International Journal of Scientific & Engineering Research, Volume 5, Issue 1, January-2014
ISSN 2229-5518

Optimal placement of SVC in electrical power distribution systems using Genetic Algorithm

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Abstract— Placement of static voltage compensators and bus compensators in order to enhance the voltage is a common and fundamental issue in the power field. Nowadays, electrical systems are one of the most advanced man-made systems in terms of size, technology and price. Therefore, economical usage and optimization are very important. Developing facilities and increasing network load lead to fragile systems such that there have been some obstacles in the field of power stability due to voltage instability worldwide. One fundamental component of static voltage compensators is bus capacitor which plays an important role in static voltage instability. System loss and voltage profile are very important in optimal resource design. Therefore, placement of the mentioned parts plays an important role in enhancing the voltage stability. In this article, genetic algorithm is used to enhance voltage. Stimulation results have shown that genetic algorithm is very useful.

Index Terms— Reactive Power Compensation, Static VAR Compensator, Optimization, Genetic Algorithm, FACTS devices.

1 Introduction

One of the most significant issues in power systems is reactive power compensation. These days, FACTS tools are very important in supporting network with reactive power and promoting network voltage stability. Voltage instability in power systems occurring after global cutoff is considered as the most important concern recently. Voltage instability point is named maximum loading point. Loading increase, environmental limitations and revised structure of power system lead to need for suitable control in order to maintain network stability. Load distribution control and better voltage stability are obtained using FACTS tools. SVC is a component of series reactive power compensator which is controlled according to network parameters. There are multiple methods for placing FACTS tools in power network. Hierarchical methods are among the recommended methods to place the mentioned tools traditionally. This method is performed precisely in small networks but for bigger networks, more scientific methods are required. Generally speaking, other methods such as genetic algorithm, fuzzy logic and neural networks are used to place FACTS tools. One significant application of FACTS tools is to increase system portability and to pass power through desirable passages[1,2].

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1 Static VAR compensator

Static voltage compensator is a variable ***Susceptance*** whose value can be changed in capacitor continuously. Main plan of static voltage compensator in the form of control theristor reactor is shown in figure 1 [3].

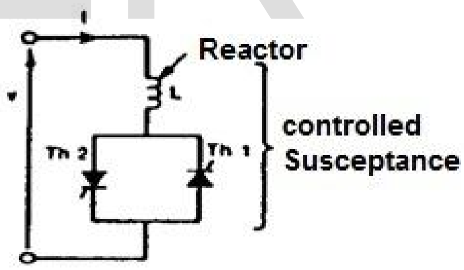

Fig.1. Thyristor controlled reactor

Controller elements of two theristors are attached together is series and reverse way. Each theristor passes the current in a half cycle. If fire angle of two theristors delayed equally, reactor current will delay also. Reactor current deviates from continuous status. When fire angle increases then current main component amplitude will diminish. Current decrease and fire angle increase are attributed to self-inductance increase. In this way, fire angle changes lead to self-inductance changes. Therefore, a controllable ***Susceptance*** is achieved which is used as static compensator. By having a series capacitor in this assembly, compensating ***Susceptance*** changes on the both positive and negative domains are possible in the continuous form.

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2.1 SVC system modeling

Block diagram of the used control system is shown in figure 2. Main role of SVC is to control reactive voltage in generator buses. Auxiliary signals such as speed, frequency and phase angle difference are added to primary controller in order to enhance system dynamic performance.

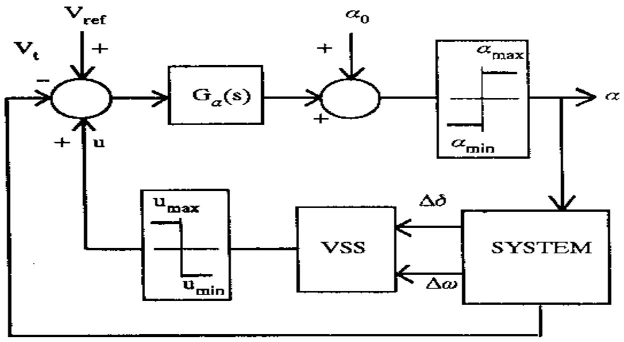

Fig.2. SVC control system diagram

Using speed feedback, SVC control equation in written as below:

$$\alpha = \alpha_0 + \frac{K_\alpha . \exp(-sT_d)}{(1+sT_\alpha)(1+sT_s)}[V_{ref} - V_s + K_\omega(\omega - \omega_0)] \quad (1)$$

