Analysis and Design of Power System Stabilizers and FACTS Based Stabilizers using GA

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Abstract— Transmission networks of modern power systems are becoming increasingly stressed because of growing demand and restrictions on building new lines. One of the consequences of such a stressed system is the threat of losing stability following a disturbance. Flexible ac transmission system (FACTS) devices are found to be very effective in a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin. Flexible AC Transmission System (FACTS) such as Static Synchronous Compensator (STATCOM) and Static VAR Compensator (SVC), employ the latest technology of power electronic switching devices in electric power transmission systems to control voltage and power flow. A static synchronous compensator (STATCOM) is a shunt device of the flexible AC transmission systems (FACTS) family. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from power system. When system voltage is low, STATCOM generates reactive power and when system voltage is high it absorbs reactive power. In this research work, STATCOM controller based on Genetic algorithm is proposed in single machine infinite bus system (SMIB). Proposed controller is implemented under MATLAB/SIMULNK environment.
Key words: STATCOM, MATLAB, FACTS, Transmission System

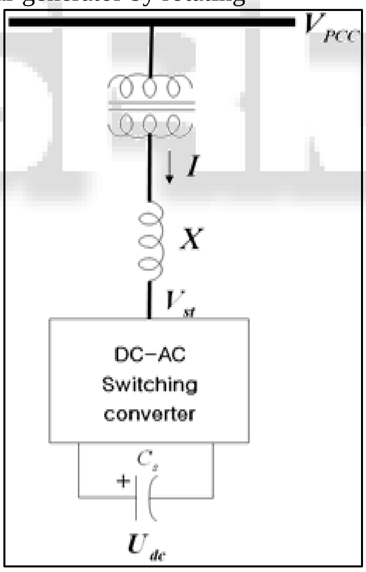
I. INTRODUCTION

The power transfer capability of long transmission lines is usually limited by thermal capability, dielectric strength and a number of stability issues. Economic factors, such as high cost of long lines and revenue from the delivery of additional power, give strong incentives to explore all economically and technically feasible means of raising the stability limit. The family of FACTS devices makes use of gate turn-off thyristors (GTOs) in high power converter conjurations that can be controlled to behave as three phase sinusoidal voltage sources, to provide fast control of active and reactive power through a transmission line. The family of FACTS devices includes the Static Var Compensators (SVCs), Static Synchronous Compensators (STATCOMs), Thyristor Controlled Series Compensators (TCSCs), the Static Synchronous Series Compensators (SSSCs), and the Unified Power Flow Controllers (UPFCs). The FACTS technology is not a single high power controller but rather a collection of controllers which can be applied individually or in coordination with other to control one or more of the inter related system parameters like voltage, current, impedance, phase angle and damping of oscillations at various frequencies below the rated frequency. Among all FACTS devices, static synchronous compensators (STATCOM) plays much more important role in reactive power compensation and voltage support because of its attractive steady state performance and operating characteristics. The fundamental principle of a STATCOM installed in a power system is the generation ac voltage source by a voltage source inverter (VSI) connected to a dc capacitor.

A. Working Principal of STATCOM

The basic principle of reactive power generation by voltage-sourced converter is akin to that of the conventional rotating synchronous machine. The basic voltage-sourced converter scheme for reactive compensation is shown schematically in Figure 1. From a dc input voltage source, the converter produces a set of controllable three-phase output voltages provided by the charged capacitor *Sm*ith the system frequency of the ac power system.

A phase shift between the two voltages, d, allows real power to flow and thus can be used to regulate the dc bus voltage, as in (1).In addition, the reactive current or power can be controlled by adjusting the relative voltage of the converter output voltage, as in (2). Figure-1: A single-line diagram of var generator by rotating



a voltage-sourced switching converter .

$$P(\delta) = \frac{V_{PCC}V_{st}}{X} Sin\delta \quad (1)$$

$$Q(V_{st}) = \frac{V^2{}_{PCC} - V_{PCC}V_{st}cos\delta}{X} \quad (2)$$

B. Mathematical Description of STATCOM

According to mathematical model of STATCOM, thedynamic model of STATCOM can bedescribed as in equation (2)

$$L\frac{dI_{abc}}{dt} + RI_{abc} = U_{abc} - V_{abc} \quad (3)$$

Equations (3) can be transformed to synchronously rotatingreference frame using the Park's transformation, as in (4)

$$f^e_{dq} = T(\theta)f_{abc} \quad (4)$$

WhereT (θ)is the matrix of converting three-phase abcframe into the synchronous reference frame involved with the d an d q components when it is not considered the zero components.

