Enhancement of AC Transient Stability Through Multiterminal DC (MTDC) Systems

by

Abdulaziz Jaffar Al-Nasser

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

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DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
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This thesis, written by Abdualziz Jaffar Al-Nasser under the direction of his Thesis Advisor and approved by his Thesis committee, has been presented to and accepted by the Dean of the College of Graduate Studies, in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Electrical Engineering.

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Date

إهداء

هذه الرسالة مهداه إلى .....

زوجتي أم جعفر .... لصبرها ..... وتفانيها ....وتشجيعها .....

وللأمل القادم..

أولادي ..... جعفر ....وعلي.....وحسن.....

حتى تكون لهم حافزا على الدرب.....

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LIST OF SYMBOLS

V_{dr} Rectifier direct voltage

V_{di} Inverter direct voltage

I_{dr} Rectifier direct current

I_{di} Inverter direct current

α Rectifier firing angle

γ Inverter extinction angle

$V_r\angle\theta r$, AC voltage on the primary side of converter

$Vi\angle\theta i$ transformer at rectifier and inverter ends respectively

$V_{sr}\angle\psi r$, Secondary AC voltage of converter transformer at

$V_{si}\angle\psi i$ rectifier and inverter ends respectively

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ABSTRACT

Transient stability is an important part of power system design and operation. This thesis deals with the application of Multiterminal Direct Current(MTDC) systems for transient stability enhancement because of its fast response at exchanging electrical power with AC system.

A mathematical model for the MTDC system components has been developed in the thesis. All the differential equations of MTDC system and controllers are modeled in an algebraic form and are solved by the trapezoidal rule.

A linear Programming optimization model has been developed as a mean to seek for an optimum control strategy. The method uses the Golden Search approach to improve the solution as another new control scheme. Two types of control schemes with generator rotor slip and other signals as an input to the controllers have been studied .

The developed controlling schemes have been applied using two multimachine power systems. A comparative study between the control methods has been carried out. The transient stability performance with applying Linear Programming and Golden Search is found to be superior compared to the other methods.

ARABIC ABSTRACT

الموجز

تعتبر الاستقرار يه العابرة جـزءا هاما في تصميم و تشغيل نظام الطاقة. يتناول هذا ا لبحث استعمالات أنظمة التيار المستمر المتعدد الأطراف لتحسين أداء الاستقرار يه العابرة لسرعة تجاوبها في تبديل الطاقة الكهربائية للأنظمه ذات التيار المتردد كأحد المزايا لها . وقد تم عمل نموذج رياضي من اجل تمثيل أنظمة التيار المستمر المتعدد الأطراف . وقد تم وضع جميع المعادلات التفاضلية للنظام واليات التحكم المستخدمة في البحث في شكل معادلات جبرية ومن ثم حل تلك المعادلات بتطبيق قاعدة المنحرفات.

كما تم أيضاو ضع نموذج معادلات خطية مثلى و تطبيق نظرية البرمجة الخطية كطريقة جديدة للتحكم و دمج هذه الطريقة مع نظرية البحث الاعتدالي للوصول إلى حل افضل كطريقة أخرى مقترحة . و أجريت أيضا دراسة لنوعين من آليات التحكم التقليدية تعمل على إشارة انزلاق دوران المولد الكهربائي وإشارات أخرى لاستخدامها في ألتحكم.

و تم تطبيق تلكم الطرق المقترحة على نظامي طاقة متعددي المولدات حيث ادخل عليهما نظام التيار المستمر ذات الثلاثة أطراف. وفي النهاية أجريت دراسة مقارنة بين الطرق المذكورة وخلصت الرسالة إلى أن استعمال طريقة دمج نظرية البرمجة الخطية مع نظرية البحث الاعتدالي أعطت افضل ألنتائج لتحسين إلاستقرارية العابرة لأنظمة التيار المتردد .

CHAPTER 1

INTRODUCTION

1.1 General

Transient Stability is an important part of power system design and operation. Stability, in general, can be defined as the oscillatory response of a power system during the transient period following a disturbance [1]. The transient Stability analysis is performed to investigate the performance of a power system under a sudden disturbance such as short circuit's faults, followed by their clearance under the action of protective relays. In all stability studies, the objective is to determine whether or not the rotors of the machine being perturbed, return to constant speed operation.

The transient stability of AC power systems is a subject that has been thoroughly covered in literature. Many methods have been investigated. In literature two lines of research have been pursued in the research for improvement of transient stability [2].The first one is related to generation side modification technique, and the second relates to transmission side modification technique. They are listed as follows:

A. <u>Generation Side Modification Technique</u>

This technique can be divided as:

1. Control of field voltage.

2. Control of field voltage on 2-axis excitation system.
3. Control of Turbine valve.

B. Transmission Side Modification Technique

This technique can be subdivided as:

1. Insertion of Series Capacitances.
2. Insertion of Series Resistance.
3. Dynamic braking resistors.
4. Single pole or selective pole trip.
5. 120° phase rotation.
6. Thyristor controlled VAR system.
7. Thyristor controlled quadrature voltage injection.
8. Super conducting Magnetic Energy Storage.

This thesis deals with the application of High Voltage Direct Current (HVDC) to enhance the transient stability of AC systems. HVDC transmission was realized over 50 years ago to have noticeable advantages over AC for bulk transmission at high voltages, under certain conditions. The main obstacle was the low ratings of mercury arc valves.

As improvements in the design of semi-conductor were proceeding, the number of HVDC system being embedded in AC systems were also increasing. Examples of such systems are [3]:

- the Pacific North West Intertie (U.S.A.)
- the Stegall DC Tie (U.S.A.)

- the Eel River HVDC Systems (Canada)
- the Radison-Sandy Pond HVDC Systems (Que'bec-New England)

With the ever increasing interest in HVDC systems, the potential to go further to Multiterminal DC (MTDC) systems projects are increasing. The world first commercial 3 MTDC system is the Italy Corsica- Sardino system[4]. In 1986, a parallel tap was commissioned in Corsica to the existing Italy-Sardino monopolar two terminals DC system that had existed since 1976. The world's first 5 MTDC project, is under execution(1988-1996). It will interconnect Hydro-Quebic (Canada)-New England (USA)[4].

In the western United States [5], the potentials of utilizing the controllability of the HVDC lines to reduce the complexity of other remedial schemes is realized. This will help to increase the stability performance of the system so that the impact of existing and future projects can be minimized.

In Canada, the Western Systems Coordinating Council has realized that the existing AC system has some limitations on power transfer, and improvements in power transmission capacity can be achieved by adding modulation to the HVDC system that is parallel to this AC line[6].

Some advantages of HVDC transmission [7,8]:

- Ability to interconnect AC systems of different frequencies.
- Distance is not limited by stability considerations.

- No contribution to short-circuit infeeds with the AC systems.
- No charging current to diminish the usefulness of the line.
- Simpler line construction.
- Earth return may be possible in certain circumstances.
- Cable insulation can be worked at a higher voltage gradient.
- Lower corona loss and radio interference, especially in fall weather, for a given conductor diameter and voltage.

In transient stability concepts, an AC network is termed as *stable,* if after a disturbance, it returns to an equilibrium position. If, however, it goes beyond certain limit, during the swing of the AC network, the AC network is called *unstable*[4].

The fast controllability of power in an HVDC link can be used to improve the transient stability of the AC system in which the HVDC link is embedded. The power can be reversed in a short time [1]. Thus, the HVDC link can be viewed as alternative to fast valving or braking resistor[9].

It has been also recognized that a properly controlled DC link can enhance the transient stability characteristics of the AC system in which it is embedded, as an inherent feature. This is due to the change in the transmitted power, within it's rating, with a fast response in a way to balance the difference between generation and load requirements, thus minimizing the torques on the rotors [9].

This thesis deals with the enhancement of AC transient stability through the control of the multiterminal HVDC system using optimization techniques. In the

next section, a literature survey was conducted to investigate and summarize the work done to study this important feature multiterminal direct current systems (MTDC).

1.2 Literature Survey

Throughout the literature survey, the following were found to be the main areas related to AC-MTDC systems.

1. AC-MTDC simulation methods
2. AC-MTDC control schemes
3. Applied Optimization Techniques in AC- MTDC systems for different purposes.

1.2.1 Functional Model for Steady-State and Transient Stability Analysis of Two- Terminal Systems

Several models have been proposed for the simulation of AC/DC systems in transient stability studies. Among these is the IEEE report[10]. IEEE committee documented two- terminal HVDC system model structures for power system steady-state and transient state stability. The modularity of the control systems was claimed to make the extension to multiterminal systems relatively easy. The model consists of three major modules, which are the AC/DC network interface,

the DC controller and the AC controller. The aim of the AC controller is to utilize the AC conditions as inputs (small or large signals) and provide control information to the DC controller. The purpose of the DC controller is to schedule the current, power, voltage order of the terminals. The AC/DC network interface is intended to reconcile the AC conditions and the DC conditions by means of visualizing the mode of operation. The input signals used are currents, voltages, real power of both AC and DC quantities. Generally speaking, the control signals that have been used as inputs are: speed deviation from synchronous speed, tie line power change, inverter AC busbar angle change and a combination of these signals[7].

In the Southwest U. S. MTDC line, connecting Phoenix, Mead and Los Angelos networks[11], two types of modulation were used to enhance the stability. They are the gamma and the large power modulations. The former was found to be suitable when the system is marginally stable. The latter was found suitable when the system is transiently unstable.

1.2.2 Applying Optimization Techniques in AC-MTDC for Different Purposes

Optimization techniques have been applied in AC-MTDC systems for few purposes. For example, reference[12] proposed an interesting systematic method based on the linear programming formulation is used to find the DC network solution of a general multiterminal HVDC system and it's mode of operation. The main idea is based on the fact that at an operating point, the sum of the cosine function of the control angles of both rectifiers and inverters is minimum, subject to the control and network constraints. The problem formulation is as follows:

a) Objective function

$$f = \text{Min} \sum_{i=1}^{m} g_i \qquad (1.1)$$

Where, $g_i = 1 + \cos \theta_i$, the angle θ_i represents the ignition and extingintion angles.

b) Constraints:

1. Network voltage equations
2. Network current equation
3. Limit of operating control angles
4. Limit of current orders

The solution that will be given by the LP model is feasible.

Another area where optimization techniques were successfully applied is correcting the voltages in AC-MTDC systems [3]. The problem was formulated in a linear programming model. The objective function is to minimize the absolute values of the corrections to be made. The constraints are the system voltage and current equations, the loading buses voltage changes, reactive and active power changes for generator buses, thermal (current) rating for transmission lines, and voltage limits for the MTDC buses to prevent the voltage controlling terminal.

Hamzei and Ong [14] have proposed an interesting optimization model for coordination the injections of a multiterminal DC system to *dynamically* control the power flows in certain lines of an integrated AC/DC system. The objective function was to minimize the active power changes.

1.2.3 AC-MTDC Simulation Methods

Two main algorithms have been used for the simulation of AC-DC systems, namely digital transient models and the Electro-Magnetic Transient Program (EMTP)[15].

Digital models are usually customized to suit specific problem. Based on Uhlmann's work [16]to relate AC/DC system quantities, Breuer, Luini, and Young developed a model for the presentation of 2-terminal DC systems in transient stability program [17]. Relationships between direct voltages and currents are represented in terms of differential equations. A group of researchers[18] computed AC-DC system disturbances to study the coordination of generator and converter transient models. A set of differential equations that vary with the converter's topology, using time variant Thevenin equivalents, was solved immediately.

As a logical extension of the methods used for 2-terminal DC systems, a group work [19] formed a digital simulation for AC-MTDC systems. Structurally, the program was divided into three sections, namely, AC system, whose differential equations are solved implicitly using trapezoidal rule, and DC network,

whose transmission line's capacitances were neglected to facilitate computations. The DC terminal control that uses known MTDC control methods.

Introducing the microprocessor - to model the Quebec-New England MTDC control system made modeling a real challenge since it was used along with a modified Electro-Magnetic Transient Program (EMTP) version [20].

EMTP approach, has been developed for transient simulation of power systems that included controlled semi-conductor devices. This approach is effective for large scale systems in the case of slow transient studies.

1.3 Thesis Research

From the literature review it is clear that the idea of using optimization techniques to MTDC systems to enhance the transient stability of AC systems through MTDC systems has not been thoroughly investigated. Moreover, only few optimization models have been proposed to solve the different aspects of AC- MTDC systems, but none of them is built to optimize the whole system performance during sudden changes such as faults. It is not, also, clearly defined what type of controllers and input signals, or combination of signals will be suitable to enhance the AC system. Therefore, there is a need for a thorough study of the application of MTDC systems to enhance the transient stability limit and rotor oscillations of the AC system.

This thesis is directed towards the achievement of the following objectives:

1. To building a model of MTDC in the steady state.
2. To building a model of the AC-MTDC in the transient state.
3. To model and integration of external controllers to the simulated AC-MTDC systems.
4. To build an optimization model for the MTDC system to optimally stabilize AC machine rotors.
5. To investigate various controls and their effectiveness.
6. To conduct a comparative study of the used enhancing methods.

1.4 THESIS DESCRIPTION

This thesis is divided into six chapters. Chapter 1 gives an introduction and thorough literature survey about AC-MTDC systems. It, also, describes the motivation and objective of this thesis. Chapter 2 will present a general background about the principles of MTDC. Chapter 3 presents models for MTDC components and the applied external controllers along with the application of trapezoidal rule to the solution of the various differential equations. Chapter 4 deals with the formulation of an optimization model of linear nature for the AC-MTDC transient stability problem. Chapter 5 presents the results of power system responses under transient conditions to the different applied controlling methods. Chapter 6 presents general conclusions and proposes future extensions to the thesis work.

CHAPTER 2

GENERAL BACKGROUND

2.1 Introduction

This chapter will be devoted to explain the different aspects of MTDC systems and their role in power systems.

2.2 Principles of MTDC

A multiterminal DC system has more than two converter stations, some of them operating as rectifiers and others as inverters. Some major differences between 2-terminal and MTDC systems are [21]:

a) Whereas in two terminal systems, both the rectifier and the inverter have in common the same current, in MTDC systems, each terminal has the potential to operate at a different current and power. This requires each terminal, except one, to control its own current with the remaining terminal, setting the voltage at a current imposed by the other terminals. Any incompatible set of current orders or limits can take the system out of services. This is why the current settings are coordinated via some form of system current balances.

b) Transient disturbances at one terminal affect the power distributions at the other terminals.

c) Any future multiterminal expansions should consider the rating of the different sections of the existing MTDC systems.

d) System protections should discriminate between line sections.

e) The need for control system strategies and power scheduling is very important issue.

MTDC systems can be installed either in series or parallel configuration. Choosing between parallel and series MTDC systems shall take into consideration the following points [22]:

1. Reversal of power is possible in series systems without mechanical switching. This is not possible in parallel systems.

2. The parallel connection has the advantage of staged development in converter stations by adding parallel converters.

3. Parallel operations have the advantage of less valves and line losses compared to series systems.

4. Insulation coordination is a problem in series systems as the voltage along the line varies.

5. A permanent fault in a line section leads to total shutdown of series systems.

6. Control and protection of series systems is a natural extension of two terminal systems. However, those of parallel systems are not straightforward and require communication links [9,23]. This means that any failure at any inverter could cause overloading or loss of power in case of rectifier failure.

2.3 Advantages of MTDC Systems

MTDC systems have technical and economical advantages over two terminal systems such as [4]:

1. Providing greater flexibility in dispatching the power between 3 or more AC systems.
2. Offering better control over despatching power as per the instructions of the master control center.
3. Damping quickly frequency oscillations and electromechanical oscillations in interconnected power systems.
4. Increasing the transient stability limits without increase in installed capacity due to the inherent overload capability.

2.4 MTDC Control Schemes

In this section, the main methods to control MTDC systems will be discussed.

2.4.1 Current Margin Method

In this method, one of the stations which is operating at the angle limit (minimum firing angle (α), or minimum extinction angle (γ)) determines the DC voltage (dependent on the AC voltage and the tap ratio). The remaining terminals operate as current controlling terminals[24]. The current through the voltage setting terminal (n for example) is given by:

$$\mathbf{I_n} = - \sum_{j=1}^{n} \mathbf{I_j} \qquad \textbf{(2.1)}$$

Where n is the number of terminals.

In equation (2.1), the inverter currents are treated as negative, while the rectifier currents are treated as positive.

The current reference at the voltage setting terminal is chosen to satisfy the following equation:

$$\sum_{j=1}^{n} I_{jref} = I_{margin} \qquad (2.2)$$

Where I_{margin} is a positive quantity and I_{jref} is the current order limits for each converter station.

Fig. 2.1 shows a possible operation point. The converter with the lowest voltage will act as the voltage control terminal and the rest operate on constant current.

This current margin is necessary for a smooth transition from angle (voltage) control to current control.

The central controller that regulates the current orders at all the converter stations is called Current Reference Balancer (CRB). This CRB is shown on fig. 2.2.

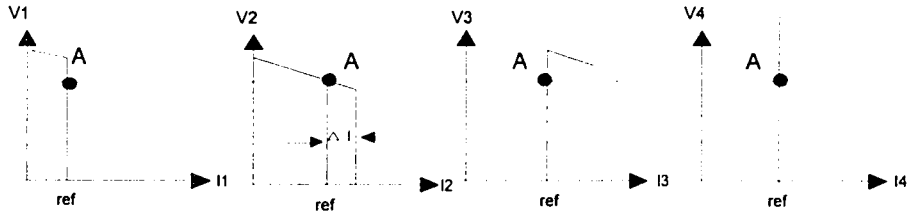

Fig. 2.1: Contrl Diagram of 4 MTDC System

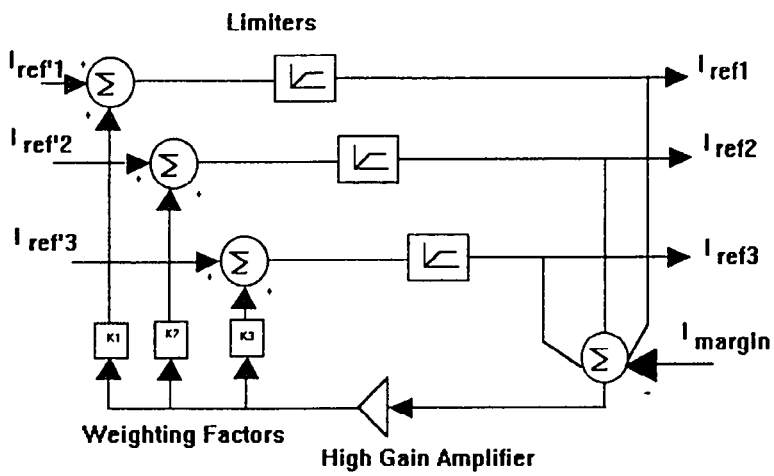

Fig. 2.2 : Current Margin Method

2.4.2 Decentralized Current Reference Balancing (DCRB)

The DCRB method is a technique, by which, the current orders in an MTDC system is independent of communication link between the converters. This is primarily used in restarting the MTDC system after the occurrence of a fault which necessitates a momentary shut-down of the DC system.

The balancing requirements may be expressed in mathematical terms as minimizing[25]:

$$\varepsilon = \sum_{j=1}^{n} \sigma_j (I_j - I_j^{sch})^2 \qquad (2.3)$$

subject to constraints of

$$\sum_{j=1}^{n} I_j = 0 \qquad (2.4)$$

which is Kirchhoff's Current law, and

$$I_j^{min} \leq I_j \leq I_j^{max} \;, \; j = 1, \ldots, n \qquad (2.5)$$

which is a limitation to the capability and operation of the converters. In the above equations:

n : the number of available converters in the MTDC system,

I_j^{min} (I_j^{max}) : is the minimum (maximum) value of the jth converter operating current, and

$\sigma_{j=1,.....,n}$: pre-selected weighting factors for balancing

I_j^{sch} : scheduled current

The above model is a quadratic programming problem which can be solved by either analog or digital means. The converter operating currents can be measured, locally, and are used for local determination of the respective converter current orders as

$$I_j^{ord} = I_j + \delta_j \; I_m \qquad (2.6)$$

Where:

I_j^{ord} is the current order for the jth converter,

I_m is the MTDC system current margin, and

δ_j is a positive pre-selected scalar for jth converter

The individual values of δj's should satisfy the following equation:

$$\sum_{j=1}^{n} \delta_j = 1 \qquad (2.7)$$

CHAPTER 3

MODELLING OF AC-MTDC SYSTEMS AND EXTERNAL CONTROLLERS

3.1 Introduction

This chapter is divided into two main sections. In the first section, the MTDC system is modelled mathematically by a set of equations of non-linear nature. As an example, a five(5) terminal MTDC system will be used. The Newton Raphson algorithm will be used to solve these equations.

In the second section, the MTDC system and the applied controllers are simulated in the transient state. Trapezoidal rule will be used to solve this system.

3.2 Mathematical Formulation of AC-MTDC Equations in the Steady State

The following assumptions have been adopted in the formulation of the AC- MTDC equations:

1) The converters AC busbar voltage is of sinusoidal waveform, i.e., harmonics are filtered.
2) Converter transformers have negligible resistances.

3) The valves of the converters are ideal and have no voltage drop, hence no power loss.

From the converter theory, any simple two-terminal AC-DC Link can have the following equations:

$$I_r = I_i = \frac{\sqrt{6}\, I_d}{\pi} \qquad (3.1)$$

or equivalently,

$$I_r = I_i = K\, I_d \qquad (3.2)$$

Where $K = \frac{\sqrt{6}}{\pi}$

I_r, I_i are the r.m.s fundamental components of the rectifier and inverter currents respectively

I_d is the direct voltage

Also,

$$Vd_r = \frac{3\sqrt{6}}{\pi} V_r \cos(\alpha) - \frac{3X_{cr}}{\pi} I_d \qquad (3.3)$$

Where,

Vd_r : is the rectifier direct voltage

α : is the firing angle

V_r : is the rectifier AC voltage

X_{cr} : is the commutation reactance of the system

Similarly,

$$Vd_i = \frac{3\sqrt{6}}{\pi} V_i \cos(\gamma) - \frac{3x_{cr}}{\pi} I_d \qquad (3.4)$$

Where,

Vd_i : is the inverter direct voltage

γ : is the extinction angle

V_r : is the inverter AC voltage

For the transmission line, applying the ohm's law gives:

$$Vd_r = Vd_i + R_d I_d \qquad (3.5)$$

Where,

R_d : is the transmission line DC resistance

Now, a mathematical model for five (5) converter MTDC system, two (2) rectifiers and three (3) inverters as shown in Fig. 3.1 will be derived. Filters are considered as part of the AC system. The DC links are considered to operate in the usual manner with constant current control at the rectifier and extinction angle

at the inverter sides. The following analysis can be made regarding the associated unknowns.

Fig.3.1 shows the associated unknown variables of the MTDC and these are as follows:

For Rectifier Side

V_{r1}, θ_{r1}, I_{r1}, φ_{r1}, V_{sr1}, ψ_{r1}, V_{dr1}, I_{dr1}, α_{r1}

V_{r2}, θ_{r2}, I_{r2}, φ_{r2}, V_{sr2}, ψ_{r2}, V_{dr2}, I_{dr2}, α_{r2}

For Inverter Side

V_{i1}, θ_{i1}, I_{i1}, φ_{i1}, V_{si1}, ψ_{i1}, V_{di1}, I_{di1}, γ_{i1}

V_{i2}, θ_{i2}, I_{i2}, φ_{i2}, V_{si2}, ψ_{i2}, V_{di2}, I_{di2}, γ_{i2}

V_{i3}, θ_{i3}, I_{i3}, φ_{i3}, V_{si3}, ψ_{i3}, V_{di3}, I_{di3}, γ_{i3}

The transformer turns ratio and the converter AC busbar voltages are considered constant at a particular instant. Hence, the total number of unknowns are 45. In order to reduce the number of unknowns, the following can be done:

(a) The AC primary voltages are assumed to be known (both angles and voltages).

This reduces the number of unknowns into 35.

(b) The primary currents can be calculated in terms of the known secondary currents, using equation 3.1. This further reduces the number of unknowns into 30.

(c) The firing and extinction angles are specified for control purposes. The voltage control angles are left unknown. Thus the final number becomes 26 as follows:

φ_{r1}, V_{sr1}, ψ_{r1}, V_{dr1}, I_{dr1}, α_{r1}
φ_{r2}, V_{sr2}, ψ_{r2}, V_{dr2}, I_{dr2}, α_{r2}
φ_{i1}, V_{si1}, ψ_{i1}, V_{di1}, I_{di1}, γ_{i1}
φ_{i2}, V_{si2}, ψ_{i2}, V_{di2}, I_{di2}, γ_{i2}
φ_{i3}, V_{si3}, ψ_{i3}, V_{di3}, I_{di3}, α_{r1}/ α_{r2}/ γ_{i1}/ γ_{i2}/ γ_{i3}

From Fig. 3.1, the currents at the rectifier sides, and similarly at the inverter sides can be put as:

$$\mathbf{I_{r1}\angle\varphi_{r1} = V_{r1}\angle\theta_{r1} * Y_{r1} - V_{sr1}\angle\psi_{r1} * T_{r1} * Y_{r1}} \qquad \mathbf{(3.6)}$$

$$\mathbf{I_{r2}\angle\varphi_{r2} = V_{r2}\angle\theta_{r2} * Y_{r2} - V_{sr2}\angle\psi_{r2} * T_{r2} * Y_{r2}} \qquad \mathbf{(3.7)}$$

$$\mathbf{I_{i1}\angle\varphi_{i1} = V_{i1}\angle\theta_{i1} * Y_{i1} - V_{si1}\angle\psi_{i1} * T_{i1} * Y_{i1}} \qquad \mathbf{(3.8)}$$

$$\mathbf{I_{i2}\angle\varphi_{i2} = V_{i2}\angle\theta_{i2} * Y_{i2} - V_{si2}\angle\psi_{i2} * T_{i2} * Y_{i2}} \qquad \mathbf{(3.9)}$$

$$\mathbf{I_{i3}\angle\varphi_{i3} = V_{i3}\angle\theta_{i3} * Y_{i3} - V_{si3}\angle\psi_{i3} * T_{i3} * Y_{i3}} \qquad \mathbf{(3.10)}$$

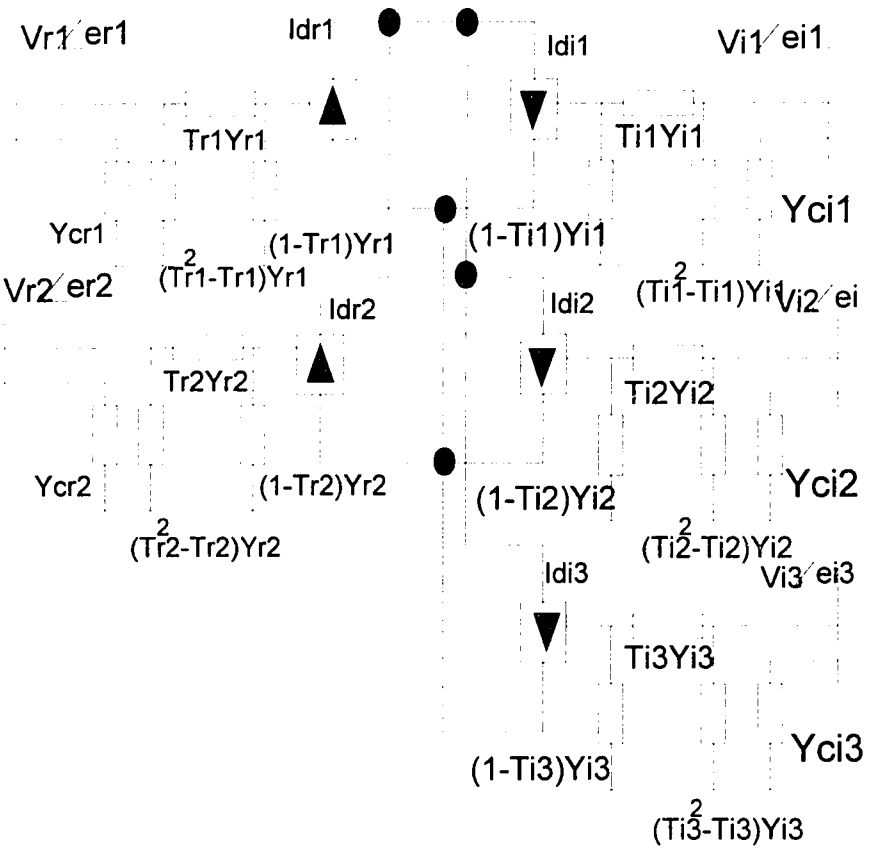

Fig.3.1: Representation of Five(5)MTDC System

Where,

T_r, T_i : are the transformer tap changer positions at rectifier and inverter sides respectively.

