IMPROVEMENT OF POWER SYSTEM STABILITY USING SSSC WITH PID CONTROLLER APPLYING GENETIC ALGORITHM

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CERTIFICATE

This is to certify that the project report entitled, "IMPROVEMENT OF POWER SYSTEM STABILITY USING SSSC WITH PID CONTROLLER APPLYING GENETIC ALGORITHM" submitted by Deepti Ranjan Palo and Binodeswar Das in partial fulfillment of the requirements for the award of degree of Bachelor of Technology in Electrical & Electronics Engineering in the department of Electrical Engineering of VSSUT, BURLA is a bonafide work carried out by them under my supervision and guidance. In my opinion the report fulfills the requirements relating to the nature and standard of work for bachelor of technology degree.

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ABSTRACT

The development of the modern power system has led to an increasing complexity in the operation of power systems, and also presents new challenges to power system stability, and in particular, to the aspects of transient stability. Flexible AC Transmission System (FACTS) devices are found to be very effective in stressing a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin. FACTS controller, such as Static Synchronous Series Compensator (SSSC) employ the latest technology of power electronic switching devices in electric power transmission systems to control voltage and power flow, and play an important role as a stability aid for and transient disturbances in an interconnected power systems. This project investigates the improvement of transient stability of a SMIB power system, using SSSC with PID controller which is an effective FACTS device capable of controlling the active and reactive power flows in a transmission line by controlling appropriately its shunt parameters. The effectiveness of SSSC in improving the critical clearing time (CCT) and damping power system oscillations is evaluated in a **Single Machine Infinite Bus (SMIB) power system**. Modeling and Simulation of SSSC in a SMIB power system has been carried out in MATLAB/SIMULINK environment. At first, Machine speed deviation and Load angle (delta) profiles have been studied for an uncompensated system and then compared with the results obtained after compensating the system using a SSSC.The improvement in CCT at different loading conditions are evaluated. Further, a supplementary damping controller is designed to damp the power system oscillations. A Proportional Integral Derivative (PID) controller structure is employed to modulate the SSSC reference voltage during power system oscillations. The PID controller parameters are optimized using Genetic Algorithm (GA) using an ITAE error criteria. Simulation results are presented to show the effectiveness of the proposed approach.

1. INTRODUCTION

Power System stability has been recognized as an important problem for secure system operation since the 1920s. Historically, transient instability has been the dominant stability problem on most systems, and has been the focus of much of the industry's attention concerning system stability.

A clear understanding of different types of instability and how they are interrelated is essential for the satisfactory design and operation of power systems. Evaluation of first swing stability (FSS) limit is one of the important aspects in power system planning and operation studies [4]. A first swing stable system may be considered as stable if the system has adequate damping. Lack of adequate damping may cause growing oscillations and ultimately the system may become unstable. The FSS limit can be improved by controlling the output power of the severely disturbed machine(s) during transient period. Flexible ac transmission system (FACTS) devices placed at strategic locations are found to be very effective in addressing the above issue [1-8].

The power electronic based Flexible AC Transmission Systems (FACTS) have been developed and used as economical and efficient means to control the power transfer in the interconnected AC transmission systems [1]. This allows forcing the power transit in the lines with higher transmission capacity. It is able to control independently the throughput active and reactive powers. The power flow can be increased, firstly by decreasing the line impedance with a capacitive reactance, secondly by increasing the voltages and finally by increasing the phase angle between these voltages.

A power system is a complex network comprising numerous generators, transmission lines, variety of Loads and transformers. As a consequence of increase in demand for power, some transmission lines are more loaded than was planned when they were built. So with the increased power transfer, transient stability also increasingly has become important for secure operation.

Power system electro mechanical oscillations are one of the most complex phenomena of power system dynamics [1].The complexity of the electro-mechanical oscillations and therefore the difficulty to control them, is due to the fact that they exhibit a wide variety of frequencies and patterns. The pattern of an oscillation is characterized by not only mode shape but also by the participation factors and the sensitivities with respect to the control action. So a supplementary damping controller could be designed to modulate the SSSC bus voltage in order to improve damping of system oscillations. That's where the role of PID controller comes in to existence. PID controllers are the most common controllers in industry. In fact, 95% of control loops use PID and the majorities are PI. Accordingly, there are many tuning techniques, and most are based on:

- Empirical methods, such as Ziegler-Nichols methods.
- Analytical methods, for instance, the root locus based techniques.
- Methods based on optimization.

These obtain PID parameters by optimizing an IAE index and a linear model with the following structure. In all of these cases, PID tunings are obtained for an operation point where the model can be considered linear. This implies there is sub-optimal tuning when a process operates outside the validity zone of the model. This situation is common when the reference is not a set point but a trajectory (robot control, heating trajectories in furnaces).An alternative method to solve this problem is to obtain a model for different operational zones, tune a PID controller for each, and establish a mechanism for changing from one controller to another depending on the operation zone (gain planning).

Another alternative is tuning a PID controller by taking into account all non-linearity's and additional process characteristics. At this point appears the idea of using Genetic Algorithms (a global optimization technique) to obtain a PID tuning that meets all the requirements established in a minimization index by the designer.

Genetic Algorithms are a series of steps for solving an optimization problem using genetics as the underpinning model (Chambers, 1995). More specifically, Genetic Algorithms use the concept of Natural Selection – or survival of the fittest – to help guide the selection of candidate solutions. In essence, Genetic Algorithms use an iterative process of selection, recombination, mutation and evaluation in order to find the fittest candidate solution [Haupt and Haupt (2004), Whitley (n.d.) and Chambers (1995)]. This project is a software design-and-code project with the aim being to use MATLAB to develop a software application to optimize a PID Controller using a purpose built Genetic Algorithm as the basis of the optimization routine.

The core of the project is the research, design, coding and testing of the Genetic Algorithm optimization program. However, the project will then attempt to interface the Genetic Algorithm optimization routine with an existing rotary-wing control model using MATLAB. Without the use of a Genetic Algorithm, the PID Controller would rely upon classical analytical optimization techniques. Such techniques are best suited to problems with only a few variables because of the need to develop a mathematical model of the system from which the use of derivatives can be used to find the optimal solution. In comparison, a Genetic Algorithm can handle multiple variables and only requires the ability to develop a mathematical model to configure a set of inputs (the variables) in order for the model to produce an optimal output (the cost). Hence a PID Controller with three main variables – normally denoted as Kp, Ki, Kd and – is ideally suited to using a Genetic Algorithm to optimize the controller's response as it is a multi-variable system and it has well understood and proven cost functions, such as Integral Time Absolute Error (ITAE), Integral Absolute Error (IAE) and Integral Squared Error (ISE).

2. BASIC CONCEPTS OF STABILITY

2.1. DEFINITION

According to **IEEE** standard definition "Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact."

2.2. DESCRIPTION

The definition applies to an interconnected power system as a whole. Often, however, the stability of a particular generator or group of generators is also of interest. A remote generator may lose stability (synchronism) without cascading instability of the main system. Similarly, stability of particular loads or load areas may be of interest; motors may lose stability (run down and stall) without cascading instability of the main system. [4]

The power system is a highly nonlinear system that operates in a constantly changing environment; loads, generator outputs and key operating parameters change continually. When subjected to a disturbance, the stability of the system depends on the initial operating condition as well as the nature of the disturbance. Stability of an electric power system is thus a property of the system motion around an equilibrium set, i.e., the initial operating condition. In an equilibrium set, the various opposing forces that exist in the system are equal instantaneously (as in the case of equilibrium points) or over a cycle (as in the case of slow cyclical variations due to continuous small fluctuations in loads or aperiodic attractors).

Power systems are subjected to a wide range of disturbances, small and large. Small disturbances in the form of load changes occur continually; the system must be able to adjust to the changing conditions and operate satisfactorily. It must also be able to survive numerous disturbances of a severe nature, such as a short circuit on a transmission line or loss of a large generator. A large disturbance may lead to structural changes due to the isolation of the faulted elements. At an equilibrium set, a power system may be stable for a given (large) physical disturbance, and unstable for another. It is impractical and uneconomical to design power systems to be stable for every possible disturbance [2].

The design contingencies are selected on the basis they have a reasonably high probability of occurrence. Hence, large-disturbance stability always refers to a specified disturbance scenario. A stable equilibrium set thus has a finite region of attraction; the larger the region, the more robust the system with respect to large disturbances.

2.3. CLASSIFICATION OF POWER SYSTEM STABILITY

A typical modern power system is a high-order multivariable process whose dynamic response is influenced by a wide array of devices with different characteristics and response rates. Stability is a condition of equilibrium between opposing forces. Depending on the network topology, system operating condition and the form of disturbance, different sets of opposing forces may experience sustained imbalance leading to different forms of instability. **Fig. 1** gives the overall picture of the power system stability problem, identifying its categories and subcategories

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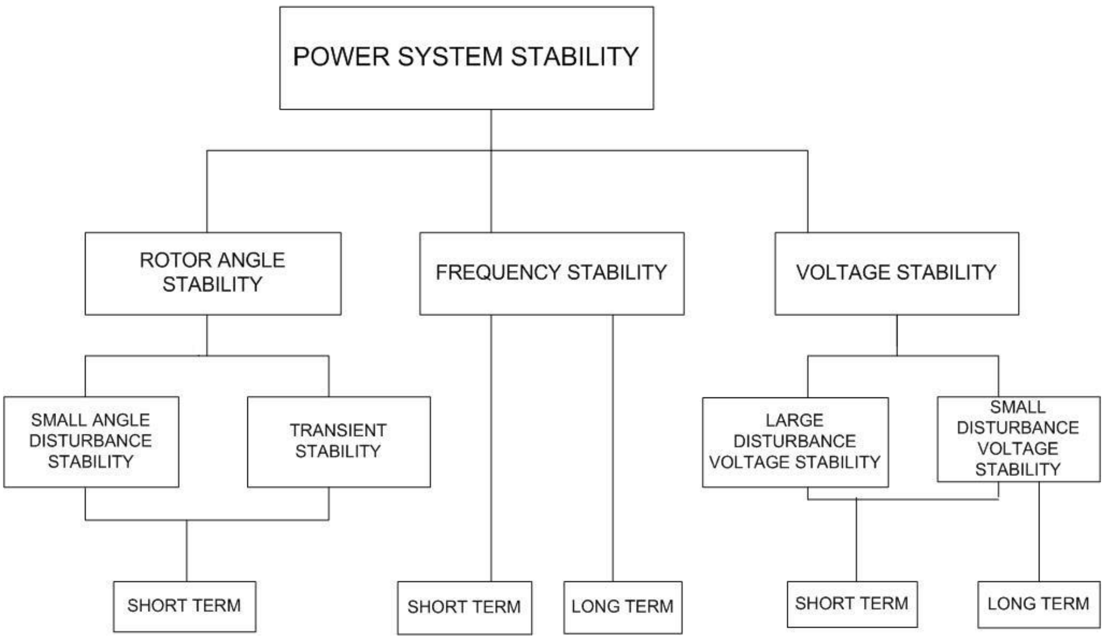


Figure 1-Classification of Power System Stability

2.3.1 Rotor angle stability

Rotor angle stability refers to the ability of synchronous machines of an interconnected power system to remain in synchronism after being subjected to a disturbance. It depends on the ability to maintain/restore equilibrium between electromagnetic torque and mechanical torque of each synchronous machine in the system. Instability that may result occurs in the form of increasing angular swings of some generators leading to their loss of synchronism with other generators.

