STATE FEEDBACK CONTROL OF POWER SYSTEM OSCILLATIONS

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by

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National Institute of Technology
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CERTIFICATE

This is to certify that the thesis entitled "STATE FEEDBACK CONTROL OF POWER SYSTEM OSCILLATIONS" submitted by Anirban Dasgupta (Roll no.:10602064) and Aneek Mukherjee (Roll no.:10602055) in the partial fulfillment of the requirement for the degree of Bachelor of Technology in Electrical Engineering, National Institute of Technology, Rourkela, is an authentic work carried out by them under my supervision. To the best of my knowledge the matter embodied in the thesis has not been submitted to any other university/institute for the award of any degree or diploma.

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Abstract

Damping of electromechanical oscillations in power systems is one of the major concerns in the operation of power system since many years. The oscillations may be local to a single generator or generator plant (local oscillations), or they may involve a number of generators widely separated geographically (inter-area oscillations). These oscillations causes improper of the power system incorporating losses. Local oscillations often occur when a fast exciter is used on the generator, and to stabilize these oscillations, Power System Stabilizers (PSS) were developed. Inter-area oscillations may appear as the systems loading is increased across the weak transmission links in the system which characterize these oscillations. If not controlled, these oscillations may lead to total or partial power interruption. Electricité de France developed two state feedback controllers aiming to effectively damp electromechanical oscillations present in power systems. These are Desensitized Four Loop Regulator (DFLR) and Extended Desensitized Four Loop Regulator (EDFLR). The DFLR is designed to damp local electromechanical oscillations while the EDFLR aims at damping both local and inter-area oscillations. The dynamics of the DFLR and EDLFR are needed to be studies in order to model them. These models are to be incorporated with the generator models to get a power system model with state feedback control. On simulating the system in Simulink with the controllers we will get the power system model with state feedback control and we can observe how these controllers are helpful in damping the oscillations.

CONTENTS

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

This considers the problem of damping the power system oscillations using feedback controllers. Damping of power system oscillations is essential since these oscillations cause fluctuations in voltage and frequency. Several studies have been made to design suitable controllers for effective damping of such oscillations. A power system model developed in MATLAB - Simulink based on the Desensitized Four Loop Regulator (DFLR) and Extended Desensitized Four Loop Regulator (EDFLR) strategies of [1]. The effectiveness of these controllers to damp electromechanical oscillations has been studied here by simulation.

1.2 BACKGROUND

1.2.1 OSCILLATIONS

A power system contains several modes of electromechanical oscillation as a result of interactions of its subsystems, for example one generator rotor swings with respect to other in a multi-machine power system. Such oscillations cause continuous variations in the state variables of the power system like voltage, current, power and frequency of the different nodes of the system which may affect the ancillary devices attached to the system.

There are two major types of oscillations that are frequently encountered in power systems:

1. local oscillations
2. inter area oscillations

Local oscillations occur when a generator's states or that of a group of generators at a generating station swings against the rest of the system's states. The oscillations of this kind are in the range of 1Hz to 2 Hz [1].

Inter-area oscillations involve combinations of many synchronous machines on one area of a system swinging against synchronous machines on another area of the system. These are usually associated with groups of machines swinging relative to other groups over their interconnections.

The characteristic frequency of inter-area mode of oscillations is usually in the range of 0.2 to 1 Hz [1]. These are much more difficult to damp compared to the local modes of oscillations.

The classical, most cost effective and well-studied method to damp power system oscillations is by using Power System Stabilizer (PSS) along with the Automatic Voltage Regulator (AVR).

1.2.2 WHAT IS AVR?

Automatic Voltage Regulator is a device which automatically controls and stabilizes the terminal voltage output of the generator using feedback. It is designed in such a manner to achieve good damped response even if the generator is disconnected from the network. However a static AVR that uses constant feedback gains has a destabilizing effect on electromechanical oscillations. Whenever the terminal voltage tends to fall due to load, the drop is approximately fed back to increase the excitation and vice-versa such that the required terminal voltage is maintained in the output terminals.

1.2.3 POWER SYSTEM STABILIZER

A Power System Stabilizer (PSS) is used to improve the power system stability. It is installed in the Automatic Voltage Regulator of the Generator. It is an additional block in a generator excitation control, that improves the overall power system dynamic performance, especially for the control of electromechanical oscillations. Auxiliary stabilizing signals such as shaft speed, terminal frequency or power is used by the PSS to change the input signal to the AVR. This is a very effective method of enhancing small-signal stability performance of a power system network. The generator output is decided by the turbine mechanical torque. But its output power also can be changed by changing excitation value transiently. The changing of generator output power is detected and the excitation value is controlled by the PSS. The use of PSS has become increasingly popular to improve the stabilization of the system.

1.3 OBJECTIVE

The objective of the present work is to implement the DFLR and the EDFLR into the power system model to demonstrate the use of these controllers at damping the electromechanical oscillations occurring in the power system. As it is well known that the power system electromechanical oscillation phenomenon is highly undesirable for effective operation of a power system, it is required to damp these oscillations efficiently and effectively. Before applying these controllers in any power system it is beneficial to simulate the power system along with the controllers in order to get a beforehand knowledge about how effectively these controllers can work when properly tuned. For that purpose we need to obtain mathematical model of these controllers. Then we need to study the generator models following IEEE standards. Finally by combining the controller and plant, the complete closed loop power system model with state feedback control is to be simulated.

Chapter 2

STATE FEEDBACK CONTROLLERS

2.1 STATE FEEDBACK CONTROL

In state feedback control, the state variables are fed back to the input of the system instead of the output variables. State variables are those system variables that summarizes the past that is useful for prediction.

This technique can only work if the system is controllable. The future behavior can be predicted from the state if all the states are known. This mode of feedback control is easy to implement and has a wider range of applications.

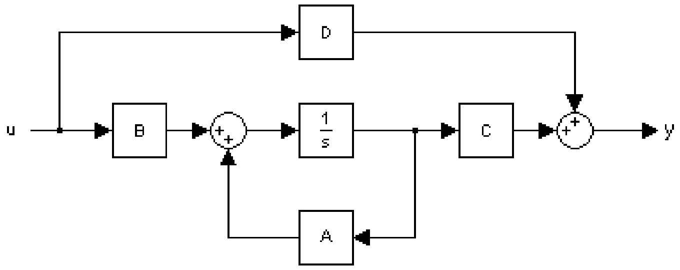


Fig 2.1 State feedback control model

2.2 THE DFLR AND THE EDFLR

The AVR and the PSS were traditionally designed from the transfer function representation of the system and its frequency response. The DFLR and the EDFLR are the stable state feedback controllers aimed at damping power system oscillations. The DFLR is aimed at damping local oscillations. It is a robust controller and it offers good performance in spite of variations in generator operating conditions. It comes from the state space form of single machine infinite bus system. The three state variables are terminal voltage, active power and speed deviation. It feeds back the three states multiplied by the corresponding state feedback gains. The gains are obtained by the desensitization method based on optimal control theory [5]. The EDFLR is aimed at damping both local and inter-area oscillations. It is the result of the application of an extended version of the desensitization method to a more complicated design circuit with two generators.

