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Optimal Placement of STATCOM using Heuristic Techniques

R. Siva Subramanyam Reddy*, and T. Gowri Manohar**

ABSTRACT

As the world wide electric utility industry grow up with deregulation; utility transmission systems are reaching their limits, making the need for reliable power greater than ever. Due to ever-growing load demand in the power system witnesses a gradual drop in the system voltage profile. It is precisely the inability of the power system to generate the required reactive power that propounds the cause of voltage collapse, with this effect the losses (Active Power and Reactive Power) in the system gradually increased. The recent developments in power electronics with high power advanced switching devices have introduced Flexible AC Transmission Systems (FACTS), which can facilitate the control of power flow, increase the power transfer capability, decrease the generation cost, improve the security and enhance the stability of the power systems. They allow the operation of the power systems more flexible, secure and economical through controlling various electrical parameters of transmission circuits. The modeling and placement of STATCOM shunt FACTS device is the major task in this type of problems. Earlier many of the engineering conventional optimization techniques applied to real world problems suffers with optimal solutions. In this paper, some of the advanced techniques (Heuristic techniques) like Genetic Algorithm (GA), and Particle Swarm Optimization (PSO) are introduced to find the optimal location of STATCOM shunt FACTS device in a standard IEEE 14,30,57 Bus systems in order to improving the voltage profile and reduce the losses(Active power &Reactive power) in power transmission system.

Keywords:Power system, Voltage profile, STATCOM, GA, PSO, Losses (KW and KVAR)

1. INTRODUCTION

The electric supply industry operation and control become now days more and more complex due to reliable, secure and continuous increased power especially in a large interconnected power system. In general most of the generating stations are far away from the load center; hence it is required to control some of the parameters such as voltage profile, load angles, power factor, and frequency in order to meet the above requirements. Erecting new transmission lines that are subject to environmental and regulatory policies. On the other hand, power flows in some of the transmission lines are well below their thermal limits, while certain lines are overloaded, which has an overall effect of deteriorating voltage profiles and decreasing system stability and security. In addition, existing traditional transmission facilities, in most cases, are not designed to handle the control requirements of complex, highly interconnected power systems. This overall situation requires the review of traditional transmission methods and practices and the development of new concepts which would allow the use of existing generation and transmission lines up to their full capabilities without a reduction in system stability and security.

With the recent developments in the area of FACTS, the STATCOM is one of shunt connected key FACTS controller due to its better performance, fast response and superior functional characteristics compared to other shunt controllers [1, 14]. In this paper the suitable placement of STATCOM is based on some of the optimization techniques like Genetic Algorithm (GA), and Particle Swarm Optimization (PSO) are used to reduce the power system losses and improves the voltage profile of the various IEEE Bus

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systems (IEEE-14, 30, 57) more effectively compare to conventional optimization techniques like Fast voltage collusive index, Load suitability index.

This paper is divided into four sections. In section 1 introduction about the power systems and importance of FACTS and placement of FACTS using Optimization techniques and in section 2, the power flow control, the importance of using NR method for modeling of STATCOM FACTS device to the power system. In section 3 introduces the overview of various optimizing techniques used to find the optimal placement of STATCOM into the power system. Section 4 discussed the results and conclusions of the present work by placing STATCOM device.

2. POWER FLOW ANALYSIS

Load flow study in power system parlance is the steady state solution of the power system networks.

Power flow studies, commonly referrers to as load flow are the backbone of power system analysis and design. The power transmission line can be represented by a two-bus system "*k*" and "*m*" in the ordinary form. The active power and the reactive power transmitted between bus nodes *k* and *m* is given by:

$$P = \frac{V_k * V_m}{X} \sin(\delta_k - \delta_m) \tag{1}$$

$$Q = \frac{V_k^2}{X} - \frac{V_m * V_k}{X} \cos(\delta_k - \delta_m) \tag{2}$$

Where V_k and V_m are the voltages at the nodes, $(\delta_k - \delta_m)$ the angle between the voltages and X, the line impedance. The power flow can be controlled by altering the voltages at a node, the impedance between the nodes and the angle between the end voltages [2, 3].