2.3.2 Voltage Stability

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. It depends on the ability to maintain/restore equilibrium between load demand and load supply from the power system.

2.3.3 Frequency Stability

Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load.

2.4. SWING EQUATION

The given equation below is called swing equation and it describe the rotor dynamics for a synchronous machine (generating and motoring).it is a second order differential equation where the damping term(proportional to$\frac{d\delta}{dt}$)is absent because of a lossless machine and the fact that the torque of damper winding has been ignored. Since the electrical power Pe depends upon the sine of angleδ, the swing equation is a nonlinear second order differential equation.

$$\frac{2H}{\omega_S}\frac{d^2\delta}{dt^2} = P_M - P_E \text{......................} (1)$$

2.5 EQUAL AREA CRITERION

For single machine infinite bus system a method known as "**Equal Area Criterion of Stability**" is employed. The use of this method eliminates partially or wholly the calculations of swing curve and thus save a considerable amount of work. The method is applicable to any two machine system but not to any multi machine system. The principle of this method consists of the basis that when δ oscillates around the equilibrium point with constant amplitude, transient stability will be maintained.

Starting with the swing equation we have

$$\frac{d\delta}{dt} = \sqrt{\int_{\delta_0}^{\delta} \frac{2(P_S - P_E)}{M} d\delta} \ldots\ldots\ldots\ldots \text{(2)}$$

Where δ_0 is the torque angle at which the machine is operating while running at synchronous speed under normal conditions. In the above condition the torque angle was not changing i.e. before the disturbance$\frac{d\delta}{dt} = 0$. Hence the condition for transient stability is given by$\int_{\delta_0}^{\delta} P_A \, d\delta = 0$.This means that the area under the curve P_A should be zero which is possible only when P_A has both accelerating and decelerating power . For a generator action$P_S > P_E$ for positive area A_1 and $P_E > P_S$ for negative area A_2 for stable operation. Hence the name equal area criteria.The equal area criterion is useful in determining the maximum limit on the load that the system can take without exceeding stability limit. This can happen as long as area between P_S line and the P_E curve is equal to the area between the initial torque angle $\delta_0$and the P_S line .In case the area $A_2$is less than the areaA_1, the system becomes unstable.

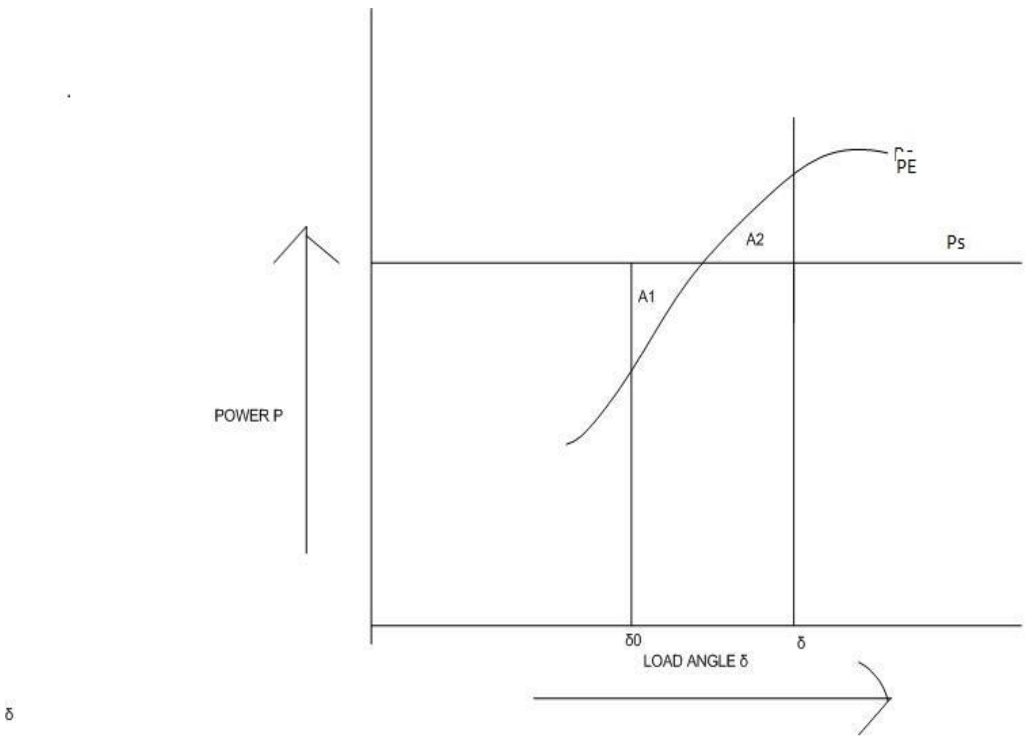
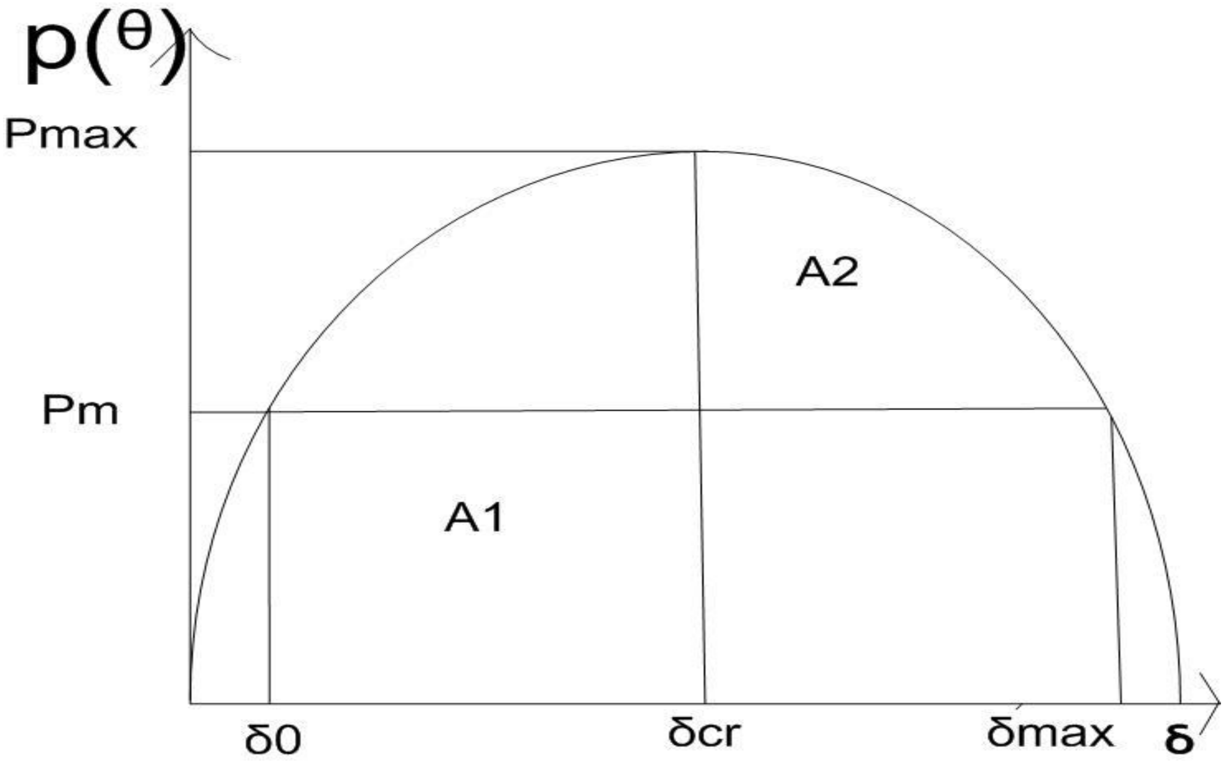


Figure 2-Equal Area Criteria

2.6. CRITICAL CLEARING TIME

The value of clearing time corresponding to a clearing angle can be established only by numerical integration except in this simple case. The equal area criterion therefore gives only qualitative answer to system stability as the time when the breaker should be opened is hard to establish. As the clearing of the faulty line is delayed, A_1increases and so does $\delta_1$to find A_2=A_1 till δ_1=δ_{max}as shown in the figure given below. For a clearing time (angle) larger than this value, the system would be unstable as A_2<A_1 .The maximum allowable value of the clearing time and angle for the system to remain stable are known respectively as critical clearing time and angle.



(Figure 3-Graph to plot curve between P vs. δ)

3. OPPORTUNITIES FOR FACTS

The possibility that current through a line can be controlled at a reasonable cost enables a large potential of increasing the capacity of existing lines with larger conductors and use of one of the FACTS Controllers to enable corresponding power to flow through such lines under normal and contingency conditions. These opportunities arise through the ability of FACTS Controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle and the damping of oscillations at various frequencies below the rated frequency.

These constraints cannot be overcome, while maintaining the required system reliability, by mechanical means without lowering the useable transmission capacity .By providing added flexibility, FACTS Controllers can enable a line to carry power closer to its thermal rating. Mechanical switching needs to be supplemented by rapid-response power electronics .It must be emphasized that FACTS is an enabling technology, and not a one-on-one substitute for mechanical switches. 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 others to control one or more of the interrelated system parameters mentioned above. A well-chosen FACTS Controller can overcome the specific limitations of a designated transmission line or a corridor. Because all FACTS Controllers represent applications of the same basic technology, their production can eventually take advantage of technologies of scale. Just as the transistor is the basic element for a whole variety of microelectronic chips and circuits, the high-power transistor is the basic element for a variety of high-power electronic Controllers.

FACTS technology also lends itself to extending usable transmission limits in a step-by-step manner with incremental investment as and when required. A planner could foresee a progressive scenario of mechanical switching means and enabling FACTS Controllers such that the transmission lines will involve a combination of Mechanical and FACTS Controllers to achieve the objective in an appropriate, staged Investment scenario.