.2.1 DFLR & EDFLR STRATEGIES

2.2.1.1 DFLR

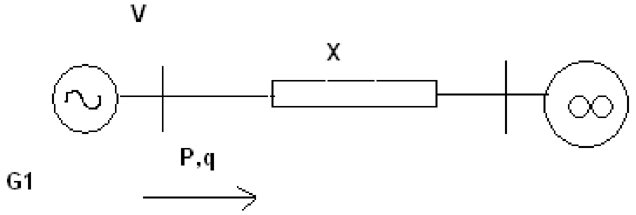


Fig 2.2 Single machine infinite bus system

The state feedback structure arises from the state space representation of the design circuit as shown in figure 2.2. The circuit represents the local oscillatory phenomenon through the single electromechanical oscillation of the generator against the infinite bus. The figure 2.4 presents a scheme of the state-space model. The terminal voltage V, the connection reactance X, the active power P and the reactive power q describe the operating conditions. The control input is the excitation voltage E_{fd} . The measured outputs are the terminal voltage V, the active power P_e and the speed deviation ω. To eliminate the steady state error between the terminal voltage and reference voltage, integral action is included in the voltage regulation loop.

$$\dot{e} = V_{ref} - V_t$$

The resulting state feedback controller with integral gain is obtained whose general structure is shown the figure below.

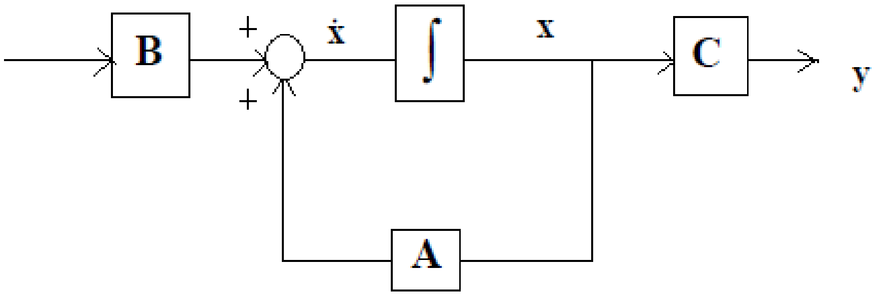


Fig 2.3 State space model of DFLR

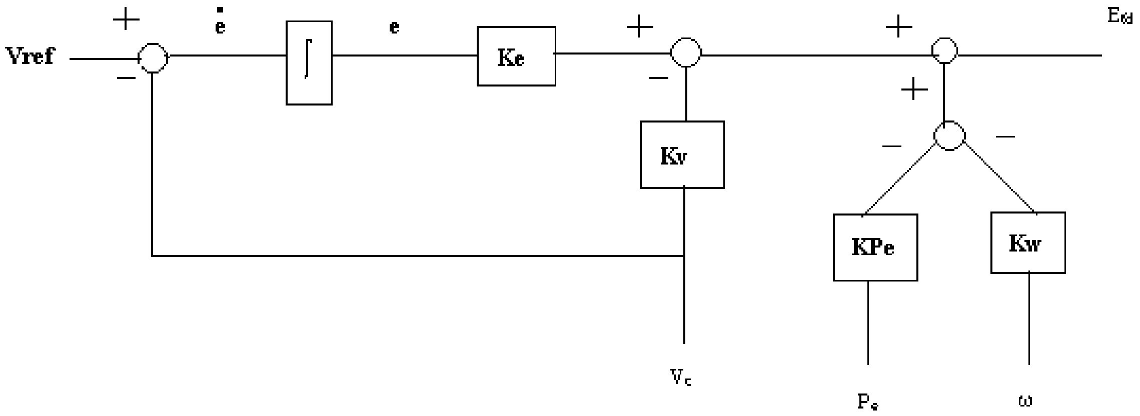


Fig 2.4 A Four loop regulator structure

This controller obtains the signal E_{fd} as the sum of each of the three measured variables multiplied by a gain.

$$E_{fd} = -(K_{Vt} * V_t + K_{pe} * P_e + K_{\omega} * \omega) \qquad (1.1)$$

The four gains are calculated according to a desensitization method of [1]. Such a controller provides simultaneously both the voltage regulation and damping to local oscillations, it may be equivalent to a coordinated AVR + PSS tuning.

2.2.1.2 THE EDFLR

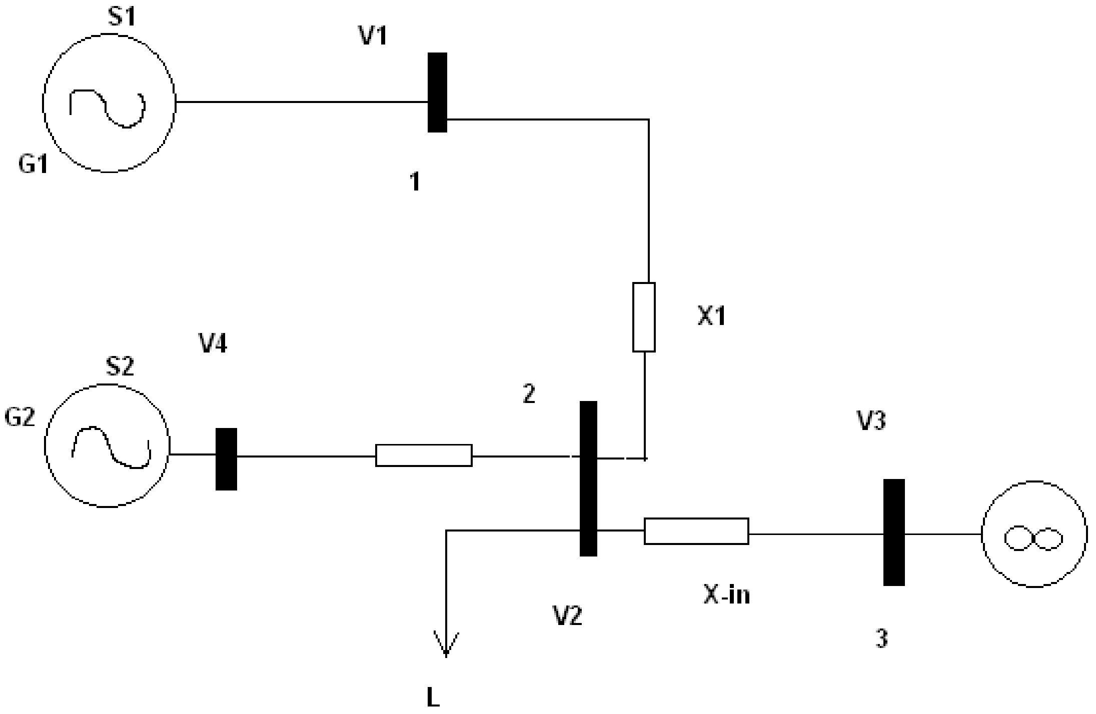


Fig 2.5 Design circuit of EDFLR

Next let us consider a system of two generators aimed to represent two electromechanical oscillations:

1] a local mode of G_1 against G_2 mainly controlled by X_l

2] an inter-area mode of G_1 and G_2 against the infinite bus controlled mainly by X_{in}.

The apparent power S_2 controls the participation of G_1 in the inter-area mode. The frequencies of the local and inter-area modes and the participation factor of the generator of the inter-area mode are the parameters of the design circuit.

2.3 CONVERSION TO AVR + PSS STRUCTURE

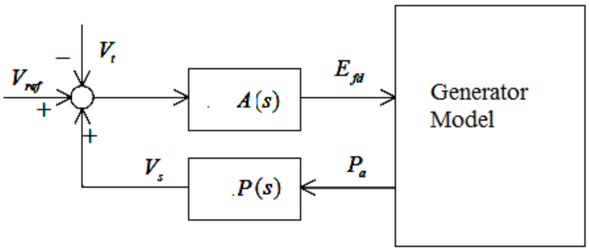


Fig 2.6 Standard AVR + PSS structure

The input signal used for the PSS is the accelerating power $P_a = P_m - P_e$
The control signal E_{fd} obtained from the standard structure where V_{ref} *is* zero since it is assumed that no change in the reference voltage occurs. All variables and functions are expressed by their Laplace transform [5].

$$E_{fd}(s) = A(s) * (-V_t(s)) + A(s) * P(s) * P_a(s) \tag{1.2}$$

If E_{fd} (s) is obtained from the four loop regulator structure then

$$E_{fd}(s) = -K_e(s) * e(s) - K_{vt}(s) * V_t(s) - K_\omega(s)\omega(s) - K_{Pe}(s)P_e(s) \tag{1.3}$$

The four gains are represented by transfer functions to consider the general case associated with the EDFLR. The main objective is to obtain the transfer functions A(s) and P(s) as a function of these four gains. Hence, all measured variables should be expressed as a function of V_t and P_a .

