Voltage Stability Enhancement by Optimal Placement of STATCOM using Genetic Algorithm

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Abstract- *Voltage security is a crucial issue in power systems especially under heavily loaded conditions. In the new scheme of rearrangement, voltage stability Issue becomes even more serious. Due to the increase of stability margins, Flexible Alternating Current Transmission System (FACTS) devices are the alternatives to mitigate voltage instability by reactive power flow and voltage control criteria. The main purpose of this paper is to identify the optimal Placement of Static Synchronous Compensator (STATCOM) to increase the power system voltage profile using Genetic algorithm. The proposed method established to improvement of voltage security margin. It is implemented to a modified Sample 5-bus system.*

Keywords- Voltage Stability Enhancement, Newton Raphson (Nr) Power Flow, Static Synchronous Compensator (STATCOM), sample 5 Bus System.

I. INTRODUCTION

POWER systems components mainly consist of generators, transformers, switches, transmission lines, passive or active compensators and loads. Power system networks are complex systems that are nonlinear, non-stationary, and subject to disturbances and faults. Strengthening of a power system can be accomplished by improving the voltage Enhancement, increasing the transmission capacity and others. Flexible Alternating Current Transmission System (FACTS) devices are a different solution to address some of those Issues [5]. The Flexible Alternating Current Transmission System devices can be categorized into three types, such as series Compensators, shunt Compensators and combined series-shunt Compensators. In principle, the series Compensators inject voltage in series with the line and the shunt Compensators inject current into the network at the point of connection. The combined series-shunt Compensators inject current into the network with the shunt part of the controllers and voltage in series in the line with the series part of the Compensators.

In the case of voltage Enhancement, shunt Flexible Alternating Current Transmission System devices, such as STATCOM and SVC are normally used. This Paper is focused on the steady state performance of multiple STATCOM devices in the power system. Particularly, it is desired to determine their optimal Placement of STATCOM.

This paper introduces the application of optimal Placement of a new STATCOM in the power system Network. It is organized as follows: In Section II STATCOM Model. In Section III the basic concepts of genetic algorithm; In Section IV the basic concepts of Load flow Analysis. In section V Procedure for Proposed Method and Sample 5 bus system data. In section VI simulation results are presented. In section VII conclusions are given.

II. STATCOM MODEL

A. STATCOM Basic Concept

Static Synchronous Compensator (STATCOM) is a second generation Flexible Alternating Current Transmission System device used for shunt reactive power compensation. The principle of Static Synchronous Compensator is the reactive power compensation where the reactive power and voltage magnitude of the system can be adjusted such as shown in Fig. 1. It consists of three parts: coupling transformer, voltage source converter (VSC), and capacitor. The reactive power is distributed in the power system by the converter control.

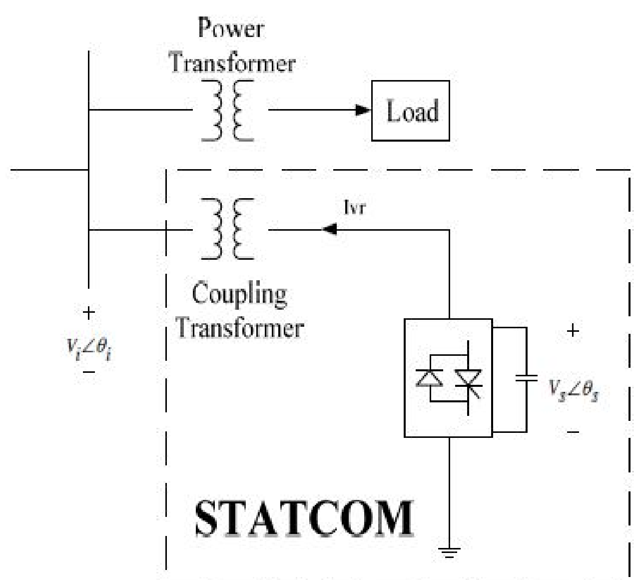

Fig-1: STATCOM Connected to Power System

Where

$V_i \angle \theta_i$: the bus voltage and its phase angle of power system.
$V_s \angle \theta_s$: the STATCOM voltage and its phase angle

The SATCOM real P and reactive power Q are shown in (1) and (2).