Y_r,Y_i : are the transformer admittances at rectifier and inverter sides respectively. By equating the real parts and imaginary parts, ten(10) equations can be obtained:

$$K * I_{dr1} * \cos\varphi_{r1} = B_{r1} * (T_{r1} * V_{sr1} * \sin\psi_{r1} - V_{r1} * \sin\theta_{r1}) \quad (3.11)$$

$$K * I_{dr2} * \cos\varphi_{r2} = B_{r2} * (T_{r2} * V_{sr2} * \sin\psi_{r2} - V_{r2} * \sin\theta_{r2}) \quad (3.12)$$

$$K * I_{di1} * \cos\varphi_{i1} = B_{i1} * (T_{i1} * V_{si1} * \sin\psi_{i1} - V_{i1} * \sin\theta_{i1}) \quad (3.13)$$

$$K * I_{di2} * \cos\varphi_{i2} = B_{i2} * (T_{i2} * V_{si2} * \sin\psi_{i2} - V_{i2} * \sin\theta_{i2}) \quad (3.14)$$

$$K * I_{di3} * \cos\varphi_{i3} = B_{i3} * (T_{i3} * V_{si3} * \sin\psi_{i3} - V_{i3} * \sin\theta_{i3}) \quad (3.15)$$

$$K * I_{dr1} * \sin\varphi_{r1} = B_{r1} * (V_{r1} * \cos\theta_{r1} - T_{r1} * V_{sr1} * \cos\psi_{r1}) \quad (3.16)$$

$$K * I_{dr2} * \sin\varphi_{r2} = B_{r2} * (V_{r2} * \cos\theta_{r2} - T_{r2} * V_{sr2} * \cos\psi_{r2}) \quad (3.17)$$

$$K * I_{di1} * \sin\varphi_{i1} = B_{i1} * (V_{i1} * \cos\theta_{i1} - T_{i1} * V_{si1} * \cos\psi_{i1}) \quad (3.18)$$

$$K * I_{di2} * \sin\varphi_{i2} = B_{i2} * (V_{i2} * \cos\theta_{i2} - T_{i2} * V_{si2} * \cos\psi_{i2}) \quad (3.19)$$

$$K * I_{di3} * \sin\varphi_{i3} = B_{i3} * (V_{i3} * \cos\theta_{i3} - T_{i3} * V_{si3} * \cos\psi_{i3}) \quad (3.20)$$

Where,

B_r, B_i : are the imaginary parts of the transformer admittance.

From equation 3.3, another five (5) equations can be obtained:

$$V_{dr1} = K_{r1} * V_{r1} * \cos\alpha_{r1} - K_1 * X_{cr1} * I_{dr1} \quad (3.21)$$

$$V_{dr2} = K_{r2} * V_{r2} * \cos\alpha_{r2} - K_2 * X_{cr2} * I_{dr2} \quad (3.22)$$

$$V_{di1} = K_{i1} * V_{i1} * \cos\alpha_{i1} - K_3 * X_{ci1} * I_{di1} \quad (3.23)$$

$$V_{di2} = K_{i2} * V_{i2} * \cos\alpha_{i2} - K_4 * X_{ci2} * I_{di2} \quad (3.24)$$

$$V_{di3} = K_{i3} * V_{i3} * \cos\alpha_{i3} - K_5 * X_{ci3} * I_{di3} \quad (3.25)$$

If the real parts at both sides of the converter are equated, then another five (5) equations can be obtained:

$$V_{dr1} = K_{r1} * V_{sr1} * \cos(\psi_{r1} - \varphi_{r1}) \quad (3.26)$$

$$V_{dr2} = K_{r2} * V_{sr2} * \cos(\psi_{r2} - \varphi_{r2}) \quad (3.27)$$

$$V_{di1} = K_{i1} * V_{si1} * \cos(\psi_{i1} - \varphi_{i1}) \quad (3.28)$$

$$V_{di2} = K_{i2} * V_{si2} * \cos(\psi_{i2} - \varphi_{i2}) \quad (3.29)$$

$$V_{di3} = K_{i3} * V_{si3} * \cos(\psi_{i3} - \varphi_{i3}) \quad (3.30)$$

From KCL at point C, we have:

$$I_{dr1} + I_{dr2} + I_{di1} + I_{di2} + I_{di3} = 0 \quad (3.31)$$

And from KVL we have the following equations:

$$K_{r1} * V_{r1} * \cos\alpha_{r1} = -(K_{i1} * V_{i1} * \cos\gamma_{i1} + I_{dr1} * (Rd_{r1} + K_1 X_{cr1}) - I_{di1} * (Rd_{i1} - K_3 * X_{ci1})) \quad (3.32)$$

$$K_{r1} * V_{r1} * \cos\alpha_{r1} = -(K_{i2} * V_{i2} * \cos\gamma_{i1} + I_{dr1} * (Rd_{r1} + K_2 X_{cr1}) - I_{di2} * (Rd_{i2} + K_4 X_{ci2})) \quad (3.33)$$

To solve these 26 equations, the Newton Raphson Algorithm is applied. In this Algorithm the following equation is used:

$$F(X^p) = -J(X^p)\Delta X^{p+1} \quad (3.34)$$

Where, J is the Jacobian matrix, whose elements are partial derivations of the function F (X). The $(i,j)^{th}$ element is given by $\frac{\partial F_i}{\partial X_j}$

ΔX^p is the solution correction vector and can be obtained from:

$$\Delta X^p = -J^{-1}(X^p)F(X^p) \quad (3.35)$$

Where,

i is the number of the equations

j is the order of the unknown variable in respect of which the partial derivatives are taken.

3.3 MTDC Link Transient Representation

In this section, the MTDC transmission lines will be mathematically modeled in differential form in the transient state. The equations will then be solved via the Trapezoidal Rule. Equation (3.5) which represents the relationship between the direct voltages and currents of the transmission lines is not applicable for modeling the transmission lines in the transient state.

The transmission line can be represented by a T- section model, as shown in Fig 3.2, and the following equations describe the model:

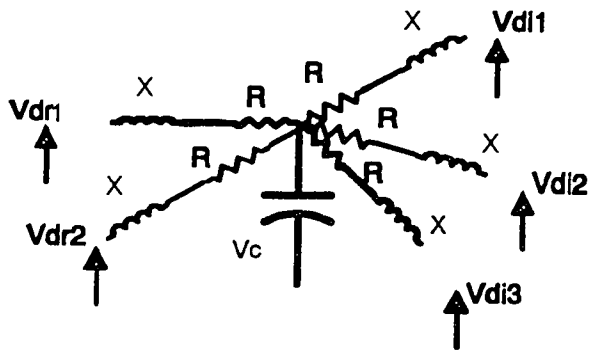

Fig. 3.2 : Presentation of the 5 MTDC Transmission Lines in the Transient State

$$V_{dr1} = R * I_{dr1} + (X/\omega) * PI_{dr1} + V_c \quad (3.36.A)$$

$$V_{dr2} = R * I_{dr2} + (X/\omega) * PI_{dr2} + V_c \quad (3.37.A)$$

$$V_{di1} = - R * I_{di1} - (X/\omega) * PI_{di1} + V_c \quad (3.38.A)$$

$$V_{di2} = - R * I_{di2} - (X/\omega) * PI_{di2} + V_c \quad (3.39.A)$$

$$V_{di3} = - R * I_{di3} - (X/\omega) * PI_{di3} + V_c \quad (3.40.A)$$

$$PV_c = X_c * \omega * (I_{dr1} + I_{dr2} - I_{di1} - I_{di2} - I_{di3}) \quad (3.41)$$

The resistances and inductances of the line sections are assumed to be equal. The capacitances of the different transmission lines are lumped up to one capacitance to facilitate the simulation.

3.4 Applying Trapezoidal Rule

The above differential equations can be described as follows:

$$(X/\omega) * PI_{dr1} = (V_{dr1} - V_c - R * I_{dr1}) \quad (3.36.B)$$

$$(X/\omega) * PI_{dr2} = (V_{dr2} - V_c - R * I_{dr2}) \quad (3.37.B)$$

$$(X/\omega) * PI_{di1} = (V_{di1} - V_c - R * I_{di1}) \quad (3.38.B)$$

$$(X/\omega) * PI_{di2} = (V_{di2} - V_c - R * I_{di2}) \quad (3.39.B)$$

$$(X/\omega) * PI_{di3} = (V_{di3} - V_c - R * I_{di3}) \quad (3.40.B)$$

Or

$$PI_{dr1} = (V_{dr1} - V_c - R * I_{dr1}) * (X/\omega) \quad (3.36.C)$$

$$PI_{dr2} = (V_{dr2} - V_c - R * I_{dr2}) * (X/\omega) \quad (3.37.C)$$

$$PI_{di1} = (V_{di1} - V_c - R * I_{di1}) * (x/\omega) \quad (3.38.C)$$

$$PI_{di2} = (V_{di2} - V_c - R * I_{di2}) * (x/\omega) \quad (3.39.C)$$

$$PI_{di3} = (V_{di3} - V_c - R * I_{di3}) * (x/\omega) \quad (3.40.C)$$

Equations form (3.36.C and 3.37.C) can be transformed into the standard trapezoidal form:

$$y_{n+1} = C_{n+1} + M_{n+1} \bullet X_{n+1} \quad (3.42)$$

Where,

$$C_{n+1} = (1 - 2 \bullet B_{n+1}) \bullet y_n + B_{n+1} \bullet G \bullet X_n$$

$$M_{n+1} = B_{n+1} \bullet G$$

By putting equation 3.36.C can be written as:

$$PId_{r1} = (\frac{Vd_{r1} - V_c}{R} - Idr1) / T \quad (3.43)$$

Where $T = \frac{\omega}{x}$, then

$$y_{n+1} = \frac{h}{2} \bullet (\frac{1}{T}(G \bullet X_{n+1} - y_{n+1}) + \frac{1}{T}(G \bullet X_n - y_n)) + y_n$$

(3.44)

or,

$$I_{dr1} = IDR1 + IDX - (XX_{r1}) \quad (3.45)$$

Where,

$$IDR_1 = (1 - 2 \bullet B_{n+1}) \bullet I_{dro} + B_{n+1} \bullet G \bullet XX_{r1}$$

$$B_{n+1} = \frac{h}{2T + h}$$

$$G = 1$$

$$XX_{r1} = \frac{(V_{dr1} - V_c)}{R}$$

$$IDX = B_{n+1} * G$$

For equations (3.38.C, 3.39.C, 3.40.C) take the same form except XXr1 is equal to:

$$XX_{r1} = \frac{(V_c - V_{dr1})}{R}$$

By applying the same transformation equation (3.41) can be put as :

$$V_c = V_{cc} + V_{cx} *(I_{dr1} + I_{dr2} - I_{di1} - I_{di2} - I_{di3}) \quad (3.46)$$

$$V_{cc} = V_{co} + B_c *(I_{dr1} + I_{dr2} - I_{di1} - I_{di2} - I_{di3}) \quad (3.47)$$

Where,

$$V_{cx} = B_c, \quad B_c = \frac{h}{2T_c}$$

3.5 Modelling of External Controllers

A MTDC link is capable of changing the transmitted power, within its rating, with fast response. This flexibility in control, together with an external controllers, can vary the transmitted power in accordance with the AC system requirements.The power (basically currents signals) can be modulated in response to any of several signals that give indications of the state of the AC systems . These signals could be:

(a) Speed deviation from synchronous speed, $\Delta\omega$.

(b) A tie line power change, ΔP_{tie}.

(c) The inverter AC busbar angle change, $\Delta\theta$.

(d) A combination of the above signals.

The signals are applied through controllers of various transfer functions. Infinite number of transfer functions can be used. However only two transfer functions will be considered in this study. They are shown in Figure 3.3.

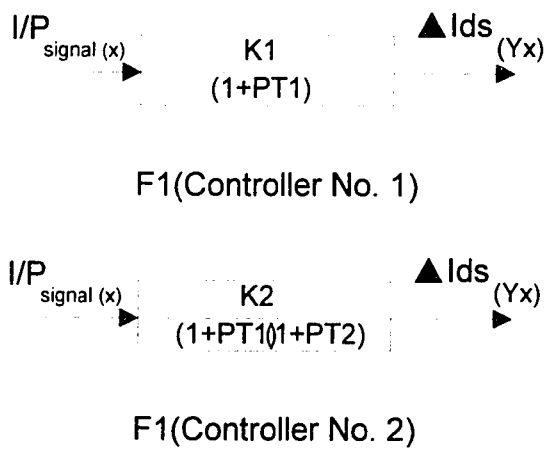

Fig.3.3 : External Controllers Transfer Functions

Controller 1, for example, the Transfer Function can be put as:

$$\frac{X * K_x}{(1 + PT_x)} = \Delta I_{ds} = Y_x \qquad (3.48)$$

Or,

$$\frac{(X * K_x - Y_x)}{T_x} = PY_x \qquad (3.49)$$

Where **X** : is the input signal

Y_X : is the output signal

T_X : is the time constant

This can be also be transformed into the pervious mentioned Trapezoidal form.

A computer program has been developed, which is capable of solving the AC-MTDC system in the transient state . It's flow chart is shown on figure 3.4.

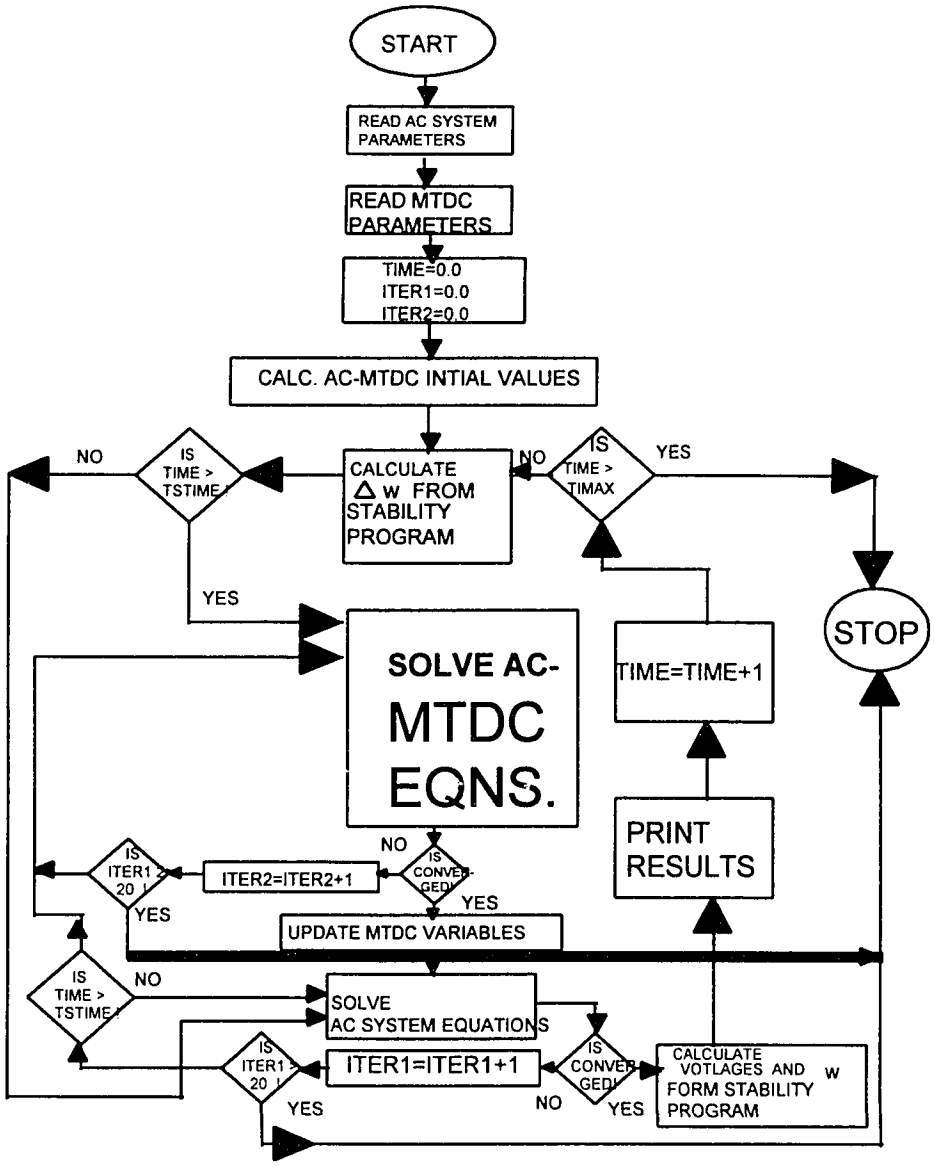

Fig. 3.4 : Flow chart of transient stability program of AC- MTDC systems.

CHAPTER 4

THE OPTIMIZATION MODEL

4.1 introduction

The interest in applying optimization techniques for solving (or optimizing) power systems problems is increasing day by day. The reason for this is that researchers seek to determine the best (optimum) course of action of a decision problem under the restriction of constraints [25]. Any optimization tool (whether linear or non-linear) consists of two (2) main components:

a) An objective function, and
b) System constraints

Before we start to analyze and model the research problem, the following shall be noted:

1. The power system is non-linear by nature.
2. The AC and the MTDC system are solved via Newton Raphson Algorithm which is of linear formation.

In this thesis, the method of feasible direction will be employed to find the best setting of the HVDC side to stabilize the AC system. The method of feasible

direction generates an improving feasible direction and this determines a step size in the direction obtained.

4.2 Feasible Direction Approach

The class of *Feasible Directions Methods* solves a non-linear programming problem by moving from a feasible point to an improved feasible point [26]. That is, given a feasible point X_k, a direction d_k is determined such that for $\lambda > 0$ and sufficiently small, the following two properties are true:

1. $X_k + \lambda^* d_k$ is feasible, and
2. the objective value at $X_k + \lambda^* d_k$ is better than the objective value at X_k.

The method of feasible direction involves two steps. The first step is to generate direction. In the second one, the step size in the generated direction is determined. These two steps will be explained below.

4.2.1 Generating Improving Feasible Directions

Given a feasible point $\mathbf{X_k}$, a nonzero vector $\mathbf{d_k}$ is a feasible improving direction if $\nabla f(\mathbf{x_k})^t\, \mathbf{d_k} < 0$, and $\mathbf{d_k}$ satisfies the set of constants. The feasible set is determined by a set of linear inequalities and equations given as $\mathbf{A_1 d} \leq \mathbf{0}$, and $\mathbf{Ed=0}$. The improving direction is generated by minimizing $\nabla f(\mathbf{x_k})t\, \mathbf{d_k}$ subject to

the constraints $\mathbf{A_1 d_k} \leq \mathbf{0}$ and $\mathbf{E d_k = 0}$. This can be formulated as the following linear program:

$$\text{Minimize} \quad \nabla f(\mathbf{x_k})_t \, \mathbf{d} \tag{4.1}$$

$$\text{subject to} \quad \mathbf{A_1 d_k} \leq \mathbf{0} \tag{4.2}$$

$$\mathbf{E d_k = 0} \tag{4.3}$$

4.2.2 Step Size Generation

Given that direction generated in the previous step, the next step is to determine the step size in the direction $\mathbf{d_k}$. Firstly, the bounding interval for λ is found by using the Interval Bounding Algorithm[27]. Then, Golden Search is employed to find the optimal λ^*_k. This is given below.

Step no. 1: Find the interval [a,b] where λ lies, using Interval Bounding Algorithm.

Step no. 2: Use Golden Search Method to obtain λ^*_k.

Step no. 3: The new solution will be:

$$\mathbf{X_k = X_k + \lambda^*_k \, d_k} \tag{4.4}$$

4.2.3 Stopping Criteria

The feasible direction method is terminated when $\| d_k \| \leq \varepsilon$. The steps of the feasible direction method are given on fig. 4.1.

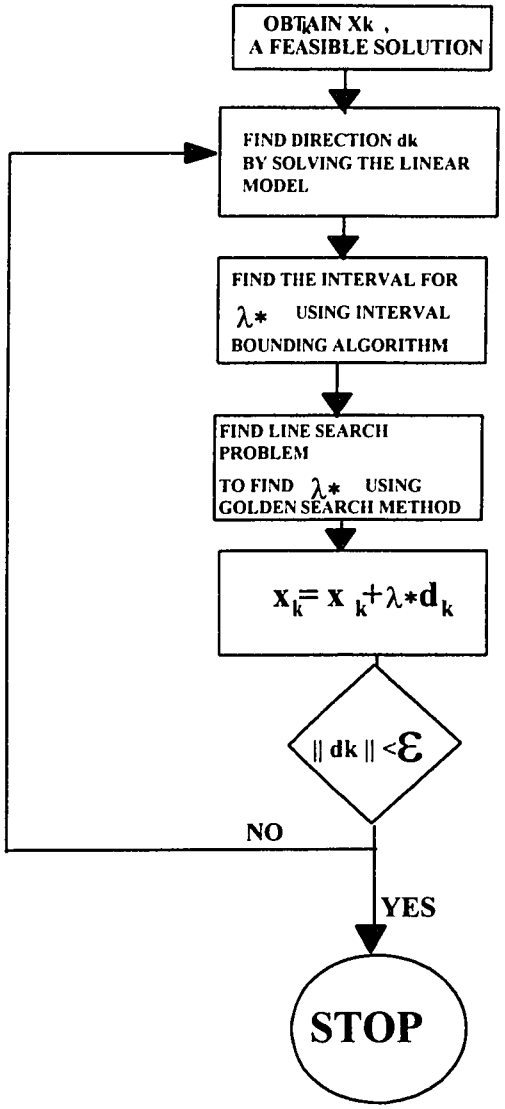

Fig. 4.1 : Flow chart of the feasible direction approach

4.3 Linear Programming Method

Linear Programming (LP) defines a particular class of optimization problems in which the constraints of the system can be expressed as linear equations or inequalities and the objective function is a linear function of the design variables [27].

The standard form of an LP problem with m constraints and n variables can be represented as follows:

$$\textbf{Maximize or Minimize } Z = c_1x_1 + c_2x_2 + \ldots\ldots\ldots\ldots\ldots\ldots + c_nx_n$$

$$\textbf{Subject to} \quad \begin{array}{l} a_{11}x_1 + a_{12}x_2 + \ldots\ldots\ldots\ldots\ldots\ldots + a_{1n}x_n = b_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots\ldots\ldots\ldots\ldots\ldots + a_{2n}x_n = b_2 \\ \cdot \qquad \cdot \qquad \cdot \quad \cdot \\ \cdot \qquad \cdot \qquad \cdot \quad \cdot \\ a_{m1}x_1 + a_{m2}x_2 + \ldots\ldots\ldots\ldots\ldots\ldots + a_{mn}x_n = b_m \end{array}$$

$$x_j \geq 0 \quad j = 1, 2, \ldots\ldots\ldots\ldots n.$$

The Linear Programming form can be solved by Simplex Method.

4.4 Implementation of the Feasible Direction Method

Transient stability studies are aimed at determining if the system will remain in synchronism following major disturbances such as transmission system faults, sudden load changes, loss of generating units, or line switching[28]. If the machines of the system are found to remain in synchronism within the first second, the system if said to be stable[28]. When a fault occurs, each machine will tend to accelerate or decelerate depending on the algebric difference between the electrical power and the mechanical power it sees. This is expressed in the swing equation as shown in equation 4.5. The accelerating power **Pa** accounts for any unbalance between the mechanical power $\mathbf{P_{mi}}$ and the electrical power **Pei**. Reducing the difference between these two quantities will certainly reduce the change for the rotor speeds. The mechanical power can not be changed quickly enough to achieve this purpose. High voltage MTDC systems have been realized to have the ability to quickly change the electrical power through their systems.This inherent feature of MTDC systems will be utilized to support the AC systems during faults by properly relieving the electrical power through them. In order to build up an appropriate optimization model, we should firstly define the AC-MTDC transient system objective function and constraints.

$$\mathbf{Mi}\,\frac{\mathbf{d}}{\mathbf{dt}}\omega\mathbf{i} = \mathbf{Pa} = \mathbf{Pmi}-\mathbf{Pei} \qquad (4.5)$$

$$P_i = P_{mi} - E_i^2 G_{ii} \tag{4.6}$$

M_i : Inertia constant

ω_i : Rotor speed

P_{ei} : Electrical power output

P_{mi} : Mechanical power input

G_{ii} : Conductances

E_i : Terminal voltages

P_a : Accelerating power

The objective function can be formulated as minimizing the sequare of the difference between the electrical power and the mechanical power or, in other words, the net torque.

$$\text{Min } Z = (P_m - P_e)^2 \tag{4.7}$$

Minimizing, of course, shall be done through the MTDC system. So, this equation shall be linked to the MTDC variables.

The model constraints are the AC and MTDC network limits. Since, both are solved through Newton-Raphson Method as shown in equations 3.34 and 3.35, then, the constraints are of linear form and are inherent in equation 4.8. In equation 3.34 $F(X^P)$ is actually the residuals of the AC and DC systems or $R_{ac,dc}$.

$$R_{ac,dc} = - J_{ac,dc} \, \Delta X_{ac,dc} \tag{4.8}$$

Since our objective is to link the DC constraints to the above objective function, equation 4.8 can be written as :

$$R_{dc}' = - J_{dc} \; (\Delta X_{dc} + \Delta X_{aux}) \qquad (4.9)$$

Let ΔX_{aux} be equal to $\lambda \mathbf{d}$ then equation 4.9 becomes:

$$R_{dc}' = - J_{dc} \; (\Delta X_{dc} + \lambda \mathbf{d}) \qquad (4.10)$$

Two important things to be clarified about the residuals:

1. The residuals mentioned in equation 4.8 are different from the ones of equations 4.9 and 4.10, otherwise the introduced $\lambda \mathbf{d}$ will vanish and no values will be obtained for the directions ($\mathbf{d}$).
2. The residuals can not be zeroes otherwise a trivial solution is faced with zero directions. That is why, to get non zero directions, the residuals of equations 4.9 and 4.10 are set to small values but different from those of equation 4.8.

If ΔX_{aux} is considered as the constraints to the objective function, Then the Gradient method can be applied to solve this problem. The model becomes as shown in equation 4.11.

$$\mathbf{Min} \;\; Z = \nabla f (y) \, d \qquad (4.11)$$

Subject to :

$$R_{dc}' = - J_{dc} \; \Delta X_{aux} \tag{4.12}$$

Or

$$R_{dc}' = - J_{dc} \; \lambda d \tag{4.13}$$

Z is the above objective function to be minimized. $\nabla f(y)$ can be numerically calculated , which is $-2(P_m - P_e) * \frac{\partial P_e}{\partial \chi}$. Equations 4.7 and 4.9 are the required optimization model which is of linear form and hence can be solved via Linear Programming Method. The steps of the solution methodology are given on fig. 4.1.

It worth noting that when applying Golden Search Method, the objective function is not a direct function of the DC variables denoted by **X**. It is, however, a function of the AC variables. Therefore, after obtaining X_{k+1} and use this for evaluation of the objective function.

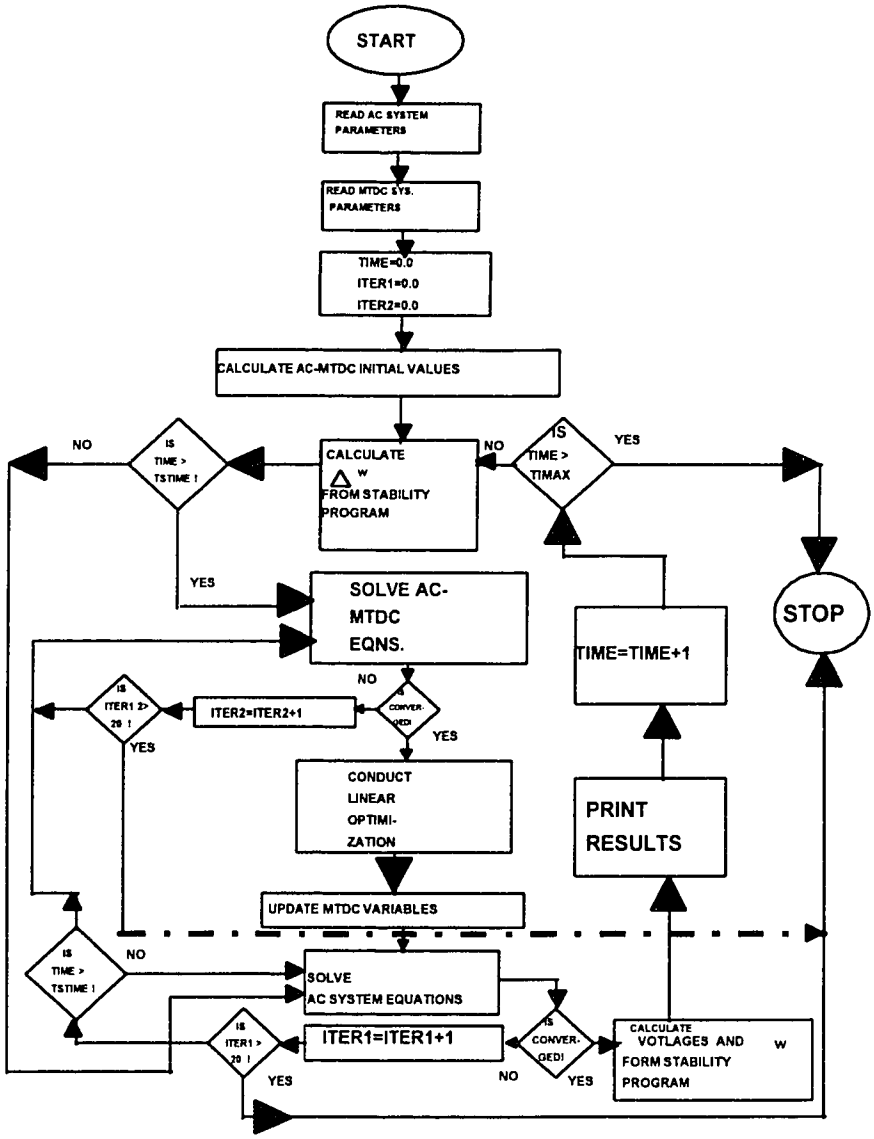

Fig. 4.2 : Flow chart of transient stability program of AC- MTDC systems with applying linear optimization.