The integration error can be written in terms of the terminal voltage

$$e(s) = \frac{V_t(s)}{s} \tag{1.4}$$

The speed deviation is related to the accelerating power by the swing equation of the rotor, which is given as -

$$\omega(s) = \frac{1}{2Hs}(P_m(s) - P_e(s)) = \frac{Pa(s)}{2Hs} \tag{1.5}$$

The integrators of error and speed deviation are approximated by the first order transfer function because neither the AVR nor the PSS transfer functions have a pure integrator. The infinite gain of the integrator is limited to T at low frequencies, but in case T is sufficiently high, the crossover frequency is low enough to be out of the frequency range of interest (0.1 Hz – 10 Hz).

$$\frac{1}{s} \simeq \frac{T}{1+sT}\,\frac{1}{s} \simeq \frac{T}{1+sT} \tag{1.6}$$

Approximating the integrators of error and speed deviation by the first order transfer function with time constants of respectively T_{AVR} and T_{PSS} and substituting the resulting expressions in (2), $E_{fd}(s)$ is given in terms of $V_t(s)$ and $P_a(s)$, we obtain the following expression

$$E_{fd} = \left(\frac{T_A K_e(s)}{1+sT_A} + K_v(s)\right)(-V_t(s)) + \left(-\frac{-K_\omega(s)T_P}{2H(1+sT_P)} + K_{Pe}(s)\right)P_a(s) \tag{1.7}$$

From the comparison of (1.2) and (1.7), the transfer functions of the AVR and PSS are

$$A(s) = \left(\frac{T_A K_e(s)}{1+sT_A} + K_v(s)\right) \; A(s) = \left(\frac{T_A K_e(s)}{1+sT_A} + K_v(s)\right) \tag{1.8}$$

$$P(s) = \left(-\frac{-K_\omega(s)T_P}{2H(1+sT_P)} + K_{Pe}(s)\right) * \frac{1}{A(s)} \tag{1.9}$$

Thus we have obtained the gains A(s) and P(s) in terms of the four gains. If we know these four gains we can simplify the controllers to the standard form.

2.4 MODELLING

A set of gains $K_{vt} =31.202$, $K_{pe}= 13.417$, $K_w=-2.387$, $K_e=12.788$ has been obtained by desensitization method in [1], using which one may represent the DFLR model equivalently in AVR+PSS structure as shown in the following figures 2.7 and 2.8

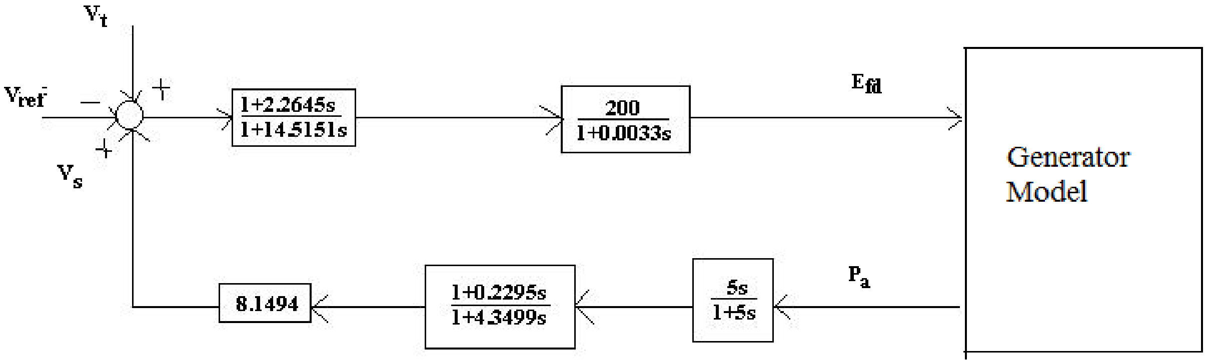


Fig 2.7 DFLR CONVERTED TO AVR+PSS STRUCTURE

We can see that the AVR is composed of a gain of 200, the delay of the static exciter (a time constant of 0.0033 s) and a transient gain reduction block (a lag network) to reduce the steady state error of the voltage. The PSS is formed by a washout filter (with a time constant of 5 s), a lag phase compensation network, and the PSS gain.

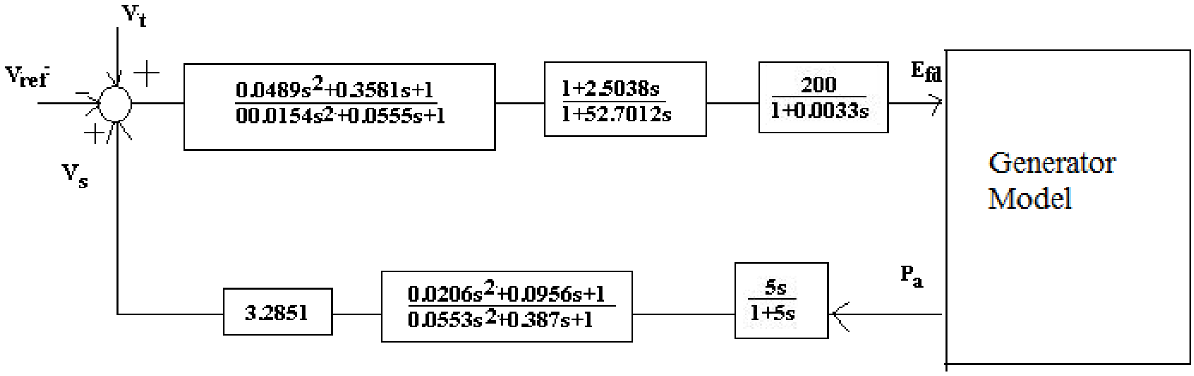


Fig 2.8 EDFLR CONVERTED TO AVR+PSS STRUCTURE

Chapter 3

GENERATOR MODELING

3.1 INTRODUCTION

The basic techniques for studying the stability of interconnections of synchronous generators were in the process of development in the late nineteenth century and the early years of last century. The basic idea of transforming stator variables into quantities which rotate in synchronism with the rotor was developed by Blondel, Park, and others. This remains the basis for synchronous machine analysis even in this present day.

The techniques that were developed earlier at the start remained relatively untouched to some extent until the last three or four decades of the twentieth century. Although theoretically it was possible to develop relatively complex generator models earlier, but the computational capability were limited and such models were impractical for use for large-scale stability studies. However, with the popularization of the digital computer, the scenario changed significantly and computational capability continues to grow at a very fast rate. In addition, the electric power systems is growing complex and with very sophisticated generator and system controls the demands on stability programs have greatly increased.

3.2 POWER SYSTEM STABILITY

3.2.1 GENERAL BACKGROUND

Basically, the system's ability to maintain synchronous operation after a severe disturbance is mainly focused in power system stability studies. However, with fast growth in interconnections, more use of new technologies and the increased need to operate power systems in highly stressed conditions, other forms of stability studies are been done [6]. Instability in a power system is may come in many different ways depending on the system configuration, operating mode, and form of disturbance.

Analysis of stability problems is greatly simplified by classifying them into appropriate categories. These are based on the following considerations:

— The physical nature of the resulting instability
— The size of disturbance considered, impacting on the applicable method of analysis.