Where Xs :is coupling transformer equivalent reactance
$\delta : \theta_s - \theta_i$

The Static Synchronous Compensator is a combination of a VSC and an inductive reactance and shunt connected to power system network. This convert supplies leading current to the AC network if the converter output voltage V_i is made to lead the corresponding AC network voltage V_S. Then it supplies reactive power to the AC network by capacitive action. Equally, the converter absorbs lagging current from the AC network; if the converter output voltage V_i is made to lag the AC network voltage V_S then it absorbs reactive power to the AC network by inductive action. If the output voltage is equal to the AC network voltage, the reactive power exchanges.

B. Modeling of Static Synchronous Compensator

The Static Synchronous Compensator can act as on equivalent voltage source series reactance. Voltage source can transform the current source by way of Norton Theorem as shown in Fig. 2.

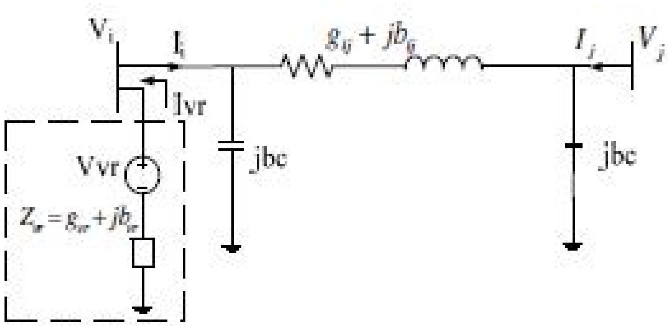

Fig.2.Transmission line equivalent model and Shunt STATCOM equivalent model circuit Diagram.

According to Fig. 2 with STATCOM model inferential reasoning as follows: Bus i and Bus j the beginnings and ends injection current show in (3) and (4)

$I_{ivr} = I_i + I_{vr}$
$= (V_i - V_j)(g_{ij} + jb_{ij}) + V_i jb_c + V_i(g_{vr} + jb_{vr})$ (3)
$I_j = (V_j - V_i)(g_{ij} + jb_{ij}) + jb_c V_j$ (4)

Where
$V_i = |V_i|\cos\theta_i + j|V_i|\sin\theta_i$
$V_j = |V_j|\cos\theta_j + j|V_j|\sin\theta_j$

Polar to Cartesian coordinate transformation is used in (5)
$e + jf = |V|\cos\theta + j|V|\sin\theta$ (5)

Where e: is the bus voltage real-part
f: is the bus voltage imaginary-part

Therefore I_{ivr}, I_j can be rewritten as show in (6) and (7)

$$I_{ivr} = \{g_{ij}(e_i - e_j) - b_{ij}(f_i - f_j) - b_c f_i + g_{vr} e_i - b_{vr} f_i\} + j\{g_{ij}(f_i - f_j) + b_{ij}(e_i - e_j) + b_c e_i + g_{vr} f_i + b_{vr} e_i\} \quad (6)$$

$$I_j = \{g_{ij}(e_j - e_i) - b_{ij}(f_j - f_i) - b_c f_i\} + j\{b_{ij}(e_j - e_i) + g_{ij}(f_j - f_i) + b_c e_i\} \quad (7)$$

Then I_{ivr}, I_j divides into the real part, imaginary part respectively to differential state variable *ei, ej, fi, fj*.

We can obtain the new admittance matrix and equivalent injection current with the relations shown in equ. (8).

$$I = Y_{matrix}^{New} V \quad (8)$$

III. GENETIC ALGORITHM

Genetic Algorithm is a well-known evolutionary search technique that can result as feasible as well as an optimal solution. Genetic Algorithm starts with a random initial population in order to select the best individuals. Crossover, mutation and selection all together are the functions associated with Genetic Algorithm. Ordinary (binary) Genetic Algorithm can be modified using real codes so-called real- Genetic Algorithm (RGA), in which decoding is not needed to be done, while it may increase the speed and the accuracy of search process. The major issues of real- Genetic Algorithm can be addressed in crossover as well as mutation and selection stages in the following those stages are explained in details.