CHAPTER 5

STUDY OF TRANSIENT STABILITY ENHANCEMENT BY CONTROLLERS AND LINEAR PROGRAMMING OPTIMIZATION METHOD

5.1 Introduction

In this chapter, the mathematical models that have been developed in chapters 3 and 4 for the components of MT DC system and the optimization method respectively will be simulated on digital computer as shown on figs. 3.4 , 4.1 and 4.2. Two multimachine (20 bus, 6 machines and 24 bus, 5 machines) systems will be investigated without control, with the two previously mentioned controllers of different signals and optimizing the system through Linear Programming Method.

For each system, two (2) selected faults will be conducted, of which the results will be shown. The results consist mainly of the response of the system due to:

A) No control

B) Applying controller 1and 2 schemes.

C) Applying optimization without Golden Search Technique (with the assumption that λ = 1.0.

D) Applying optimization using Golden Search Technique.

The current, rotor angles, and voltage wave forms of the relevant terminals will be presented. In this study the concern is mainly on the transient stability of the AC system during the first second.

5.2. 20 Bus System Study

A 20 bus system, whose single line diagram is shown on fig. 5.1 has been selected for study due to its unacceptable performance for 3- phase faults. The system data is shown in appendix II. Three (3) MT DC system have been proposed as shown on fig.5.1.

5.2.1 Fault No. 1

A three phase fault was applied on bus BURD for 50 ms. The system behavior to fault no.1 is shown on fig. 5.2 without any control. For each of the applied schemes, rectifier current increase and the rotor angles of generators will be presented.

5.2.1.1 Control Scheme -I

The controllers no.1 and 2 as defined in chapter 3 are used to enhance the transient stability. Three signals are applied separately to the controller. These signals are rotor slip, generator power and electric power-mechanical difference signals. The time constant ($\tau 1$) of controller no 1 is fixed at 0.1 and

those two of controller no.2 at 0.001. The relevant gain values (K) are shown on the associated plottings.

5.2.1.2 Control Scheme -II

The Linear Optimization Model derived in Chapter 3 is applied in this scheme. λ is assumed to be equal to unity. This is so done to study the affect of the Direction Matrix obtained from the LP model on the transient stability of the system.

5.2.1.3 Control Scheme -III

Golden Search Method along with scheme II has been applied in this scheme. Golden Search will seek for the optimum λ^*. This, of course, will require freezing the time and iteration to find λ^* as shown on the previous flow chart fiq.no 4.2.

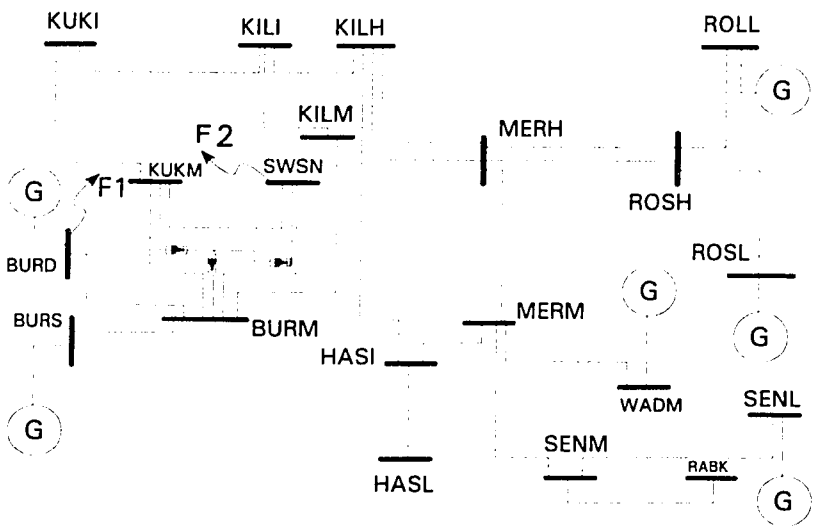

Fig. 5.1 : System #1(20 Bus, 6 machines, 3 MTDC Power System)

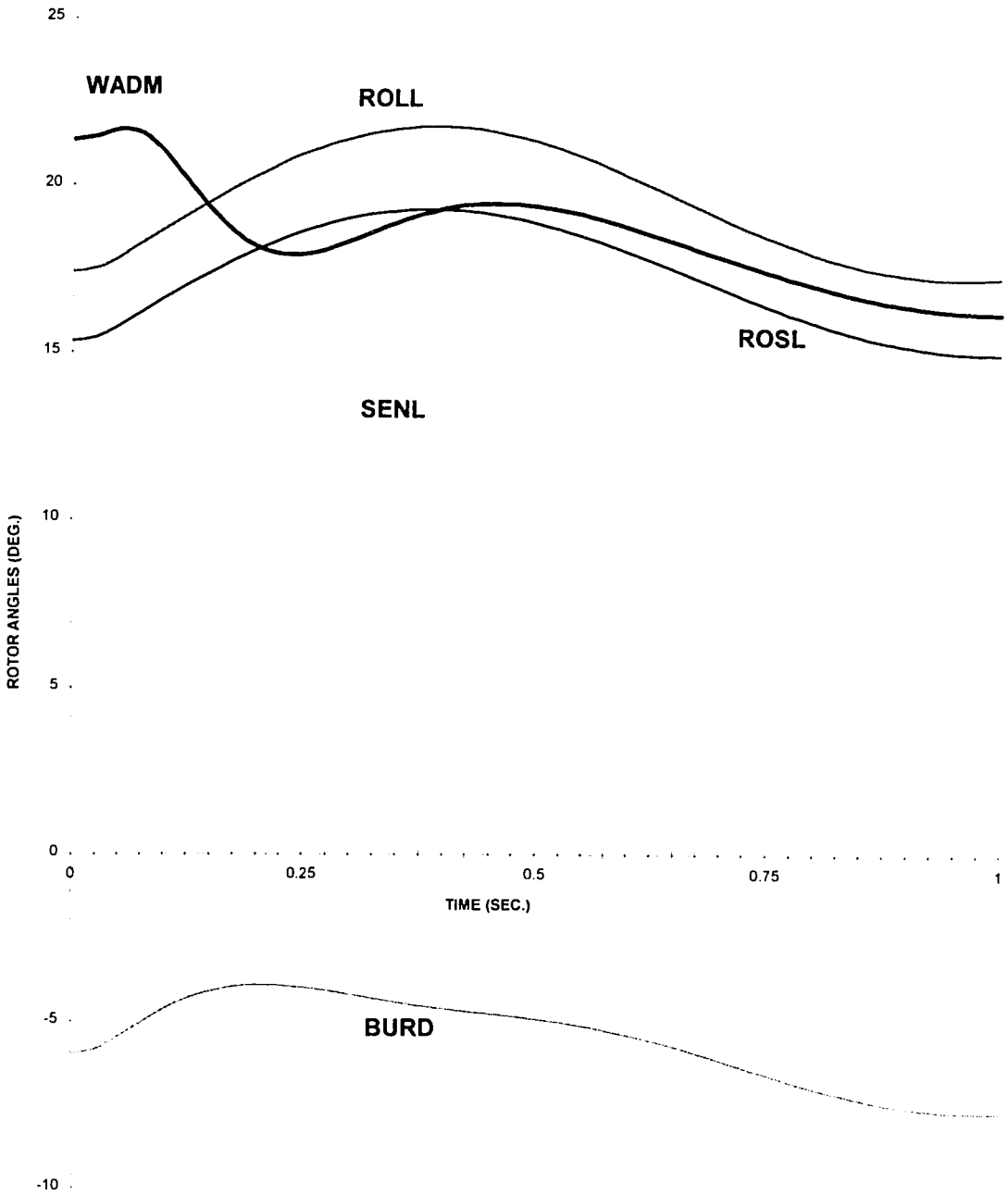

Fig. 5.2 : Rotor angles without any control for system #1 due to fault no.1

5.2.1.4 Results and Discussion

5.2.1.4. A Current Wave forms

Figures 5.3 through 5.9 show the various rectifier current response to the above mentioned control schemes. These figures clearly indicate that the rectifier current increases due to control scheme I & II with different quantities whereas slightly decreases in response to scheme III. The applied gains for control scheme I are the K values.

5.2.1.4.B Rotor angles Wave forms

The rotor angles response of generators SENL and ROLL are shown on Figures 5.10 and 5.11. Control scheme I and II tend to worsen the stability for both generators compared with no control scheme. With respect to controller no1 and 2 of scheme I, the response is almost the same. Scheme III, however, improves the behavior slightly.

5.2.1.4.C Voltage Wave forms

During severe faults, such as the subject fault, the power system is more likely to suffer form undervoltages especially near the faulty sections of the system. Voltage wave forms of generators BURD (faulty BUS) and ROLL are shown on Figures 5.12 and 5.13 respectively. The voltage recovers in exactly the same manner for the different control schemes. For generator BURD being the faulty bus will suffer more severe under voltages.

same manner for the different control schemes. For generator BURD being the faulty bus will suffer more severe under voltages.

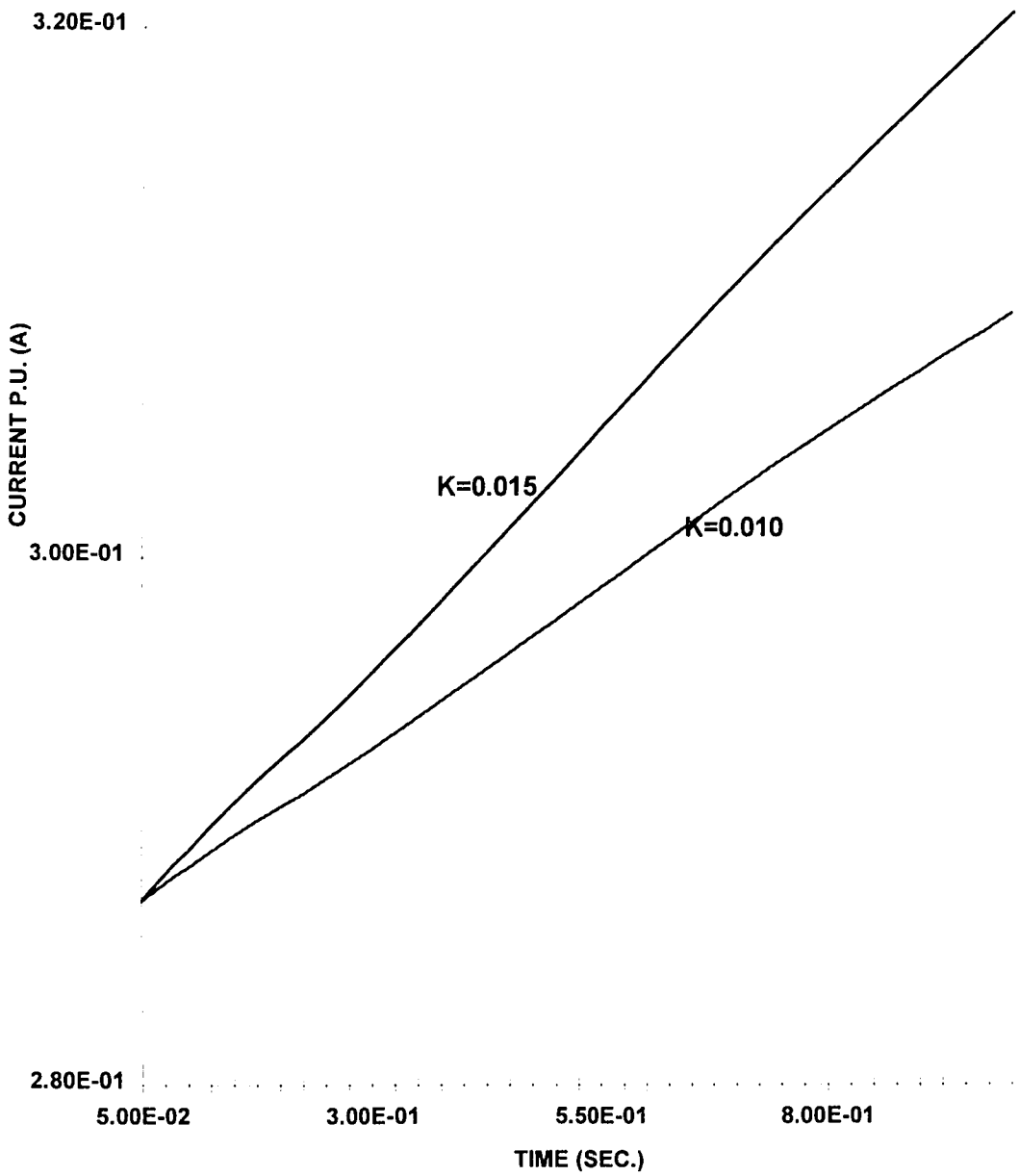

Fig 5.3 : Current increase for rectifier of system #1 due to fault no.1 with slip signal of controller no.1

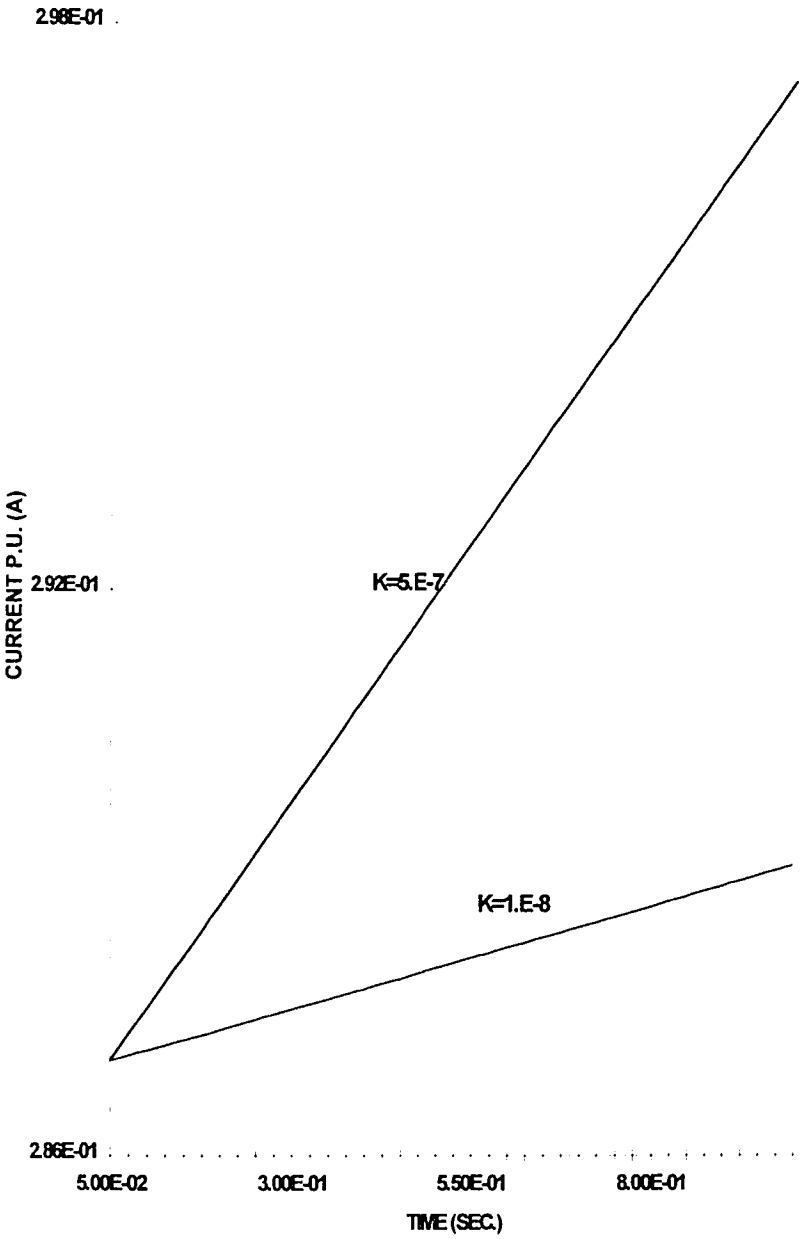

Fig. 5.4 : Current increase for rectifier of system #1
due to fault no.1 with power signal of controller no.1

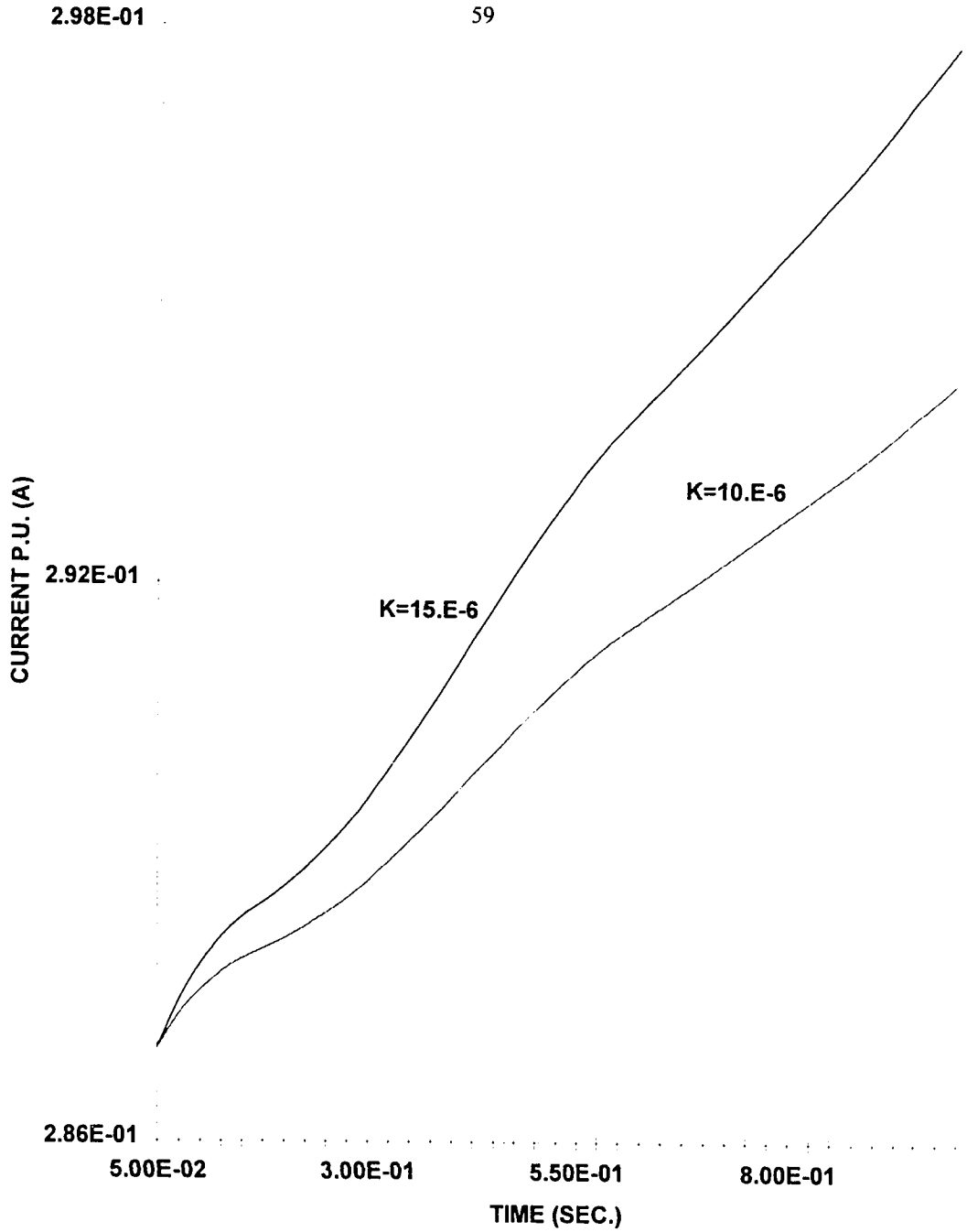

Fig. 5.5 : Current increase for rectifier of system #1 due to fault no.1 with power-mechanical difference signal of controller no.1

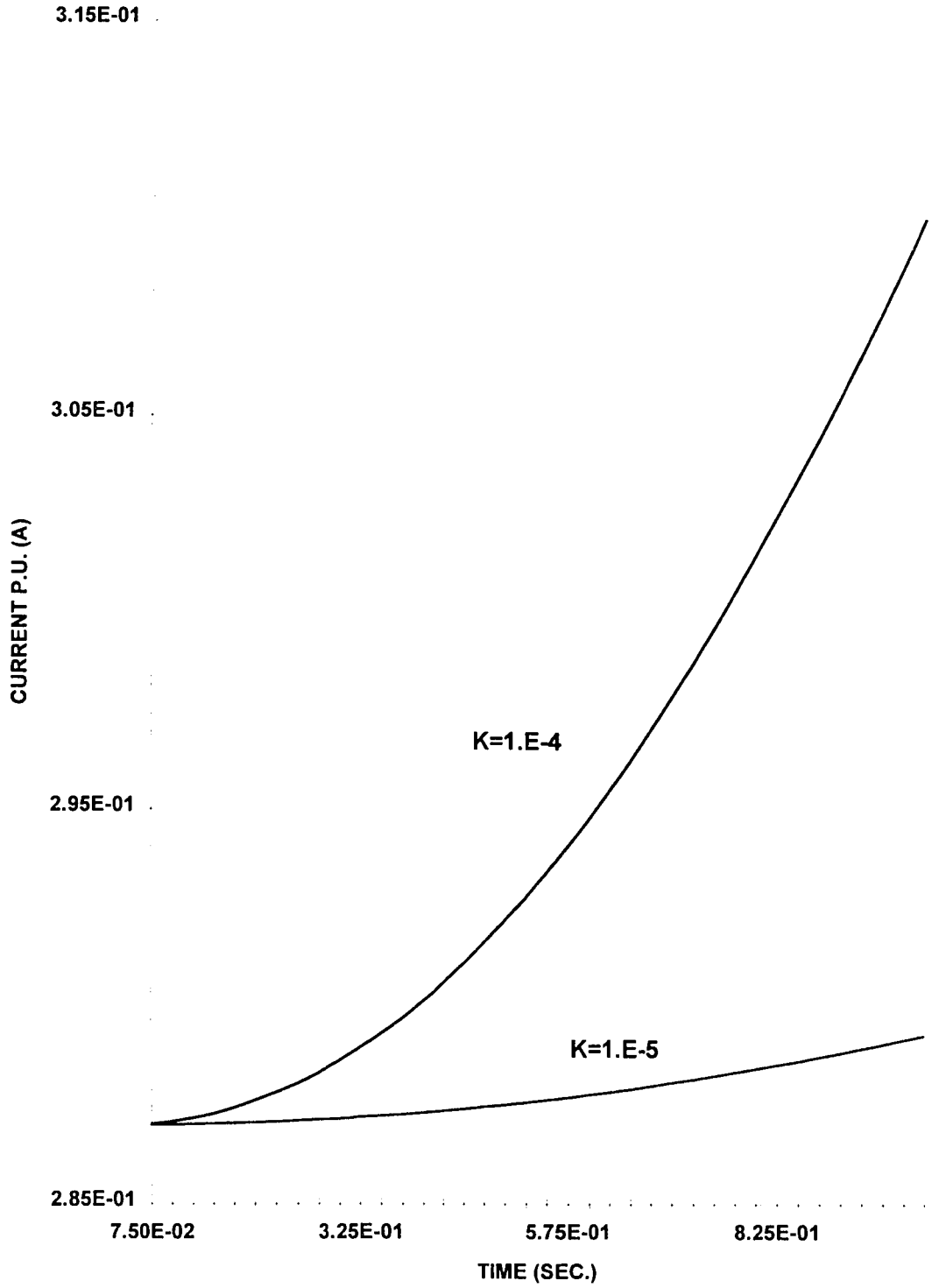

Fig 5.6 : Current increase for rectifier of system #1 due to fault no.1 with slip signal of controller no.2

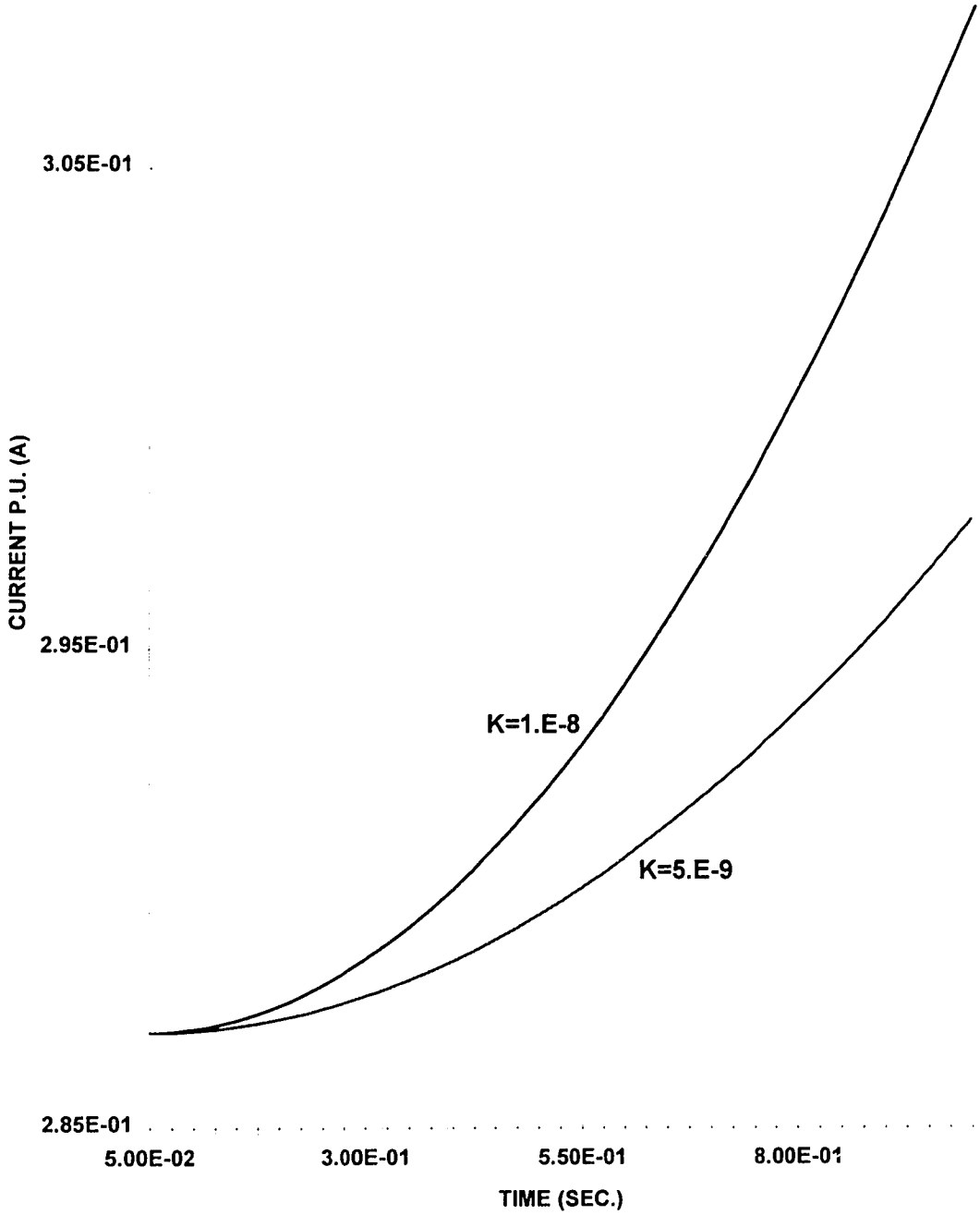

Fig 5.7 : Current increase for rectifier of system #1 due to fault no.1 with power signal of controller no.2