Based on the physical nature of the phenomena, power system stability may be classified into three main categories [6]:

(a) Rotor-angle stability
(b) Voltage stability
(c) Frequency stability

3.2.2 ROTOR-ANGLE STABILITY

Rotor-angle stability [6] is the ability of interconnected synchronous machines in a power system to remain in synchronism under normal operating conditions and even after being subjected to a disturbance. An important factor to study is the manner in which the torque or power outputs of the synchronous machines vary as their rotors oscillate. The mechanism by which synchronous machines maintain synchronism with one another is by the development of restoring torques whenever there are forces which tend to accelerate or decelerate the machines with respect to each other.

The change in electromagnetic torque of a synchronous machine following a perturbation can be resolved into two components [6]:

(i) a synchronizing torque component, in phase with the rotor-angle deviation
(ii) a damping torque component, in phase with the speed deviation.

The lack of sufficient synchronizing torque results in aperiodic instability, whereas insufficient damping torque results in oscillatory instability i.e. it will continue to oscillate.

For convenient analysis and for gaining insight into the nature of stability problems, it is helpful to categorize [6] rotor-angle stability into the subcategories based on the size of disturbance considered.

They are:

a) Large-disturbance angle stability is also known as transient stability. It is the ability of the power system to maintain synchronism when subjected to a severe disturbance, like a transient fault on a transmission circuit. The resulting system response involves large deviations of generator rotor angles. The power-angle relationship of synchronous machines is nonlinear which influences such response. Usually, the disturbance changes the system in such a manner that the conditions after the disturbance will be different from those just before the disturbance. Instability is mainly due to insufficient synchronizing torque. In large power systems, transient instability may not always occur.

b) Small-disturbance angle stability is the ability of the power system to maintain synchronism under small disturbances like those that continually occur in the normal operation of the power system. The disturbances are considered to be sufficiently small and linear approximations of system equations are permissible for purposes of analysis which hardly lead to any error. Small-signal analysis using linear techniques provides valuable information about the inherent dynamic characteristics of the power system.

Instability that may result can be of two forms[6]:

(i) increase in rotor angle through a non-oscillatory or aperiodic mode due to lack of synchronizing torque

(ii) rotor oscillations of increasing amplitude due to lack of sufficient damping torque.

At present, in power systems, the small-disturbance angle stability problem is usually that of insufficient damping of oscillations. The stability of the following types of oscillations is of concern [6]:

— Local-mode oscillations, associated with units in a power plant swinging against the rest of the power system.

— Inter-area-mode oscillations, associated with the swinging of a group of generators in one area against a group of generators in another area.

— Torsional-mode oscillations, associated with the turbine-generator shaft system rotational components of individual generators.

3.2.3 VOLTAGE STABILITY

Voltage stability is the ability of a power system to maintain constant stable voltages at all buses in the system under normal operating conditions and even after being subjected to any disturbance. Instability may be a progressive fall or rise of voltage of some buses with only moderate deviation of generator angles. The main cause of voltage instability is the inability of the power system to maintain a proper balance of reactive power throughout the system. This is significantly influenced by the characteristics of system loads and voltage control devices.

It is useful to classify voltage stability into the following two subcategories based on the size of disturbance considered [6]:

a) Large-disturbance voltage stability is the system's ability to maintain steady voltages even after severe disturbances. The stability analysis is done based on the dynamic performance of the power system over a period of time. The study period may extend from a few seconds to several minutes.
b) Small-disturbance voltage stability is the system's ability to maintain steady voltages following small perturbations, such as incremental changes in load.

3.2.4 FREQUENCY STABILITY

Frequency stability is the ability of a power system to maintain the frequency within a nominal range [6]. It depends on the ability of the system to restore balance between its generation and load with minimum loss. Analysis of frequency stability is carried out using time-domain simulations.

In the case of large interconnected power systems, simulations required may include severe disturbances beyond the normal design criteria. This may result in cascading and splitting of the power system into a number of separate sections with generators in each section remaining in synchronism. Stability in this case is a question of whether or not each section will reach an acceptable state of equilibrium with minimum loss of load.

3.3 MODELING REQUIREMENTS

Following the IEEE standards [6] one can easily see that several models for Synchronous machines are available, use of which may vary based on the problem under consideration. A brief account of these models extracted from [6] is presented here.

The following requirements in representing synchronous machines for different categories of stability studies are:

a) For large-disturbance rotor-angle stability analysis, mainly for generators with high-initial response excitation systems, the magnetic saturation effects should be accurately represented at flux levels corresponding to normal operation. With discontinuous excitation controls, the excitation remains at its peak for about two seconds leading to very high flux levels. If saturation effects are minimized, the results of analysis would be very optimistic.

It is important to represent the dynamics of the field circuit, because it significantly influences the effectiveness of excitation system in enhancing large-disturbance rotor-angle stability.

b) For small-disturbance rotor-angle stability analysis, representation of the field circuit as well as the rotor damper circuits is essential.

c) For voltage stability studies, the voltage control and reactive power supply capabilities of generators are of prime importance. During conditions of low system voltages, the reactive power demand on generators may exceed their field-current limits. In such situations, usually the generator field currents are automatically limited by some current limiters.

d) Frequency stability problems are generally associated with the deficiencies in equipment response and poor coordination of control and protection equipment. Stability is determined by the overall response of the system as evidenced by its mean frequency. Under conditions of large variations in voltage and frequency, the generator models used should be capable of accurately representing the responses of control and protective devices like the voltage regulator, power system stabilizer, V/Hz limiter and protection, and over-excitation and under-excitation limiters.

3.3.1 TYPES OF MODELS AVAILABLE

According to IEEE standards [6], synchronous generators are most commonly constructed with a three-phase armature winding on the stator and an excitation winding on the rotor. The excitation winding is also known as the field winding. In addition, synchronous generator rotors include other conducting paths in which currents can be induced during a transient. In some cases, the designer intentionally includes these conducting paths like the pole-face damper windings. In other cases, they are inherent to the machine design, like the currents which can be induced in the rotor body of a solid-rotor turbo generator.

Earlier for the analysis of synchronous machines, it was recognized that analyses can be greatly simplified if they are performed in a reference frame rotating with the rotor. For such analyses, the armature currents and voltages are transformed into two sets of orthogonal variables, one set aligned with the magnetic axis of the field winding, known as the rotor direct axis (d-axis), and a second set aligned along the rotor at a position 90 electrical degrees from the field-winding magnetic axis. This second axis is known as the rotor quadrature axis (q-axis).

Much of the simplification associated with such an approach stems from two key features:

1) Under steady-state operating conditions, all of the currents and fluxes, including both those of rotor windings and the transformed armature windings, have constant values.

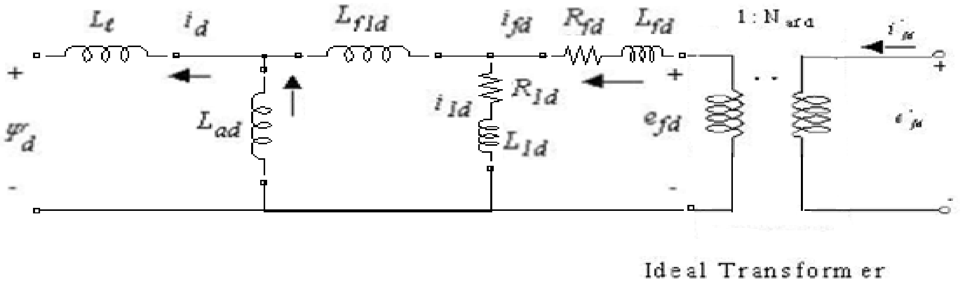
2) By choosing the two axes 90 electrical degrees apart, fluxes produced by currents in the windings on one axis do not produce flux linkages in the windings on the other axis. Thus, these sets of windings are orthogonal.