A. Crossover

Crossover is one of the main features of real- Genetic Algorithm that makes it different from binary Genetic Algorithm. Three kinds of convex cross over technique are used in this paper based on the following formulas.

$O_1 = \lambda P_1 + (1-\lambda) P2$
$O_1 = \lambda P_2 + (1-\lambda) P_1 \qquad \lambda \in \{0, 1\}$
$O_1 = \lambda_1 P_1 + (1-\lambda_1) P_2$
$O_1 = \lambda_2 P_2 + (1-\lambda_2) P_1 \qquad \lambda_1, \lambda_2 \in \{0, 1\}$

Where: P1, P2 are the two parents, 01, 02 are two their off spring and λ_1, λ_2 are two random numbers.

B. Mutation

Mutation is for introducing artificial variation in the population to avoid previous convergence to a local optimum. An arithmetic mutation operator that has proved successful in a number of studies is dynamic or non-uniform mutation. It is designed for fine-tuning aimed to achieve a high degree of accuracy and exactness in this paper. For a given parent P, if the gene P_k is selected for mutation, then the resulting gene is selected with equal probability from the two following choices:

$$O_K = P_k - r(P_k + a_k)(1 - t/T)^b$$
$$O_K = P_k + r(b_k - P_k)(1 - t/T)^b$$

Where: a_k and b_k are lower band and upper band of P_k and r is a uniform random number chosen from (0, 1). t is the number of current generation, T is the maximum number of generation and b is the parameter determining the degree of non-uniformity, that is assumed to be 3. It can be said that non uniformity decreases as the number of generation increases.

C. Selection

In general, selection is based upon a random choosing process, where one of the selection methods is known as roulette-wheel. The length of each segment on this line corresponds to the fitness value of each individual. A random number will be generated and the individual whose segment spans the random number will be selected (trial). This technique is analogous to a roulette wheel with each slice proportional in size to the appropriate value.

IV. LOAD FLOW ANALYSIS

A. Introduction

Load flow study in power system is the steady state solution of the power system network. The power system is modeled by an electric network and solved for the steady-state powers and voltages at various buses. The direct analysis of the circuit is not possible, as the load are given in terms of complex powers slightly than impedances, and generators work more like power sources than voltage sources. The main data gotten from the load flow Analysis comprises of magnitudes and phase angles of load bus voltages, reactive powers and voltage phase angles at generator buses, active and reactive power flow on transmission lines together with power at the reference bus, other variables being specified.

This statistics is essential for the continuous monitoring of the current state of the system and for the analyzing the effectiveness of the different plans for the future, such as adding new generator sites, meeting increased load demand and locating new transmission sites. In load flow analysis, we are mainly interested in voltages at various buses and power injection into the transmission line. In addition, power flow analysis is required for many other analyses such as transient stability and contingency analysis studies. The main objective of a power flow study is to determine the steady state operating condition of the electrical network. The steady state may be determined by finding out the flow of active and reactive power throughout the network and the voltage magnitudes and phase angles at all nodes of network. Such statistics is used to carry out safety assessment analysis, where the nodal voltage magnitudes and active and reactive power flows in transmission lines and transformers are carefully observed to assess whether or not they are within suggested operating limits.

In solving a power flow problem, the system is assumed to be working under balanced conditions and a single-phase system is used. In a power system each bus or node is associated with four quantities i.e. voltage magnitude |V|, phase angle δ, active power P, and reactive power Q. In a load flow analysis as two out of the four quantities are specified and the remaining two are required to be obtained through the solution of the equations. Based on the difference between power flow in the sending and receiving ends, the losses in a particular line can also be calculated.

B. Methods of Load Flow Analysis

1. Gauss-seidel method,
2. Newton – Raphson method,
3. Fast Decupled method.

Based on the above load flow methods, the newton Raphson method is taken for this proposed system.