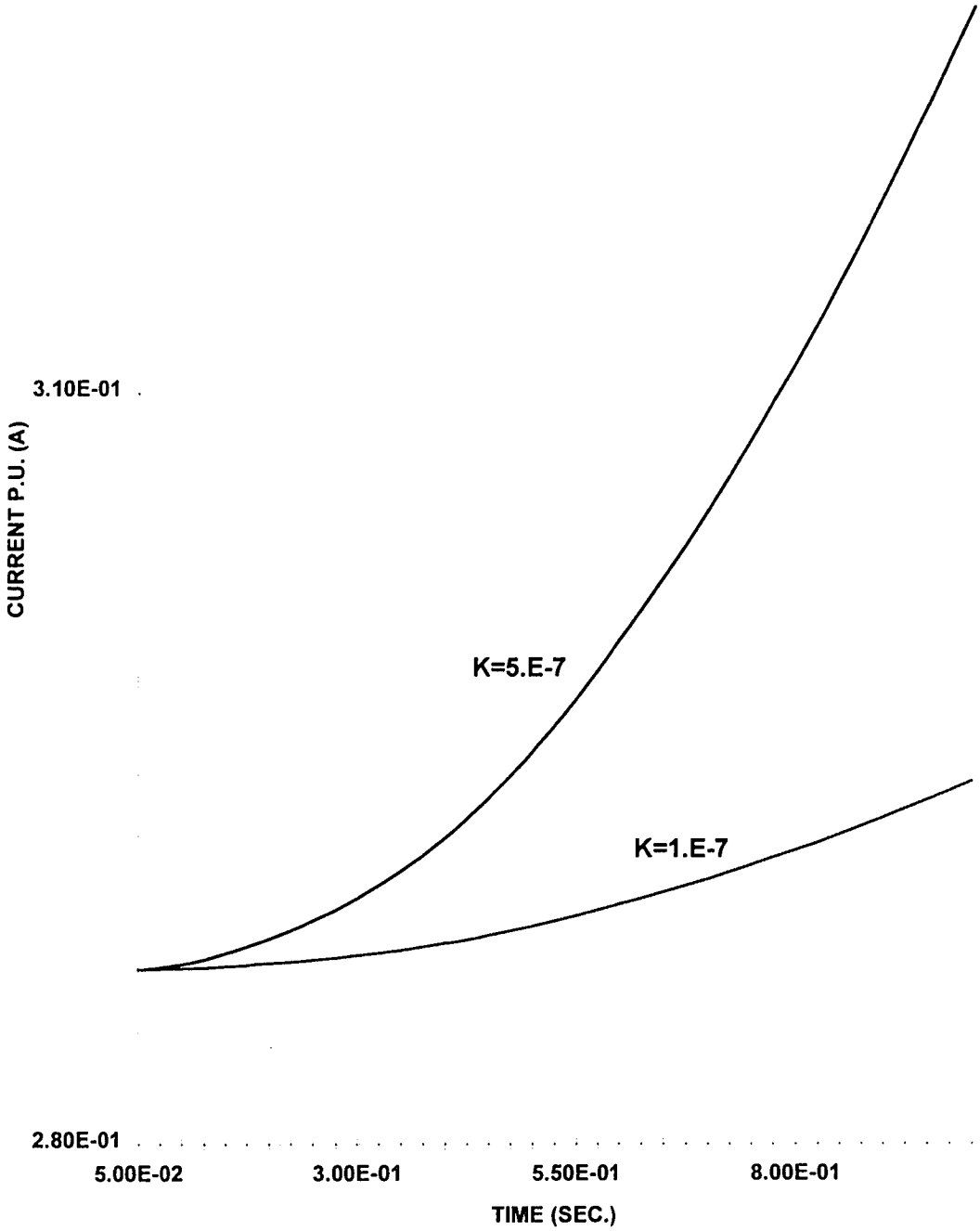

Fig 5.8 : Current increase for rectifier of system #1 due to fault no.1 with power-mechanical signal of controller no.2

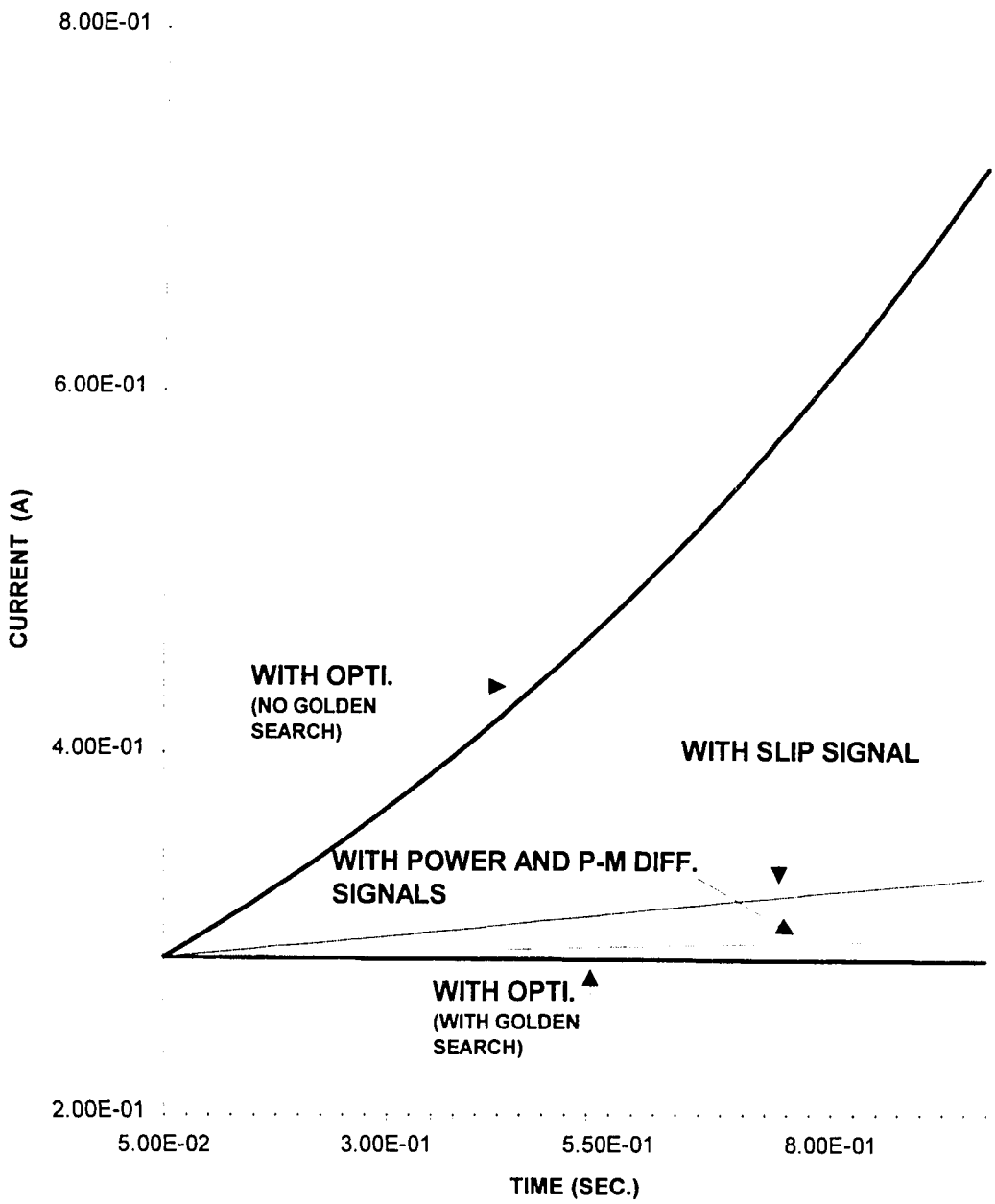

Fig. 5.9 : Current increase of rectifier of system #1 due to fault no.1 with optimization and conroller no.1 signals .

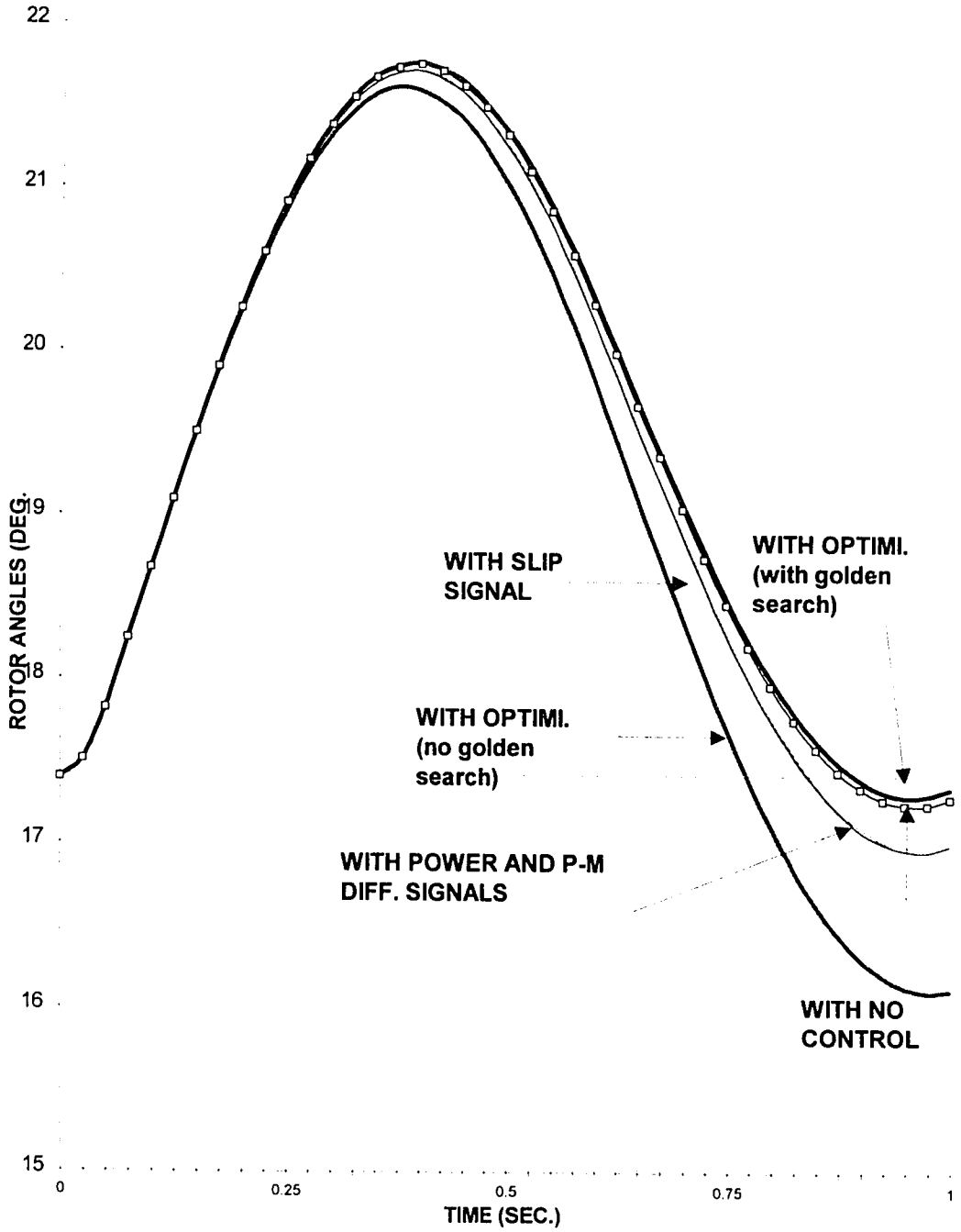

Fig 5.10 : Rotor angles of generator ROLL of system #1 due to fault no.1 with no control, optimization and controller no.1 signals

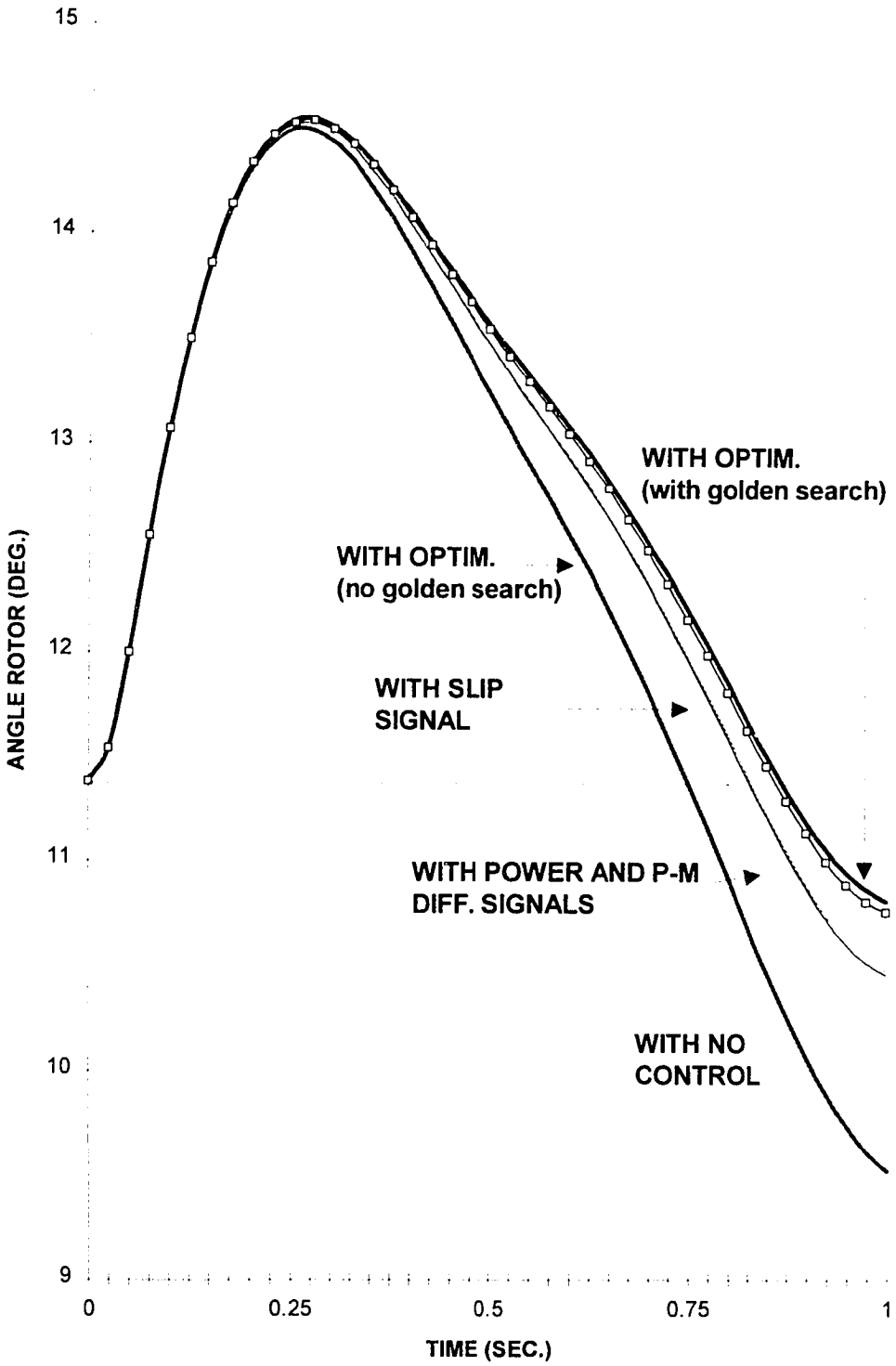

Fig 5.11 : Rotor angles of generator SENL of system #1 due to fault no.1 with no control, optimization and controller no.1 signals.

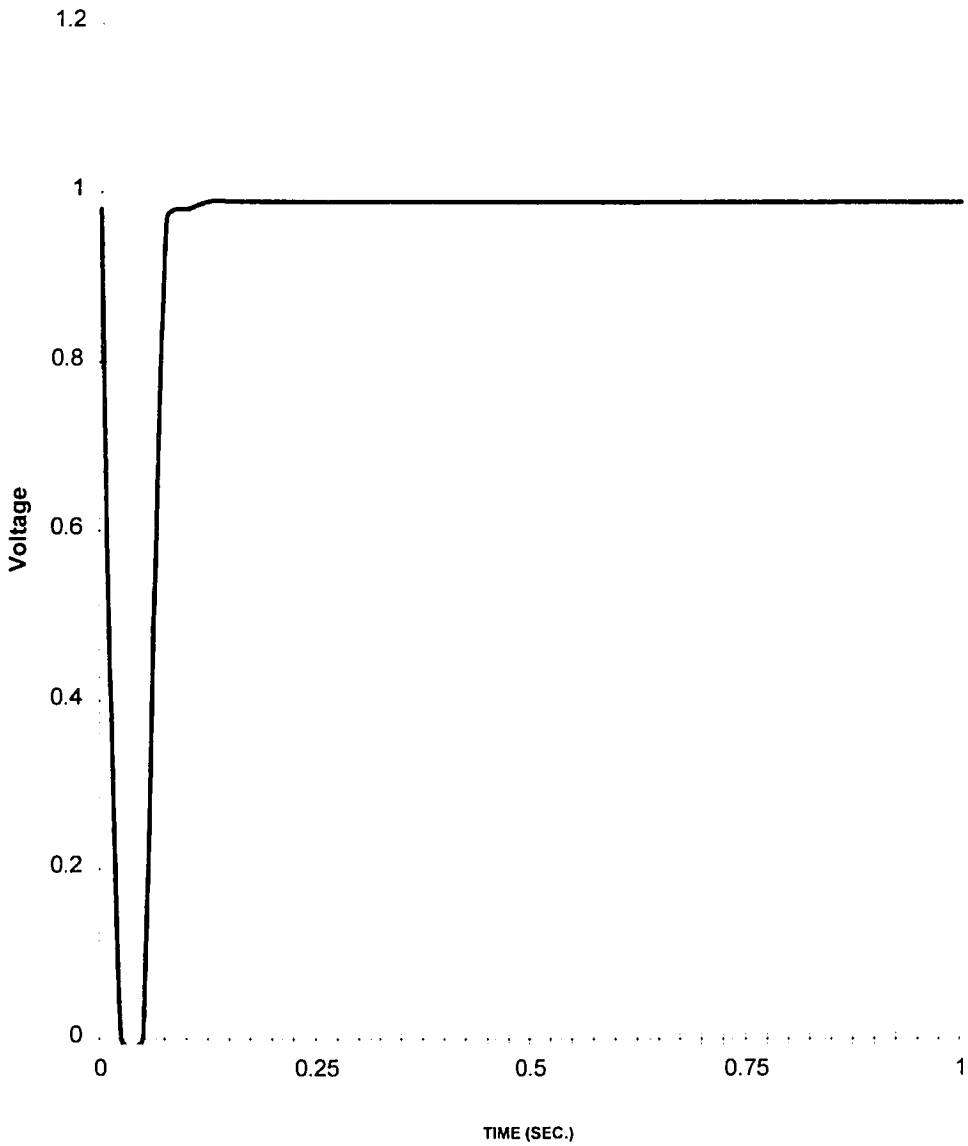

Fig. 5.12 : Voltage provile responce at bus BURD (faulty bus) due to no control and various control methods

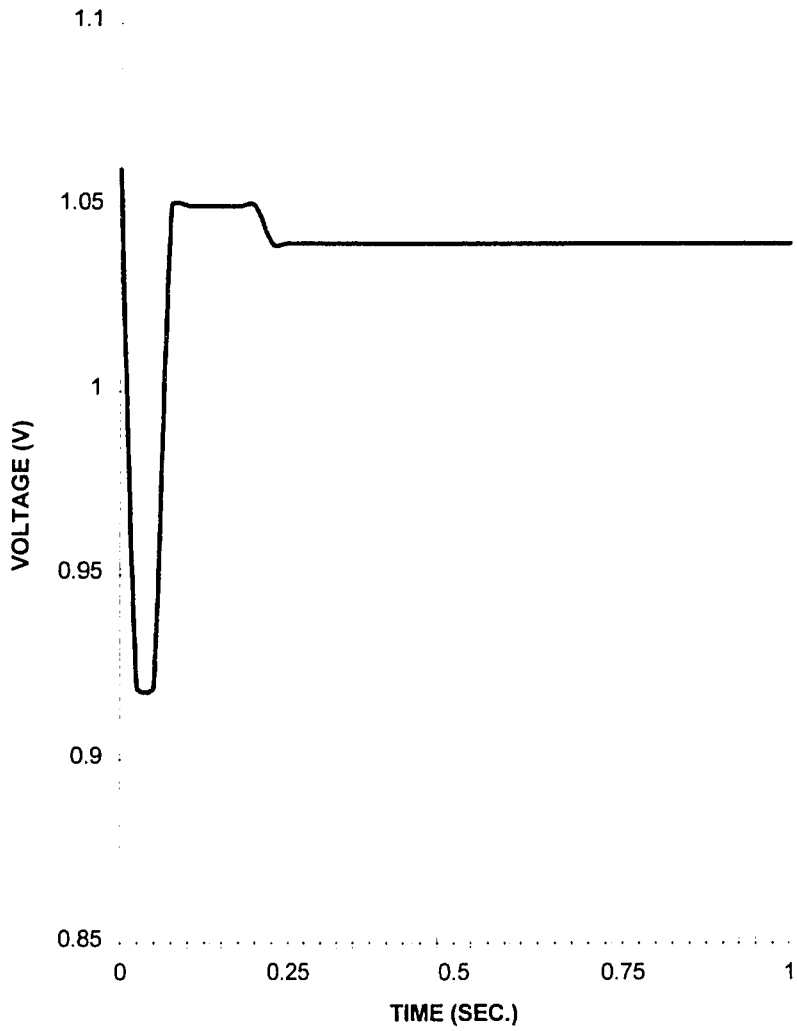

Fig. 5.13 : Voltage profile response at bus ROLL due to no control and various control methods

5.2.2 Fault No. 2

A another three phase fault was applied on bus SWSN for 50 ms. The system behavior is shown on fig. 5.14 without any control. For each of the applied schemes, rectifier current, rotor angles and voltages of generators will be presented . Time constants for controller 1and 2 are the same of fault no.1.

5.2.2.1 Results and Discussion

5.2.2.1. A Current Wave forms

Figure 5.15 shows the various rectifier current response to the control schemes. The rectifier current increases due to control scheme I & II with different quantities whereas slightly decreases in response to scheme III. For this fault, the different current waveforms for control scheme I are of the same trend of those of fault 1. As an example of these is what is shown on figure 5.16.

5.2.2.1.B Rotor angles Wave forms

The rotor angles response of generators BURD and WADM are shown on Figures 5.17 through 5.18 respectively. For generator BURD, the three control schemes improve the performance of the system. Control schemes II and III have the same affect. Control scheme I in general have very small positive affect.

5.2.2.1.C Voltage Wave forms

Voltage wave forms of generators BURD is shown on Figure 5.19 .The voltage recovers very quickly in the same manner for the different control schemes.

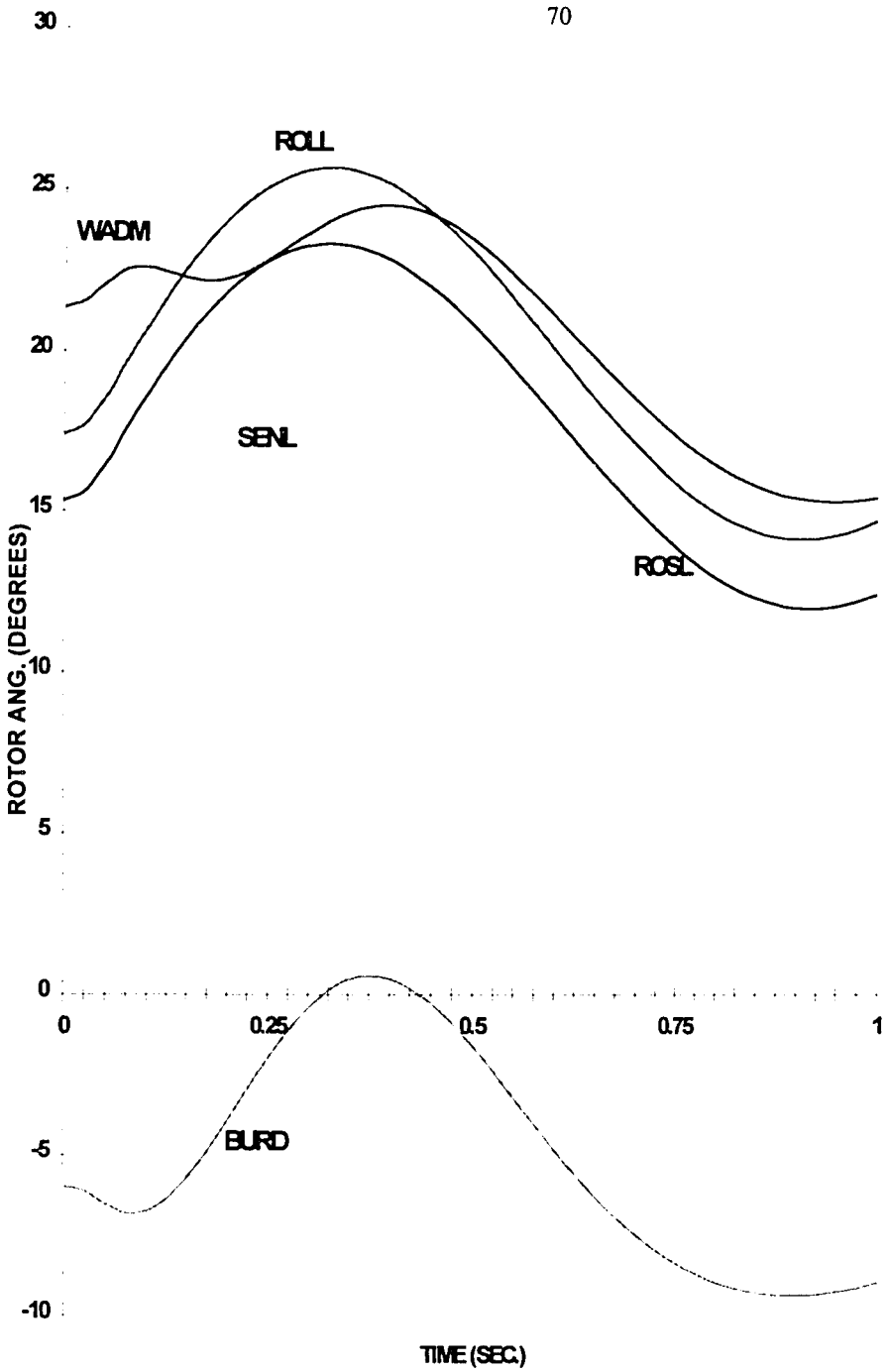

Fig. 5.14 : Rotor angles without any control for system #1 due to fault no.2.