This greatly simplifies the flux-current relationship of the model and gives rise to a model structure consisting of two independent networks, one for the direct axis and one for the quadrature axis.

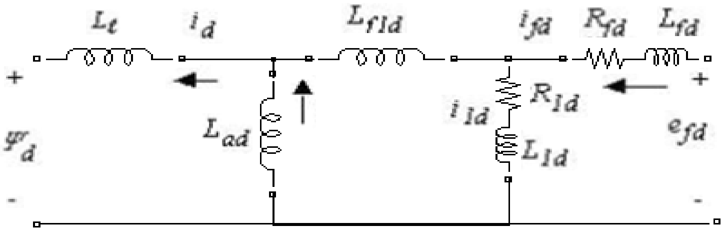
3.3.2 DIRECT-AXIS MODEL STRUCTURES

The direct axis of a synchronous machine is a two port network [6]. It corresponds to the direct-axis equivalent armature winding and the field winding. An accurate representation of the direct axis must fully account for the characteristics of both of these terminals. The simplest direct-axis representation assumes that there are no other current paths in the direct axis other than the direct-axis armature winding and the field winding. But, it is known that damper-winding currents play a significant role in determining the characteristics of the direct axis. Hence, the most common direct axis model includes an additional winding, known as the direct-axis damper winding.

Part (a) of Figure 3.1 shows the equivalent-circuit representation for the direct-axis model with a single damper winding drawn in simulink. This equivalent circuit includes an ideal transformer, representing the fact that there are differing numbers of turns on the armature and field winding, just as is the case for the primary and secondary windings of a transformer.



(a) using ideal transformer



(b) without ideal transformer

Fig 3.1 D-axis equivalent circuits

Commonly synchronous machines are represented using a per-unit representation, rather than actual units, in which case an ideal transformer may or not be required, depending upon the choice of the base for the per unit system. Whether in actual units or in per unit, the ideal transformer is typically left out of the equivalent circuit, resulting in the equivalent circuit of part (b) of Figure 3.1 in which the field voltage and current are reflected to the armature winding.

3.3.3 QUADRATURE-AXIS MODEL STRUCTURES

As there is no rotor winding with terminals on the quadrature axis, the quadrature axis needs be represented only as a single-port network [6]. In addition to the quadrature-axis armature winding, varying numbers of damper windings can be included in the quadrature-axis model. The flux-current relations for the quadrature-axis models are directly analogous to those presented earlier for the direct-axis.

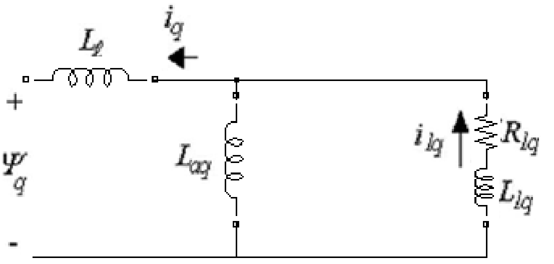


Fig 3.2 Q-axis equivalent circuit

3.3.4 CONSTANT-VOLTAGE-BEHIND-REACTANCE MODEL

The simplest model that can be used to represent a synchronous machine is by a constant voltage and a single series reactance representation [6]. In the steady state, this representation includes the synchronous reactance and the voltage behind synchronous reactance. This voltage is proportional to the field current supplied to the generator. In this representation, saliency is neglected and the synchronous reactance is set equal to the direct-axis synchronous reactance of the machine. The transient model of this type is assumed to be valid for the initial time period of an electromechanical transient and can be used to roughly estimate the first-swing stability of a synchronous machine. During a simulation in transient state, the magnitude of the model's internal voltage is kept constant, but the internal angle is changed corresponding to the rotational dynamics of the generator rotor.

Advantage of this simple model is that the interfacing of the generator and network equations can be fulfilled more quickly during transient simulations. Also it requires relatively little data.

3.4 MODELING CONSIDERATIONS

3.4.1 BASED ON CATEGORIES OF STABILITY

3.4.1.1 TRANSIENT STABILITY

Transient stability analysis is the detailed study of power system performance when subjected to a severe fault [6]. Power systems are designed and operated so as to be stable for a set of contingencies referred to as the design contingencies. These contingencies are selected on the basis that they have significant probability of occurrence with a large number of elements are given comprising the power system.

In transient-stability studies, the important issues are:

— Calculation of generator power or torque during the fault period.

— Calculation of post-fault generator power, angle, and voltage for a period of up to several seconds after the fault cleared.

3.4.1.2 SMALL-DISTURBANCE ANGLE STABILITY

Small-disturbance stability analysis is the study of the ability of the power system to maintain synchronous operation when subjected to small perturbations [6]. The modeling of the power system, including synchronous generators, is quite similar to that for transient stability analysis. Only balanced operation is considered and the system equations may be linearized for purpose of analysis. Generator models used for assessing small-disturbance stability should accurately account for damper circuit effects, field circuit dynamics, and excitation control. One of the effective means of enhancing small-signal stability is the use of power system stabilizers.

3.4.2 BASED ON ROTOR STRUCTURE

3.4.2.1 SALIENT-POLE GENERATORS

Salient-pole generators with laminated rotors are usually constructed with copper-alloy damper bars located in the pole faces [6]. These damper bars are often connected with continuous end-rings to form a squirrel-cage damper circuit that is effective in both the direct axis and the quadrature axis. The damper circuit in each axis may be represented by one circuit. Salient-pole machines with solid-iron poles may justify a more detailed model structure with two damper circuits in direct axis.

3.4.2.2 CYLINDRICAL-ROTOR GENERATORS

In cylindrical-rotor machines, slots are present over part of the circumference to accommodate the field winding [6]. The tops of these slots contain wedges for mechanical retention of the field turns. These wedges are usually made of a nonmagnetic metal, and may be either segmented or of full length. In many constructions, a conductive ring under the field end-winding retaining ring is used to improve conduction at these connection points with fingers extending under the ends of the slot wedges. Copper strips are often inserted under the wedges to provide improved conduction between wedge segments and to improve damper-circuit action. In some cases, a complete squirrel-cage winding is formed, while in other cases the conductive paths contribute only marginally to damper-circuit action.

3.4.3 USE OF SIMPLIFIED MODELS

3.4.3.1 NEGLECT OF DAMPER CIRCUITS

A simplification to the synchronous generator model is to neglect the effects of damper circuits [6]. The primary reason for this approximation is that often machine parameters related to the damper circuits are not readily available mainly for older units. Neglect of damper circuits' effects introduces some degree of loss of accuracy. This may be acceptable to a certain extent.

3.4.3.2 CLASSICAL MODEL

The classical model is simple for computing as it allows the transient performance of the generator to be represented by a simple voltage source of fixed magnitude behind an effective reactance [6]. Such a model is now used for screening studies, such as contingency screening and ranking for transient stability limit search applications.

3.5 MACHINE MODELLING

3.5.1 SYNCHRONOUS GENERATORS MODEL

Mathematical models of a synchronous machine vary from elementary classical models to more detailed ones. The detailed models are transient and subtransient models.

The following equations link the mechanical variables with the electrical variables, and result in the block diagram representation depicted in Figure 3.3:

$$(D+\tau_j S)=T_m-(E''_q I_q+E''_d I_d)\ (D+\tau_j S)=T_m-(E''_q I_q+E''_d I_d) \qquad (1.10)$$

Where,

D = the damping constant

τ_j = the inertia time constant

T_m = the input mechanical torque

E''_d = sub-transient generated voltage in the direct axis

E''_q = sub-transient generated voltage in the quadrature axis

I_d = the armature current in the direct axis

I_q = the armature current in the quadrature axis

For eigenvalue or time domain simulation studies, it is necessary to include the effects of the excitation controller, which indirectly controls the reactive output of a generator.