4. STATIC SYNCHRONOUS SERIES COMPENSATOR

The SSSC is one of the most recent FACTS devices for power transmission series compensation. It can be considered as a synchronous voltage source as it can inject an almost sinusoidal voltage of variable and controllable amplitude and phase angle, in series with a transmission line. The injected voltage is almost in quadrature with the line current. A small part of the injected voltage that is in phase with the line current provides the losses in the inverter. Most of the injected voltage, which is in quadrature with the line current, provides the effect of inserting an inductive or capacitive reactance in series with the transmission line. The variable reactance influences the electric power flow in the transmission line. Commonly used operating modes of SSSC is:

i) Constant voltage injection mode.

ii) Constant impedance emulation mode

iii) Constant power control mode

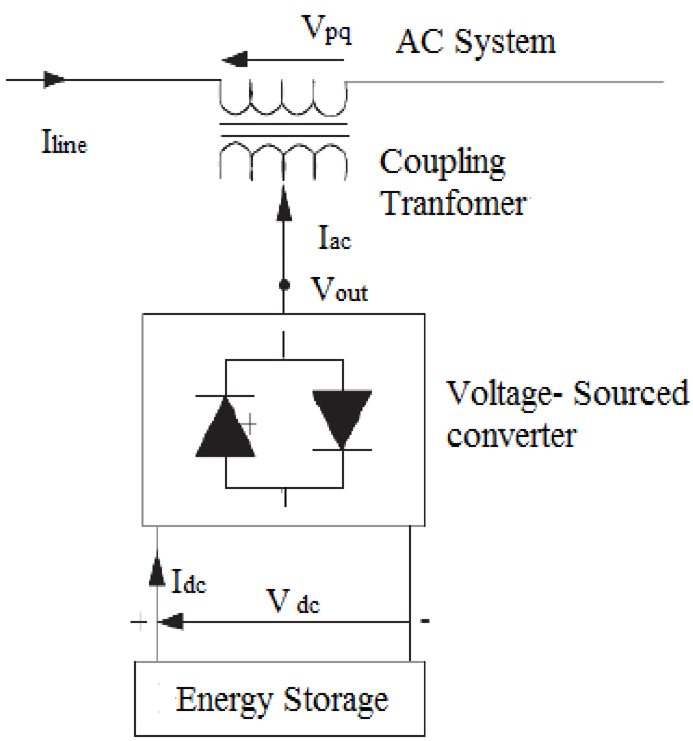
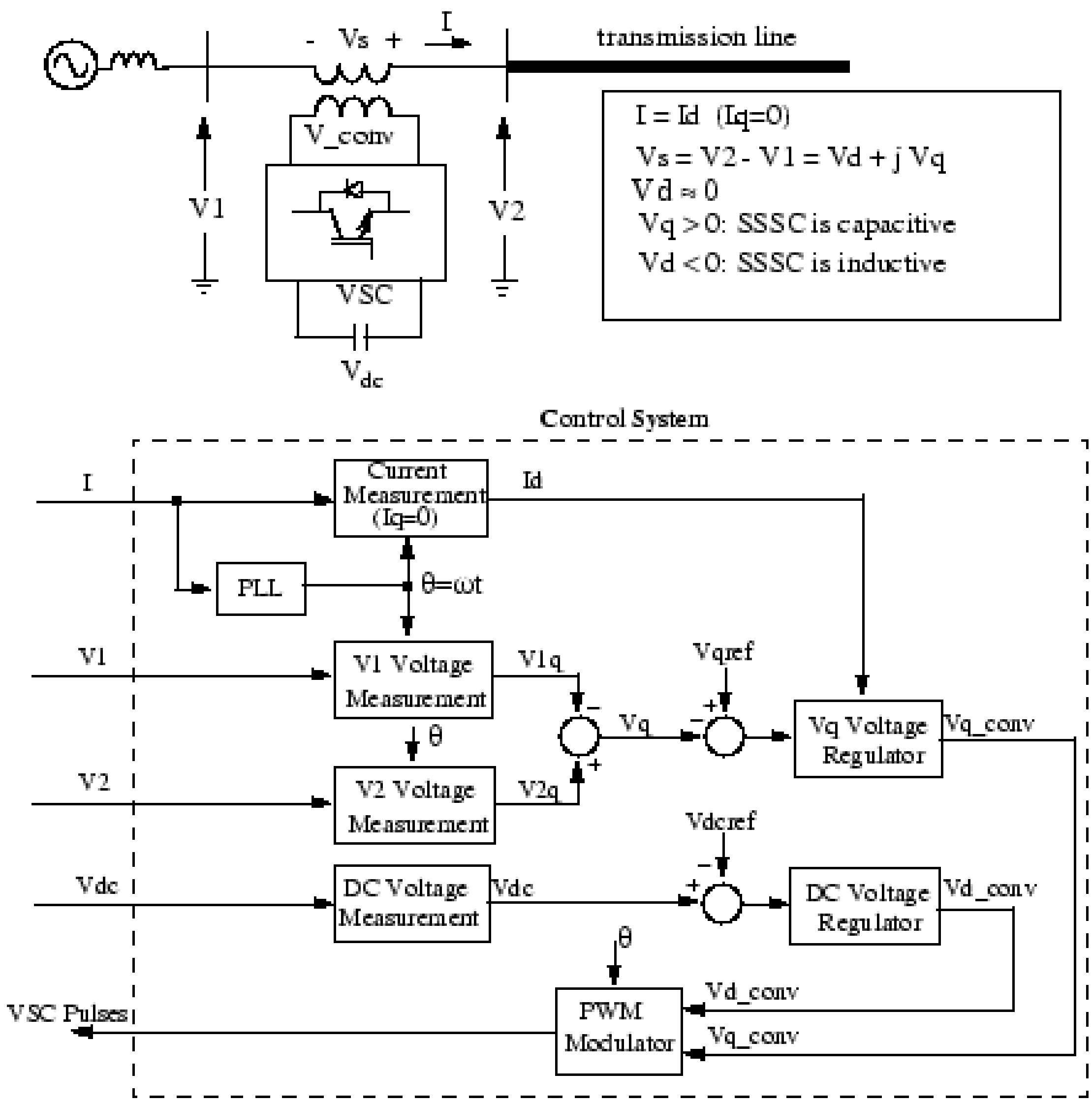


Figure 4: The basic configuration of a SSSC

Figure 5: Single line diagram of SSSC



As the SSSC does not use any active power source, the injected voltage must stay in quadrature with line current. By varying the magnitude Vq of the injected voltage in quadrature with current, the SSSC performs the function of a variable reactance compensator, either capacitive or inductive. The variation of injected voltage is performed by means of a Voltage-Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V_conv from a DC voltage source.

A capacitor connected on the DC side of the VSC acts as a DC voltage source. A small active power is drawn from the line to keep the capacitor charged and to provide transformer and VSC losses, so that the injected voltage Vs is practically 90 degrees out of phase with current I. In the control system block diagram Vd_conv and Vq_conv designate the components of converter voltage V_conv which are respectively in phase and in quadrature with current.

Two VSC technologies can be used for the VSC:

VSC using GTO-based square-wave inverters and special interconnection transformers. Typically four three-level inverters are used to build a 48-step voltage waveform. Special interconnection transformers are used to neutralize harmonics contained in the square waves generated by individual inverters. In this type of VSC, the fundamental component of voltage V_conv is proportional to the voltage Vdc. Therefore Vdc has to varied for controlling the injected voltage.

VSC using IGBT-based PWM inverters. This type of inverter uses Pulse-Width Modulation (PWM) technique to synthesize a sinusoidal waveform from a DC voltage with a typical chopping frequency of a few kilohertz. Harmonics are cancelled by connecting filters at the AC side of the VSC. This type of VSC uses a fixed DC voltage Vdc. Voltage V_conv is varied by changing the modulation index of the PWM modulator. The SSSC (Phasor Type) block models an IGBT-based SSSC (fixed DC voltage). However, as details of the inverter and harmonics are not represented, it can be also used to model a GTO-based SSSC in transient stability studies.

The control system consists of:

1. A phase-locked loop (PLL) which synchronizes on the positive-sequence component of the current I. The output of the PLL (angle $\Theta=\omega t$) is used to compute the direct-axis and quadrature-axis components of the AC three-phase voltages and currents (labeled as Vd, Vq or Id, Iq on the diagram).

2. Measurement systems measuring the q components of AC positive-sequence of voltages V1 and V2 (V1q and V2q) as well as the DC voltage Vdc.
3. AC and DC voltage regulators which compute the two components of the converter voltage (Vd_conv and Vq_conv) required to obtain the desired DC voltage (Vdcref) and the injected voltage (Vqref). The Vq voltage regulator is assisted by a feed forward type regulator which predicts the V_conv voltage from the Id current measurement.

The SSSC block is a phasor model which does not include detailed representations of the power electronics. You must use it with the phasor simulation method, activated with the Powergui block. It can be used in three-phase power systems together with synchronous generators, motors, dynamic loads and other FACTS and Renewable Energy systems to perform transient stability studies and observe impact of the SSSC on electromechanical oscillations and transmission capacity at fundamental frequency.