2.1. Newton-Raphson Power Flow

The Newton-Raphsonmethod is a powerful and faster method of solving non-linear algebraic equations in alarge-scalepowerflowsystem networks and also it is found to be more efficient and practical method. It is sure to convergencecharacteristics in most cases. The power flow Newton-Raphson algorithm is expressed by the following relationship.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial p}{\partial \theta} & V\frac{\partial p}{\partial V} \\ \frac{\partial Q}{\partial \theta} & V\frac{\partial Q}{\partial V} \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \frac{\Delta V}{V} \end{bmatrix} \tag{3}$$

Where ΔP and ΔQ are bus active and reactive power mismatches, while θ and V are bus magnitude and angle, respectively [4].

2.2. Static Synchronous Compensator (STATCOM) Power Flow Model

It is acceptable to expect that for the aim of positive sequence power flow analysis the STATCOM will be represented by a synchronous voltage source with maximum and minimum voltage magnitude limits [4]. The synchronous voltage source stands for the fundamental Fourier series component of the switched voltage waveform at the AC converter terminal of the STATCOM. The bus at which the STATCOM is connected is represented as a PV bus, which may change to a PQ bus in the case of limits being violated. In this case, the generated or absorbed reactive power would reach the maximum limit. The STATCOM

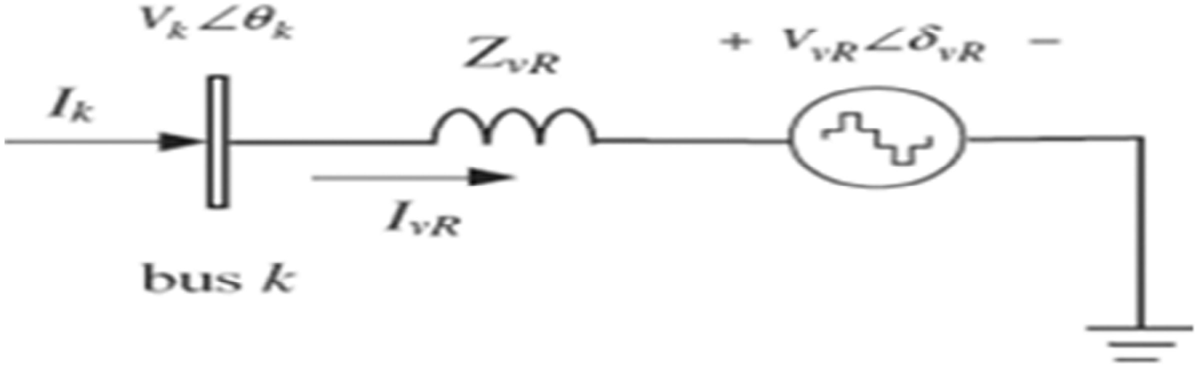

Figure 1: STATCOM Equivalent Circuit

equivalent circuit shown in Figure 1. And is used to obtain the mathematical model of the controller for incorporation in power flow algorithms [5,6].

After performing some complex operations, the following active and reactive power equations are obtained for the converter and bus k, respectively:

$$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR} V_k [G_{vR} \cos(\delta_{vR} - \theta_k) + B_{vR} \sin(\delta_{vR} - \theta_k)] \tag{4}$$

$$Q_{vR} = -V_{vR}^2 B_{vR} + V_{vR} V_k [G_{vR} \sin(\delta_{vR} - \theta_k) - B_{vR} \cos(\delta_{vR} - \theta_k)] \tag{5}$$

$$P_k = V_k{}^2 G_{vR} + V_k V_{vR} [G_{vR} \cos(\theta_k - \delta_{vR}) + B_{vR} \sin(\theta_k - \delta_{vR})] \tag{6}$$

$$Q_k = -V_k{}^2 B_{vR} + V_k V_{vR} [G_{vR} \sin(\theta_k - \delta_{vR}) - B_{vR} \cos(\theta_k - \delta_{vR})] \tag{7}$$

Using these power equations, the linearized STATCOM model is given below, where the voltage magnitude V_{vR} and phase angle δ_{vR} are taken to be the state variables [7-9].