$$T(\theta) = \frac{2}{3}\begin{vmatrix} \cos\theta & \cos\left(\theta - \frac{2}{3}\pi\right) & \cos\left(\theta + \frac{2}{3}\pi\right) \\ -\sin\theta & -\cos\left(\theta - \frac{2}{3}\pi\right) & -\cos\left(\theta + \frac{2}{3}\pi\right) \end{vmatrix} \quad (5)$$

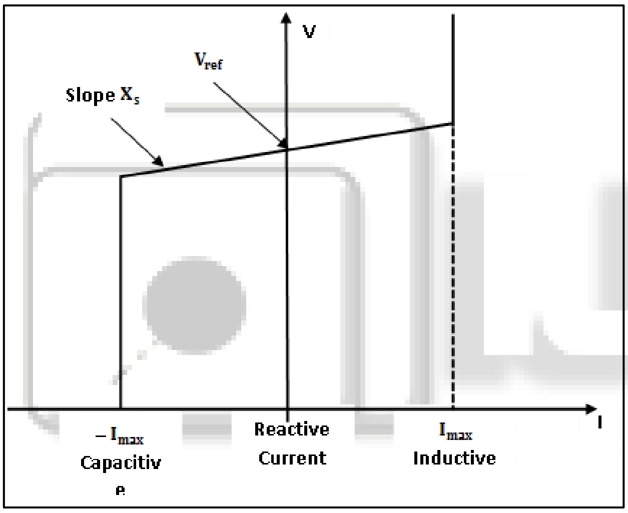
The power balance equation of the converter is

$$P = u_{dc} C \frac{dU_{dc}}{dt} \quad (6)$$

So, the state equation for STATCOM is

$$\frac{d}{dt}\begin{vmatrix} \Delta i_d \\ \Delta i_q \\ \Delta u_{dc} \end{vmatrix} = \begin{bmatrix} \frac{-R}{L} & \omega & \frac{-m}{L}\cos\delta \\ -\omega & \frac{-R}{L} & \frac{m}{L}\sin\delta \\ \frac{3m}{2C}\cos\delta & \frac{-3m}{2C}\sin\delta & -R_p C \end{bmatrix}\begin{vmatrix} \Delta i_d \\ \Delta i_q \\ \Delta u_{dc} \end{vmatrix} + \begin{vmatrix} \frac{-1}{L} & 0 & \frac{m}{L}\sin\delta_0\, u_{dc0} \\ 0 & \frac{1}{L} & \frac{m}{L}\cos\delta_0\, u_{dc0} \\ 0 & 0 & \frac{-3m}{2C}(\sin\delta_0 i_{d0} + \cos\delta_0\, i\delta_{q0}) \end{vmatrix}\begin{vmatrix} \Delta i_d \\ \Delta i_q \\ \Delta u_{dc} \end{vmatrix} \quad (7)$$

C. V-I Characteristics of STATCOM



The V-I characteristics are depicted by the following equation:

$$V = V_{ref} + X_s . I \quad (8)$$

Where
V = Position voltage
I = Reactive Current
X_s = Slope
P_{norm}= Converter rating

D. Motivation and Objective

If a fault occurs in single machine infinite bus (SMIB) system then the quality of power degrades. It is called small signal disturbance. Asecure system provides a constant frequency and constant voltagewithin limits tocustomers. To achieve this aim a highly reliable and cost effective longterm investmenttechnology is required. Stability limits can define transfer capability.Also in a complexinterconnected system, stability has a great impact to increase thereliability and theprofits.Although this interconnection gives the system a complicated dynamic. It hasadvantages such as reduced spinning reserves and a lower electricity price. Toachievethese benefits, appropriate control is required to synchronize the machinesafter adisturbance occurs.