V-I CHARACTERISTICS OF SSSC

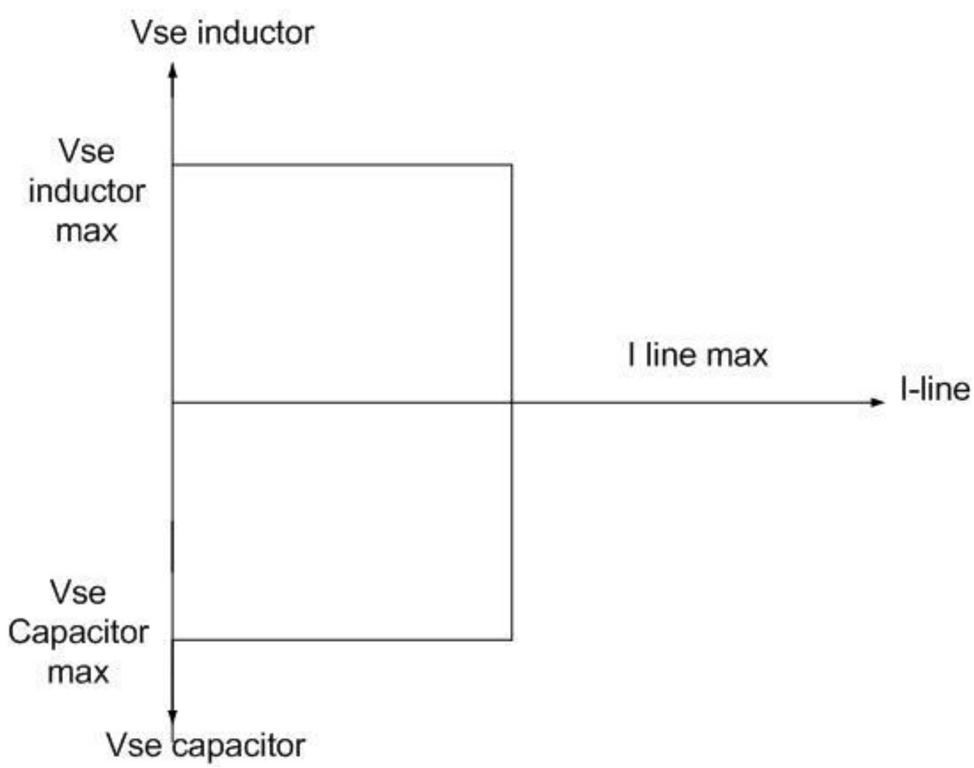
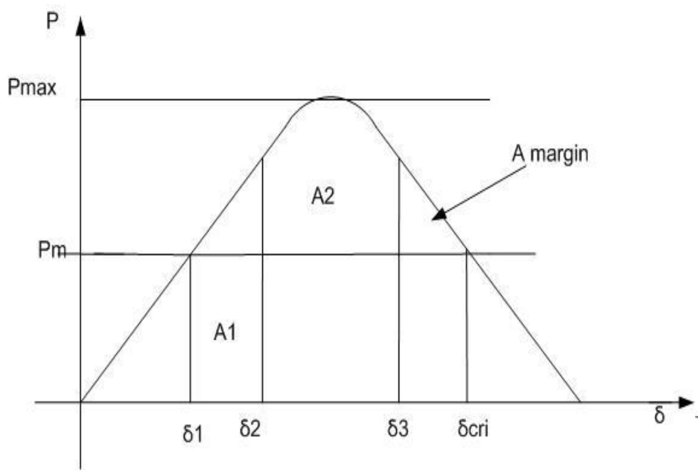


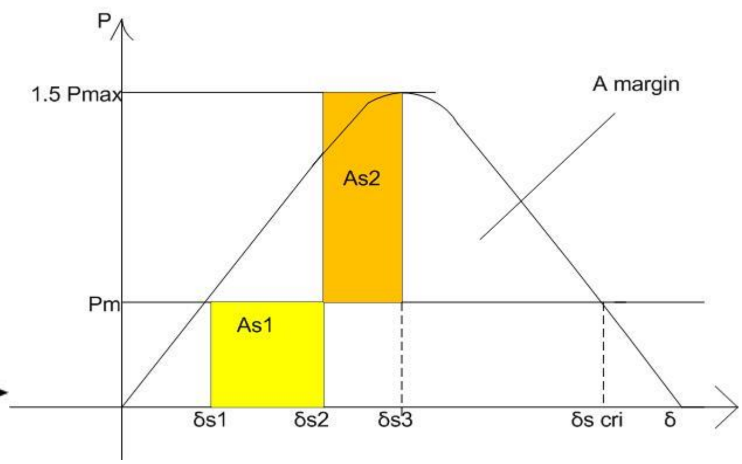
Figure 6: V-I Characteristic of SSSC

The SSSC can provide capacitive voltage and inductive voltage up to its specified maximum current rating. The SSSC can generate a controllable compensating capacitive or inductive voltage, which implies that the amount of transmittable power can be increased as well as decreased from natural power.

5. IMPROVEMENT OF TRANSIENT STABILITY BY SSSC

The improvement of transient stability can be explained in the simple two machine system by Equal area Criteria. Consider the two machine system with and without SSSC compensation. Assume the systems with and without SSSC compensation are subjected to the same fault for the same period of time. Both systems are transmitting equal power (Pm) before the fault occurs at the angles δ_1 and δ_{s1} respectively.The dynamic behavior of the systems is illustrated in the figure.





7(a) 7(b)

Figure 7(a) &7(b): Equal area criteria to illustrate the transient stability margin for a simple two machine system without and with respectively.

During the fault, the transmitted electric power becomes zero while the mechanical input power to the generators remains constant, Pm. Therefore the sending-end generator accelerates from the steady state angles $\delta_1 1$ and δ_{s1} to angles δ_2 and δ_{s2} respectively, when the fault clears. The accelerating energies are represented by areas A1 and As1. After the fault clearing, the transmitted electric power exceeds the mechanical input power and therefore the sending machine decelerates. However, the accumulated kinetic energy further increases until a balance between the accelerating and decelerating energies, represented by areas A1, As1, and A2, As2, respectively, is reached at the maximum angular swings, δ_3 andδ_{s3}, respectively. The areas between the P versus δ curve and the constant Pm line over the intervals defined by angles δ_3 and $\delta_{scrit}$and δ_{s3} and δ_{scrit}, respectively, determine the margin of transient stability, represent by areas Amargin and Asmargin. margin of transient stability, represent by areas Amargin and Asmargin Comparison of these two figures clearly shows a substantial increase in the transient stability margin in the system with SSSC.

5. PID CONTROLLER

A Proportional-Integral-Derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. They are structurally simple and exhibit robust performance over a wide range of operating conditions .A PID controller calculates an error value as the difference between a measured process variable and a desired set point [10].

The controller attempts to minimize the error by adjusting the process through use of a manipulated variable. In the absence of the complete knowledge of the process these types of controllers are the most efficient of choices. The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change [11]. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element.

In the absence of knowledge of the underlying process, a PID controller has historically been considered to be the most useful controller [12]. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point, and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

PID controller is one of the most common controlling devices in the market. Because of its very simple control structure and the linear control methodology, PID control is generically important in many industries and has been widely used in electrical, mechanical, hydraulic, fluidic, and pneumatic systems [21]. It can provide the set point regulation of zeroing error under arbitrary low frequency disturbances, and it owns robust characteristics for those modeling errors. Three term controllers are easier to adjust at the design stage.

The design of PID controller is to determine the values of coefficients: K_p, K_i and $\boldsymbol{K_d}$, which could make the controller stabilize the given system. When the controller is used in industries, the performance of the feedback system under the control of the designed PID controller should also be considered. Those parameters should be adjusted so that acceptable performance, such as the rising time, settling time, gain margin, etc. could be obtained. Many controller design methods, such as a model based approach using state space models, state feedback control, and quadratic optimization [10], fixed order controller design in discrete-time system [12],model free synthesis approach based on time series data [11],etc. have been presented in the past years. The tuning methodologies of the PID controller have been developed over the years based primarily on empirical observations and industrial experience.

Stabilizing a given system is the necessary requirement for PID controller design. The performance attainment problems are also very important, especially in industry application. As we have mentioned before, one the entire stabilizing set of the coefficients of PID controller has been obtained, the performance test can be implement for each of the point. The performance specification can be added to the PID controller design.

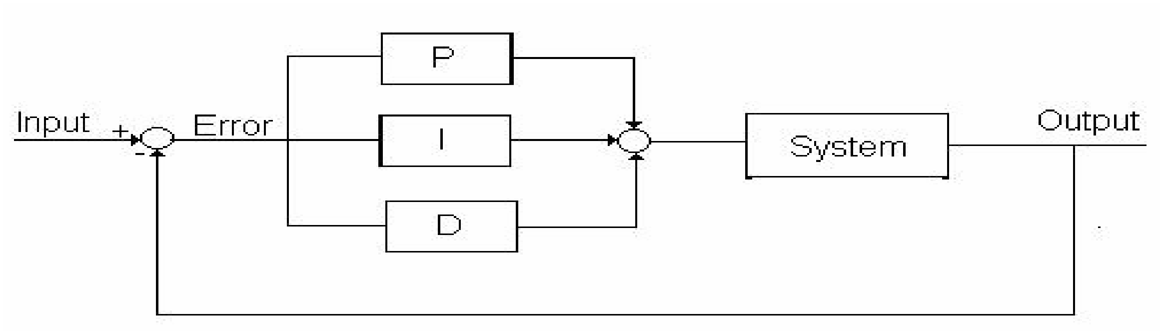


Figure 8:Block Diagram of Conventional PID Controller

5.1. PID CONTROLLER THEORY

Proportional Control

The proportional controller output uses a 'proportion' of the system error to control the system. However, this introduces an offset error into the system.

P_{term} =K_p*Error................................ (3)

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (see the section on loop tuning). In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicates that the proportional term should contribute the bulk of the output change.

Integral Control

The integral controller output is proportional to the amount of time there is an error present in the system. The integral action removes the offset introduced by the proportional control but introduces a phase lag into the system.

$I_{term} = K_i * \int(\text{Error})\, dt$……………… (4)

The integral term accelerates the movement of the process towards set point and eliminates the residual steady state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot theset point value.

Derivative Control

The derivative controller output is proportional to the rate of change of the error. Derivative control is used to reduce/eliminate overshoot and introduces a phase lead action that removes the phase lag introduced by the integral action.

$$D_{term} = K_d * [\text{d (Error)/dt}] \ldots\ldots\ldots\ldots\ldots \text{(5)}$$

Derivative action predicts system behavior and thus improves settling time and stability of the system [9], [10]. An ideal derivative is not causal, so that implementations of PID controllers include an additional low pass filtering for the derivative term, to limit the high frequency gain and noise.[11].

Problem formulation

In the present study, speed deviation is taken as input to the PID controller.
An integral time absolute error of the speed deviations is taken as the objective function J expressed as:

$$J = \int_{t=0}^{t=tsim} |\, \Delta\omega \,| . t . dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

Where, $\Delta\omega$ is the speed deviation in and t_{sim} is the time range of the simulation. For objective function calculation, the time domain simulation of the power system model is carried out for the simulation period. It is aimed to minimize this objective function in order to improve the system response in terms of the settling time. The problem constraints are the SSSC controller parameter bounds. Therefore, the main aim of the problem is to minimize “J”.

5.2. LIMITATIONS OF PID CONTROLLER

While PID controllers are applicable to many control problems, and often perform satisfactorily without any improvements or only coarse tuning, they can perform poorly in some applications, and do not in general provide optimal control. The fundamental difficulty with PID control is that it is a feedback system, with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise. While PID control is the best controller in an observer without a model of the process, [2] better performance can be obtained by overtly modeling the actor of the process without resorting to an observer.

PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or hunt about the control set point value. They also have difficulties in the presence of non-linearities, may trade-off regulation versus response time, do not react to changing process behavior and have lag in responding to large disturbances.