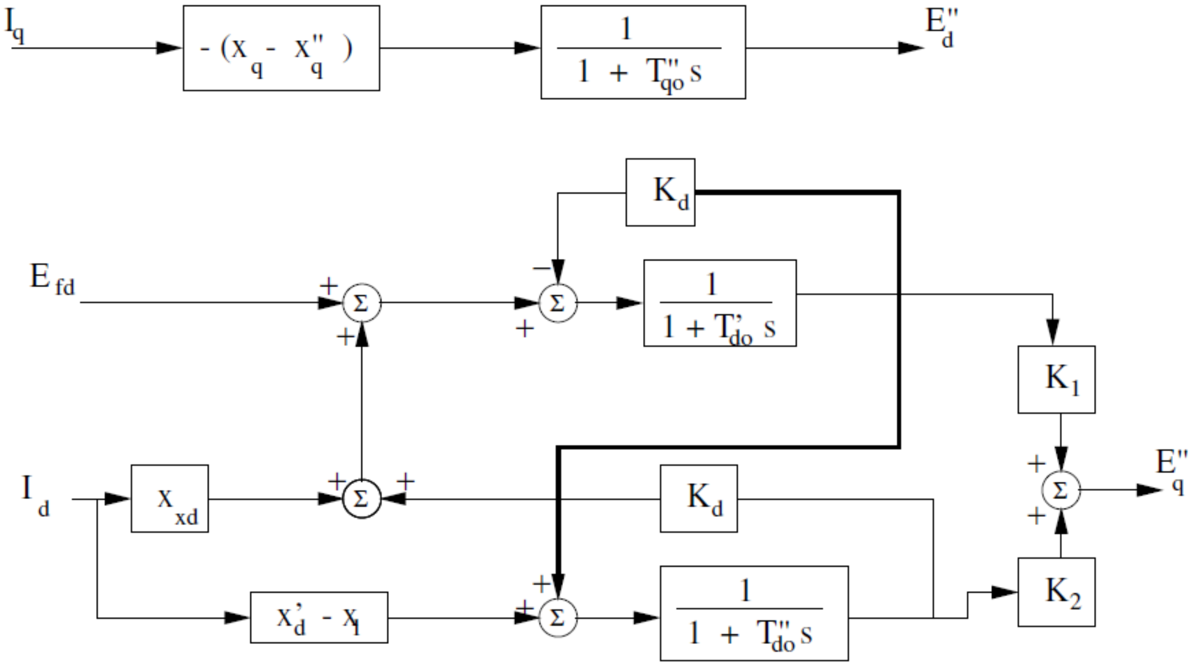


Fig 3.3 Machine sub-transient model

Chapter 4

SIMULATION STUDIES

4.1 WHAT IS SIMULINK?

Simulink is a software package used extensively for modeling, simulating, and analyzing dynamic systems. It has the advantage of supporting linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, i.e., have different parts that are sampled or updated at different rates. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations

With the help of MATLAB 2009a and its Simulink feature, the power system model along with its state feedback control is developed and simulated. The blocks used to simulate are mainly:

- Transfer Function Block
- Gain Block
- Sum Block
- Product Block
- Constant Source
- Scope as Sink

After mathematically obtaining the generator model and the controller models, it is developed in Simulink and then simulated. The main models used are the controller model and the synchronous machine salient pole model. The results of the simulations are as follows.