II. LITERATURE REVIEW

The design problem of PSS and STATCOM controllers are formulated as an optimization problem.Using the developed linearized model of a power systemequipped with STATCOM-based stabilizer & PSS, theparticle swarm optimization (PSO) algorithm is employedto search for optimal controllers parameters. In addition,the paper presents a singular value decomposition (SVD) based approach to asses and measures the controllability of the poorly damped electromechanical modes bydifferent controllers' inputs.

static synchronous compensator (STATCOM)in order to simultaneous voltage support and damping of Low Frequency Oscillations(LFO) at a Single-Machine Infinite-Bus (SMIB) power system installed with STATCOM.PI type controllers are considered as STATCOM internal controllers and the parameters ofthese PI type controllers are tuned using Particle Swarm Optimization (PSO) and GeneticAlgorithms (GA). Also a stabilizer supplementary controller based STATCOM isconsidered for increasing power system damping. In order to comparison and analysis, thePSO and GA controllers are compared. Numerous simulations show the ability o f STATCOM in simultaneous control of voltage and damping of power system oscillations.Also simulation results emphasis on the better performance of PSO in comparison with GA.

Power system stability enhancement via a power system stabilizer (PSS) and FACTS-based stabilizers is thoroughly investigated in this paper. The design problem of PSS and different FACTS controllers is formulated as an optimization problem. An eigenvalue-based objective function to increase the system damping and improve the system response is proposed. Then, a real-coded genetic algorithm (RCGA) is employed to search for optimal controller parameters. In addition, this study presents a singular value decomposition (SVD) based approach to assess and measure the controllability of the poorly damped electromechanical modes by different inputs.

III. PROBLEM DEFINITION

The STATCOM basically consists of a step-down transformer with a leakage reactance, a three-phase GTO or IGBT voltage source inverter (VSI), and a DC capacitor. The AC voltage difference across the leakage reactance produces reactive power exchange between the STATCOM and the power system, such that the AC voltage at the bus bar can be regulated to improve the voltage profile of the power system, which is the primary duty of the STATCOM.

The STATCOM is a voltage-sourced-converter (VSC)-based shunt-connected device. Byinjecting a current of variable magnitude in quadrature with the line voltage, the STATCOM caninject reactive power into the power system.TheSTATCOM does not employ capacitor orreactor banks to produce reactive power as does the SVC. but instead uses a capacitor tomaintain a constant dc voltage for the inverter operation.