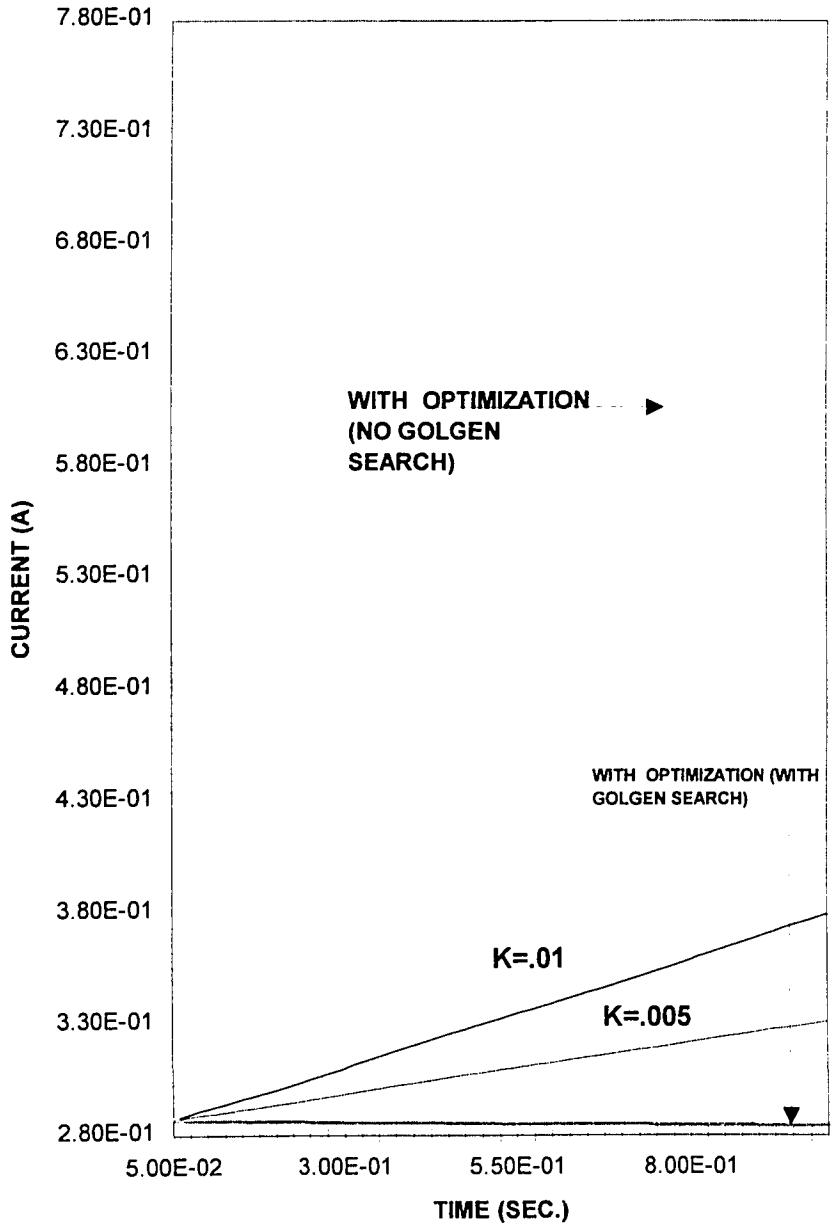

Fig 5.15 : Current increase for rectifier of system #1 due to fault no.2 with slip signal of controller no.1and optimization

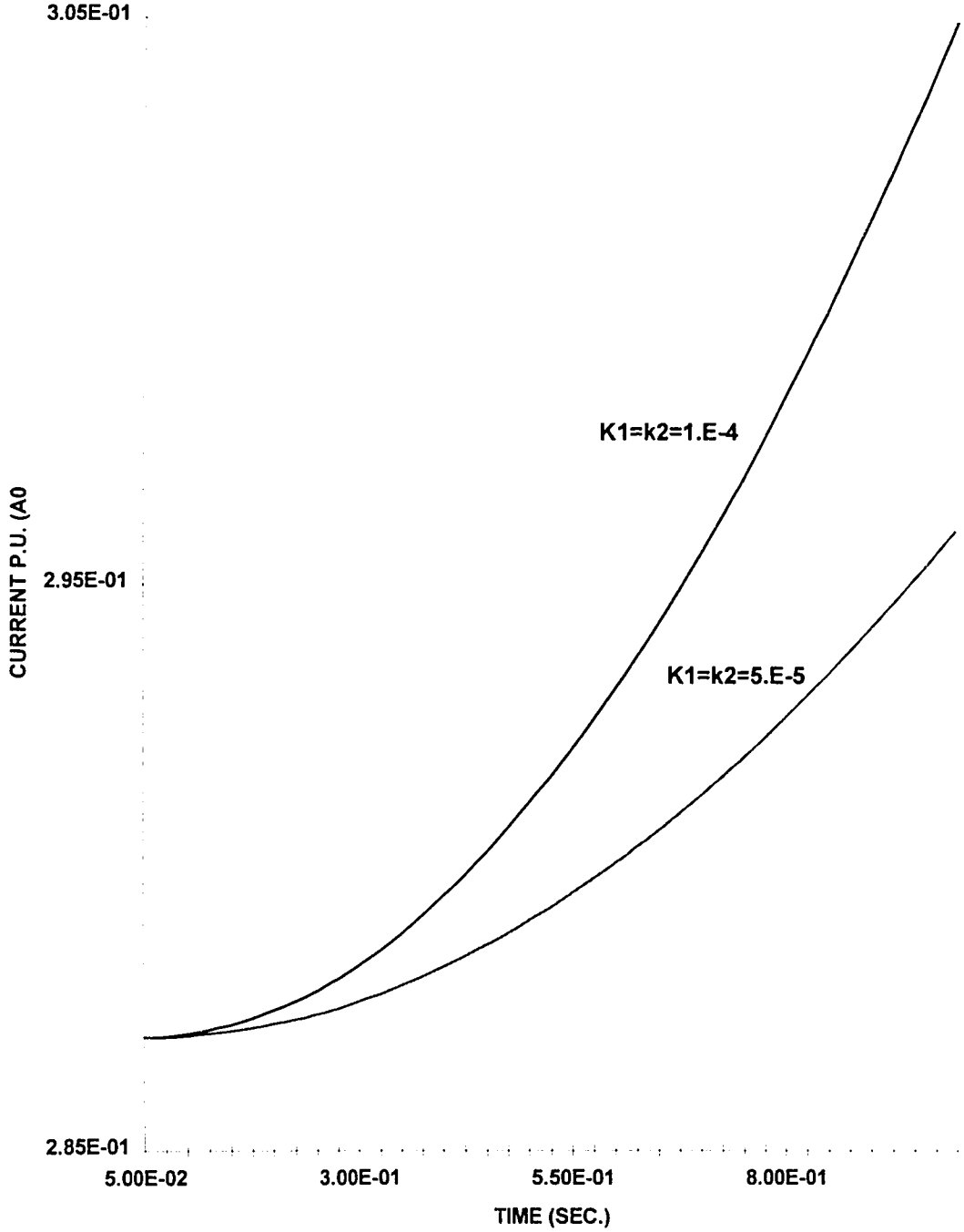

Fig. 5.16 : Current increase for rectifier of system #1 due to fault no.2 with slip signal of controller no.2.

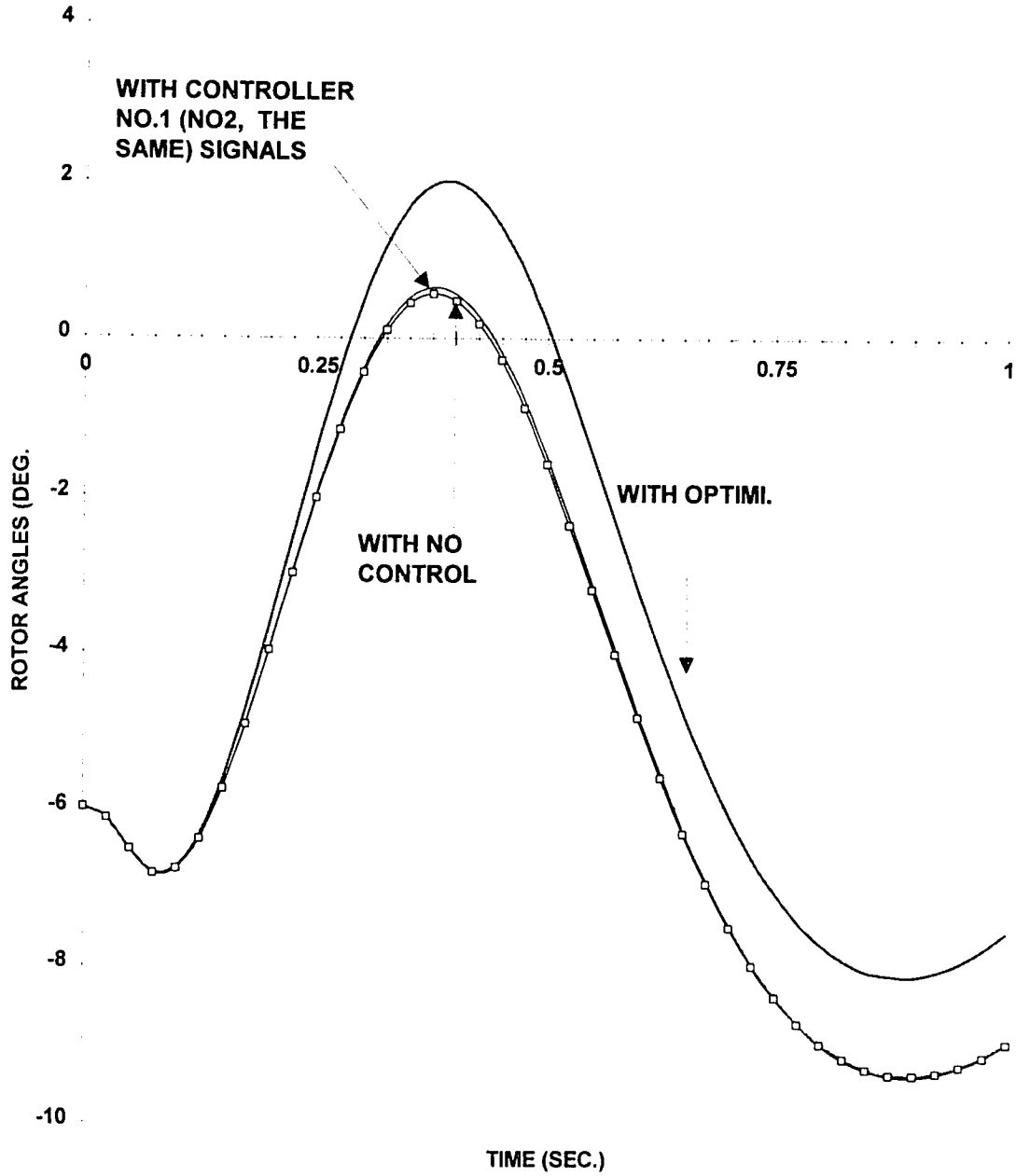

Fig. 5.17 : Rotor angles of generator BURD of system #1 due to fault no.2 with no control, optimization and controller no.2(01) signals.

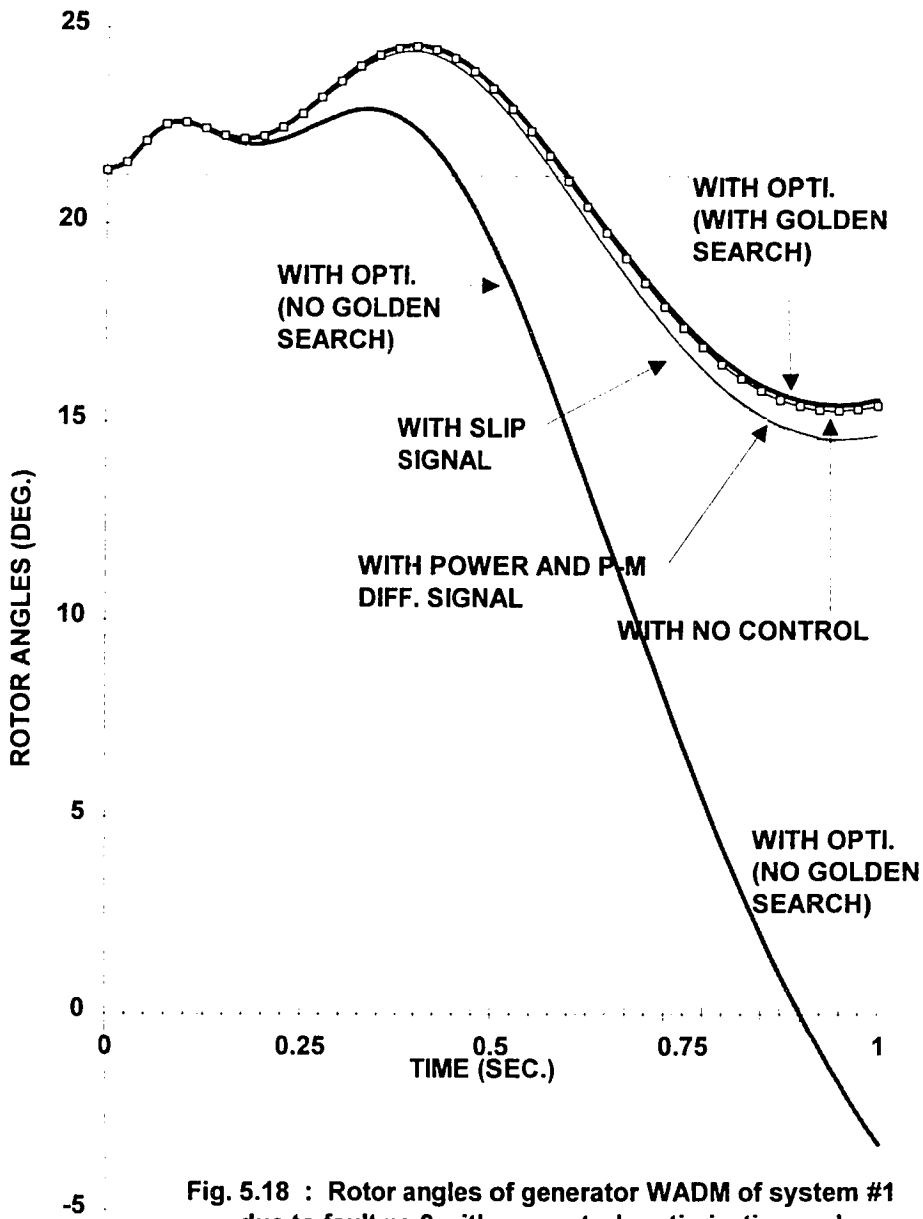

Fig. 5.18 : Rotor angles of generator WADM of system #1 due to fault no.2 with no control, optimization and controller no.2(01) signals.

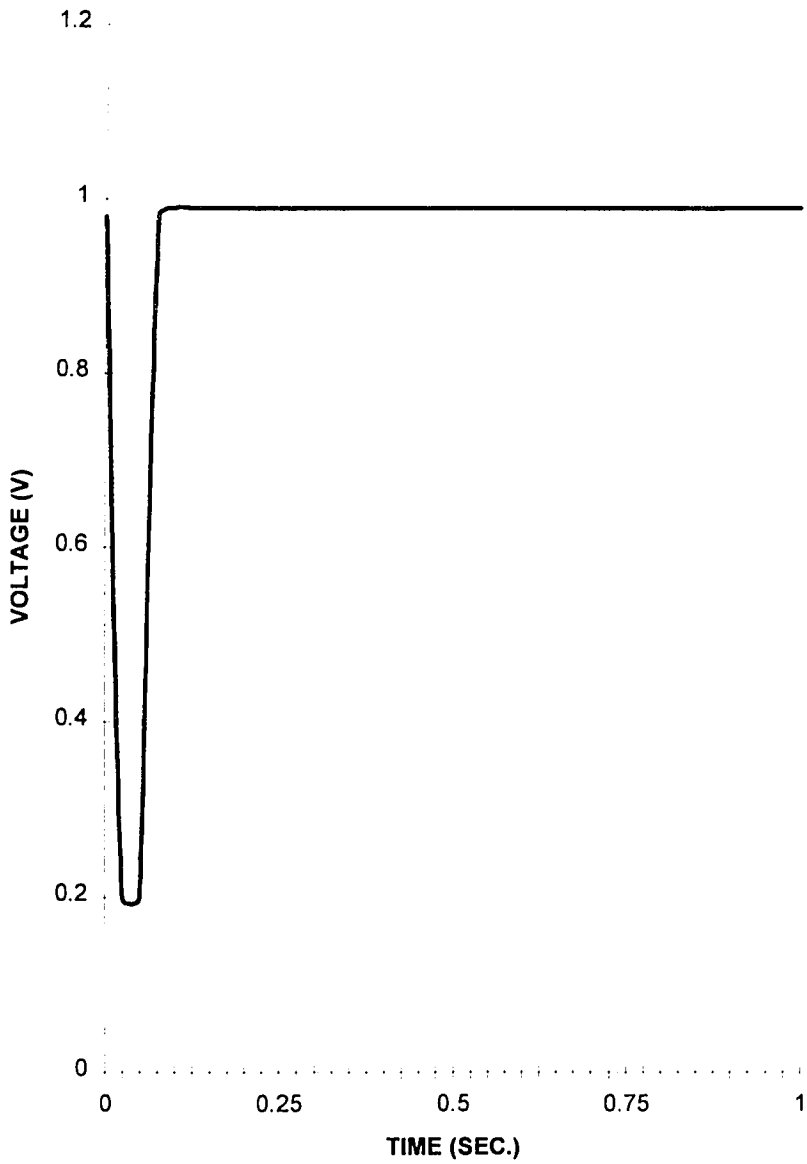

Fig. 5.19 : Voltage profile response at bus BURD due to no control and various control methods

5.3. 24 Bus System Study

The second system under study is a 24 bus and 5 machines system whose single line diagram is shown in fig. 5.20. Three (3) MTDC system have been proposed. The system data is shown in appendix II. Two faults have been selected, F1 close to inverter no.1 and F2 close to inverter no.2. This were chosen on purpose in order to examine the ability of the optimization model of correctly responding to the nearby faults.

5.3.1. Fault No. 1

Another three phase fault was applied on bus GENERATOR 11 for 50 ms. The system behavior is shown on fig. 5.21 without any control. This figure shows that the speed of generator no.04 is far away from those of the rest of the generators. For this reason, the focus will be on this machine.

5.3.1.1 Results and Discussion

5.3.1.1. A Current Wave forms

Figure 5.22 shows the rectifier current response to the three schemes. For the three of them the current increases. Scheme III increases more rapidly ,then scheme II and slowly scheme I increases. With respect to scheme I, the rotor slip signal gave higher increase.

In figure 5.23, the current increase for the optimization model for inverter 1 is smaller than that of inverter 2. This can be justified by the fault being close to it. So, the decrease is logic and acceptable. An attempt was carried out to test the stability of the solution of the system by enforcing high gains for scheme I and by selecting big values for λ. The result is reflected on figure 5.24. With the high gain values for controller 1 and 2, the currents steeply increases causing quick divergence for the system. In the other hand, the current is smoothly increasing in case of optimization and convergence of the solution is still obtainable.

5.3.1.1.B Rotor angles Waveforms

The rotor angles response of generator 04 is shown on Figure 5.25. The generator is driven away from synchronism due to the fault. Although control scheme I and II improve the performance of the system, they unsuccessfully try to stabilize the machine. Scheme II is closer to succeed. With respect to controller no1 and 2 of scheme I, the effect of the slip signal is more than the other signals. Only scheme III manages ot stabilize the machine.

5.3.1.1.C Voltage Waveforms

The occurred fault is close to generator 04. Scheme III suggests as was explained higher increase of current and thus much energy to be relieved more probably from this machine. This is why the machine is temporally exposed to lower undervoltages in case of scheme III compared to other schemes as shown on figure 5.26.

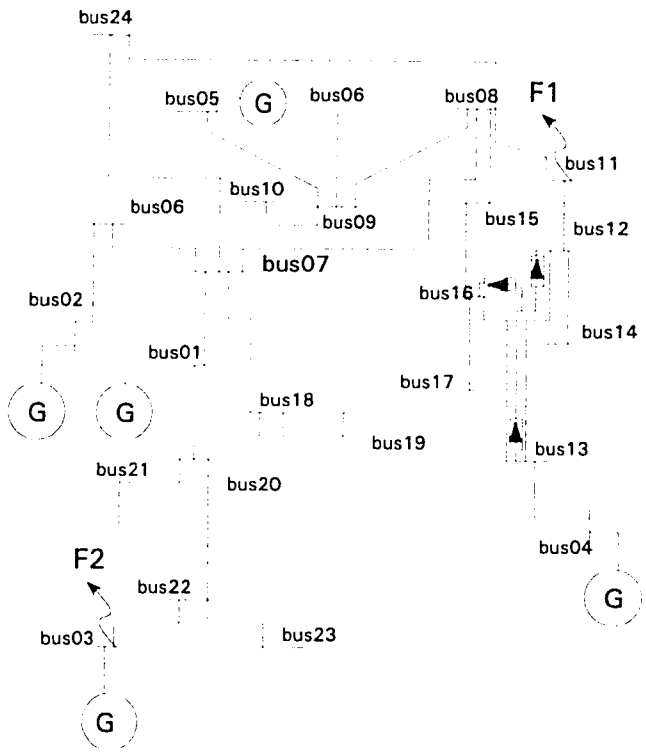

Fig. 5.20 : System no.2 (24 bus , 5 generators)

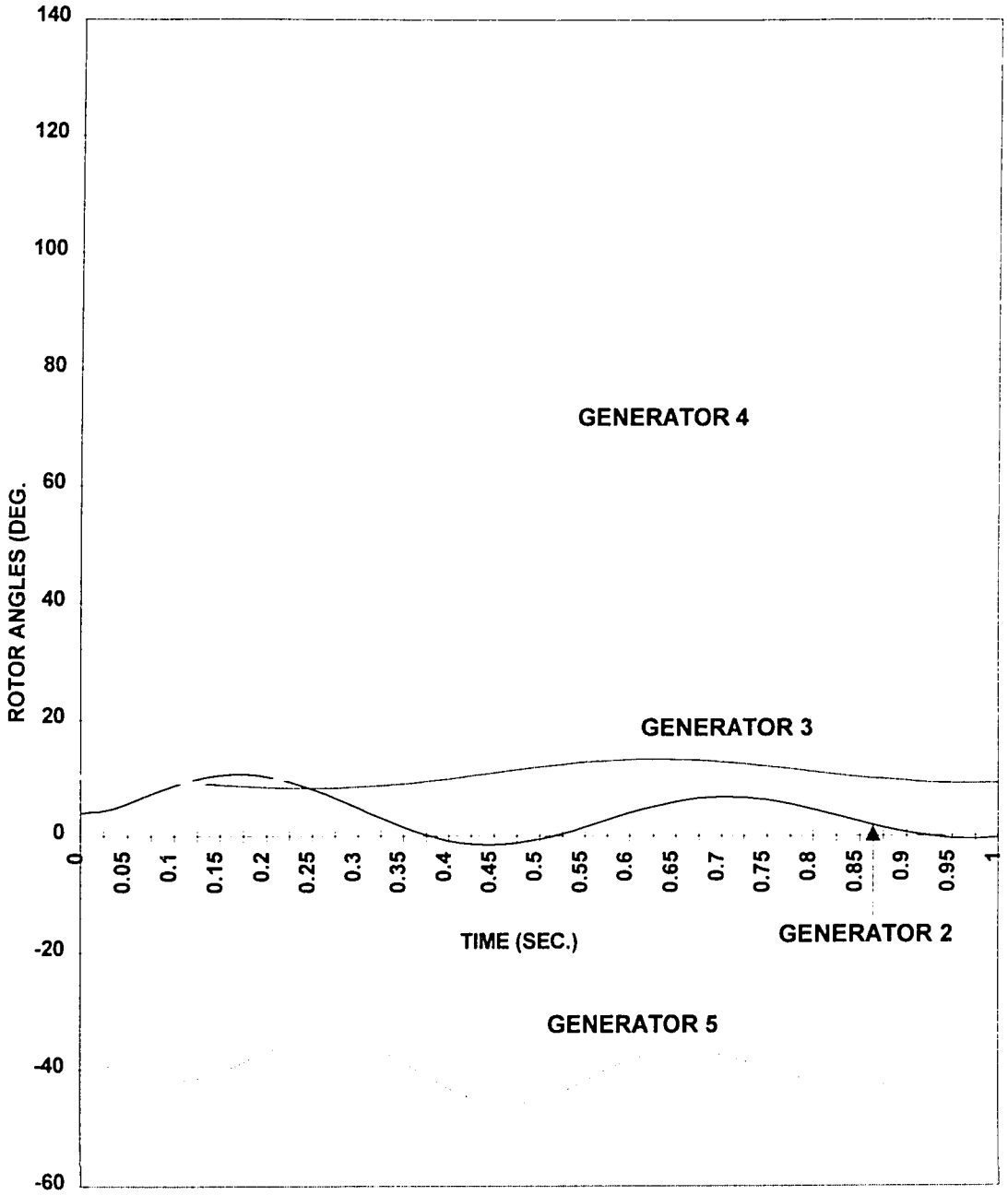

Fig. 5.21 : Rotor angles of system #2 generators (referred to Gen.no.1) with fault no.2 and no control

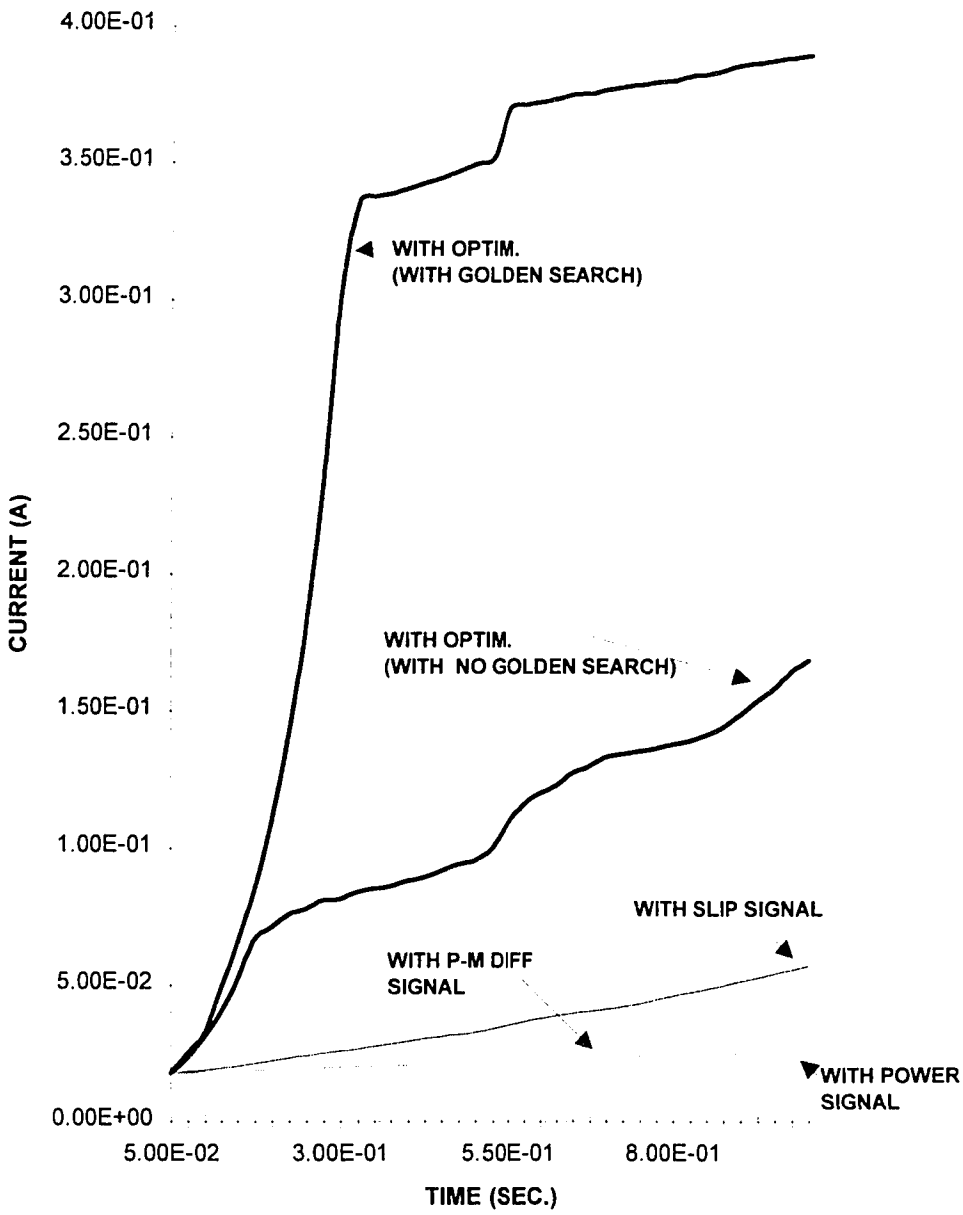

Fig. 5.22 : Rectifier current increase due to fault no.1 for system #2 with optimization and controller no.1 signals

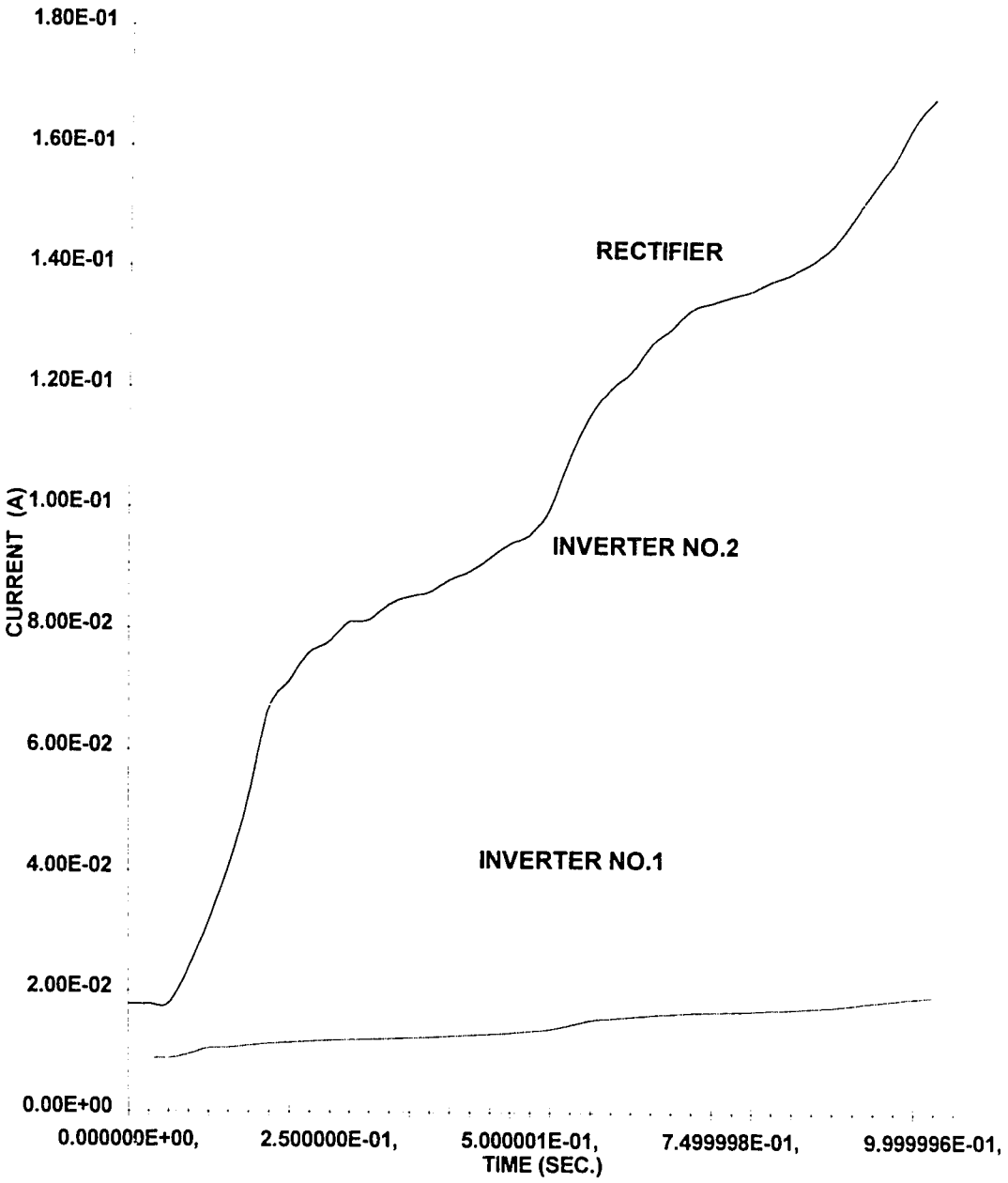

Fig. 5.23 : Current increase of the three converters for system #2 due to fault no. 1