6. OVERVIEW OF GENETIC ALGORITHM

GA is a stochastic global adaptive search optimization technique based on the mechanisms of natural selection. Recently, GA has been recognized as an effective and efficient technique to solve optimization problems. Compared with other optimization techniques. GA starts with an initial population containing a number of chromosomes where each one represents a solution of the problem which performance is evaluated by a fitness function. Basically, GA consists of three main stages: Selection, Crossover and Mutation. The application of these three basic operations allows the creation of new individuals which may be better than their parents. This algorithm is repeated for many generations and finally stops when reaching individuals that represent the optimum solution to the problem.

Genetic Algorithms are computer based processes for which optimization of a problem is achieved by mimicking nature's own process of Natural Selection – also referred to as survival of the fittest (Buckland, 2005a). Before the concept of Genetic Algorithms can be studied in detail, it is relevant to review the concept of optimization itself, and propose a simple model for optimization that can be used to better understand what is required of any optimization routine. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. Often Genetic Algorithms encode the parameters of a real-world problem and then attempt to maximize an associated fitness function (Whitley n.d., p. 1). Thus, whereas nature applies the process of natural selection continuously, Genetic Algorithms apply the process iteratively until a set of encoded parameters is found that maximizes the modelling function. Hence Genetic Algorithms are often used as a function optimizing technique.

The key difference between Genetic Algorithms and analytical optimization is that in effect Genetic Algorithms are a population-based model that searches the fitness space to find the optimum parameters. Whereas analytical optimization attempts to mathematically model the process and optimize using either calculus or numerical techniques.

6.1. ADVANTAGES AND DISADVANTAGES

ADVANTAGES

As already stated, Genetic Algorithms have numerous inherent advantages over classical numerical optimization techniques. Haupt & Haupt (2005, sec. 1.5) suggest that some of the advantages of Genetic Algorithms are that they:

- Can handle discrete and continuous variables.
- Don’t require the calculation of function derivatives.
- Are suited to parallel computing (still the current means from which personal computers are attempting to gain significant increases in processing power).
- Can provide a list of optimal variables.
- Can handle complex cost surfaces (local minima/maxima do not flat the method) and can handle large numbers of variables.

DISADVANTAGES

- Finding the optimal solution to complex high dimensional, multimodal problems often requires very expensive fitness function evaluations. In real-world problems such as structural optimization problems, a single function evaluation may require several hours to several days of complete simulation.
- Genetic algorithms do not scale well with complexity. That is, where the number of elements which are exposed to mutation is large there is often an exponential increase in search space size. This makes it extremely difficult to use the technique on problems such as designing an engine, a house or plane.

- GAs may have a tendency to converge towards local optima or even arbitrary points rather than the global optimum of the problem. This means that it does not "know how" to sacrifice short-term fitness to gain longer-term fitness.

- Operating on dynamic data sets is difficult, as genomes begin to converge early on towards solutions which may no longer be valid for later data.

- GAs cannot effectively solve problems in which the only fitness measure is a single right/wrong measure (like decision problems), as there is no way to converge on the solution. In these cases, a random search may find a solution as quickly as a GA.

The generic Genetic Algorithm process is shown in Figure 9.

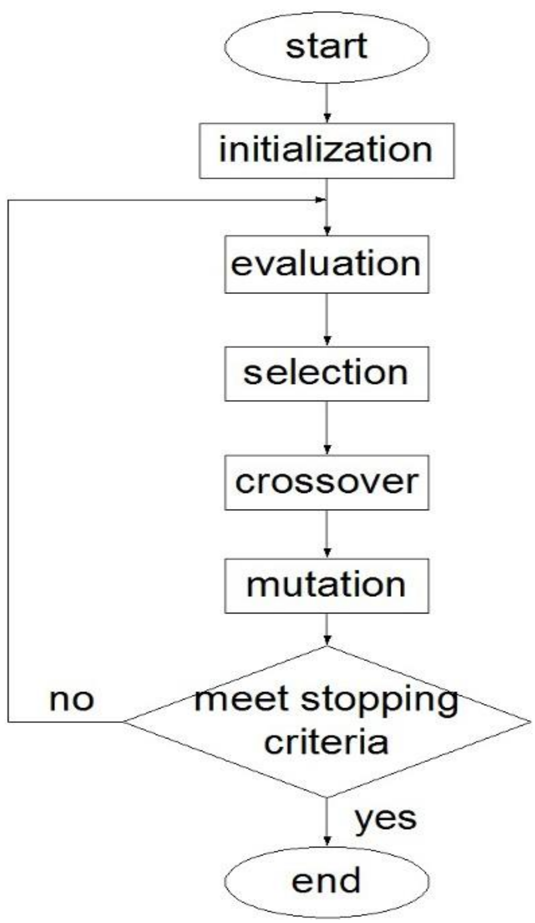


Figure 9: Flow chart for Genetic Algorithm

6.2. CHARACTERISTICS OF APPLIED GA

- Population=20
- Scaling function=rank
- Creation function=@gacreationuniform
- Selection=@selectionstochunif
- Crossover=0.8000
- Elite count=2
- Generation=20
- Mutation function={[1x1 function_handle] [1] [1]}
- Crossover function=@crossoverscattered
- Plot interval=1
- Penalty factor=100
- Migration direction='forward'
- Fraction=0.2
- Interval=20

6.3. OBJECTIVE FUNCTION OF G.A.

The most challenging part of creating a genetic algorithm is writing the objective functions. In this project, the objective function is required to evaluate the best PID controller for the system. An objective function could be created to find a PID controller that gives the smallest overshoot, fastest rise time or quickest settling time. However in order to combine all of these objectives an objective function is designed to minimize the performance indices of the controlled system instead. The objective function is given in equation (9).

6.4. OVERVIEW OF BINARY CODED G.A.

GA has many variants like Real coded GA, Binary coded GA, Saw tooth GA, Micro GA, Improved GA, Differential Evolution GA. This paper is based on Binary coded G.A. The binary coded genetic algorithm is a probabilistic search algorithm that iteratively transforms a set (called a population) of mathematical objects (typically fixed-length binary character strings), each with an associated fitness value, into a new population of offspring objects using the Darwinian principle of natural selection and using operations that are patterned after naturally occurring genetic operations, such as crossover and mutation.

1. Encoding

In genetic Algorithm, coding is expressing the individual by the binary strings of 0‟s & 1‟s. In the instance one every individual has there dimension and every dimension is expressed by a 10- bit string of 0‟s & 1‟s.

2. Selection

The selection operator selects chromosomes from the current generation to be parents for the next generation. In this method, a few good chromosomes are used for creating new offspring in every iteration. Then some bad chromosomes are removed and the new offspring is placed in their places. The rest of population migrates to the next generation without going through selection process.

3. Crossover

Crossover is the GA's primary local search routine. The crossover/reproduction operator computes two offspring for each parent pair given from the selection operator. The crossover operator is used to create new solutions from the existing solutions available in the mating pool after applying selection operator. This operator exchanges the gene information between the solutions in the mating pool. The most popular crossover selects any two solutions strings randomly from the mating pool and some portion of the strings is exchanged between the strings. The selection point is selected randomly. A probability of crossover is also introduced in order to give freedom to an individual solution string to determine whether the solution would go for crossover or not.

4. Mutation

Mutations are global searches. A probability of mutation is again predetermined before the algorithm is started which is applied to each individual bit of each offspring chromosome to determine if it is to be inverted. Mutation changes the structure of the string by changing the value of a bit chosen at random.[7] Mutation is the occasional introduction of new features in to the solution strings of the population pool to maintain diversity in the population. Though crossover has the main responsibility to search for the optimal solution, mutation is also used for this purpose. Mutation operator changes a 1 to 0 or vise versa, with a mutation probability of .The mutation probability is generally kept low for steady convergence. A high value of mutation probability would search here and there like a random search technique.

6.5. GENETIC ALGORITHMS CODES FOR OPTIMIZATION

```
clc
%clear all
global KP KI KD
FitnessFunction = @SSSC_objective;
nvars = 3;
LB = [-20,-20,-20];
UB = [20,20,20];
opts = gaoptimset('Generations',20);
val = gaoptimget(opts,'Generations');
% options = gaoptimset(opts,'Generations',50);
opts = gaoptimset(opts,'PopulationSize',20);
% val = gaoptimget(options, 'Generations');
%opts = gaoptimset(opts,'Generations',150);
%[x,fval,exitflag,output] = ga(FitnessFunction,nvars,
[],[],[],[],LB,UB,[],opts);
[x,Fval,exitFlag,Output]=ga(FitnessFunction,nvars,[],[],[],[],LB,UB,[],opts)
KP=x(:,1)
KI=x(:,2)
KD=x(:,3)
```

7. POWER OSCILLATION DAMPING (POD) CONTROLLER

Satisfactory damping of power oscillations is an important issue addressed when dealing with the rotor angle stability of power systems. To improve the damping of oscillations in power systems, supplementary control laws can be applied to existing devices. These supplementary actions are referred to as Power Oscillation Damping (POD) control.

The increase in loading level of transmission lines sometimes can lead to voltage collapse due to a shortage of reactive power. At times generator power oscillations when subjected to disturbance, limit the inter-area power flow. This stability limit can be increased with proper placement and control of flexible AC transmission systems (FACTS) devices. Recently, the use of this device for power oscillation damping has also attracted attention. To attain this objective, supplementary controllers referred to as power oscillation damping controllers (PODs) are often used. In this work, POD control has been applied to the FACTS device SSSC.The presented approach solves the optimal siting of the FACTS as well as selection of the proper feedback signals and the controller design problem. In case of contingencies, changed operating conditions can cause poorly damped or even unstable oscillations since the set of controller parameters yielding satisfactory damping for one operating condition may no longer be valid for another one. In this case, an advantage can be taken by re-tune the POD controller's parameters.

8. SIMULATION CIRCUITS AND RESULTS

8.1. IMPLEMENTATION OF SSSC

SSSC is applied in considered transmission line at bus B2 i.e. in series with the transmission line and implemented in simulation. The power system was chosen for simulation which has high source impedance and high transmission line impedance. This was essential to demonstrate the effect of voltage control and power increase in a highly impedance system by a SSSC.