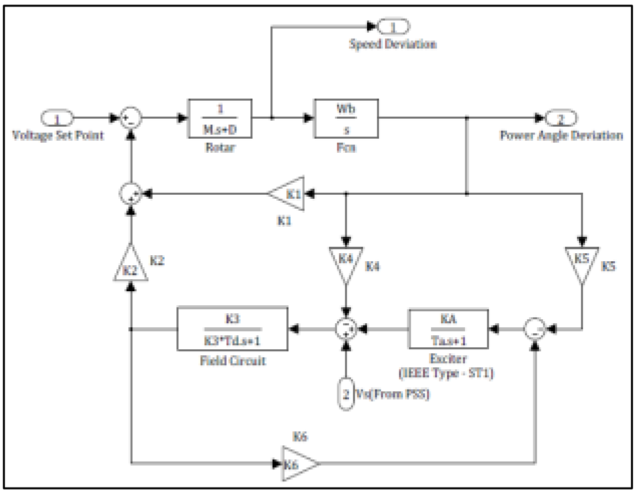


Fig. 3.1: SMIB system

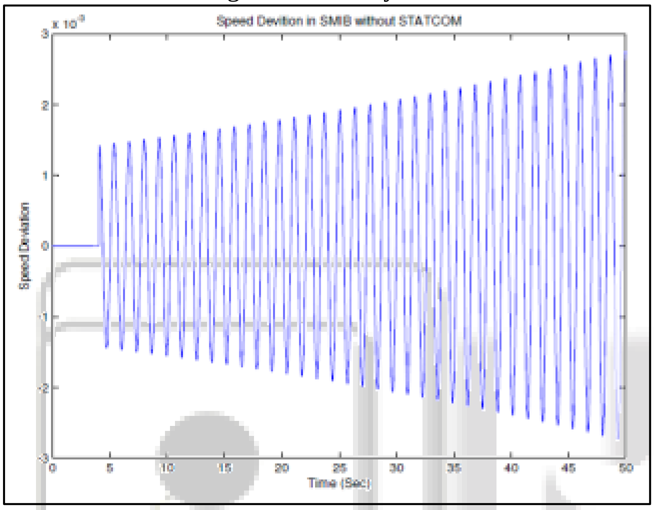


Fig. 3.2: Speed deviation in fault condition without any stabilizer

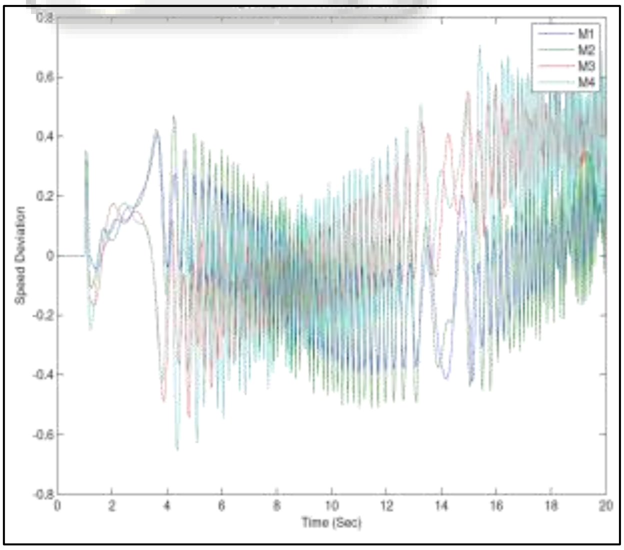


Fig. 3.3: Speed Deviation without STATCOM

The Single machine system has wide application in real time power distribution systems but its response in fault condition make it unstable and unreliable as shown in figures above. The in this work we are analysing performance of STATCOM under the fault conditions for both system.

IV. Proposed Methodology

A. Modelling of SMIB

Consisting the generator, excitation system, AC network etc. A SMIB power system model as shown in Fig. 1 is used to obtain the Modified Heffron-Phillip's model parameters.This is a simplified representation of a generator is connected to the load through a transmission line. IEEE Model 1.0 is used to model the synchronous generator

For the study of single machine infinite bus system a Heffron Phillips model can be obtained by linearizing the system equations around an operating condition. The obtained hefffron model is as in figure and the parameters are K_1 = 0.5320, K_2 = 0.7858, K_3 = 0.4494, K_4 = 1.0184,K_5 = -0.0597, K_6 = 0.5746, K_A = 20, M = 7.

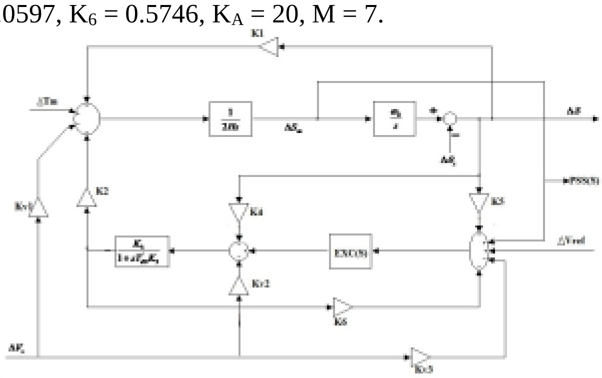


Fig 4.2: Heffron Phillips model – SMIB

After all these STATCOM is installed in SMIB phillipheffron model as shown below:

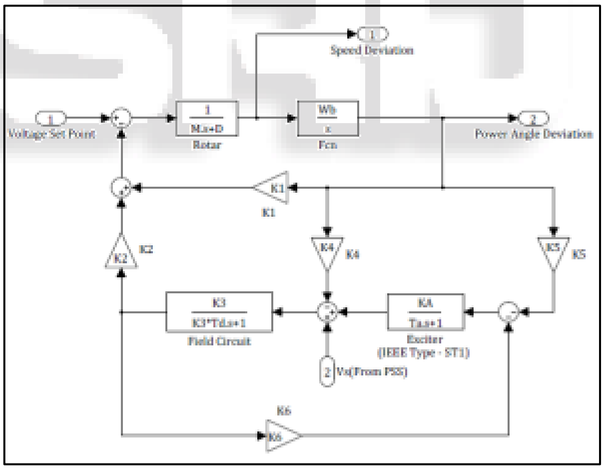


Fig. 4.3: Simulink Implementation of SMIB

B. Genetic Algorithm

Genetic algorithms (GA) were first introduced by John Holland in the 1970s (Holland 1975) as a result of investigations into the possibility of computer programs undergoing evolution in the Darwinian sense.