C. Newton-Raphson Method

The Newton-Raphson (NR) method is a powerful method of solving non-linear algebraic equations. Because of its quadratic convergence, Newton's method is mathematically superior to the Gauss-Seidel method and is less prone to disagreement with ill-conditioned problems. It works faster, and is sure to converge in most cases as compared to the Gauss-Siedel (GS) method. It is indeed the practical method of load flow solution of large power networks. Its only drawback is the large requirement of computer memory, which can be overcome through a compact storage scheme. One of the main strengths of the Newton-Raphson method is its reliability towards convergence.

Different to non-Newton-Raphson solutions, convergence is independent of the size of the network being solved and the number and kinds of control equipment present in the system. Hence in the proposed work Newton-Raphson method is preferred. The Formula used are

$$P_i = \sum_{j=1}^{n} |V_i|\,|V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j)$$

$$Q_i = -\sum_{j=1}^{n} |V_i|\,|V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j)$$

Jacobian Matrix

$$\begin{bmatrix} \Delta P_1 \\ \vdots \\ \Delta P_{n-1} \\ \Delta Q_1 \\ \vdots \\ \Delta Q_{n-m} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial \delta_1} & \cdots & \frac{\partial P_1}{\partial \delta_{n-1}} & \frac{\partial P_1}{\partial |V_1|} & \cdots & \frac{\partial P_1}{\partial |V_{n-m}|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_{n-1}}{\partial \delta_1} & \cdots & \frac{\partial P_{n-1}}{\partial \delta_{n-1}} & \frac{\partial P_{n-1}}{\partial |V_1|} & \cdots & \frac{\partial P_{n-1}}{\partial |V_{n-m}|} \\ \frac{\partial Q_1}{\partial \delta_1} & \cdots & \frac{\partial Q_1}{\partial \delta_{n-1}} & \frac{\partial Q_1}{\partial |V_1|} & \cdots & \frac{\partial Q_1}{\partial |V_{n-m}|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_{n-m}}{\partial \delta_1} & \cdots & \frac{\partial Q_{n-m}}{\partial \delta_{n-1}} & \frac{\partial Q_{n-m}}{\partial |V_1|} & \cdots & \frac{\partial Q_{n-m}}{\partial |V_{n-m}|} \end{bmatrix} \begin{bmatrix} \Delta \delta_1 \\ \vdots \\ \Delta \delta_{n-1} \\ \Delta |V_1| \\ \vdots \\ \Delta |V_{n-m}| \end{bmatrix}$$

V. FLOW CHART AND SAMPLE 5-BUS SYSTEM

A. Flow Chart

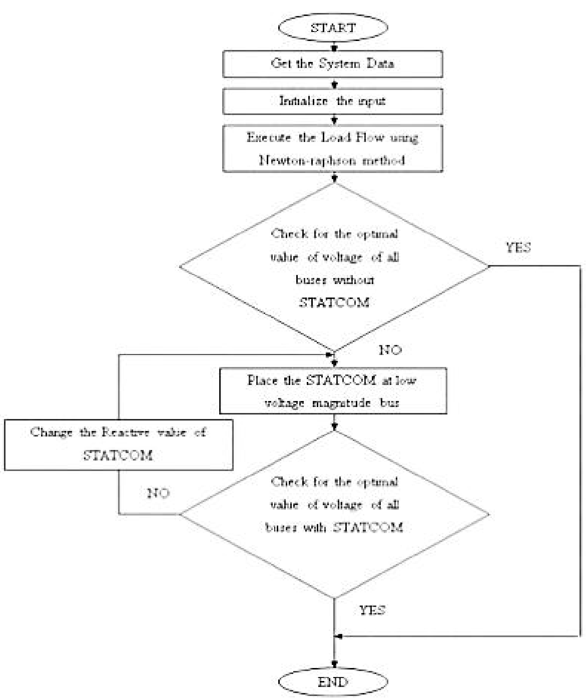

Fig-3: Proposed System Flow Chart

B. Procedure for Proposed Method:

1. Read the data from the sample system.
2. Run the load flow analysis by Newton-Raphson method using MATLAB (without STATCOM).
3. Checks for the optimal voltage level in all the buses if not optimal go to next step else end the program.
4. Place the STATCOM in Low magnitude voltage bus.
5. Run the load flow analysis by Newton-Raphson method using MATLAB (with STATCOM)
6. If the voltage is not optimal go to step 5 else end the process.
7. Stop the process

