 will be considered as critical. The impedance of line with TCSC (0.2440p.u and 0.2230 p.u) is connected in line 18 (between buses 5 and 6) to perform the test for the normal and critical cases. On placing line TCSC (between buses 5 and 6) FVSI value is decreased from 0.4377 to 0.4260(for normal case) and it is decreased from 0.9210 to 0.4973 (for critical case) (refer table 3). For critical case, the system voltages get reduced below the minimum limit. The voltage of the load bus (bus 5) connected in line 18 during critical load is 0.9435 (below the minimum value of 0.9500) (see Figure.3.).

Table 2. Control Variables for IEEE 14-Bus System

Test case	Variables	Minimum (p.u)	Maximum (p.u)
14 bus system	Voltage	0.95	1.10
	Tap setting	0.90	1.10
	X_{TCSC}	$-0.8X_{line}$	$0.2X_{line}$

Table 3.Real Power Loss for Normal and Critical Case (p.u)

Line Losses			
Case 1 (Normal load)		Case 2 (Critical load)	
Before placing TCSC	After placing TCSC	Before placing TCSC	After placing TCSC
0.1351	0. 1328	0.6021	0. 5846

Table 4. FVSI Values of Each Line of IEEE 14-Bus System

Line No	FVSI values			
	Case 1(Base load)		Case2(Critical load)	
	Before placing TCSC	**After placing TCSC**	**Before placing TCSC**	**After placing TCSC**
1	0.0475	0.0475	0.3096	0.3096
2	0.0143	0.0143	0.0285	0.0285
3	0.0060	0.0060	0.5604	0.5604
4	0.0292	0.0292	0.0584	0.0584
5	0.0118	0.0118	0.0236	0.0236
6	0.0305	0.0305	0.0609	0.0609
7	0.0029	0.0029	0.0060	0.0060
8	0.0164	0.0164	0.0329	0.0329
9	0.0188	0.0188	0.0377	0.0377
10	0.0355	0.0355	0.0711	0.0711
11	0.0149	0.0149	0.0312	0.0312
12	0.0314	0.0314	0.0659	0.0659
13	0.0159	0.0159	0.0333	0.0333
14	0.0980	0.0980	0.2000	0.2000
15	0.0290	0.0290	0.0598	0.0598
16	0.0000	0.0000	0.0000	0.0000
17	0.3605	0.3605	0.7502	0.7502
18	**0.4377**	**0.4260**	**0.9210**	**0.4973**
19	0.1829	0.1829	0.3348	0.3348
20	0.0698	0.0698	0.1443	0.1443

Table 5. Voltage Magnitudes of the IEEE 14-bus System

Bus No.	Voltage			
	Case 1(Base load)		Case2(Critical load)	
	Before placing TCSC	**After placing TCSC**	**Before placing TCSC**	**After placing TCSC**
1	1.0600	1.0600	1.0600	1.0600
2	1.0450	1.0450	1.0450	1.0450
3	1.0100	1.0100	1.0100	1.0100
4	1.0190	1.0246	0.9846	0.9968
5	**1.0190**	**1.0367**	**0.9435**	**0.9935**
6	1.0200	1.0200	1.0200	1.0200
7	1.0438	1.0461	1.0113	1.0123
8	1.0400	1.0400	1.0400	1.0400
9	1.0313	1.0313	0.9801	0.9836
10	1.0268	1.0301	0.9778	0.9818
11	1.0463	1.0509	1.0178	1.0181
12	1.0512	1.0512	1.0302	1.0302
13	1.0429	1.0429	1.0177	1.0117
14	1.0169	1.0288	0.9522	0.9802

Table 3 shows the real power loss of IEEE 14 bus system before and after placing TCSC for the two cases (normal load and critical load). Table 4 shows the Fast voltage stability Index (FVSI) values of each line of IEEE 14-bus system. Figures 1 and 2.show FVSI value variations of IEEE 14-bus system without and with inclusion of TCSC for normal and critical cases. Table 5 shows the voltage magnitudes of IEEE 14-bus system without and with inclusion of TCSC for normal and critical cases. From the test results, it is clearly shown that the system voltage magnitudes have been improved, losses and Fast Voltage Stability Index (FVSI) values are reduced with inclusion of TCSC in weakest line. Table 5 shows the voltage improvement of load buses.