GA are part of a broader soft computing paradigm known as evolutionary computation. They attempt to arrive at optimal solutions through a process similar to biological evolution. This involves following the principles of survival of the fittest, and crossbreeding and mutation to generate better solutions from a pool of existing solutions.

Genetic algorithms have been found to be capable of finding solutions for a wide variety of problems for which no acceptable algorithmic solutions exist. The GA methodology is particularly suited for optimization, a problem solving technique in which one or more very good solutions are searched for in a solution space consisting of a large number of possible solutions. GA reduce the search space by continually evaluating the current generation of candidate solutions, discarding the ones ranked as poor, and producing a new generation through crossbreeding and mutating those ranked as good. The ranking of candidate solutions is done using some pre-determined measure of goodness or fitness.

1) How GA Works

A genetic algorithm is a probabilistic search technique that computationally simulates the process of biological evolution. It mimics evolution in nature by repeatedly altering a population of candidate solutions until an optimal solution is found

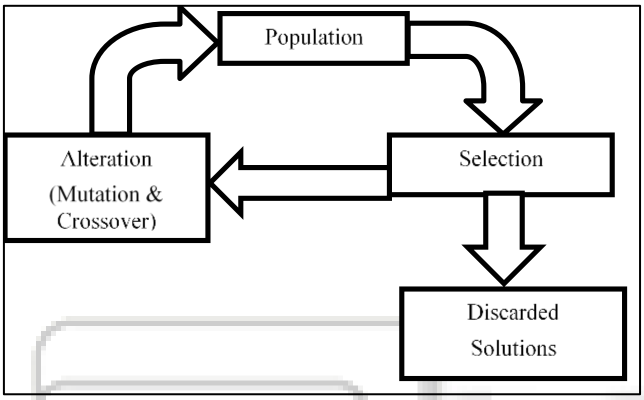


Fig. 4.5: Genetic algorithm evolutionary cycle

The GA evolutionary cycle starts with a randomly selected initial population.The changes to the population occur through the processes of selection based on fitness, and alteration using crossover and mutation. The application of selection and alteration leads to a population with a higher proportion of better solutions. The evolutionary cycle continues until an acceptable solution is found in the current generation of population, or some control parameter such as the number of generations is exceeded.

The smallest unit of a genetic algorithm is called a gene, which represents a unit of information in the problem domain. A series of genes, known as a chromosome, represents one possible solution to the problem. Each gene in the chromosome represents one component of the solution pattern.

The steps in the typical genetic algorithm for finding a solution to a problem are listed below:

1) Create an initial solution population of a certain size randomly
2) Evaluate each solution in the current generation and assign it a fitness value.
3) Select "good" solutions based on fitness value and discard the rest.
4) If acceptable solution(s) found in the current generation or maximum number of generations is exceeded then stop.
5) Alter the solution population using crossover and mutation to create a new generation of solutions.
6) Go to step 2.