8.2 SIMULINK CIRCUITS

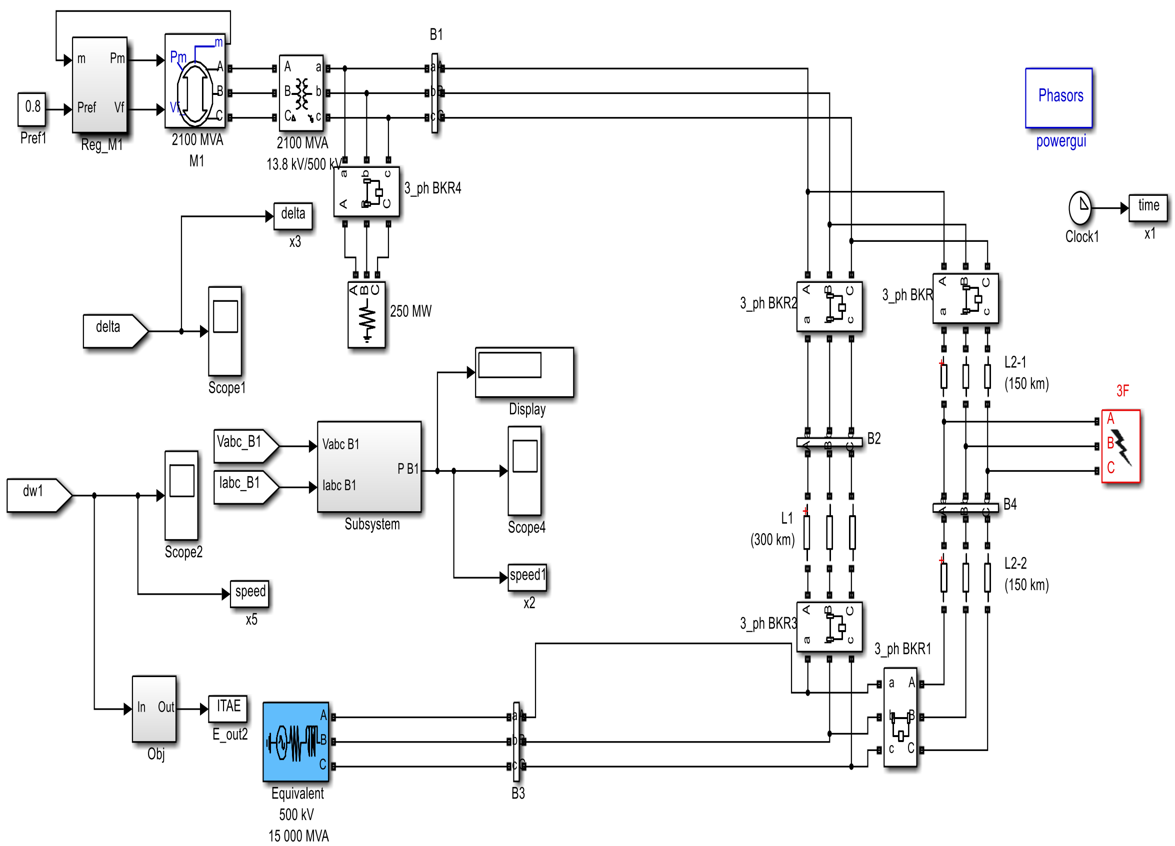
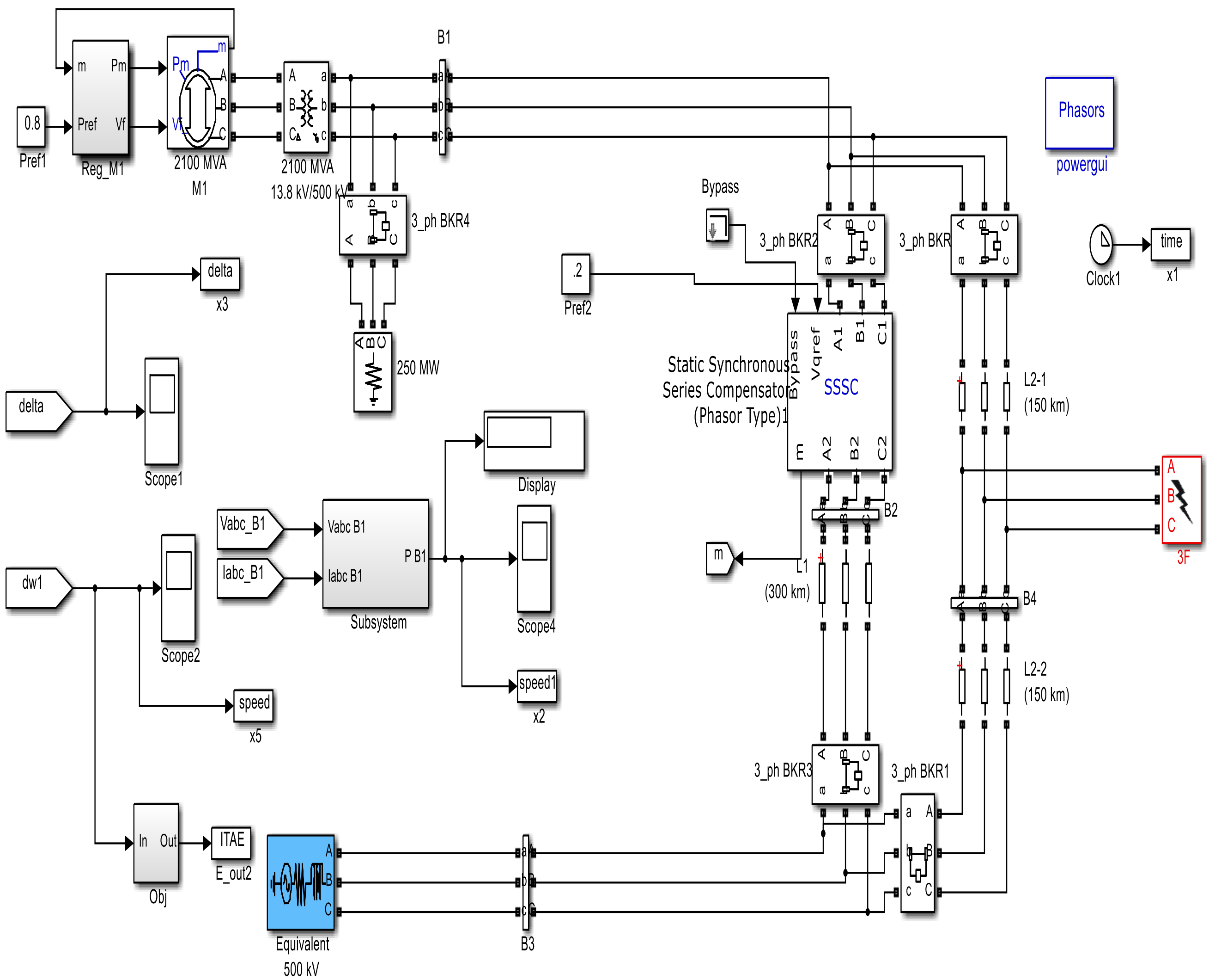


Figure 10: Simulink circuit without SSSC

8.3. CIRCUIT DESIGN

The power grid consists of a 2100 MVA, 13.8 KV alternator, a transformer of 2100 MVA, 13.8/500 KV and a load of 250 MW connected by a 300 km long transmission line. SSSC has a rating of +/- 100 MVA. The SSSC block is a phasor model which does not include detailed representations of the power electronics. The total capacitance of the DC link is in farads. This capacitance value is related to the SSSC converter rating and to the DC link nominal voltage. The energy stored in the capacitance (in joules) divided by the converter rating (in VA) is a time duration which is usually a fraction of a cycle at nominal frequency.



(Figure 11: SSSC in series with transmission line)

8.4. IMPLEMENTATION OF G.A BASED PID CONTROLLER

In the proposed work a SSSC model is called by a program which is coded in Mat lab for a fitness function i.e. cost function. In order to use GA to tune the PID controller for SSSC. Variables Kp, Ki, &Kd are coded to solve string structures. The length of string is usually determined according to the desired solution accuracy. Here 10 bits are used to code each variable. We can use 8 bit & 4 bit also. Thereafter select the random strings from the population to form the mating pool. In order to **use roulette-wheel selection** procedure, we calculate the average fitness of the population. Then the mating pool strings are used in the crossover operation. The next step is to perform mutation on strings in the intermediate population. The resulting population becomes the new population. The whole process is coded in mat lab & after running the program we get the optimized values of Kp, Ki &Kd . The simulation modal for the entire system is given below and also the genetic algorithm parameters are chosen for the optimization.