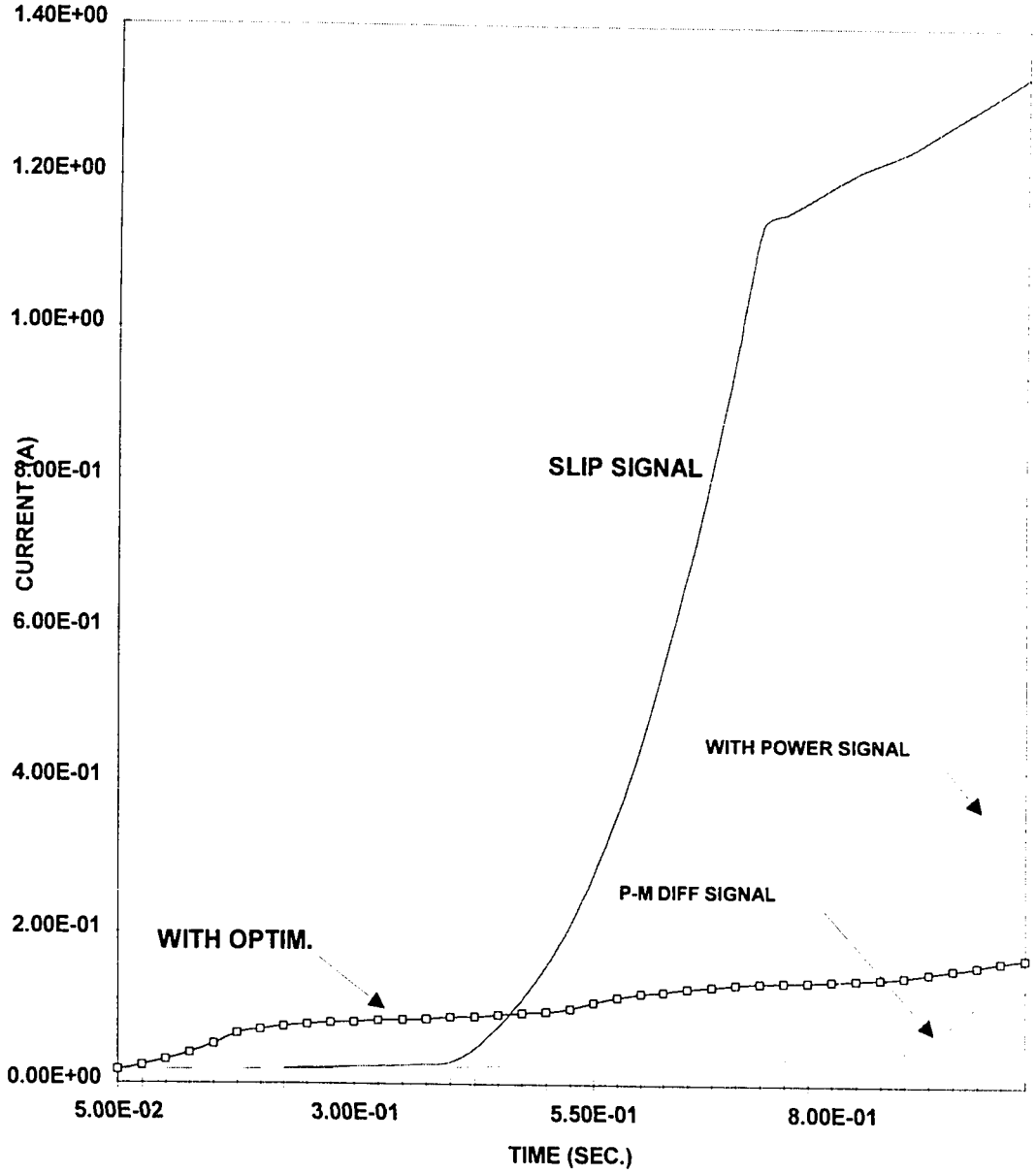

Fig. 5.24 :Current increase of rectifier of system #2 due to fault no.1 with optimization and controller no.2 signals (without limiting)

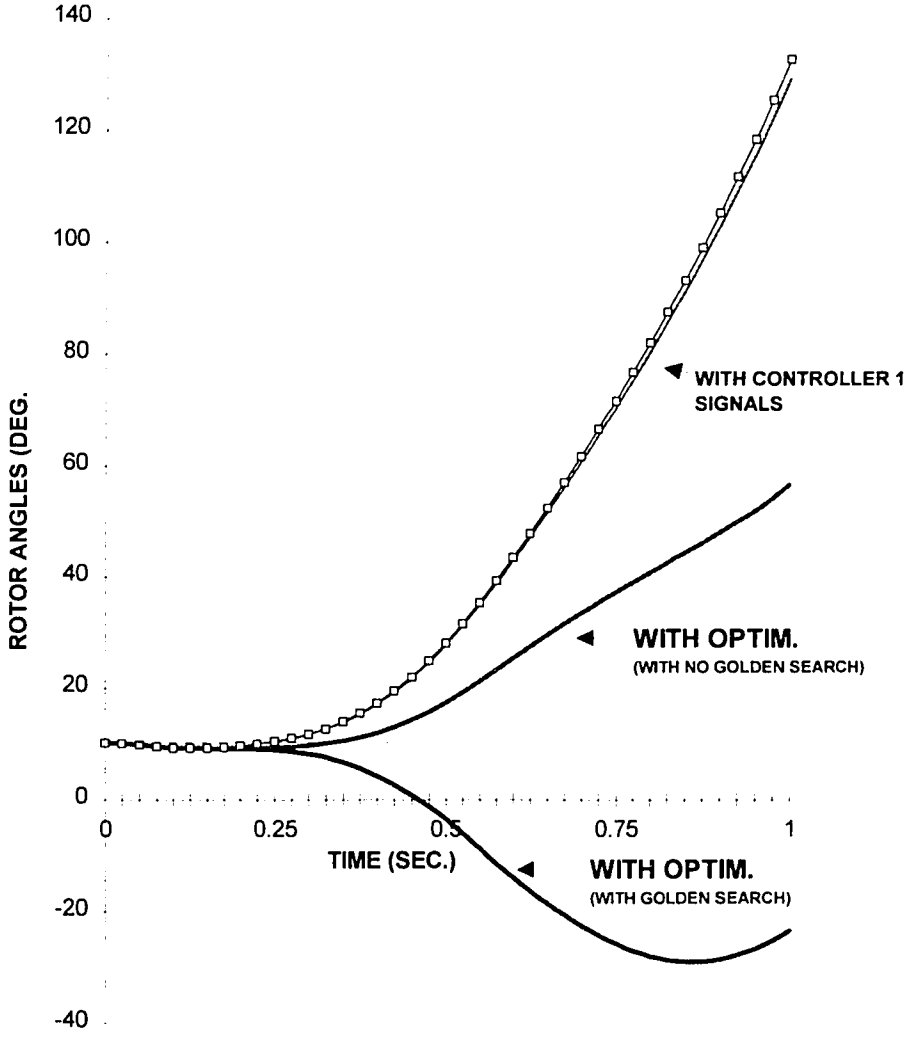

Fig. 5.25 : Rotor angles of generator n0.4 of system #2 due to fault no.1

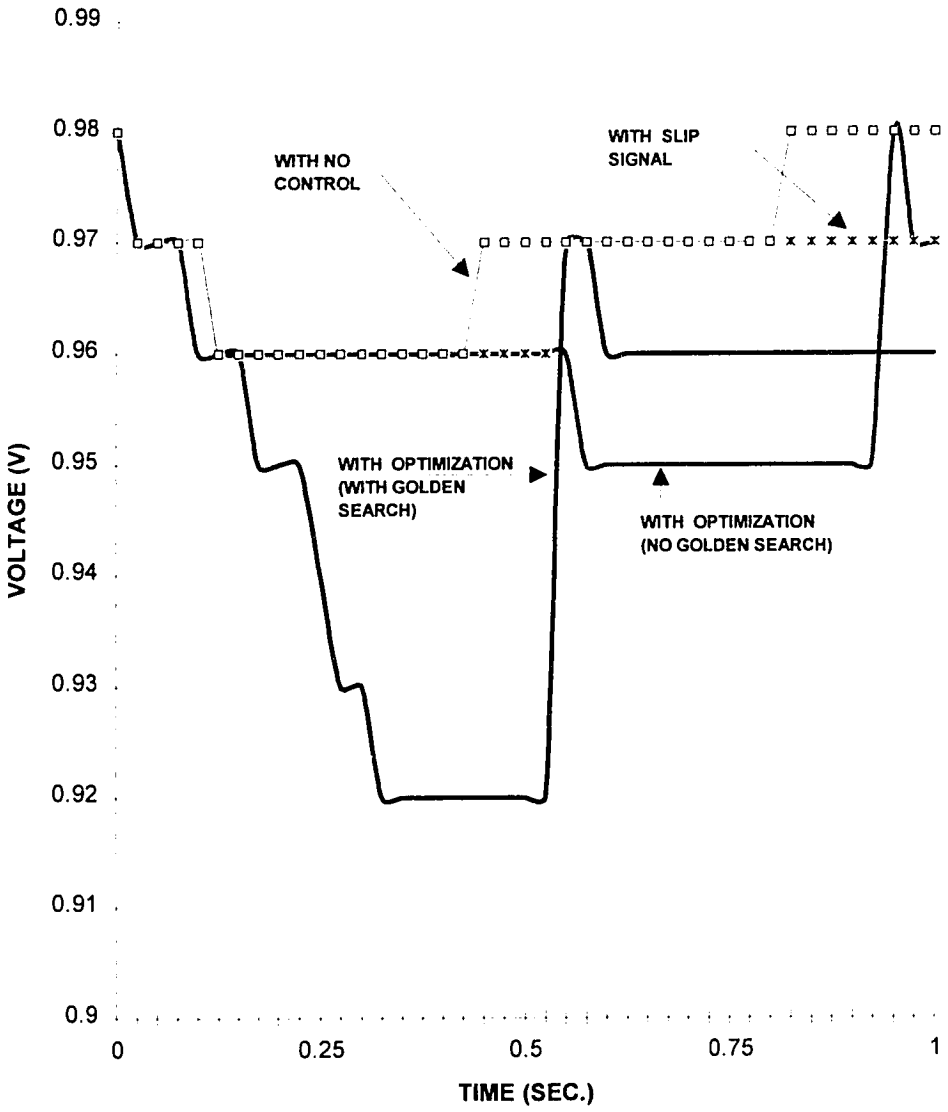

Fig. 5.26 : Voltage profile response at bus NA04 due to no control and various control methods

5.3.2 Fault no. 2

Another three phase fault (F2) was applied on bus 03 for 50 ms. The system behavior is shown on figure 5.27 without any control. Current, rotor angles and voltage wave forms for generator 04 will be presented.

5.3.2.1 Results and Discussion

5.3.2.1 A Current Waveforms

Figure 5.28 shows the rectifier current response to the three schemes. Scheme II and III produce the same degree of current increase. No obvious differences between controller no.1and 2. In figure 5.29, the current increase when using optimization model for inverter 2 is smaller than that of inverter 1. This is opposite to the performance of the previous fault no. 1.

5.3.2.1 B Rotor angles Waveforms

The rotor angles response of generator no.04 is shown on Figure 5.30. The generator is driven away from synchronism due to the fault. The three control schemes improve, only slightly, the performance of the system but not enough to stabilize and bring back the machine into synchronism. This is unlike the situation with fault no.1. A reason for this could be that the MTDC system and generator no.04 are away from the event and have a little contribution to the system.

5.3.2.1.C Voltage Waveforms

As shown on figure 5.31, generator no.04 suffers an oscillating under voltage, due to applying optimization, worse than that with no control. This under voltage, however, is better than the one caused by that of fault no.1.

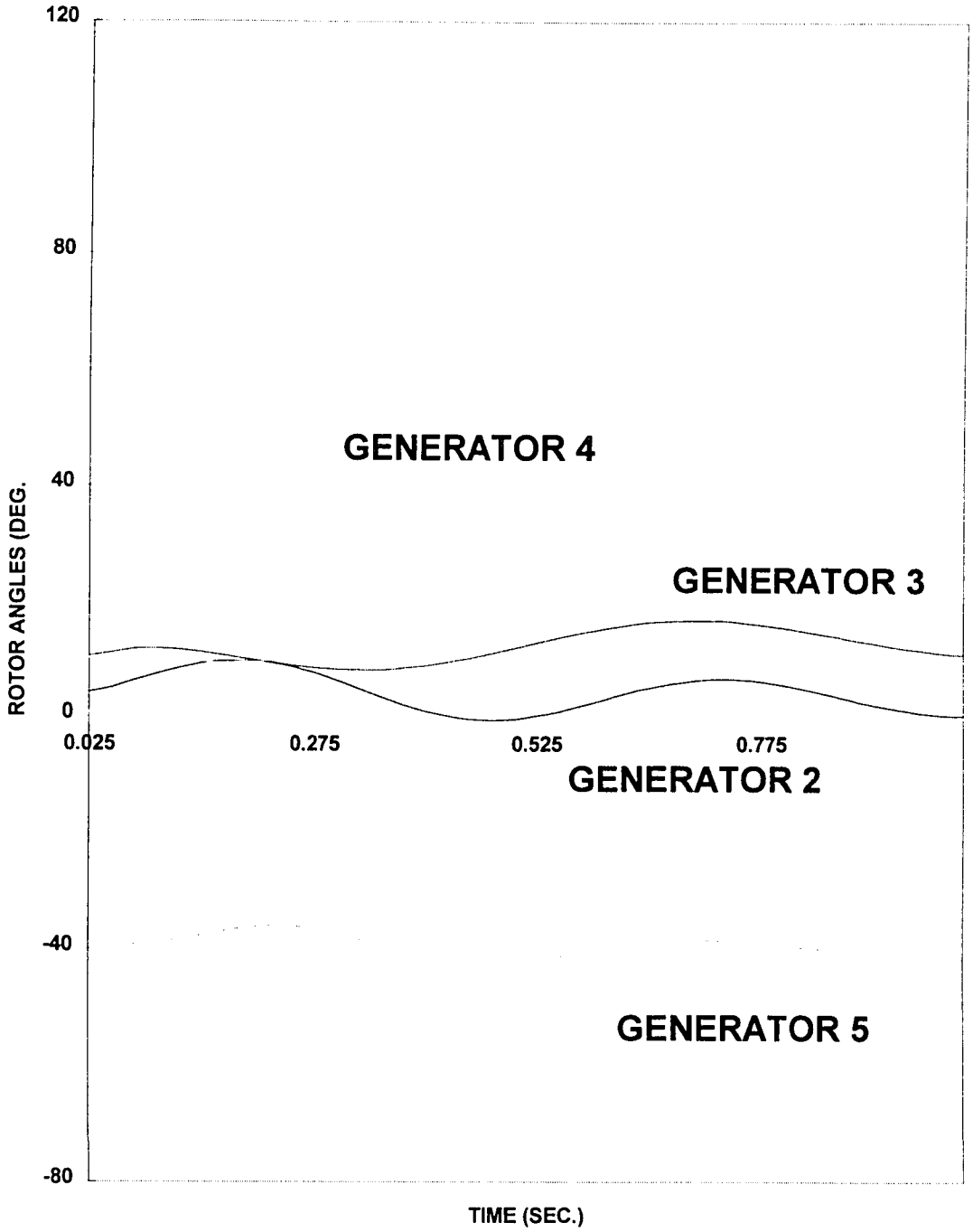

Fig. 5.27 : Machines rotor angles of system #2 due to fault no.2 without any control

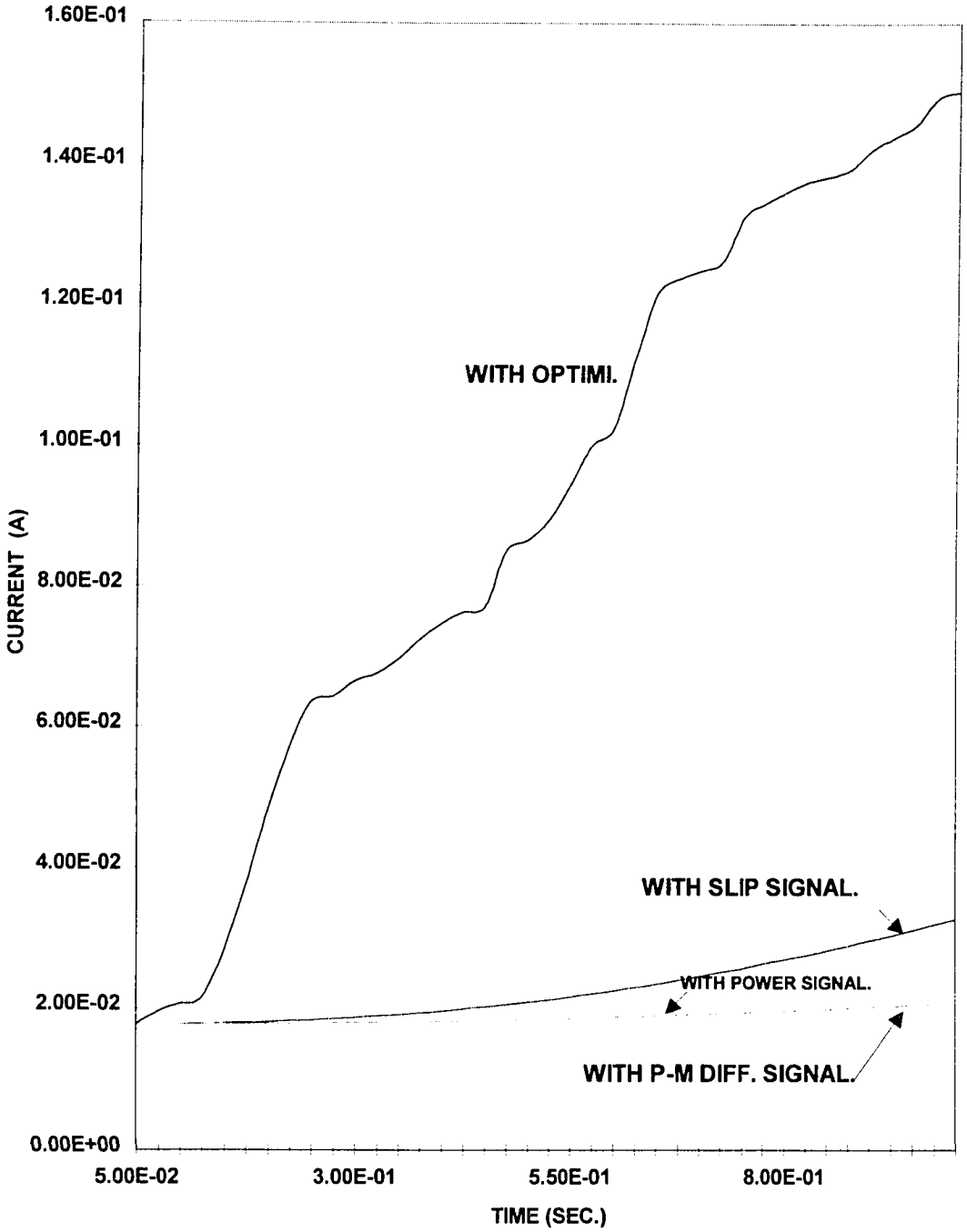

Fig. 5.28 : Current increase of rectifier of system #2 due to fault no.2 with optimization , and controller no.2 signals

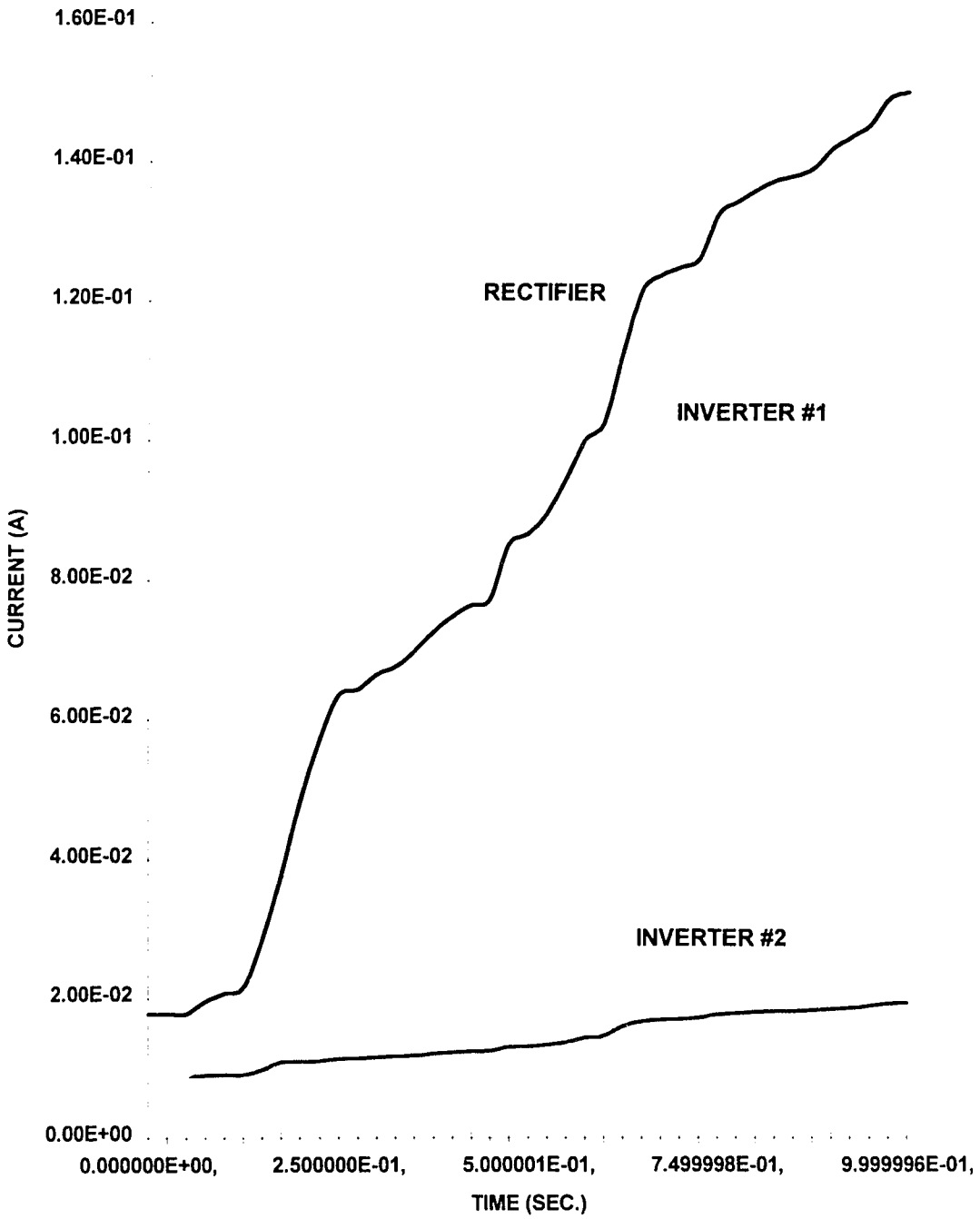

Fig. 5.29 : Current increase of the three converters due to optimization for system #2 (fault no2)

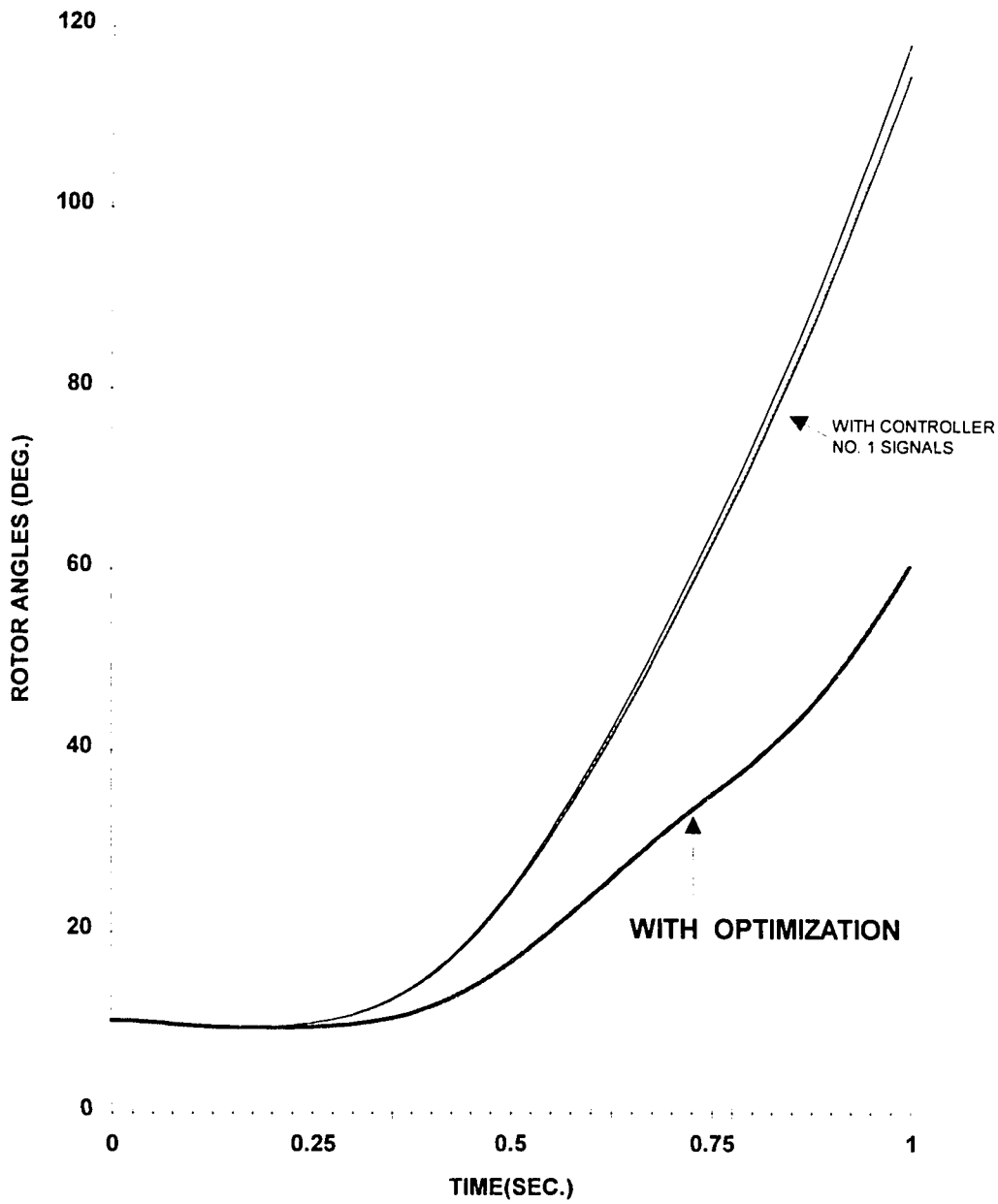

Fig. 5.30 : Rotor angles od Gen. 04 of system #2 due to fault no.2 with no control , optimization and controller no.1 signals

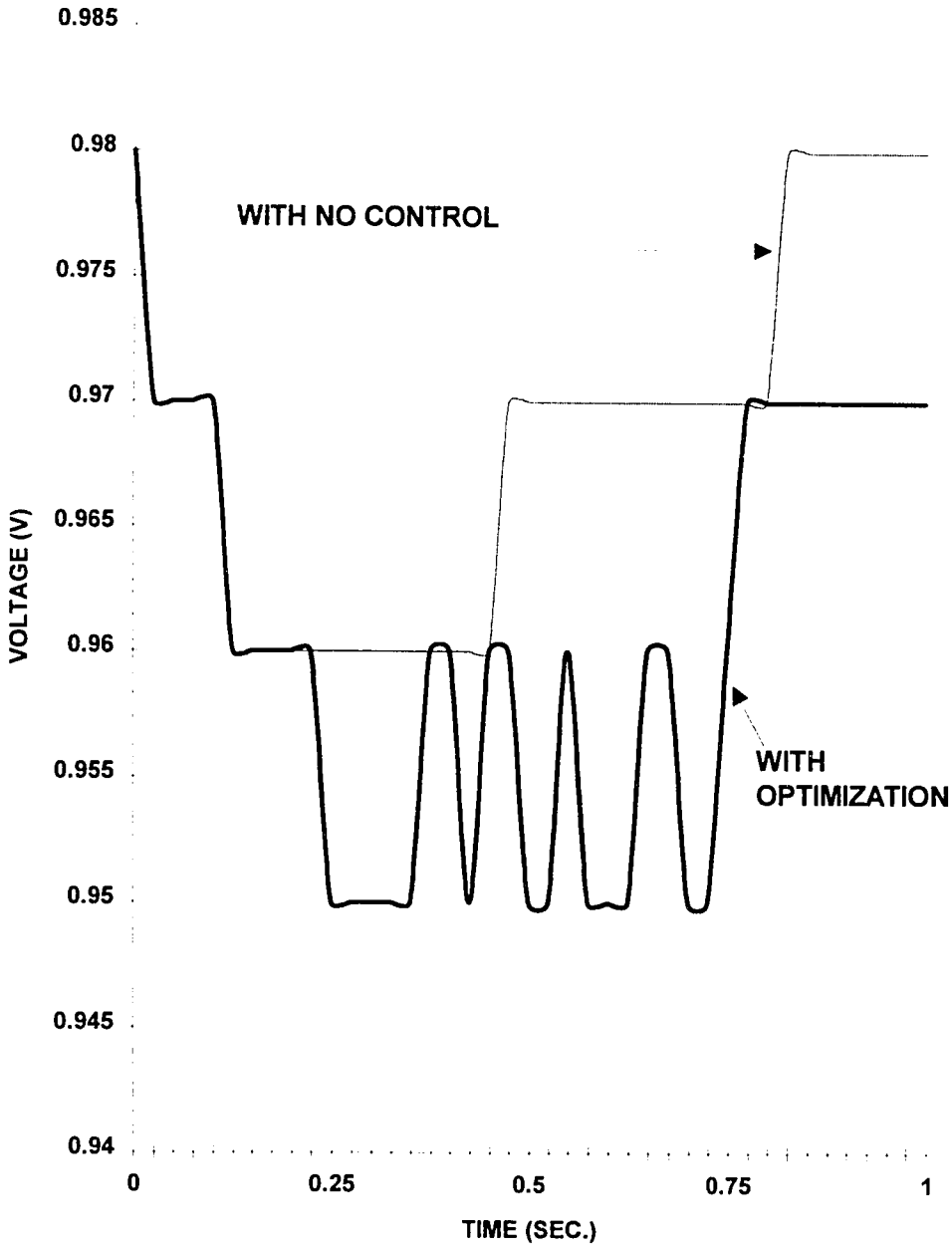

Fig. 5.31 : voltage profile of Gen. 04 due tofault no. 2 with no control and optimization

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

In this thesis, three main control schemes have been applied to improve the AC transient stability through MTDC systems. These control schemes were applied to two muitimachine systems, on which two three phase faults were conducted on each. A summery of the results is shown on table 6.1. This table shows the response of the AC systems for each control system due to the faults. On the last column a ranking was given for each method compared to others. It shall be noted that there is no difference in behavior between controller 1 and 2 and between power or power-mechanical difference signals.