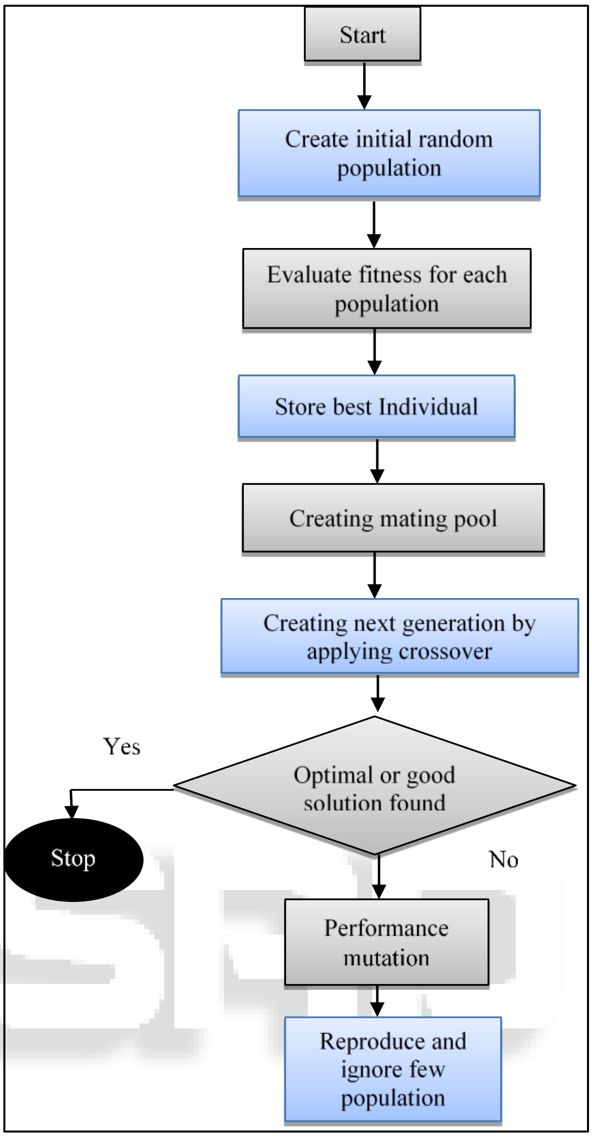


Fig. 4.7: Flow chart of GA

V. RESULTS AND SIMULATION

Proposed work is modelled in MATLAB/SIMULINK R2009b and simulated..

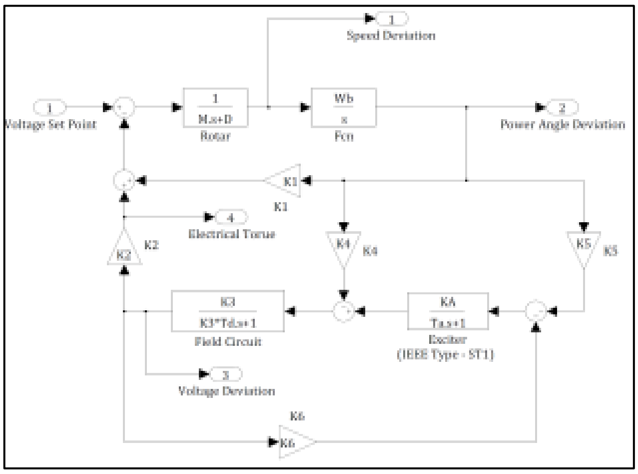


Fig. 5.1: SIMULINK model for SMIB

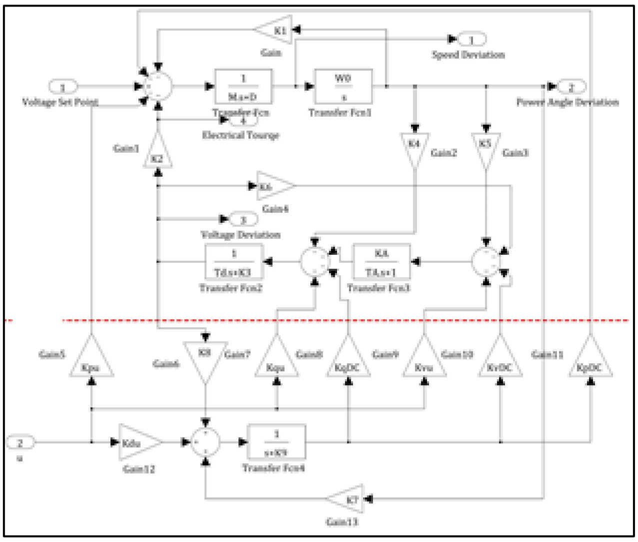


Fig. 5.2: SIMULINK model for SMIB with installed STATCOM

The test system for SMIB is a heffronphillip model of SMIB which feeding by a signal with disturbance and the results when no STATCOM is installed.