4.2 SIMULATIONS

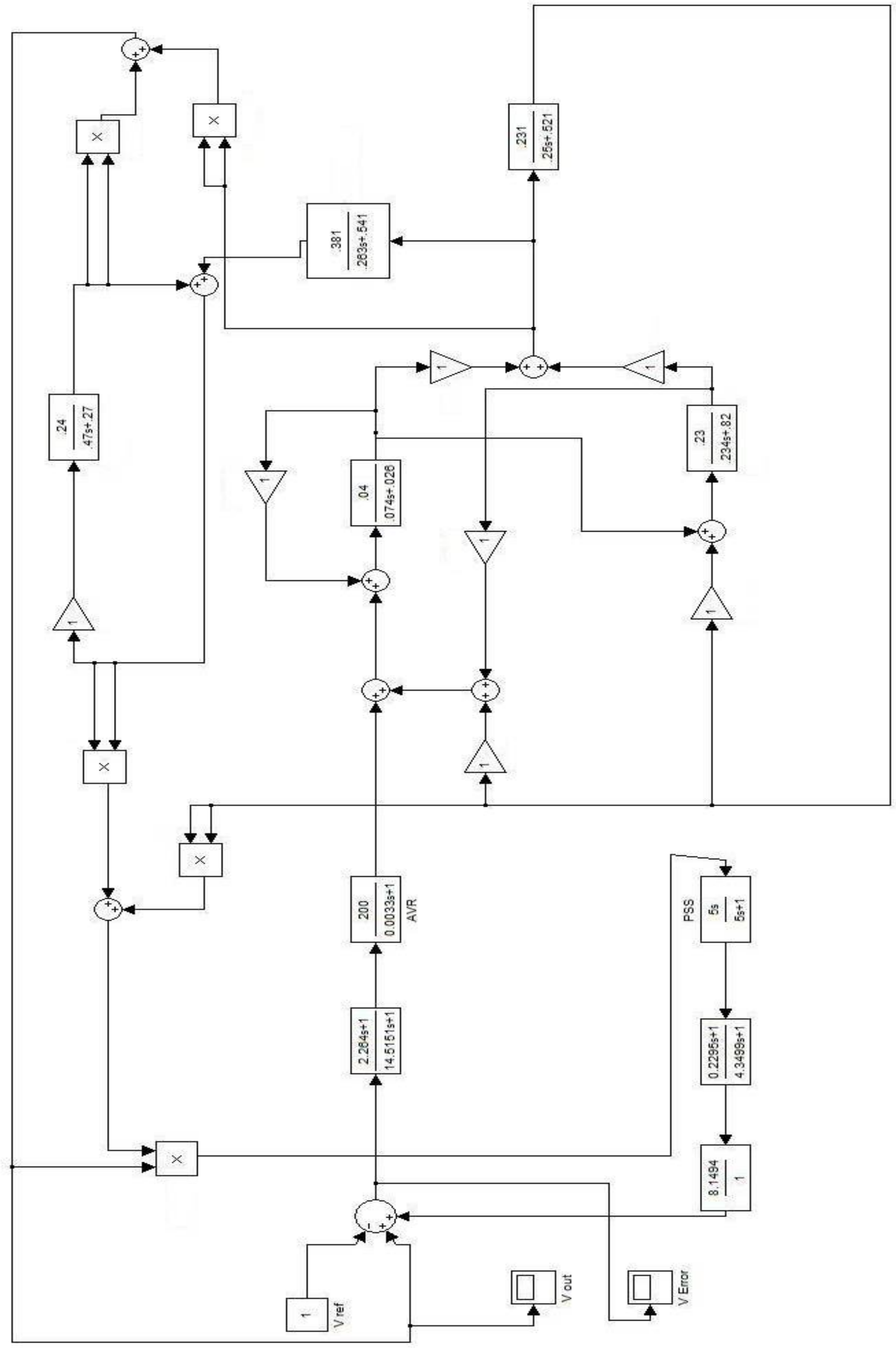


Fig 4.1 Simulink model of the power system with the DFLR

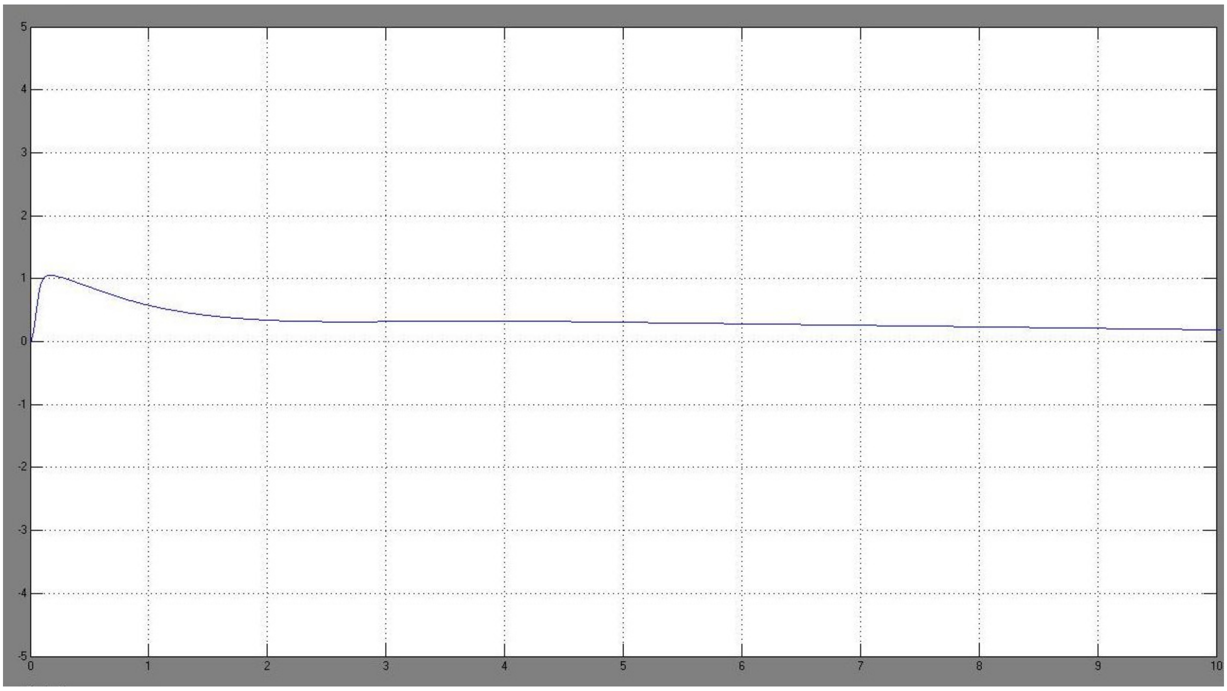


Fig 4.2 This is the output voltage. It shows how it damps the oscillation not only effectively but also very fast.