A mong the three control schemes, control scheme III, that is Linear Programming optimization method along with the feasible direction concept (Golden Search Technique), proves to be superior in always improving the system's response. One other characteristic of this scheme over the rest is that an improvement of one machine will not be on the expense of other machines. That is it will not improve one machine and worsen others as the other two schemes have on system #1 (fault no.2). In this regard, it is also, important that the MTDC system properly relieve some energy through each terminal (inverters).

	SYSTEM #1(20 BUS) F1	F2	SYSTEM #2(24 BUS) F1	F2	RANKING
CONTROLLER					
SLIP SIG.	slightly overdamp	slightly overdamp	slightly improve	slightly improve	p: (2) improve : (3)
PDM SIG.	slightly overdamp	worsen trans. stability	slightly improve	slightly improve	overdamp: (3) improve : (4)
OPTIM. ($\lambda = 1$)	slightly overdamp	largely overdamp	clearly improve	clearly improve	overdamp: (1) improve : (2)
ON (WITH GOLDEN SEARCH)	slightly improve	slightly improve	significantly improve	clearly improve	overdamp: 0 improve : (1)

Table 6.1 : Summery of main results of the study

This was very clear with the performance of system # 2 when inverter1and 2 current increases differently to fault no.1 and 2.

It shall be noted that the location, duration, type of fault and the power system configuration will affect the contribution of the applied control scheme and the MTDC system. The control scheme will enhance the transient stability if there is a room in the power system to enhance. Enhancement can not be brought from outside the system but from inside by properly and quickly changing the parameters of the MTDC system in the AC power systems .Finally , It must be emphasized that high voltage MTDC can support the AC power system during sudden faults through properly controlling the DC parameters.

6.2 RECOMMENDATIONS

The following are the thesis recommendation in applying MTDC systems to support the AC power system:

1. Modifying the Linear Programming model by imposing two new constraints:

   A) Minimum under voltage of concerned buses

   B) Thermal rating of the lines

   so that these two constraints are met within the structure of the model
2. Investigation of other optimization models.