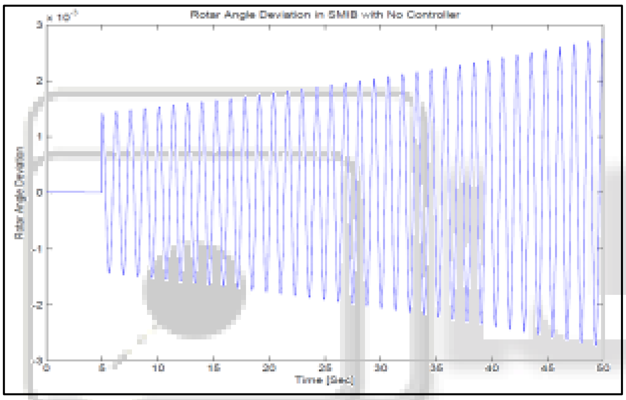


Fig. 5.3: Rotor angle deviation in SMIB with no controller a same signal is feed to after the STATCOM is installed with Genetic algorithm and the rotor angle deviation is as shown in figure 5.2.

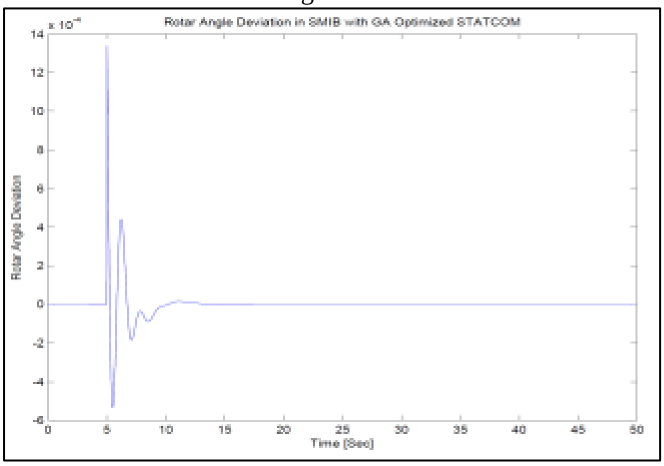


Fig. 5.4: Rotor angle deviation in SMIB with GA optimized STATCOM

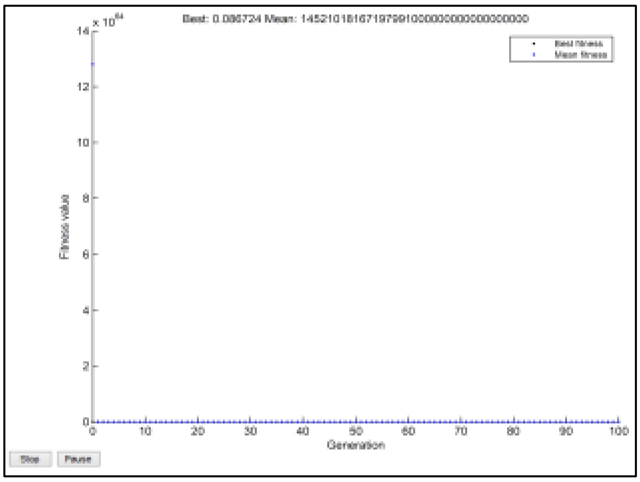


Fig. 5.5: Convergence graph for Genetic Algorithm

VI. CONCLUSION AND FUTURE SCOPE

In this Thesis, dynamic behavior of single machine system installed with STATCOM is investigated under 3-phase fault using genetic algorithm. STATCOM is designed to improve the transient stability of the given system. Proposed work is implemented using MATLAB/SIMULINK. The STATCOM is used to control power flow of power system by injecting appropriate reactive power during dynamic state. Simulation results show that STATCOM not only considerably improves transient stability but also compensates the reactive power in steady state. Therefore STATCOM can increase reliability and capability of AC transmission system .It is quite clear that before compensating a power system with FACTS device to improve transient stability, we need to assess the system stability conditions for different locations of the fault and the compensator and also with different amounts of compensation. The transient stability improvement of the single machine power system at different fault condition is investigated in this work.

The future work could be directed on:

- The arrangement rules with evolutionary algorithm to obtain the better power oscillation damping effects.
- The study can be extended by using larger power system that contains a number of FACTS-based stabilizers.

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