In this relation, angle frequency changes of controlled voltage bus or generator speed changes are ordered according to theristor circuit delay time or dead time. Admittance amplitude is a function of fire angle and it is written as below:

$$B_L = \frac{2\pi - 2\alpha + \mathrm{Sin}(2\alpha)}{\pi X_s} \qquad 90° < \alpha < 180° \quad (2a)$$

$$B_L^{\cdot} = \frac{2\pi - 2\alpha + \mathrm{Sin}(2\alpha)}{2\pi X_s} \qquad 0° < \alpha < 180° \quad (2b)$$

In the above relations, SVC total reactance is indicated by X_s which is related to reactor nominal power:

$$X_s = \frac{V_s^2}{Q_L} \quad (3)$$

3 Basic of Genetic Algorithm

Genetic algorithm is used in this article in order to place SVC and to determine the value of SVC optimally. Genetic algorithm is a useful method to search wide domains which leads to a desirable answer. Genetic algorithm works with some coded variables. The advantage of coded variables is that codes are able to change continuous environment into discrete one. One difference of genetic algorithm compared to traditional methods is that genetic algorithm deals with a collection of points at a certain moment whereas traditional methods optimize only one certain point. This means that genetic algorithm processes multiple plans at a certain time. Additionally, genetic algorithm is based on random processing or stable guided random processing. Therefore, random operators search domain according to template matching. Generally, in order to use genetic algorithm, three basic concepts must be realized: definition of target function, definition and implementation of genetic domain, and implementation of genetic algorithm operators. Genetic algorithm are based on superior survival and superior proliferation[10].

4 Program General Algorithm

4.1 initial input

In this stage, initial input including line impedance, load and relation between buses are fed into program

4-2- Determination of algorithm initial population

Each member of initial population includes four genes and each gene indicates a place for installing FACTS tools such as SVC. One member of initial population is shown below as an example:

P= {18 12 22 17}

The mentioned chromosome indicates that SVC is installed in buses 18, 12, 22, and 17. It is important to know that in this article, the place for SVC to be installed is optimized according to size and number.

4-3- calculation of SVC effect

Injected power of tools installed in selected buses is calculated.

4-4- calculation of expenditure function

In this stage, expenditure function of each member is calculated. For this purpose, charge distribution is done in the backward-forward way and bus voltage is calculated. In the following, target function is determined:

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$$Cost = w_1\left(\sum_{n=1}^{Number\ bus} 1-\frac{V_n}{V_{base}}\right)+w_2\left(\sum_{n=1}^{Number\ line} R_{line_n} I_{line_n}^2\right) \quad (4)$$

As obvious, expenditure function includes two parts: this part is related to voltage fall in network buses ,this part is related to network loss effects ,W1 and W2 are weighted coefficients of each target.

4-5- selection stage

In this stage, half of initial population with the lowest expenditure is selected according to expenditure functions calculated in the previous stage for each member.

4-6- recombination stage

In this stage, half of population selected in the previous stage is combined using an available method such as top-down method.

4-7- mutation stage

In this stage, mutation is occurred in the new population with a predefined rate in order to search total domain.

4-8- evaluation of convergence condition

In this stage, algorithm ends if the number of repetition is at the desirable level. Now, the best answer is the final answer. But, if the number of repetition is not desirable, algorithm is repeated from the stage 3. Genetic algorithm software is able to be called via the command ga(…..) in versions beyond 2009. It is necessary to write given problem in a suitable format to be matched with the mentioned command. In another way, stages 5-8 are the core parts of this command and there is no need to program these stages. It is enough to write the problem in a suitable format to be called on via this command.