C. Sample 5- bus System

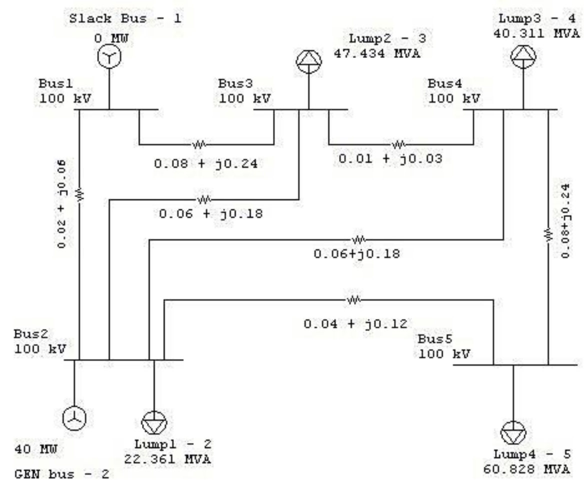

Fig-4: Sample 5-bus System

For this Paper we have considered the Sample five bus system as shown in Fig. 4, which is a seven line, two generator and three load bus. The input data for the considered system are given in Table 1 for the bus and Table 2 for transmission line. The transmission line impedances and line charging admittances are in per unit.

Table 1
Input bus Data (p.u)

BusNo.	Type	Generation		Load		Voltage	
		P	Q	P	Q	|V|	θ
1	Slack	0	0	-	-	1.06	0
2	P-V	0.4	0	0.2	0.1	1	0
3	P-Q	-	-	0.45	0.15	1	0
4	P-Q	-	-	0.4	0.05	1	0
5	P-Q	-	-	0.6	0.1	1	0

Assuming Base Quantity are 100MVA and 100KV.

Table 2
Input transmission line data (p.u)

Lineno	LineCode	Impedance (R+jX)	LineChargingadmittance
1	1-2	0.02+j0.06	0+j0.06
2	1-3	0.08+j0.24	0.+j0.05
3	2-3	0.06+j0.18	0+j0.04
4	2-4	0.06+j0.18	0+j0.04
5	2-5	0.04+j0.12	0+j0.03
6	3-4	0.01+j0.03	0+j0.02
7	4-5	0.08+j0.24	0+j0.05

VI. SIMULATION RESULTS

A. Load flow without STATCOM

The load flow result for the Sample 5-bus system is shown in Fig.5 and Table 3 respectively

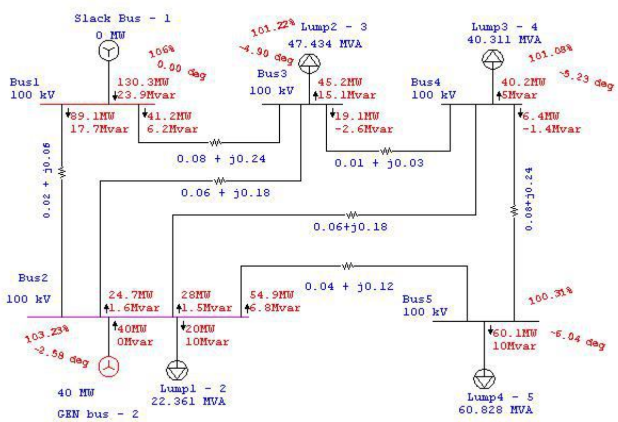

Fig-5: Load Flow Analysis using ETAB (Without STATCOM)

It is observed from the above load flow analysis using ETAB. From the power flow diagram it is clear that the largest power flow takes place in the transmission line connecting the generator buses: 89.1 MW, and 17.7 MVAR leave from Bus 1 and 87.6 MW and 17.7 MVAR arrive at Bus 2. This is also the transmission line that experiences higher active power loss (i.e. 1.5 MW). The operating conditions demand a large amount of reactive power generation by the generator connected at Bus 1 (i.e.23.9 MVAR). The generator at Bus 2 draws the excess of reactive power in the network (i.e.10 MVAR).