Table 6. Real Power Loss and Computational Time

Algorithm	Particulars	Case-1	Case-2
GA	Minimum Loss (MW)	13.400	-
NSPSO	Minimum Loss(MW)	13.460	-
BF Algorithm	Minimum Loss(MW)	13.280	58.460
	Comp. Time (Sec)	46	60

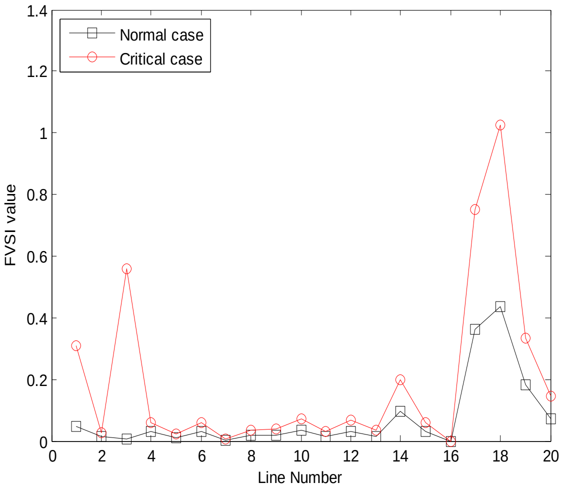

Figure 1: Line Number Vs FVSI values of IEEE 14-bus System without TCSC

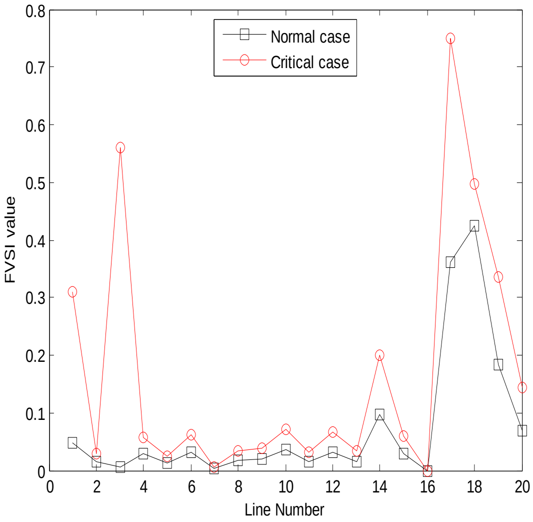

Figure 2: Line Number Vs FVSI values of IEEE 14-bus System with TCSC

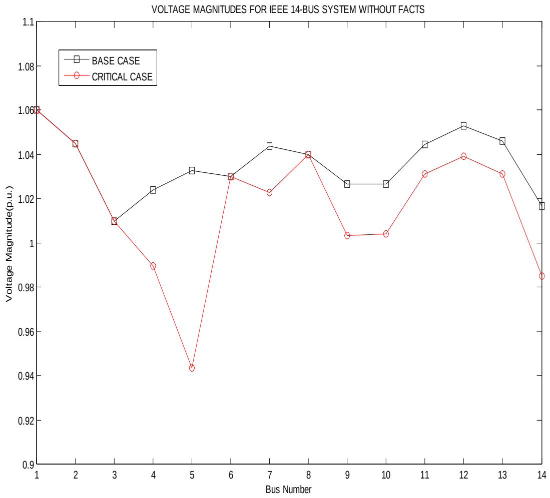

Figure 3: Bus Number Vs Voltage Magnitudes of IEEE 14 bus System with TCSC

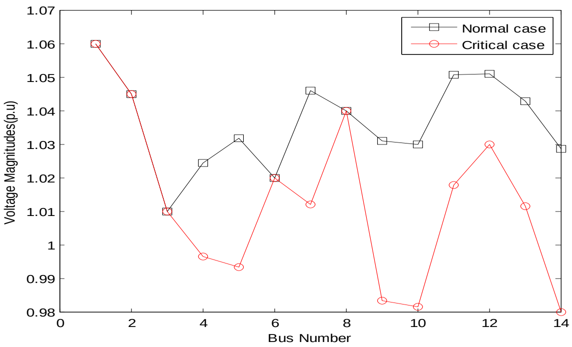

Figure 4: Bus Number Vs Voltage Magnitudes of IEEE 14 bus System with TCSC

When the TCSC is placed in line 18, the voltage gets improved to 0.9935 (see Figure. 4.). Also, on placing of TCSC between buses 5 and 6, the line losses get decreased from 60.2100 MW to 58.4600 MW for the critical case. With regard to IEEE 14-bus system, BF obtains 1.52% loss reduction compared to GA value reported [4] for the same test system and 1.97% loss reduction compared to NSPSO value reported[5]for the same test system. This shows the effectiveness of the proposed approach in minimizing the transmission line losses and voltage profile improvement simultaneously.

6. CONCLUSIONS

This paper made an attempt to find the optimal location and rating of TCSC for minimizing the losses, Fast Voltage Stability Index (FVSI) and voltage profile improvement, which are taken as objective functions using bacterial foraging optimization algorithm. Results are presented for IEEE 14-bus test reliability system. The test results show that the bacterial foraging technique has the ability to improve voltage profile along with minimization of transmission losses in the system. The power loss occurring in the various branches and voltage magnitudes of IEEE 14 bus system is evaluated using BF based power flow analysis. From the results, it is concluded that the system performs better when TCSC is connected such that the voltage profile is improved, state variables are improved and the transmission line losses are minimized.

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