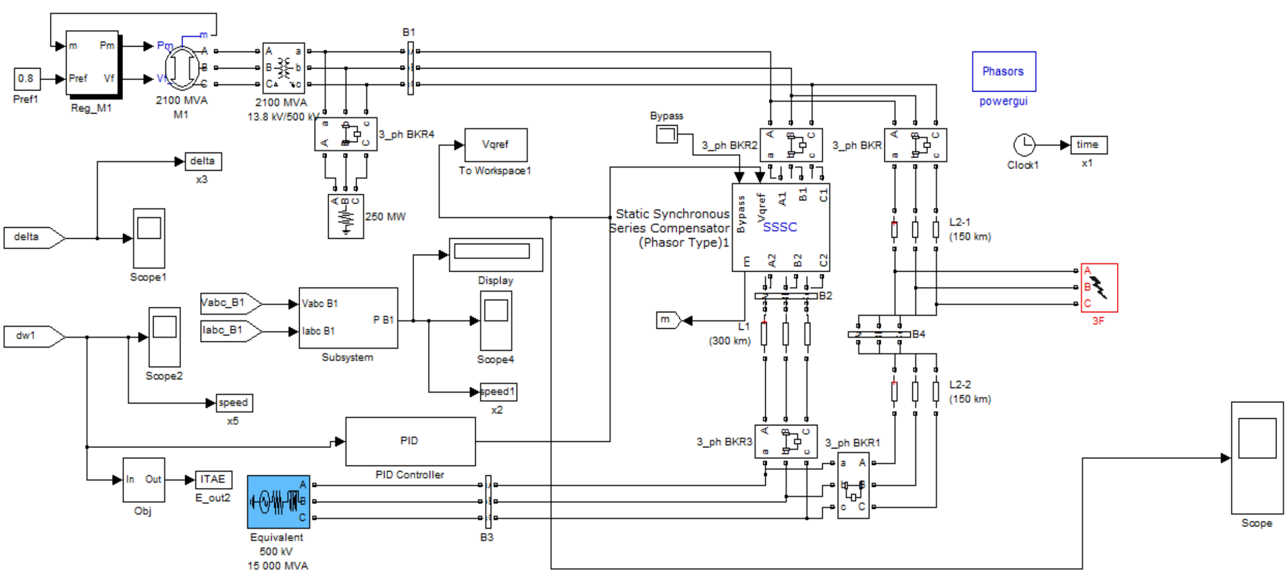


Figure 12: SSSC in series with transmission line with PID

9.SIMULATION RESULTS AND DISCUSSION

The behavior underlying the performance of a synchronous machine with the excitation system, mechanical control system, and installed FACTS controller etc. usually represented by a set of non-linear differential equations. Thus the complete mathematical description of a power system becomes difficult to solve. To simplify the computational burden, linearized models are used which gives satisfactory results under small disturbance conditions. However, linear models cannot properly capture complex dynamics of the system, especially during major disturbances. This presents difficulties for tuning the FACTS controllers in that, the controllers tuned to provide desired performance at small disturbance condition do not guarantee acceptable performance in the event of major disturbances. The complete non-liner model of the power system with FACTS can be developed in MATLAB/SIMULINK using the inbuilt non-linear power system components or by developing the non-linear models of some power system components. The SimPowerSystems (SPS) is a MATLAB based modern design toolbox is used for all simulations and SSSC based damping controller design [23]. In order to optimally tune the parameters of the SSSC based damping controller, as well as to assess its performance, the model of example power system shown in Fig. 12 is developed using SPS blockset. The optimization of the proposed SSSC based damping controller parameters is carried out by minimizing the fitness given in (6) employing GA algorithm. The model of the system under study has been developed in MATLAB/SIMULINK environment and GA program has been written in .m file. For objective function calculation, the developed model is simulated in a separate program (by another .m file using initial population/controller parameters) considering a disturbance. Form the SIMULINK model the objective function value is evaluated and moved to workspace. The process is repeated for each individual in the population. The objective function is evaluated for each individual by simulating the example power system, considering a disturbance. For objective function calculation, a 3-phase short-circuit fault in one of the parallel transmission lines is considered. The flow chart of the GA algorithm employed in the present study is given in Figure 9.Simulations were conducted on a INTEL CORE I5, 2.50 GHz, 4GBRAM computer, in the MATLAB R2012a environment. The optimization was repeated 20 times and the best final solution among the 20 runs is chosen as proposed controller parameters.

The best final solutions obtained in the 20 runs are given in Table 2.

Table1

LOADING CONDITION WITH AND WITHOUT SSSC FOR SMIB POWER SYSTEM

POSITION/LOADING	AT 80%	AT60%
WITHOUT SSSC	CCLT=359ms	CCLT=668ms
WITH SSSC	CCLT=362ms	CCLT=686ms

Table2

SSSC BASED CONTROLLER PARAMETERS WITH GA CONSIDER

LOADING	KP	KI	KD	ITAE value without controller	Max(ITAE) with controller
80%	5.2056	2.9572	0.0129	1.3502	0.4635
60%	1.9327	0.7619	0.5101	0.1323	0.3128

9.1. SIMULATION RESULTS

During normal operating condition there is complete balance between input mechanical power and output electrical power and this is true for all operating points. During disturbance, the balance is disturbed and the difference power enters into/drawn from the rotor. Hence the rotor speed deviation and subsequently all other parameters (power, current, voltage etc.) change. As the input to the SSSC controller is the speed deviation, the SSSC reference voltage is suitable modulated and varied from 0.8 to 1.2 that is in the limit of +/- 0.2. So, with the change in operating point also the SSSC controller parameters remain fixed. To assess the effectiveness and robustness of the proposed controller, two different loading conditions as given in Table2 are considered. At the first instance 80% loading with the speed deviation signal is considered as the input signal to the proposed SSSC-based controller. The two cases are given as below:

CASE I: With 80% loading

- **With and without SSSC**

The above simulation describes about a three-phase fault is simulated in middle of the lines of the infinite bus system i.e. three phase to earth fault. The simulation is done in three phases.

To start with, the pre-fault system is run for a small time. Then a symmetrical fault is applied at one end of a line. Simulation of the faulted condition continues until the line is disconnected from the buses at both of the ends of the faulted line after a fault clearing time t_{cls}. Then the post-fault system is simulated for a longer time (say, 20m s) to observe the nature of the transients. We start with t_{cls} = 0.01 s .The SSSC connected in series with transmission line.

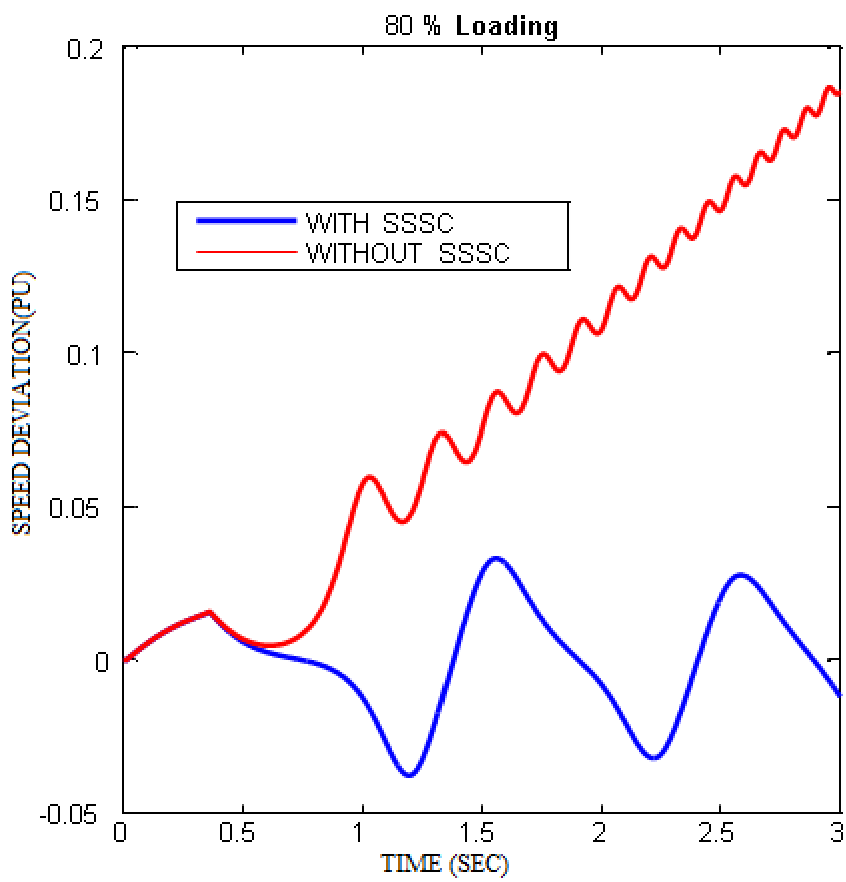


Figure 13: Speed Deviation vs. time at 80% loading

Figure 13 shows swing curve of the system with the series FACTS device SSSC. Without SSSC, the system have CCLT=359 ms. After placing of the given FACTS device, the CCLT increased to 362 ms. Without SSSC the speed deviation goes on increasing and the system becomes unstable.

SSSC with and without controller

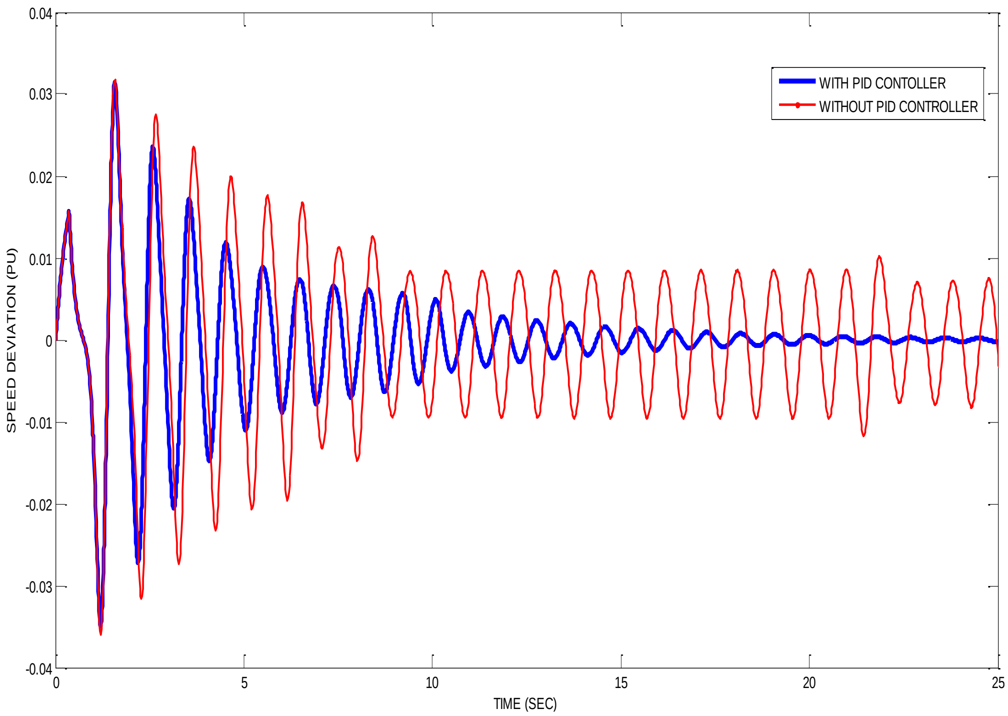


Figure 14: Speed Deviation with and without controller at 80% loading

Fig. 14 describes about the application of PID controller with SSSC at 80% loading. The above simulation results in more damping that is the system is stable in less time ie 25s with the help of PID controller.

Without the controller that is when only SSSC is placed, damping is less and system is taking more time to reach the state of stability i.e. more than 25s. Here tuning of PID controller is required for better performance. The objective of the GA is to search for the global optimal solutions in the optimization problems. When genetic algorithms is applied to find the best solutions of KP, KI and KD. When generations=20 and population=20 and the GA is run for the fitness function 'SSSC_objective' ,the value of KP, KI & KD found to be 5.2056,2.9572 & 0.0129 respectively . Also the max (ITAE) with controller= 0.4635and the max (ITAE) without controller=1.3502.

From Fig. 14 it can be seen that the classical methods of damping i.e. with SSSC only, the improvement in the system response is very poor in comparison to when using the optimization techniques. The GA optimization with the PID controller present a significant increase in the damping when compared to the classical power oscillation damping techniques. However, the GA optimization reduces the overshoot even more when compared with the classical techniques. The response time is also a significant improvement for the given optimization techniques when compared with the classical methods. The computing time required for the GA optimization is approximately 12 hours while the respective computing time required for the classical techniques is around 4-5 seconds.