Table 3
Voltage Magnitude and Phase angle for 5 bus system without STATCOM

Parameter	Bus1	Bus2	Bus3	Bus4	Bus5
VM(p.u)	1.06	1.032	1.012	1.018	1.013
VA(deg)	0	-2.58	-4.90	-5.23	-6.04

B. Load flow analysis with STATCOM

The Static Synchronous Compensator is included in the bus 3 of the sample 5-bus system to maintain the nodal voltage is equal to slack bus valve. The Placement of Static Synchronous Compensator can be is taken by the minimum valve voltage buses.

The load flow analysis result for the Sample 5-bus system with Static Synchronous Compensator at bus 3 is shown in Fig.6 and Table 4 respectively

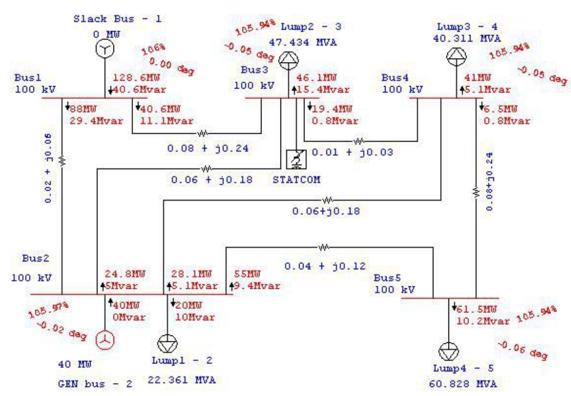

Fig-6: Load Flow Analysis using ETAB (with STATCOM)

Here the power flow analysis result indicates that the Static Synchronous Compensator generates reactive power in order to keep the voltage magnitude is equal to slack bus Voltage and power value. The largest reactive power flow takes place in the transmission line connecting bus 1(slack bus) and bus 2.

Table 4
Voltage Magnitude and Phase angle for 5 bus system with STATCOM

Parameter	Bus1	Bus2	Bus3	Bus4	Bus5
VM(p.u)	1.06	1.059	1.059	1.0594	1.0594
VA(deg)	0	-2.58	-4.90	-5.23	-6.04

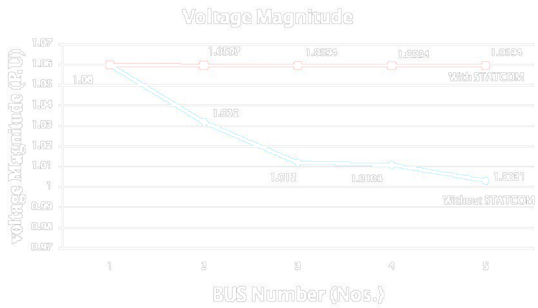

Fig-7: Voltage Magnitude (With and without STATCOM)

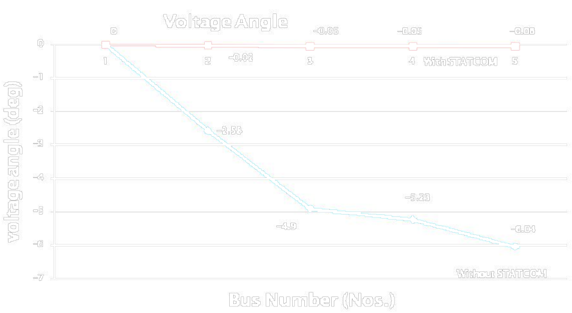

Fig-8: Voltage Angle (With and Without STATCOM)

VII. CONCLUSIONS

In this Paper, the Static Synchronous Compensator is used to control power flow of power system network by injecting suitable reactive power during dynamic state. Computer simulation results show that Static Synchronous Compensator not only considerably enhance voltage stability but also compensates the reactive power in steady state. Therefore Static Synchronous Compensator can increase reliability and capability of Flexible Alternating Current Transmission System.

It is quite clear that before compensating a power system with Flexible Alternating Current Transmission System device to enhance voltage stability, we need to assess the system stability conditions for different locations of the fault and the compensator and also with different quantities of compensation. The voltage stability Enhancement of the multi-machine power system at different fault condition is investigated in this Proposed Paper.

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