5 The objective function

Used target function is a double-purpose function in order to enhance voltage stability and reduce power loss. It is written as below:

$$Function = w_1\left(\sum_{n=1}^{Number\ bus} 1-\frac{V_n}{V_{base}}\right)+w_2\left(\sum_{n=1}^{Number\ line} R_{line_n} I_{line_n}^2\right) \quad (5)$$

In this relation R_{line} is resistance of each network line and I_{line} indicates current of each line. In the above, lower line resistance and current lead to reduced loss. In this function, V_n is the nominal voltage of each network bus and V_{base} represents the base voltage. W1 and W2 are weighted factors in target function. System limitations are: Voltage profile restriction, resource power restriction, voltage stability restriction: system must be resist against differences which lead to voltage collapse. In some articles, safety margin of 15-20% is used. In this article, given system is a 33-bus one which is shown in the following. In this system, bus voltage is calculated via backward-forward charge distribution and then, network loss is calculated. According to mentioned issues, SVC has to be placed in a optimal location to reduce network loss and enhance voltage stability. For this purpose, SVC is placed in buses 12, 17, 18, and 22 to optimize target function.

6 The results of test on a IEEE 33-bus network

The network considered in this article is a 33-bus system with radial distribution and 3.72 MW and 2.3 Mvar which is shown in the figure. This system has one main feeder and three subordinate feeders. Primary bus voltage is 1 perionit and system nominal power is 10 Mva. Base voltage equals 12.66 KV.

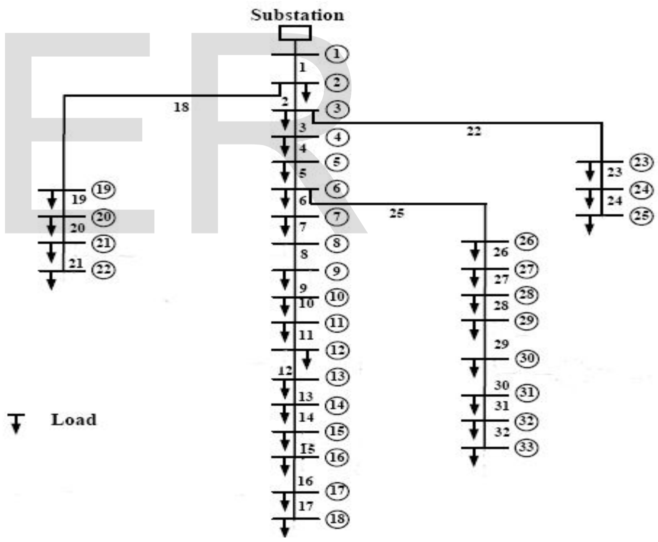

Fig. 3. single line diagram for 33-bus system with radial distribution

Other features of system are: active and reactive power of each bus, resistance and inductance of lines, the distance between buses in KM.

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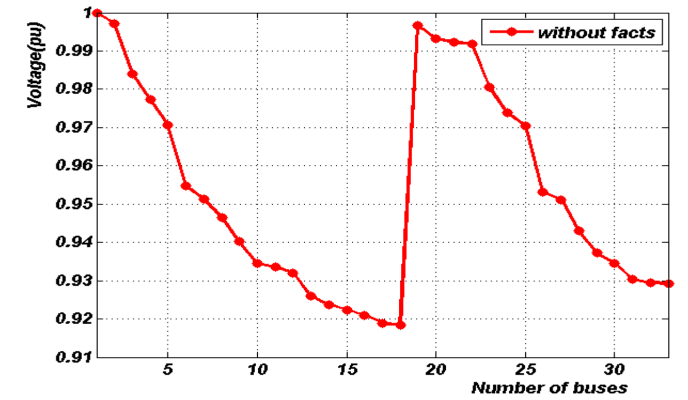