CASE II: with 60% loading

- **With and without SSSC**

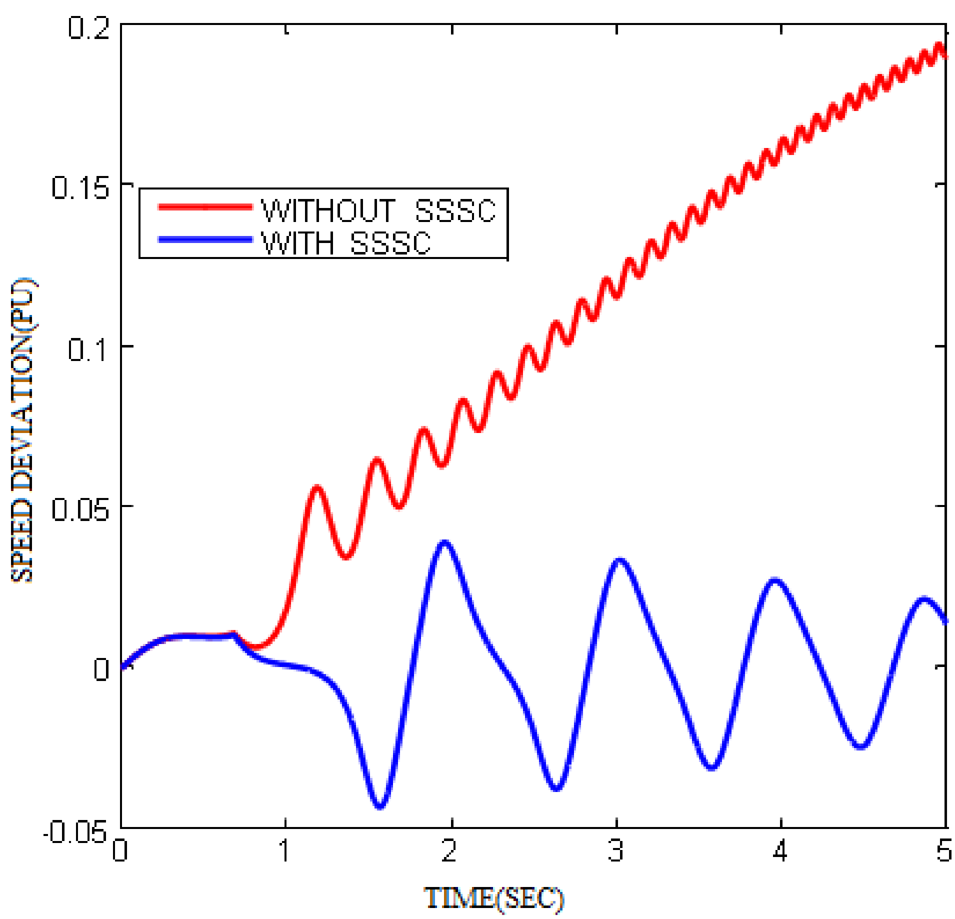


Figure 15: Speed deviation vs. time for 60% loading

Figure 15 shows speed deviation curve of the system at 60% of loading with the series FACTS device SSSC. Without SSSC, the system has CCLT=668 ms and after placing of the given FACTS device, the CCLT increased to 686 ms. It describes the oscillation in rotor speed at 600% of loading with and without SSSC.

Table -1 shows the comparison of the critical clearing time at different loading condition when SSSC is placed in series with the transmission line. We can say that when SSSC is placed in series with the transmission line with different loading ,then it is observed that at 60% loading the CCLT=6 86 millisecond which is greater than 80% loading condition, so the function of SSSC is most efficient at 60% loading.

- **SSSC with and without controller**

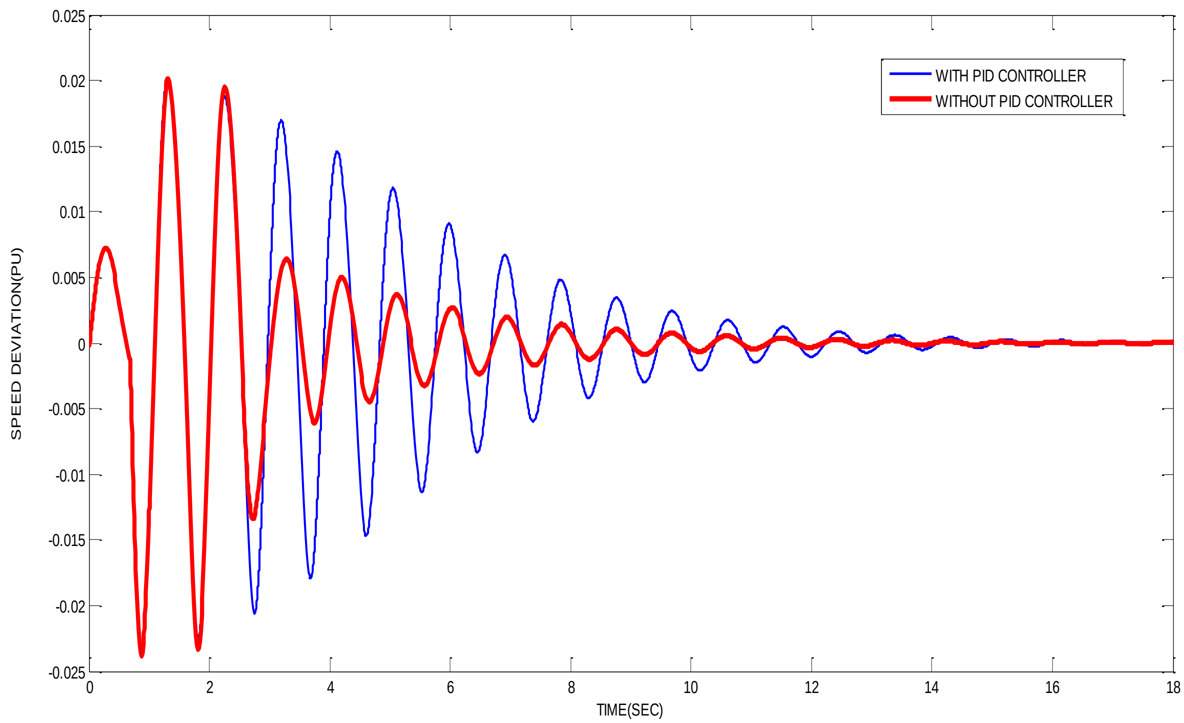


Figure 16: Speed Deviation with and without controller at 60% loading

Figure16 shows that by the application of controller damping is more and without the controller the damping is less. That is the controller helps to stabilize the system in less time than without the controller. Here the controller parameters are defined on the application of GENETIC ALGORITHMS.

Table- 2 shows the comparison of two loading conditions with and without controller. Here GA is used to find the optimal solution of the PID controller. When controller is placed for the improvement of damping, it can be observed that at 60% loading, the max(ITAE)= 0.3128 which is less than max(ITAE) of 80%. In both the cases gen and pop is taken as 20 and LB&UB is same that is [-20,-20,-20] to [20, 20, 20]. In this table the KP, KI, KD values are only of the controller with GA because without controller there would be no KP, KI and KD value. Here tuning of PID is done for better performance.

9.2. DISCUSSION

From the above simulation results of figure 14 and figure 16, we conclude that SSSC considerably improves transient stability and also damps the oscillation. SSSC acts as a synchronous voltage source as it can inject an almost sinusoidal voltage of variable and controllable amplitude and phase angle, in series with a transmission line. In this SMIB system best possible location of the FACTS device (SSSC) is found in series with one of the transmission line while the fault is given at transmission line which is parallel to the line having SSSC. We also conclude that at different loading conditions, particularly at 60% loading the CCLT is more i.e.at that loading SSSC will fully operate to its capacity that is more stability improvement.

The robustness of the proposed controller is verified at heavy loading condition that is at 80% loading under disturbance by 3-phase fault near the bus 2 at t =20 ms for 5 cycles with generator loading being changed to heavy loading condition. The system Response under this contingency is shown in Figure14 from which it is clear that the system oscillations are quickly damped with SSSC controller but the response without controller takes a longer time to damp the oscillation. Without control under this severe disturbance and the stability of the system is maintained with the proposed GA optimized SSSC-based damping controller.

The efficiency of the proposed controller is also verified at different the operating condition, the generator loading is changed to light loading condition that is to 60% as given in Table- 2. A 5 cycle 3-phase fault is assumed in one of the parallel transmission lines near bus 2 at t=20ms. The fault is cleared by tripping the faulted line and the lines are reclosed after 5 cycles. The system Response under this contingency is shown in Figure16 which clearly depicts the robustness of the proposed controller for changes in operating condition and variation in ref voltage. It can be seen that the proposed design controller damps out the system oscillation quickly in comparison to without controller.

So, it is clear from Figure 14 and Figure 16 and from table-2 that power system oscillations are highly oscillatory in the absence of SSSC-based damping controller and the proposed SSSC-based controller significantly improves the power system stability by damping these oscillations. However, application of GENETIC ALGORITHMS for optimization of the controller parameters seems to be a better choice compared to the controllers with some random parameters.

10. CONCLUSION

The vital role of FACTS devices, which are connected in long distance transmission lines, are to improve the power transfer capability and also to control the power flow in the power system network. In this project work, SSSC is employed as a series FACTS device. SSSC is connected in series with transmission line of SMIB system with various loading. MATLAB/SIMULINK environment is used for this comparative study to model and simulate SSSC connected to a SMIB transmission line. In this project, the effect of SSSC for improving transient stability of the single machine infinite bus power system is investigated in terms of the Critical Fault Clearing Time. The results were obtained with and without compensation. From the simulation results it is observed that when a SSSC is placed in series with the transmission line, transient stability is improved, and stability of power angle is enhanced by GA optimized supplementary damping controller.

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 loading condition is investigated in this work. Maximum improvement in critical fault clearing time with SSSC is observed at 60% of loading when compared with the other loading conditions.

In this study, power system stability improvement by a static synchronous compensator (SSSC) based damping controller is thoroughly investigated. The design problem is formulated as an optimization problem. GENETIC ALGORITHMS (GA) algorithm is employed to search for the optimal controller parameters. The performance of the proposed controller is evaluated under two different loading conditions i.e. at 80% and 60% loading for single-machine infinite bus power system as speed deviation as the input signal to the controller. Results show that when optimizations are considered the proposed approach is better and provides improved performance under various loading conditions and disturbances. The results were good as was shown in Table -2. However, the GA designed PID is much better in terms of the rise time and the settling time and ITAE value becomes less. It is also observed that from power system stability improvement point of view that application of some algorithms is a better choice than usual controller.

In conclusion the responses as shown in discussion, had showed to us that the designed PID with GA has much faster response than using the classical method. The classical method is good for giving us as the starting point of what are the PID values. However, the approached in deriving the initial PID values using classical method is rather troublesome. There are many steps and also by trial and error in getting the PID values before you can narrow down in getting close to the optimized values.

Finally, this work shows how simple and powerful a GA application for controller tuning can be. Because the GA is a very good optimization technique, all control specifications that can be translated to a cost index can be applied. Only the application for a PID industrial controller is shown because it is one of the most important basic controllers.

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