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_{vR} \\ \Delta P_{vR} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k} V_k & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}} V_{vR} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k} V_k & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k}{\partial V_{vR}} V_{vR} \\ \frac{\partial P_{vR}}{\partial \theta_k} & \frac{\partial P_{vR}}{\partial V_k} V_k & \frac{\partial P_{vR}}{\partial \delta_{vR}} & \frac{\partial P_{vR}}{\partial V_{vR}} V_{vR} \\ \frac{\partial Q_{vR}}{\partial \theta_k} & \frac{\partial Q_{vR}}{\partial V_k} V_k & \frac{\partial Q_{vR}}{\partial \delta_{vR}} & \frac{\partial Q_{vR}}{\partial V_{vR}} V_{vR} \end{bmatrix} \tag{8}$$

3. INTRODUCTION TO HEURISTIC TECHNIQUES

There are several Heuristicoptimization techniques such as genetic algorithms, differential evolution, tabu search, simulated annealing, ant colony optimization and Particle swarm optimization. Each of these algorithms has its own advantages. Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) are efficient and well-known stochastic algorithms. The goal of the optimization is to find the best location of a given number of FACTS devices in accordance with a defined criterion. A configuration of FACTS devices is defined by three parameters: the location of the devices, their size, and their values [10]. Wavelets are also another optimization process used in power system analysis similar to that of used in voice verification systems [11].

3.1. Overview of GA

One of the most famous meta-heuristic optimization algorithms is Genetic Algorithm (GA) which is based on natural evolution and population. To reach the near global optimum solution Genetics are used. In each iteration of GA (generation), a new set of string (i.e. chromosomes) with improved fitness is produced using genetic operators (i.e. selection, crossover, and mutation)[12].

3.2. Overview of PSO

Particle Swarm Optimization (PSO) is a population-based stochastic optimization technique developed by Kennedy and Eberhart (1995), inspired by social behavior of bird flocking or fish schooling. The main idea is based on the food-searching behavior of birds as in (Kennedy and Eberhart, 1995). It is observed that they take into consideration of the global level of information to determine their direction. The global and local best positions are computed at each iteration and the output is the new direction of search. Once this direction is detected, it is followed by the cluster of birds [10].

3.2.1. Advantages of PSO

(a) It is based on a simple concept. Therefore, the computation time is short and it requires few memories.

(b) It was originally developed for nonlinear optimization problems with continuous variables. However, it is easily expanded to treat problems with discrete variables.

(c) Compared to the GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust [13].

4. NUMERICAL RESULTS AND CONCLUSIONS

The proposed method is tested on IEEE 14 bus system. The single line diagram and Voltage profile of the respective system are shown in the Figure 2 and Figure 3 respectively. The minimum voltage of the IEEE 14 bus system without STATCOM is 0.9587p.u. The real and reactive power losses in the system are