Fig.4. voltage profile for 33-bus network without using SVC

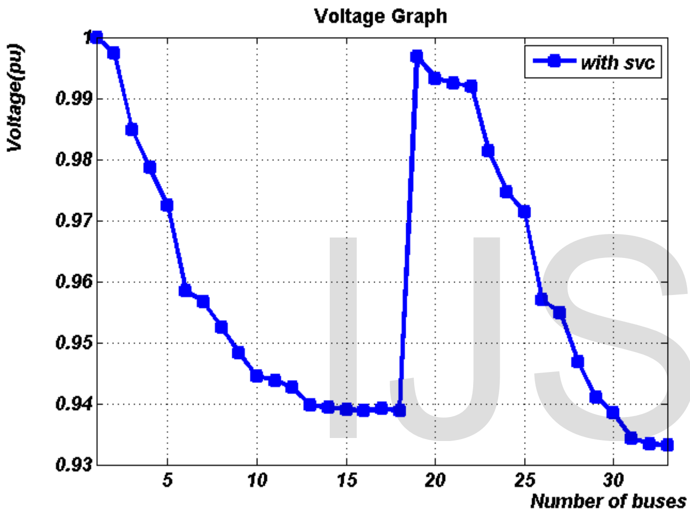

Fig.5. voltage profile for 33-bus network using SVC

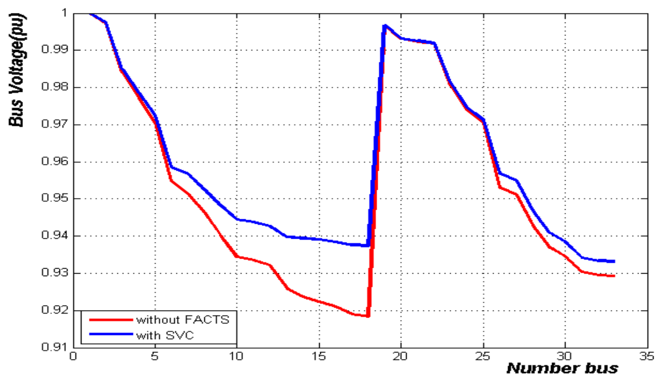

Fig. 6. voltage profile for 33-bus network using and without using SVC

7 Conclusion

One important issue in electrical power industry is to maintain and enhance the quality of generated electricity. Voltage leads to lower quality of electricity and damages. In order to use FACTS devices optimally, the optimal places must be determined. Location, type and nominal capacity of FACTS tools, lower voltage fall, reduced power loss and better voltage stability are optimization parameters. In this article, placement is done on SVC. The recommended method is also implemented on IEEE 33-bus network. Optimal replacement can be done for various purposes. In this research, the main goal is to minimize power loss reduction and to reduce voltage fall and finally to enhance voltage stability. Results have shown that SVC installation leads to power loss reduction and voltage enhancement.

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APPENDIX

Table 1

Features of IEEE 33-bus network

Impedance (Ω/km) X	Impedance (Ω/km) R	To	From	Load Q(kvar)	Load P(Kw)	Bus No.
0.0470	0.0922	2	1	0	0	1
0.2512	0.4930	3	2	60	100	2
0.1864	0.3661	4	3	40	90	3
0.1941	0.3811	5	4	80	120	4
0.7070	0.8190	6	5	30	60	5
0.6188	0.1872	7	6	20	60	6
0.2351	0.7115	8	7	100	200	7
0.7400	1.0299	9	8	100	200	8
0.7400	1.0440	10	9	20	60	9
0.0651	0.1967	11	10	20	60	10
0.1298	0.3744	12	11	30	45	11
1.1549	1.4680	13	12	35	60	12
0.7129	0.5416	14	13	35	60	13
0.5260	0.5909	15	14	80	120	14
0.5449	0.7462	16	15	10	60	15
1.7210	1.2889	17	16	20	60	16
0.5739	0.7320	18	17	20	60	17
0.1565	0.1640	20	19	40	90	18
1.3555	1.5042	21	20	40	90	19
0.4784	0.4095	22	21	40	90	20
0.9373	0.7089	23	22	40	90	21
0.3084	0.4512	24	23	40	90	22
0.7091	0.8980	25	24	50	90	23
0.7071	0.8959	26	25	200	420	24
0.1034	0.2031	27	26	200	420	25
0.1447	0.2842	28	27	25	60	26
0.9338	1.0589	29	28	25	60	27
0.7006	0.8043	30	29	20	60	28
0.2585	0.5074	31	30	70	120	29
0.9629	0.9745	32	31	100	200	30
0.3619	0.3105	33	32	70	150	31
0.5302	0.3411	34	33	100	210	32
				40	60	33

General information on the network

Total consumption power : 3720 kw

The total resistance of line: 20.5865 Ω

Total reactive power : 2300 Kvar

The total reactance of line: 17.7964 Ω