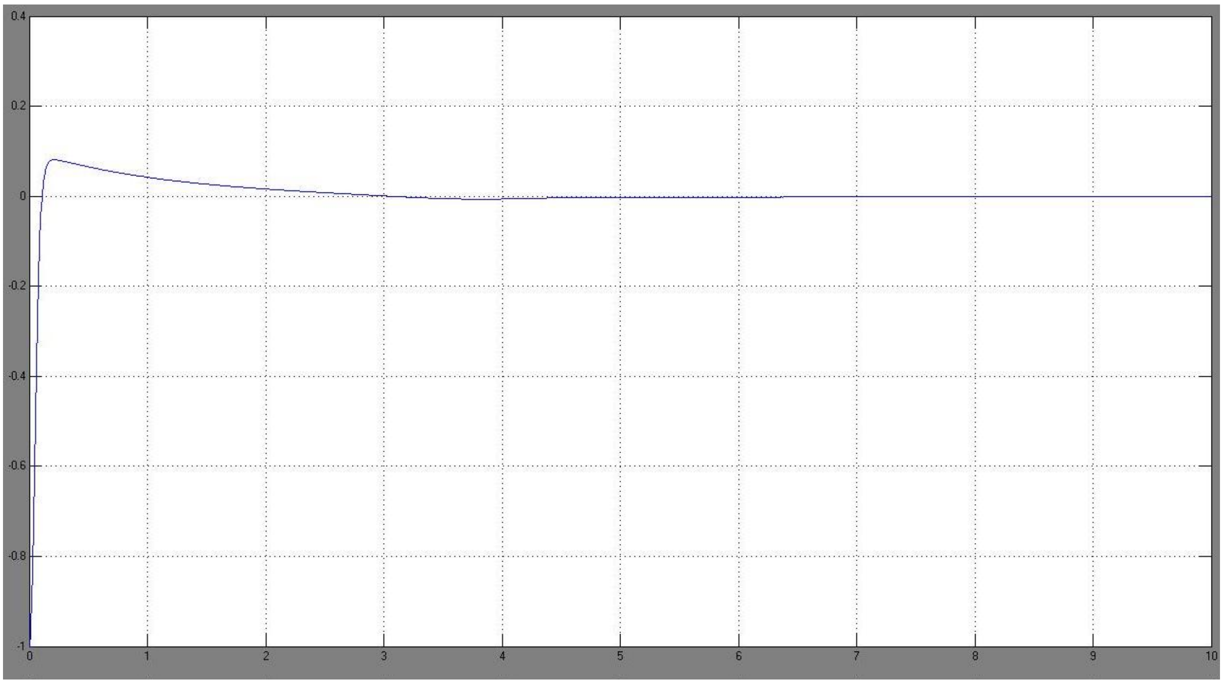


Fig 4.3 The error voltage which becomes zero finally

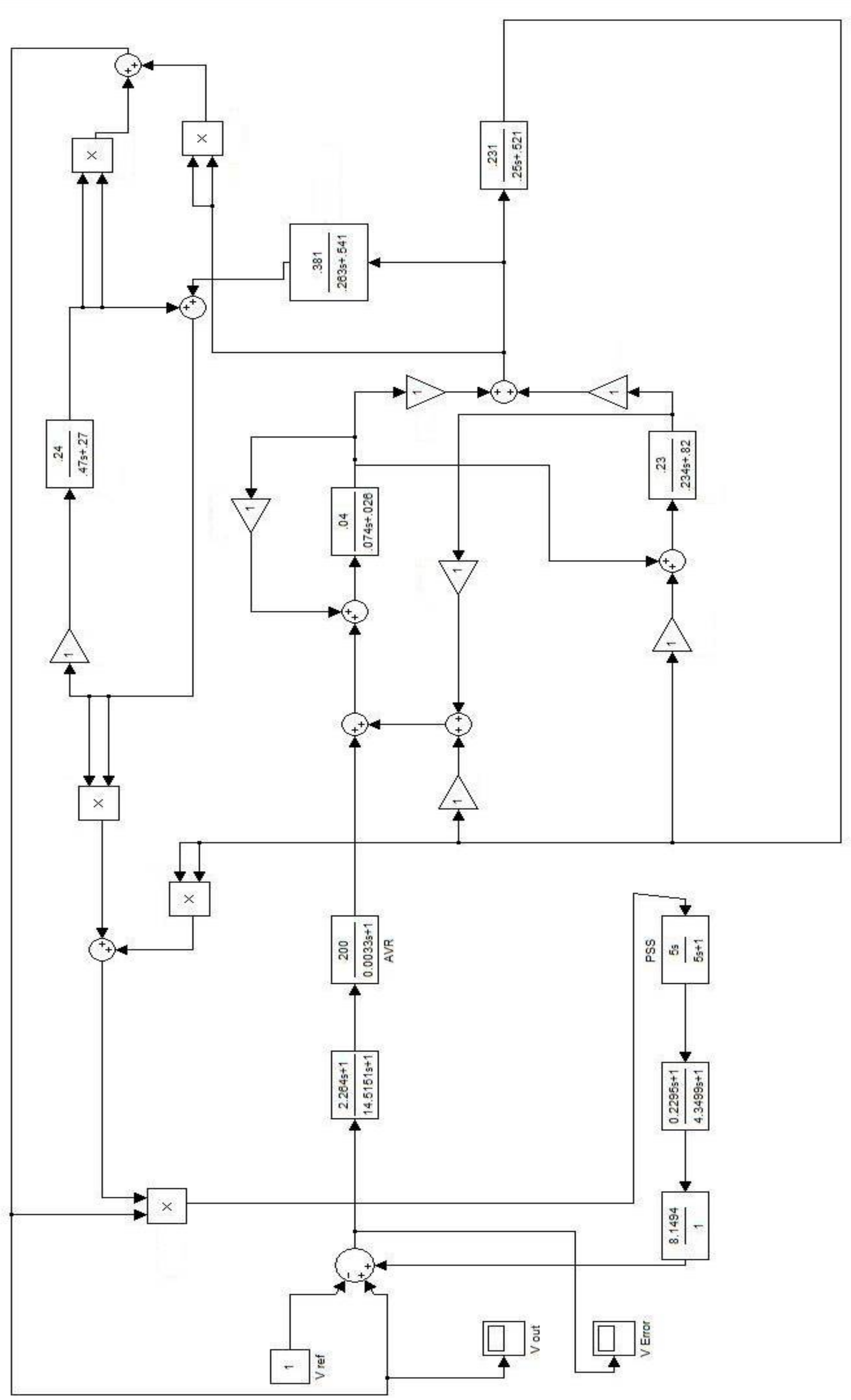


Fig 4.4 Simulink model of the power system with the EDFLR

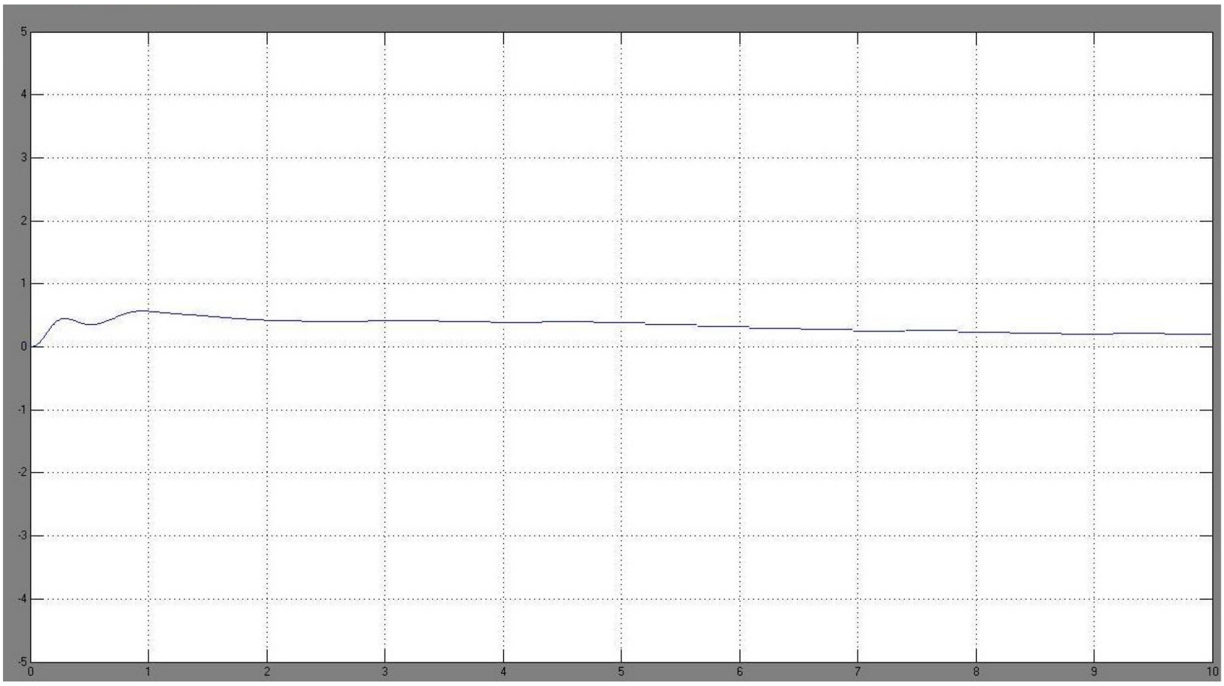


Fig 4.5 This figure shows how the model of EDFLR damps the oscillations.

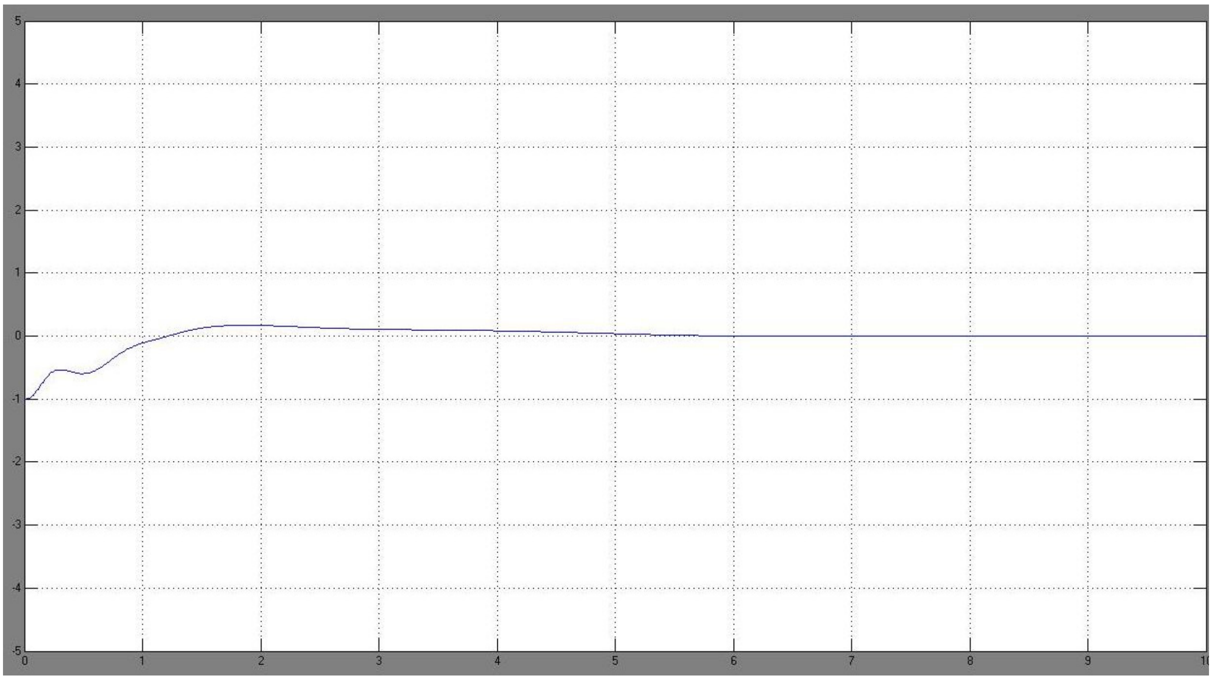


Fig 4.6 The error voltage which becomes zero after a while.

CONCLUSION

The DFLR and the EDFLR – the state feedback controllers have shown great potential to damp the power system oscillations efficiently and effectively. The MATLAB simulations reveal this fact. Proper tuning of these controllers is required for best results. The EDFLR can be used for multi-bus systems. In this work, certain specific model with certain approximations is used. The simulations can be tried out by taking into consideration the different models considering the different stability criteria. Hence different results will be obtained. Research work is still going on for further developments in these state feedback controllers and damping of electromechanical oscillations occurring in power system. By reducing the losses, the economy of the power utility grid is definitely benefitted.

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