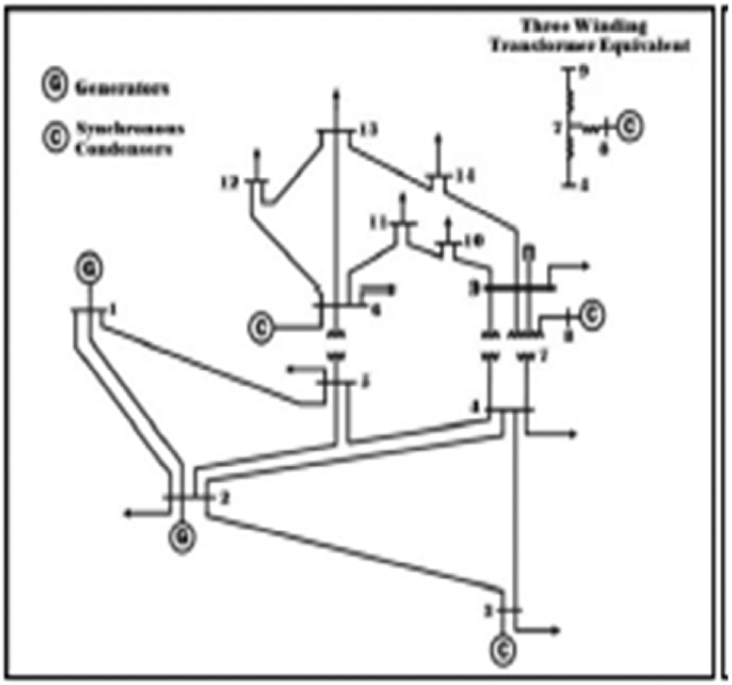

Figure 2: Single line diagram of IEEE14 bus

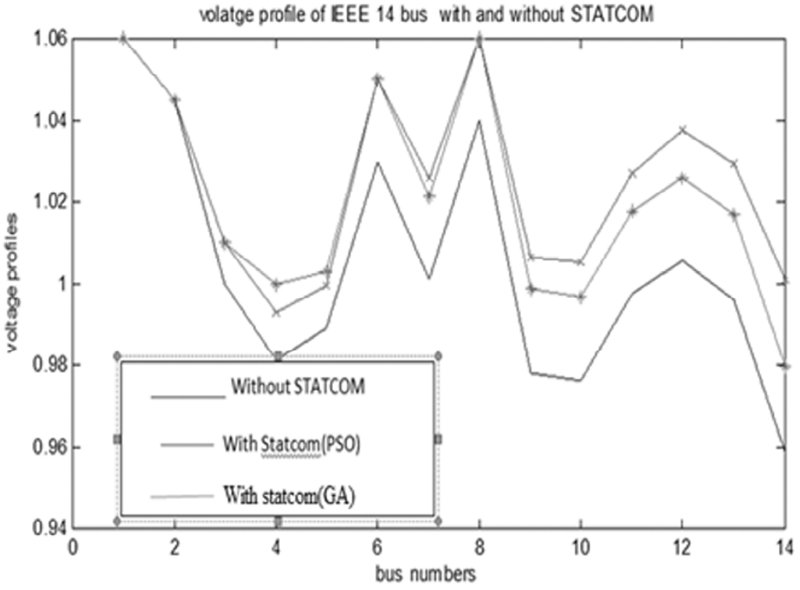

Figure 3: Voltage Profile of the IEEE 14 bus with and without STATCOM

18.999 kW and 84.434 kVAR. But after the placement of STATCOM by using optimization techniques the voltage profile was improved and power losses becomes reduced significantly as shown in Fig. 3, using GA, the STATCOM is placed at the 5th bus and the voltage profile is improved which is shown in the “Fig.” 3 .The minimum voltage is improved to 0.9800 at the 14th bus. The real and reactive power losses are reduced to 18.459 kW and 82.325 kVAR which is shown in Table 1. However voltage profile was further improved with PSO technique by optimal placement of STATCOM is shown in figure 3. The minimum voltage is improved to 0.9931 p.u at the 4th bus by placing the STATCOM at 14th bus. The real and reactive power losses are 18.191 kW and 81.934 kVAR.

4.1. IEEE 14 Bus System

The proposed methods are also applicable to two more test cases which are IEEE 30 bus and IEEE 57 bus system. The effects of STATCOM placement on those test cases are explained with the tables 2 and 3.

Table 1
Comparative analysis of IEEE 14bus by Optimizing Techniques by placing STATCOM

Method	Min. Bus Voltage (p.u.)	STATCOM Placed Bus	Real power losses (KW)	Reactive Power Losses (KVAR)
Without STATCOM	0.9587(14)	–	18.999	84.434
GA	0.9800(14)	5	18.459	82.325
PSO	0.9931(4)	14	18.191	81.934

4.2. IEEE 30 Bus System

Table 2
Comparative analysis of IEEE 30bus by Optimizing Techniques by placing STATCOM

Method	Min.Bus Voltage (p.u.)	STATCOM Placed bus	Real power Losses (KW)	Reactive Power Losses (KVAR)
Without STATCOM	0.9828(30)	–	17.759	69.759
GA	0.9923(24)	28	17.459	69.325
PSO	0.9931(24)	26	16.991	67.934

4.3. IEEE 57 Bus System

Table 3
Comparative analysis of IEEE 57 bus Optimising Techniques by placing STATCOM

Method	Min Voltage (p.u.) (Bus)	STATCOM Placed bus	Real power Losses (kW)	Reactive Power Losses (KVAR)
Without STATCOM	1.0012(57)	–	35.219	236.136
GA	1.0086(46)	55	34.459	235.025
PSO	1.014(51)	52	33.219	233.216

5. CONCLUSION

In this paper, voltage profile improvement, and power (Active and Reactive) loss reduction of the IEEE (14, 30, 57) bus test system by optimal placement of STATCOM shunt FACTS device using heuristic techniques are studied. From above analysis it is concluded that the PSO (Particle Swarm Optimization) optimization techniqueProvides suitable location of the STATCOM to maintain good voltage profile and low real power losses and reactive power losses compare to GA (Genetic Algorithm).

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