3. Apply and extend the work to five(5) terminal systems and compare the results to those of three(3) terminal systems.

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APPENDIX I

SAMPLE PROGRAM

```
C            TRANSIENT STABILITY PROGRAM
C   DIMENSION LIMITS   20 GENERATORS        ( KG )
C                 30 INDUCTION MOTORS   ( NM )
C                 50 BUSBARS          ( NK )
C                100 LINES + BUSBARS    ( NL )
C                 20 SWITCHED LINES     ( KM )
C                 20 MONITORED LINES    ( LF )
C          ALSO NOTE   IN = NK+2*NL  AND  IR = NK+3/2*NL
C
C****************************MAIN STEERING ROUTINE ********************
C
   COMMON/U1/NK,NL,NA,NANK,LIMAX,IN,IR
   COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
   COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
   COMMON/U4/JSM,NRBUS,ANGMAX,NO,PINT,PINT2,PTM,IPRE,PRTIME,NOPT,SP41
   COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
   COMMON/U8/TSTIME
   COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
   COMMON/BLD/XC(50),V1(50),PDS(50),QDS(50)
   COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
   COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
   COMMON/CONTROL/SIG1,SIG2,SP1(10),ANG1(10),Y1DX,Y1DX2,DIS1,DIS2
   COMMON/CONTROL1/PMECH1(10),PT1(10),PA(10)
   COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
  *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
   COMMON/CNTRL3/XZ(20),ZSUM(20)
   COMMON/YZAHRA/GA,GB,PASS,ALPHA,GU,GLIM,FYU,FYLIM,YY(16),ZZ(16),
  *SPTOT
   DATA ENDST/4HESUD/
   open (unit = 10 ,file ='DC3F2.dat',status='old')
   open (unit = 20 ,file ='DC3F2.out',status='old')
   open (unit = 30 ,file ='DC3F22.out',status='old')
   open (unit = 70 ,file ='ABC.out',status='old')
   JSM=0
 9999 CONTINUE
   JSM=JSM+1
C*********************************************************************
C                    INITIALISE DATA
C                    ---------------
   KG=20
   NM=30
   NK=50
   NL=100
```

```
      KM=20
      LF=20
      IN=250
      IR=200
C
      JJ=0
      NO=0
      KBF1=0
      KBF3=0
      IPC=0
      NANK=NL
      KM1=KM
      TIME=0.
      TSTEPO=0.
      PRTIME=0.
      IDC=0
      ISWD=0
C                     DATA READIN
C                     ------------
C*****READIN LOAD FLOW SOLUTION AND NETWORK DATA
      CALL SYSTEM
C
C****     READIN MONITORED LINE DATA
      CALL MONLIP
C
C*****READIN SYNCHRONOUS MACHINE DATA
      CALL GENIP
      IF(IPC.EQ.1)GOTO 750
C
C*****    SHUNT LOAD CALCULATION AND PRINT-OUT
      CALL SHUNT
C
C       FINALISE LINE ADMITTANCE LIST
      CALL PARAL
      IF(TIME.LT.-1.)GOTO 750
C
C          CONSTRUCTION OF NODAL Y MATRIX AND BUS ORDERING
C          ------------------------------------------------
      CALL ORDER
      IF(LIMAX.LE.0)GOTO 750
      IF(TIME.LT.-1.)GOTO 750
C
C*********************************************************************
C               READIN OF SWITCHING DATA
C               ------------------------
 200  CONTINUE
      KM=KM1
      CALL SWITIP
      IF(TIME.GT.TMAX)GOTO 700
      IF(TIME.LT.-1.)GOTO 750
      TSTEPO=TSTEP
      PRTIME=PINT
      KBF3=1
      IF ( IPRE  .EQ. 1 ) KBF3=0
```

```
      IF ( JJ  .EQ. 0 ) KBF3=1
C              CALCULATION OF MACHINE INITIAL CONDITIONS
C              ----------------------------------------
C     WRITE(30,*)'ISWD  1 =',ISWD
      CALL INICAL
C        SPARSE FACTORED INVERSE OF UNFAULTED NODAL NETWORK MATRIX
C        ---------------------------------------------------------
      IF(KBF3.EQ.0)GOTO 250
      CALL BIFA3
  250 IF(JJ.EQ.0)GOTO 380
C
C*********************************************************************
C                 DETERMINE STEP LENGTH
C                 ---------------------
  300 CONTINUE
TSTEP=TSTEPO
      CALL STEP
333  FORMAT(/10X,'STEP=   ',F8.4)
C                    LINE SWITCHING
C                    --------------
      CALL SWITCH
IF(TIME.LT.-1.)GOTO 750
      IF(KBF1.EQ.0)GOTO 340
CALL PARAL
CALL ORDER
IF(LIMAX.LE.0)GOTO 750
  340 CONTINUE
      IF(KBF3.EQ.0)GOTO 400
C        SPARSE FACTORED INVERSE OF SWITCHED NODAL NETWORK MATRIX
C        --------------------------------------------------------
      CALL BIFA3
  380 TSTEP=0.
      KBF3=1
      GOTO 450
C
C*********************************************************************
C                    INTEGRATION STEP
C                    ----------------
  400 CONTINUE
C***** CALCULATE CONSTANTS FOR TRAPEZOIDAL RULE
PASS=0.0
      CALL CONST
C
C***** EXTRAPOLATION OF NON-INTEGRABLE VARIABLES
      CALL EXTRA
C
C           ITERATIVE SOLUTION OF MACHINES AND NETWORK
C      USING THE TRAPEZOIDAL RULE AND SPARCE FACTORED NETWORK Z MATRIX
  450 CONTINUE
LL SOL
      GO TO 1534
      IF(TIME.LT.TSTIME) GOTO 1534
      IF(TIME.GT.3.E-1) GOTO 1534
```

```
C-------- GOLDEN SEARGH STARTS------------
      KS=1
      GA=-1.e-8
      GB=-1.e-10
      ALPHA=0.618
      PASS=0.0
      DIND=DIIS
      DIIP=DIPS
      CALL FN1
      CALL FN2
      GO TO 4007
 5111 CONTINUE
c 5111    GO TO 4007
        write(30,*)'---------------------------------'
        write(30,2001)
 2001    format(1x,'|','iteration #|',3x,'a',5x,'|',1x,'b',7x,'|')
        write(30,*)'---------------------------------'
        write(30,1001) ks,ga,gb
 1001    format(1x'|',3x,i2,6x,'|',2x,f9.3,1x,'|',2x,f9.3,1x,'|')
        write(30,*)'---------------------------------'
        write(30,3003)
 3003    format(1x,'|','  u       ',4x'|',1x,'lim',11x,'|')
        write(30,*)'---------------------------------'
        write(30,4004) gu,glim
 4004    format(1x'|',3x,f9.3,3x,'|',2x,f9.3,4x,'|')
C 4007    write(30,*)'---------------------------------'
 4007  CONTINUE
C     DI(ND)=DIND
C     DI(IP)=DIIP
      IF((GB-GA).LT.1.E-1) THEN
      GO TO 1030
      ELSE

      PASS=1.0
      CALL FN1
      CALL FN2
DI(ND)=DI(ND)+GLIM*DD(13)
       DI(IP)=DI(IP)+GLIM*DD(14)
CALL EXTRA
CALL SOL
      CALL GENOP
FYLIM=SPTOT

      DIIS=DIIS+ABS(GU*DD(13)/1.E1)
       DIPS=DIPS+ABS(GU*DD(14))

      CALL EXTRA
      CALL SOL
      CALL GENOP
      FYU=SPTOT
      DIIS=DIND
      DIPS=DIIP

      IF(FYU.GT.FYLIM) THEN
```

```
      GO TO 5222
      ELSE
       GO TO 5333
      ENDIF
      ENDIF

 5222 GA=GLIM
      GB=GB
      GLIM=GU
      CALL FN1
      DIND=DIIS
      DIIP=DIPS

       DIIS=DIIS+ABS(GU*DD(13)/1.E1)
       DIPS=DIPS+ABS(GU*DD(14))

      CALL EXTRA
      CALL SOL
      CALL GENOP
      FYU=SPTOT
      DIIS=DIND
      DIPS=DIIP
      GO TO 5444

 5333 GA=GA
      GB=GU
      GU=GLIM
      CALL FN2
      DIND=DIIS
      DIIP=DIPS

       DIIS=DIIS+ABS(GLIM*DD(13)/1.E1)
       DIPS=DIPS+ABS(GLIM*DD(14))

      CALL EXTRA
      CALL SOL
      CALL GENOP
      DIIS=DIND
      DIPS=DIIP
      FYLIM=SPTOT
      GO TO 5444
 5444 KS=KS+1
      GO TO 5111
 1030 CONTINUE

       PASS=2.0

      c      WRITE(70,*)TIME,',',GLIM
       PASS=2.0
 1031  PASS=2.0
CALL EXTRA
       CALL SOL
CONTINUE
       PASS=0.0
```

```
C------ END OF GOLDEN SEARCH---------
C***********************************************************************
 1534 CONTINUE
    PASS=0.0
C            UPDATE TIME AND STEP NUMBER
C            ---------------------------
IF(JJ.EQ.0)GOTO 535

TIME =TIME+TSTEP
IF(KBF3.EQ.1)GOTO 535
    NO=NO+1
C                  OUTPUT PRINTOUT
C                  ---------------
    CALL PRINTO
    IF(NOPT.EQ.0)GOTO 600
 535 CALL GENOP
KBF3=0
    IF(TIME.LT.-1.)GOTO 750
C
C***********************************************************************
C            CHECK FOR END OF CASE
C            ---------------------
 600 CONTINUE
    IF(JJ.EQ.0)GOTO 620
    IF(TIME.LT.TMAX-0.000001)GOTO 300
C       END OF CASE
    WRITE(20,900)
    GOTO 640
C            INITIAL POWER BALANCE CHECK
C            ---------------------------
 620 CONTINUE
    CALL POWBAL
C    IF(IPC.EQ.1)GOTO 750
C          STORE OR RESET INITIAL CONDITIONS
C          ---------------------------------
 640 CONTINUE
    TIME=0.
    NO=0
    CALL STORE
    IF(TIME.LT.-1.)GO TO 750
    IF(JJ.EQ.1)GOTO 300
    GOTO 200
C
C***********************************************************************
C                TERMINATION MESSAGES
C                --------------------
 700 WRITE(20,910)JSM
     GO TO 9999
C    SEARCH FOR SYSTEM STUDY END
 750 WRITE(20,950)
 755 READ(10,955)B
    CALL COMP8(B,ENDST,K)
    IF(K.EQ.1)GOTO 9999
    GOTO 755
```

```
C
C********************** FORMAT STATEMENTS ******************************
C                  -------------------
 900 FORMAT(//55X,11HEND OF CASE/55X,11(1H-))
 910 FORMAT(//47X,23HEND OF SYSTEM STUDY NO.,I3/47X,26(1H-)/)
 950 FORMAT(///42X,36HSYSTEM STUDY TERMINATED DUE TO ERROR/42X,36(1H-))
 955 FORMAT(A4)
C
C******************END OF MAIN STEERING ROUTINE ************************
C-----------------------------------------------------------------------
 975 STOP
    close (10 , status='keep')
    close (20 , status='keep')
    close (30 , status='keep')
    close (70 , status='keep')
    END
    SUBROUTINE SYSTEM
C          INPUT OF SYSTEM AND NETWORK DATA
C
    COMMON/U1/NK,NL,NA,NANK,LIMAX,IN,IR
    COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
    COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
    COMMON/U4/JSM,NRBUS,ANGMAX,NO,PINT,PINT2,PTM,IPRE,PRTIME,NOPT,SP41
    COMMON/BUS1/VKR(50),VKM(50),CKR(50),CKM(50),BUS(50)
    COMMON/BUS2/GG(50),BB(50),PL(50),QL(50)
    COMMON/BRANCH/IL(100),KL(100),GL(100),BL(100)
    COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
    COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
    COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
    COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
   *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
    COMMON/CNTRL3/XZ(20),ZSUM(20)
    EQUIVALENCE (KMM,IPL)
    INTEGER COUNT
    DATA END/4HEND /
    VSN=1.E-15
    open (unit = 10 ,file ='DC3F2.dat',status='old')
    open (unit = 20 ,file ='DC3F2.out',status='old')
C
C      SYSTEM DATA INPUT
    IPCHEK=0
    ITS=0
    DO 501 K=1,NK
    GG(K)=0
 501 BB(K)=0
    K=0
    N=0
    WRITE(20,556)
    DO 502 I=1,3
    READ(10,558) (BUS(J),J=1,10)
    CALL COMP8(BUS(1),END,IJK)
    IF(IJK.EQ.1)GOTO 520
    IF(I.EQ.1)WRITE(20,552)JSM
 502 WRITE(20,560) (BUS(J),J=1,10)
```

```
      DO 503 J=1,10
  503 BUS(J)=0.
      READ(10,551)F,VA,IPL,IML,MSD,MSS,NDAL,MAXIT,MEX
      IF(MAXIT.LT.1)MAXIT=30
      IF(VSN.GT.ABS(F))F=50.
      IF(VSN.GT.ABS(VA))VA=100.
      WRITE(20,557) F,VA
      F=F*3.14159
      IF(MSD.LT.1)MSD=2
      STEPF=1./FLOAT(MSD)
      IF(MSS.EQ.0)MSS=1
      IF(MSS.LE.-1)MSS=0
      MSS=-MSS*MSD
      J=0
C
C     BUSBAR DATA INPUT
      IF(IPL.LE.0)GOTO 504
      WRITE(20,570)
      GOTO 506
  504 WRITE(20,554)
      COUNT=0
  506 READ(10,550) BBUS,VL,AN,PPG,QQG,PPL,QQL
      CALL COMP8(BBUS,END,KJI)
      IF(KJI.EQ.1)GOTO 591
      IF(IPL.GE.1)GOTO 505
      WRITE(20,553) BBUS,VL,AN,PPG,QQG,PPL,QQL
      COUNT=COUNT+1
C     CHECK FOR DUPLICATE BUSBAR NAME
  505 IF(N.EQ.0)GOTO 510
      DO 508 K=1,N
      CALL COMP8(BBUS,BUS(K),KJI)
      IF(KJI.NE.1)GOTO 508
      IPCHEK=1
      WRITE(20,563)
  508 CONTINUE
  510 CONTINUE
C
      N=N+1
      IF(N.LE.NK)GO TO 531
      IF(J.EQ.0)WRITE(20,567)
      J=1
      N=NK
      IPCHEK=1
      GO TO 506
  531 CONTINUE
      CALL COPY8(BUS(N),BBUS)
      AN=AN/57.296
      VKR(N)=VL*COS(AN)
      VKM(N)=VL*SIN(AN)
      PL(N)=PPL/VA
      QL(N)=QQL/VA
      IF(COUNT.LT.5)GOTO  506
      COUNT=0
      WRITE(20,569)
```

```
      GOTO 506
  591 NK=N
C
C     LINE DATA INPUT
      L=0
      J=0
      IF(IPL.LE.0)WRITE(20,559)
      COUNT=0
  515 READ(10,555) B1,B2,RR,XX,B,TAP
      CALL COMP8(B1,END,KJI)
      IF(KJI.EQ.1)GOTO 518
      IF((ABS(RR)+ABS(XX)).LE.VSN)XX=1.E-6
      IF(IPL.GE.1)GOTO 513
      COUNT=COUNT+1
      CALL COMP8(B1,B2,KJI)
      IF(KJI.EQ.1)GOTO 512
      WRITE(20,566) B1,B2,RR,XX,B,TAP
      GOTO 513
  512 WRITE(20,565)B1,RR,XX
  513 CONTINUE
      I=0
      K=0
      DO 516 J=1,NK
      CALL COMP8(B1,BUS(J),KJI)
      IF(KJI.EQ.1)I=J
      CALL COMP8(B2,BUS(J),KJI)
  516 IF(KJI.EQ.1)K=J
      IF(I.NE.0.AND.K.NE.0)GO TO 532
C     BUSBAR NOT LOCATED
      WRITE(20,561)
      IPCHEK=1
      GO TO 515
  532 CONTINUE
      Z=RR*RR+XX*XX
      RR=RR/Z
      XX=-XX/Z
      B=.5*B
      IF(I.EQ.K)GOTO 517
      L=L+1
      IL(L)=I
      KL(L)=K
      T1=1./(1.+.01*TAP)
      T2=1.-T1
      T3=-T1*T2
      GL(L)=RR*T1
      BL(L)=XX*T1
      GG(I)=GG(I)+RR*T3
      GG(K)=GG(K)+RR*T2
      BB(I)=BB(I)+XX*T3+B
      BB(K)=BB(K)+XX*T2+B
      IF(COUNT.LT.5)GOTO 515
      COUNT=0
      WRITE(20,569)
      GOTO 515
```

```
 517 GG(I)=GG(I)+RR
     BB(I)=BB(I)+XX
     GOTO 515
 518 NA=L
     J=NANK-NK
     IF(NA.LE.J)GOTO 525
     J=NA-J
     WRITE(20,564)J
     IPCHEK=1
 525 CONTINUE
     IF(IPL.LE.0)WRITE(20,568)
C
C         ZERO UNUSED PORTIONS OF IL AND KL VECTORS
     I=NA+1
     DO 519 L=I,NL
     IL(L)=0
 519 KL(L)=0
     IF(IPCHEK.EQ.0)GO TO 533
     IPC=1
 533 CONTINUE
     RETURN
C
C        CORRECT PROGRAM TERMINATION
 520 WRITE(20,562)
     STOP
C
 550 FORMAT(A4,2X,7F10.5)
 551 FORMAT(2F10.4,2I2,8I3)
 552 FORMAT(53X,10HSYSTEM NO.,I3/53X,13(1H-)/)
 553 FORMAT(25X,A4,7F12.5)
 554 FORMAT(//48X,24HSTEADY-STATE SYSTEM DATA/48X,24(1H-)//
    251X,17HBUSBAR DATA INPUT//22X,6HBUSBAR,6X,7HVOLTAGE,6X,
    35HANGLE,6X,6HGEN MW,5X,8HGEN MVAR,5X,7HLOAD MW,3X,9HLOAD MVAR//)
 555 FORMAT(2A4,F8.5,F9.5,F8.5,F6.2)
 556 FORMAT(1H1/1X,59(2H *)/1X,119(1H-)/60(2H *)///
    * 35X,23HELECTRICAL POWER-SYSTEM,
    * 26H TRANSIENT-STABILITY STUDY/35X,49(1H-)//
    *47X,24H POWER-SYSTEM LABORATORY/
    *42X,36HDEPARTMENT OF ELECTRICAL ENGINEERING/30X,
    *'UNIVERSITY OF PETROLEUM AND MINERALS ')
 557 FORMAT(///42X,21HSYSTEM FREQUENCY   = ,F6.2,6H HERTZ/
    *42X,21HM.V.A. BASE      = ,F6.1,7H M.V.A.//)
 558 FORMAT(10A4)
 559 FORMAT(//52X,'LINE DATA INPUT'//
    *25X,'SENDING',3X,'RECEIVING',6X,'RESISTACE',4X,'REACTANCE',4X,
    *'SUSCEPTANCE',4X,'TAP'/26X,'BUSBAR',5X,'BUSBAR',10X,'P.U.',
    *10X,'P.U.',10X,'P.U.',7X,'P.C.'//)
 560 FORMAT(20X,10A4)
 561 FORMAT(10X,'**** ABOVE BUSBAR(S) NOT LOCATED *****')
 562 FORMAT(56X,'THE END'/56X,7(1H-))
 563 FORMAT(10X,'****BUSBAR NAME DUPLICATED ****')
 564 FORMAT(10X,4H****,I3,'TOO MANY LINES ****')
 565 FORMAT(25X,A4,6X,1H*,F18.5,F14.5)
 566 FORMAT(22X,2(7X,A4),3F14.5,F10.2)
```

```
  567 FORMAT(10X,'****TOO MANY BUSBAR ****')
  568 FORMAT(/45X,'SHUNT IMPEDANCE DENOTED BY -*')
  569 FORMAT(1H )
  570 FORMAT(//38X,'STEADY STATE NETWORK DATA SUPPRESSED'//)
      close (10 , status='keep')
      close (20 , status='keep')
      END
 SUBROUTINE SWITIP
C**********************INPUT OF LINE SWITCHING DATA********************
C
      COMMON/U1/NK,NL,NA,NANK,LIMAX,IN,IR
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
      COMMON/U4/JSM,NRBUS,ANGMAX,NO,PINT,PINT2,PTM,IPRE,PRTIME,NOPT,SP41
      COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
      COMMON/U7/MSW
      COMMON/U8/TSTIME
      COMMON/BUS1/VKR(50),VKM(50),CKR(50),CKM(50),BUS(50)
      COMMON/BRANCH/IL(100),KL(100),GL(100),BL(100)
      COMMON/G3/KBUS(20),KK(20),CD(20),CQ(20)
      COMMON/SW1/ISEND(20),IREC(20),GS(20),BS(20)
      COMMON/SW2/TPS(20),SS(20),STM(20),ITYPE(20),STMD(20)
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
      DATA END/4HEND /
      DATA ENDST/4HESUD/
      DATA INN/4HIN   /
      DATA IOUT/4HOUT /
      VSN=1.E-15
      open (unit = 10 ,file ='DC3F2.dat',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      open (unit = 30 ,file ='DC3F22.out',status='old')
      IF(TIME.LT.-1.)RETURN
C
C       FAULT DATA
  300 CONTINUE
      KMM=0
      MS=0
      MC=0
      TSADJ=0.
      IPCHEK=0
      TIME=0.
      READ(10,355)RBUS,NRMC,TSTEP,TMAX,ANGMAX,PINT,MSW,IB,IA,IG,PINT2,PTM
      CALL COMP8(RBUS,END,KJI)
      IF(KJI.EQ.1)GOTO 305
      CALL COMP8(RBUS,ENDST,KJI)
      IF(KJI.EQ.1)GOTO 305
      IF(VSN.GT.ABS(PINT)) PINT=TSTEP
      KO=KP
      IF(IB.GT.0)KO=KO+2
      IF(IA.LE.0.OR.NR.EQ.0)IA=0
      IF(IG.LE.0.OR.NG.EQ.0)IG=0
      IF(PINT2.LE.VSN)PINT2=PINT
```

```
      IF(PINT2.LT.PINT)PINT2=PINT
      IF(PTM.LE.VSN)PTM=00.0
      IPRE=0
      IF(VSN.GT.ABS(TMAX))TMAX=1.
      IF(VSN.GT.ABS(ANGMAX))ANGMAX=720.
      J1=JJ
      IF(JJ.EQ.0)J1=1
      WRITE(20,354)JSM,J1,NRMC,RBUS,TSTEP,TMAX,PINT,ANGMAX
C
C        SWITCHED LINES
      M=0
      IF(VSN.GT.ABS(TSTEP))GOTO 303
      NRBUS=0
      DO 307 K=1,KG
      N=KBUS(K)
      I=KK(K)
      CALL COMP8(RBUS,BUS(N),KJI)
      IF(KJI.EQ.1.AND.I.EQ.NRMC)NRBUS=K
  307 CONTINUE
      TSTIME=0.
  301 READ(10,351) B1,B2,RR,XX,B,TAP,I,T

C     WRITE(30,*)'HIGH 1',T
      IF(TSTIME.LT.T)TSTIME=T
      CALL COMP8(B1,END,KJI)
      IF(KJI.EQ.1)GOTO 304
      M=M+1
      IF(M.LE.KM)GOTO 306
      IPCHEK=1
      GOTO 301
  306 CONTINUE
      IF(M.EQ.1)WRITE(20,350)
      IF(I.GT.-1)I=1
      I1=INN
      IF(I.LT.0)I1=IOUT
      WRITE(20,352)T,I1,B1,RR,XX
      CALL COMP8(B1,B2,KJI)
      IF(KJI.EQ.1)GOTO 308
      WRITE(20,358)B2,B,TAP
      GOTO 309
  308 WRITE(20,359)
      B=0.
      TAP=0.
  309 CONTINUE
      IF(VSN.GT.ABS(RR) .AND.VSN.GT.ABS(XX))XX=0.000001
      Z=RR*RR+XX*XX
      GS(M)=RR/Z
      BS(M)=-XX/Z
      TPS(M)=1./(1.+.01*TAP)
      SS(M)=.5*B
      GS(M)=GS(M)*TPS(M)
      BS(M)=BS(M)*TPS(M)
      STM(M)=T
      STMD(M)=T
```

```
      ITYPE(M)=I
      I=0
      K=0
      DO 302 N=1,NK
      CALL COMP8(B1,BUS(N),KJI)
      IF(KJI.EQ.1)I=N
      CALL COMP8(B2,BUS(N),KJI)
      IF(KJI.EQ.1)K=N
  302 CONTINUE
      IF (I .EQ. 0 .OR. K .EQ. 0) GO TO 303
      ISEND(M)=I
      IREC(M)=K
      IF(VSN.GT.ABS(T))IPRE=1
      GO TO 301
  303 CONTINUE
      WRITE(20,353)
      TIME=-100.
      GO TO 301
  304 IF(IPCHEK.EQ.1)WRITE(20,357)KM
      IF(TIME.LE.-1)GOTO 300
      IF(M.LT.KM)KM=M
      IF(KM.EQ.0)WRITE(20,356)
      IF(MSW.LT.1)GO TO 310
  310 CONTINUE
      WRITE(20,360)
      RETURN
C
C           STABILITY RUN TERMINATION
  305 TIME=TMAX+1.
      RETURN
C
  350 FORMAT(///44X,30HSPECIFIED SWITCHING OPERATIONS/44X,30(1H-)//10X,
     1 'SWITCH     SWITCH     SENDING    RECEIVING          RESITANC
     2    REACTANCE      SUSCEPTANCE    TAP'/11X,
     3 'TIME       IN/OUT     BUSBAR       BUSBAR          P.U.
     4       P.U.        P.U.        P.C.'//)
  351 FORMAT (2A4,F8.5,F9.5,F8.5,F6.2,I2,F7.4)
  352 FORMAT(F16.4,7X,A4,5X,A4,13X,2F16.5)
  353 FORMAT(//18H SWITCH DATA ERROR)
  354 FORMAT(1H1///46X,10HSYSTEM NO.I3,11H   CASE NO.I3/
     *46X,13(1H-),3X,11(1H-)///
     143X,14HREF. M/C = NO.,I3,8H ON BUS ,A4/
     243X,24HINTEGRATION STEP (SEC) =,F9.6/
     343X,'STUDY DURATION    (SEC) =',F9.6/
     443X,25HPRINT INTERVAL    (SEC) =,F9.6/
     543X,24HSYNCH. M/C ANGLE LIMIT =,F6.0,3HDEG//)
  355 FORMAT(A4,I2,4F10.5,I3,I2,2I5,2F5.3)
  356 FORMAT(///47X,23HNO SWITCHING OPERATIONS///)
  357 FORMAT(/16X,38HSWITCHING OPERATIONS EXCEEDED LIMIT OF,I3,
     * 48H REMAINING OPERATIONS IGNORED. - CASE PRECEEDING//)
  358 FORMAT(1H+,44X,A4,32X,F16.5,F11.2)
  359 FORMAT(1H+,47X,1H*)
  360 FORMAT(//1X,119(1H-))
  347  FORMAT(/50X,' NO BLADE PITCH CONTROL ')
```

```
 346  FORMAT(/50X,'BLADE PITCH CINTROL IS APPLIED ')
 345  FORMAT(/40X,'C1=',F6.2,' C2= ',F6.3,' WN= ',F6.2,
    1/40X,' OMER= ',F6.2,'  TAWP= ',F6.3)
 344  FORMAT(/40X,'X1= ',F6.2,' X2=',F6.2,' X3=',F6.2,' X4=',F6.2,
    1/40X,'  X  =',F6.1,'  WYE = ',F6.2,'  TH=  ',F6.2,
    2/40X,' FLOW LIMITS  AWY= ',F9.4,'  BWY =',F9.4)
     close (10 , status='keep')
     close (20 , status='keep')
     close (30 , status='keep')
     END
 SUBROUTINE CONST
C       SUBROUTINE TO TRANSFORM THE D. E. INTO ALGEBRAIC FORM
C
C       Y(  X+H ) = Y( X ) + ( DY( X ) + DY( X+' ) ) * H/2*T
C           --- BECOMES ---
C       Y(X+H) = YC + YX * FUNCTION ( Y(X+H) , (X+H) )
C
     COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
     COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
     COMMON/G1/PT(20),QT(20),PE(20),H(20),DA(20),TQ(20),TD(20)
     COMMON/G2/XTD(20),XTQ(20),XSD(20),XSQ(20),RA(20)
     COMMON/G3/KBUS(20),KK(20),CD(20),CQ(20)
     COMMON/G4/AC(20),WC(20),DC(20),QC(20),DTC(20),QTC(20),
    *        AX(20),WX(20),DX(20),QX(20),DTX(20),QTX(20)
     COMMON/G7/XTTQ(20),XTTD(20),TTQ(20),TTD(20)
     COMMON/MCSAT/SATFAC(20),XP(20),SD(20),SQ(20)
     COMMON/DIF1/DEL(20),W(20),EF(20),PM(20)
     COMMON/DIF2/EQ(20),ED(20),ETTQ(20),ETTD(20)
     COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
     COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
     COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
     COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
    *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
     COMMON/CNTRL3/XZ(20),ZSUM(20)
     COMMON/YZAHRA/GA,GB,PASS,ALPHA,GU,GLIM,FYU,FYLIM,YY(16),ZZ(16),
    *SPTOT
     VSN=1.E-15
C
     open (unit = 10 ,file ='DC3F2.dat',status='old')
     open (unit = 20 ,file ='DC3F2.out',status='old')
     open (unit = 30 ,file ='DC3F22.out',status='old')
     DO  5 K=1,KG
     B1=TSTEP*0.5
     AC(K)=DEL(K)+B1*(W(K)-4.*F)
     AX(K)=B1
T2=H(K)/F
B2=TSTEP/(TSTEP*DA(K)+2.*T2)
     R1=B2*(PM(K)-PE(K)+4.*DA(K)*F)
     WC(K)=(1.-2.*DA(K)*B2)*W(K)+R1
     WX(K)=B2
     SATD=SD(K)
     SATQ=SQ(K)
C        write(30,*)'YES5'
     B1=TSTEP/(TSTEP+2.*TQ(K))
```

```
      DC(K)=(1.-B1*(1.+SATQ))*ED(K)+B1*(XSQ(K)-XTQ(K))*CQ(K)
      DX(K)=B1
 B2=TSTEP/(TSTEP+2.*TD(K))
      R1=B2*(EF(K)-(XSD(K)-XTD(K))*CD(K))
      QX(K)=B2
      QC(K)=(1.-B2*(1.+SATD))*EQ(K)+R1
      IF(VSN.GT.ABS(TTD(K)))GOTO 5
 B1=TSTEP/(TSTEP+2.*TTQ(K))
      DTC(K)=(1.-B1*(1.+SATQ))*ETTD(K)+B1*(XSQ(K)-XTTQ(K))*CQ(K)
      DTX(K)=B1
 B2=TSTEP/(TSTEP+2.*TTD(K))
      R1=B2*( SATD*EQ(K)-(XTD(K)-XTTD(K))*CD(K))
      QTC(K)=(1.-B2*(1.+SATD))*ETTQ(K)+R1
      QTX(K)=B2
    5 CONTINUE
C
IF(IDC.EQ.0)GO TO 9
c     IF(ISWD.EQ.0)GO TO 9
      IF(PASS.NE.0.0)GO TO 9
CALL DCCON
9  CONTINUE
      IF(NR.EQ.0)GOTO 10
      IF(PASS.NE.0.0)GO TO 10
      CALL AVRCON
   10 CONTINUE
      RETURN
      close (10 , status='keep')
      close (20 , status='keep')
      close (30 , status='keep')
      END
      SUBROUTINE TRAP
C       SUBROUTINE TO PERFORM INTEGRATION USING TRAPEZOIDAL RULE
C
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
      COMMON/ERRORS/ERRVOL,ERRDEL,ERRPOW,ERRAVR,ERRMOT,ERRDC,ERRCON
      COMMON/G1/PT(20),QT(20),PE(20),H(20),DA(20),TQ(20),TD(20)
      COMMON/G2/XTD(20),XTQ(20),XSD(20),XSQ(20),RA(20)
      COMMON/G3/KBUS(20),KK(20),CD(20),CQ(20)
      COMMON/G4/AC(20),WC(20),DC(20),QC(20),DTC(20),QTC(20),
     *        AX(20),WX(20),DX(20),QX(20),DTX(20),QTX(20)
      COMMON/G7/XTTQ(20),XTTD(20),TTQ(20),TTD(20)
      COMMON/MCSAT/SATFAC(20),XP(20),SD(20),SQ(20)
      COMMON/MCMODL/MODEL(20)
      COMMON/DIF1/DEL(20),W(20),EF(20),PM(20)
      COMMON/DIF2/EQ(20),ED(20),ETTQ(20),ETTD(20)
      COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
      COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
      COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
C
      open (unit = 10 ,file ='DC3F2.dat',status='old')
```

```
      open (unit = 20 ,file ='DC3F2.out',status='old')
      VSN=1.E-15
      ERRDEL=0.
      ERRVOL=0.
      ERRPOW=0.
      ERRAVR=0.
      ERRMOT=0.
      ERRDC=0.
       IF(IDC.EQ.0)GO TO 9
C       IF(ISWD.EQ.0)GO TO 9
c      IF(ITER.EQ.1) GO TO 9
      CALL DCTRA
    9 CONTINUE
C
C       AUTOMATIC VOLTAGE REGULATOR
      IF(NR.EQ.0)GOTO 10
      CALL AVRTRA
C
   10 CONTINUE
   20 DO 100 K=1,KG
      WK=WC(K)+WX(K)*(PM(K)-PE(K))
      ERR=ABS(WK-W(K))
      IF(ERR.GT.ERRDEL)ERRDEL=ERR
      W(K)=WK
C
C       MACHINE ANGLE
      D=AC(K)+AX(K)*W(K)
      ERR=ABS(D-DEL(K))
      IF(ERR.GT.ERRDEL)ERRDEL=ERR
      DEL(K)=D
C
C       MACHINE TRANSIENT VOLTAGES
      SATD=SD(K)-1.
      SATQ=SQ(K)-1.
      D=0.
      IF(MODEL(K).GE.4)GOTO 30
      XX=DX(K)
      D=(DC(K)+XX*CQ(K)*(XSQ(K)-XTQ(K)))/(1.+XX*SATQ)
      ERR=ABS(D-ED(K))
      IF(ERR.GT.ERRVOL)ERRVOL=ERR
   30 XX=QX(K)
      V=(XSD(K)-XTD(K))*CD(K)
      Q=(QC(K)+XX*(EF(K)-V))/(1.+XX*SATD)
      ERR=ABS(Q-EQ(K))
      IF(ERR.GT.ERRVOL)ERRVOL=ERR
      ED(K)=D
      EQ(K)=Q
C
C       MACHINE SUBTRANSIENT VOLTAGES
      IF(MODEL(K).LE.3)GOTO 32
      XX=DTX(K)
      D=(DTC(K)+XX*(XSQ(K)-XTTQ(K))*CQ(K))/(1.+XX*SATQ)
      ERR=ABS(D-ETTD(K))
      IF(ERR.GT.ERRVOL)ERRVOL=ERR
```

```
      XX=QTX(K)
      V=(XTD(K)-XTTD(K))*CD(K)
      Q=(QTC(K)+XX*(EQ(K)*(1.+SATD)-V))/(1.+XX*SATD)
      ERR=ABS(Q-ETTQ(K))
      IF(ERR.GT.ERRVOL)ERRVOL=ERR
   32 ETTD(K)=D
      ETTQ(K)=Q
  100 CONTINUE
C
   82 RETURN
      close (10 , status='keep')
      close (20 , status='keep')
      END
      SUBROUTINE EXTRA
C         EXTRAPOLATION OF NON-INTEGRABLE VARIABLES
C
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
      COMMON/G1/PT(20),QT(20),PE(20),H(20),DA(20),TQ(20),TD(20)
      COMMON/G3/KBUS(20),KK(20),CD(20),CQ(20)
      COMMON/DIF1/DEL(20),W(20),EF(20),PM(20)
      COMMON/MCSAT/SATFAC(20),XP(20),SD(20),SQ(20)
      COMMON/G5/EX1PE(20),EX1CD(20),EX1CQ(20),EX1SD(20),EX1SQ(20)
      COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
      COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
      COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
C
      open (unit = 10 ,file ='DC3F2.dat',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      IF(MC.GE.2)GOTO 99
      IF(MC.EQ.0)GOTO 5
    2 DO 3 K=1,KG
      EX1PE(K)=PE(K)
      EX1CD(K)=CD(K)
      EX1CQ(K)=CQ(K)
      EX1SD(K)=SD(K)
      EX1SQ(K)=SQ(K)
    3 CONTINUE
      GOTO 90
C
    5 CONTINUE
      DO 6 K=1,KG
      E1=PE(K)
      E2=CD(K)
      E3=CQ(K)
      E5=SD(K)
      E6=SQ(K)
      PE(K)=E1+E1-EX1PE(K)
      CD(K)=E2+E2-EX1CD(K)
      CQ(K)=E3+E3-EX1CQ(K)
      SD(K)=E5+E5-EX1SD(K)
```

```
      SQ(K)=E6+E6-EX1SQ(K)
C
      IF(MS.EQ.-1)GOTO 6
      EX1PE(K)=E1
      EX1CD(K)=E2
      EX1CQ(K)=E3
      EX1SD(K)=E5
      EX1SQ(K)=E6
    6 CONTINUE
C
   90 IF(NR.EQ.0)GOTO 93
      CALL AVREXT
   93 CONTINUE
   99 RETURN
      close (10 , status='keep')
      close (20 , status='keep')
      END
      SUBROUTINE SOL
C          SOLUTION OF INTEGRABLE AND NON-INTEGRABLE VARIABLES
C                    SIMULTANEOUSLY
      COMMON/U1/NK,NL,NA,NANK,LIMAX,IN,IR
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
      COMMON/ERRORS/ERRVOL,ERRDEL,ERRPOW,ERRAVR,ERRMOT,ERRDC,ERRCON
      COMMON/BUS1/VKR(50),VKM(50),CKR(50),CKM(50),BUS(50)
      COMMON/G1/PT(20),QT(20),PE(20),H(20),DA(20),TQ(20),TD(20)
      COMMON/G2/XTD(20),XTQ(20),XSD(20),XSQ(20),RA(20)
      COMMON/G3/KBUS(20),KK(20),CD(20),CQ(20)
      COMMON/G6/COSDEL(20),SINDEL(20)
      COMMON/G7/XTTQ(20),XTTD(20),TTQ(20),TTD(20)
      COMMON/MCSAT/SATFAC(20),XP(20),SD(20),SQ(20)
      COMMON/DIF1/DEL(20),W(20),EF(20),PM(20)
      COMMON/DIF2/EQ(20),ED(20),ETTQ(20),ETTD(20)
      COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
      COMMON/SW2/TPS(20),SS(20),STM(20),ITYPE(20),STMD(20)
      COMMON/ADD/VKRL(50),VKMG(50)
      COMMON/BL1/VSEC(50),SSI(50),PHI(50),DI(50)
      COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
      COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
      COMMON/YZAHRA/GA,GB,PASS,ALPHA,GU,GLIM,FYU,FYLIM,YY(16),ZZ(16),
     *SPTOT
      VSN=1.E-15
C
      open (unit = 10 ,file ='DC3F2.dat',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      open (unit = 30 ,file ='DC3F22.out',status='old')
      IF(TSTEP.LE.VSN)GOTO 5
C      INITIAL SOLUTION OF DIFFERENTIABLE EQUATIONS
CALL TRAP
C
C      ITERATIVE SOLUTION OF MACHINES AND NETWORK
```

```
    5 CONTINUE
      ITER= 0
    1 CONTINUE
      ITER=ITER+1
      IF (ITER .GT. MAXIT) GO TO 110
      DO 10 N=1,NK
      CKR(N)=0.
      CKM(N)=0.
   10 CONTINUE
   20 DO 50 K=1,KG
      R1= DEL(K)
      SI=SIN(R1)
      CO=COS(R1)
      SINDEL(K)=SI
      COSDEL(K)=CO
      N=KBUS(K)
      VR=VKR(N)
      VM=VKM(N)
      R1=RA(K)
      XDD=XTTD(K)
      XQQ=XTTQ(K)
      XX=(XDD+XQQ)*0.5
C       WRITE(30,*)'R1',R1,'XDD',XDD,'XQQ',XQQ
      DET=1./(R1*R1+XDD*XQQ)
      CR=(R1*VR+XX*VM)*DET
      CM=(R1*VM-XX*VR)*DET
      EVD=ETTD(K)
      EVQ=ETTQ(K)
      CALL CMUL(EVQ,EVD,SI,CO,EM,ER)
      CALL CMUL(VR,VM,SI,CO,VBD,VBQ)
      I=1
C        CALCULATE SD,SQ,XDSAT,XQSAT AND DET
      CALL  SATN(K,I,ITER,VBD,VBQ,XDSAT,XQSAT,DET)
      EVD=EVD-VBD
      EVQ=EVQ-VBQ
      XX=(XDSAT+XQSAT)*0.5
      CALL CMUL(EVQ,EVD,R1,XX,CQQ,CDD)
      CDD=CDD*DET
      CQQ=CQQ*DET
      CALL CMUL(CQQ,CDD,SI,CO,CMM,CRR)
      CR=CR+CRR
      CM=CM+CMM
      XX=(XDSAT-XQSAT)*0.5*DET
      CRR=XX*(EM-VM)
      CMM=XX*(ER-VR)
      SI2=2.*SI*CO
      CO2=CO*CO-SI*SI
      CALL CMUL(CRR,CMM,CO2,SI2,CRR,CMM)
      CKR(N)=CKR(N)+CR+CRR
      CKM(N)=CKM(N)+CM+CMM
   50 CONTINUE
C
      DO 60 N=1,NK
      VKR(N)=CKR(N)
```

```
      VKM(N)=CKM(N)
   60 CONTINUE
C
C     WRITE(30,*)'YMAHDI 2  '
      CALL BIFA4
C
      ERRDEL=0.
      ERRVOL=0.
      ERRPOW=0.
      ERRAVR=0.
      ERRMOT=0.
      ERRDC=0.
      ERRCNT=0.
      ERRCON=0.
      ISWD=0
      IF(IDC.EQ.0)GO TO 64
      DO 59 I=2,KM
IF(STMD(I).GT.TIME)GO TO 64
ISWD=1
 59   CONTINUE
DO 61 N=1,NK
      CKR(N)=0.
      CKM(N)=0.
      VKRL(N)=VKR(N)
      VKMG(N)=VKM(N)
   61 CONTINUE
      IF(ITER.EQ.1)GO TO 64
      IF(ISWD.EQ.0)GO TO 64
CALL DCSOL
C     WRITE(30,*)'YMAHDI 3  '
      IF(IDDV.EQ.1)GO TO 64
      DO 62 N=1,NK
      VKR(N)=CKR(N)
      VKM(N)=CKM(N)
   62 CONTINUE
      CALL BIFA4
C     WRITE(30,*)'YMAHDI 4  '
      DO 63 N=1,NK
      VKR(N)=VKR(N)+VKRL(N)
      VKM(N)=VKM(N)+VKMG(N)
   63 CONTINUE
   64 CONTINUE
      IF(NR.EQ.0)GOTO 65
      CALL AVRSOL
C     WRITE(30,*)'YMAHDI 5  '
   65 IF(JJ.EQ.0)GOTO 100
C
   70 DO 80 K=1,KG
C     WRITE(30,*)'YMAHDI 5.1',K
      N=KBUS(K)
      CALL CMUL(VKR(N),VKM(N),SINDEL(K),COSDEL(K),VBD,VBQ)
      I=2
C      CALCULATE SD,SQ,CD AND CQ
C     WRITE(30,*)'YMAHDI 5.5'
```

```
      CALL SATN(K,I,ITER,VBD,VBQ,XDSAT,XQSAT,DET)
C       WRITE(30,*)'YMAHDI 6  ','K= ',K
C       WRITE(30,*)'DET',DET,'XQSAT',XQSAT,'XDSAT',XDSAT
      P=VBD*CD(K)+VBQ*CQ(K)
C       WRITE(30,*)'11=='
      P=P+(CD(K)*CD(K)+CQ(K)*CQ(K))*RA(K)
C       WRITE(30,*)'22=='
      P1=ABS(P-PE(K))
IF(P1.GT.ERRPOW)ERRPOW=P1
PE(K)=P
80 CONTINUE

      IF(NM.EQ.0)GOTO 90
      J=2
   90 IF(TSTEP.LE.VSN)GOTO 95
CALL TRAP
C
   95 E=0.0005
      IF(ERRDEL.GT.E)GOTO 1
      IF(ERRVOL.GT.E)GOTO 1
      IF(ERRAVR.GT.E)GOTO 1
      IF(ERRMOT.GT.E)GOTO 1
C     IF(ERRDC.GT.E)GO TO 1
C     IF(ERRCON.GT.E)GO TO 1
      IF(VSN.GT.TSTEP)E=0.0006
      IF(ERRPOW.GT.E)GOTO 1
  100 CONTINUE
      IF(ITER.GT.ITS)ITS=ITER
      RETURN
  110 WRITE(20,1000)MAXIT,ERRDEL,ERRVOL,ERRPOW,ERRAVR,ERRMOT,ERRDC,ERRCON
      TIME=TMAX+100.
c      call genop
      RETURN
C
 1000 FORMAT(//31X,26H SOLUTION NOT CONVERGED INI4,
     * 28H ITERATIONS, DUE TO EITHER -//
     * 46X,19HGEN/TURB MECH EQUNSF9.5/46X,19HGENERATOR VOLTAGES F9.5/
     * 46X,19HGOVERNOR(S)       F9.5/46X,19HA.V.R.(S).       F9.5/
     * 43X,22HOR INDUCTION MOTOR(S) F9.5/
     * 43X,'OR DC EQUATIONS  ',F9.5/
     * 43X,'OR CONTROLLER EQS. ',F9.5)
      close (10 , status='keep')
      close (20 , status='keep')
      close (30 , status='keep')
      END
SUBROUTINE GENOP
C              PRINTOUT OF SYNCH. M/C CONDITIONS
C
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
      COMMON/U4/JSM,NRBUS,ANGMAX,NO,PINT,PINT2,PTM,IPRE,PRTIME,NOPT,SP41
      COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
      COMMON/U8/TSTIME
      COMMON/BUS1/VKR(50),VKM(50),CKR(50),CKM(50),BUS(50)
```

```
      COMMON/G2/XTD(20),XTQ(20),XSD(20),XSQ(20),RA(20)
      COMMON/G3/KBUS(20),KK(20),CD(20),CQ(20)
      COMMON/G6/COSDEL(20),SINDEL(20)
      COMMON/G7/XTTQ(20),XTTD(20),TTQ(20),TTD(20)
      COMMON/MCSAT/SATFAC(20),XP(20),SD(20),SQ(20)
      COMMON/DIF1/DEL(20),W(20),EF(20),PM(20)
      COMMON/DIF2/EQ(20),ED(20),ETTQ(20),ETTD(20)
      COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
      COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
      COMMON/BLD/XC(50),V1(50),PDS(50),QDS(50)
      COMMON/CONTROL/SIG1,SIG2,SP1(10),ANG1(10),Y1DX,Y1DX2,DIS1,DIS2
      COMMON/CONTROL1/PMECH1(10),PT1(10),PA(10)
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
      COMMON/YZAHRA/GA,GB,PASS,ALPHA,GU,GLIM,FYU,FYLIM,YY(16),ZZ(16),
     *SPTOT
      INTEGER NNNN
C
      open (unit = 10 ,file ='DC3F2.dat',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      open (unit = 30 ,file ='DC3F22.out',status='old')
      open (unit = 70 ,file ='ABC.OUT',status='old')
C       IF(PASS.NE.0.0) GOTO 1234
C       WRITE(70,*)'INITIAL ZSUM',ZSUM
      DO 899 I=1,10
      PA(I)=0.0
      PMECH1(I)=0.0
      PT1(I)=0.0
      SP1(I)=0.0
  899 ANG1(I)=0.0
      DO 9111 I=1,20
 9111 ZSUM(I)=0.0
  902 INSTAB=0
      IF(JJ.EQ.0)GOTO 905
      IF(PASS.NE.0.0) GOTO 1251
      WRITE(20,957)JSM,JJ,ITS,TIME,NO
 1251 continue
      GOTO 910
  905 CONTINUE
      IF(PASS.NE.0.0) GOTO 1252
      WRITE(20,950)
 1252 continue
C
  910 continue
c  910 WRITE(20,953)
C       WRITE(30,*)TPLOT(IPLOT)
      NNNN=0
      DO 920 K=1,KG
      N=KBUS(K)
      IF(NRBUS.EQ.0)GOTO 911
      IF(K.EQ.NRBUS)GOTO 911
      ANG=(DEL(K)-DEL(NRBUS))*57.2958
      R1=ANG
```

```
      GOTO 912
  911 ANG=DEL(K)*57.2958
      R1=ANG-DEL(1)*57.2958
  912 VL=W(K)-2*F
      SP=VL/(2.*F)
      PMECH=PM(K)*VA
      IF (ABS(R1) .GT. ANGMAX) INSTAB=1
      VR=VKR(N)
      VM=VKM(N)
      CALL CMUL(VR,VM,SINDEL(K),COSDEL(K),VD,VQ)
      VV=SQRT(VR*VR+VM*VM)
      PT=(VD*CD(K)+VQ*CQ(K))*VA
      QT=(VQ*CD(K)-VD*CQ(K))*VA
      CT=SQRT(CD(K)*CD(K)+CQ(K)*CQ(K))
      Q=SD(K)*ETTQ(K)+(XSD(K)-XTTD(K))*CD(K)
      IF(PASS.NE.0.0) GOTO 1253
      WRITE(20,951) BUS(N),KK(K),ANG,SP,PMECH,PT,QT,VV,CT,EF(K),Q
 1253 continue
C     IF(BUS(N).NE.BURD) GO TO 1122
      IF(PASS.NE.0.0) GOTO 1122
      IF((K).EQ.4) WRITE(70,992) BUS(N),TIME,PT,VV
 1122 CONTINUE
      NNNN=NNNN+1
      PMECH1(NNNN)=PMECH
      PT1(NNNN)=PT
      PA(NNNN)=PMECH1(NNNN)-PT1(NNNN)
      ANG1(NNNN)=ANG
      SP1(NNNN)=SP
      IF(K.EQ.NRBUS)WRITE(20,958)
  920 CONTINUE
      SPTOT=0.0
      DO 1195 J=1,KG
 1195 SPTOT=SPTOT+abs(SP1(J))
c     WRITE(30,*)TIME,(PA(I),I=1,NNNN)
      IF(PASS.NE.0.0) GOTO 1254
      WRITE(30,971)TIME,(ANG1(I),I=1,NNNN)
 1254 continue
      IF(JJ.EQ.0.AND.NRBUS.NE.0)WRITE(20,959)
C
C           OTHER OUTPUTS
      IF(IDC.EQ.0)GO TO 921
C     IF(ISWD.EQ.0)GO TO 921
      IF(PASS.NE.0.0) GOTO 1255
      CALL DCOUT
 1255  continue
  921 CONTINUE
      IF(IA.EQ.0)GOTO 922
      CALL AVROP
  922 CONTINUE
  924 IF(JJ.EQ.0)GOTO 925
      IF(KO.LE.2)GOTO 926
  925 CALL BUSOP
  926 GOTO(999,927,999,927),KO
  927 CALL MONLOP
```

```
C
 999 ITS=0
     IF(INSTAB.EQ.0)GOTO 990
C
C       MAXIMUM ANGLE EXCEEDED
     WRITE(20,955)ANGMAX
     TIME=TMAX+100.
 990 WRITE(20,952)
C     WRITE(30,*)' HELLO AGAIN'
C     WRITE(30,*)'TIME=',TIME,'TSTIME',TSTIME
     IF(TIME.LT.TSTIME) GOTO 1234
     DO 1111 I=1,KG
     IF(VSEC(MD).EQ.XZ(1)) GOTO 2050
c     WRITE(30,*) 'PMECH',PMECH1(I),'PT1',PT1(I)
     ZSUM(1)=ZSUM(1)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(VSEC(MD)-XZ(1)))
 2050 IF(VSEC(ND).EQ.XZ(2)) GOTO 2150
     ZSUM(2)=ZSUM(2)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(VSEC(ND)-XZ(2)))
 2150 IF(VSEC(IP).EQ.XZ(3)) GOTO 2250
     ZSUM(3)=ZSUM(3)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(VSEC(IP)-XZ(3)))
 2250 IF(SI(MD).EQ.XZ(4)) GOTO 2350
     ZSUM(4)=ZSUM(4)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(SI(MD)-XZ(4)))
 2350 IF(SI(ND).EQ.XZ(5)) GOTO 2450
     ZSUM(5)=ZSUM(5)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(SI(ND)-XZ(5)))
 2450 IF(SI(IP).EQ.XZ(6)) GOTO 2550
     ZSUM(6)=ZSUM(6)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(SI(IP)-XZ(6)))
 2550 IF(V1(MD).EQ.XZ(7)) GOTO 2650
     ZSUM(7)=ZSUM(7)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(V1(MD)-XZ(7)))
 2650 IF(V1(ND).EQ.XZ(8)) GOTO 2750
     ZSUM(8)=ZSUM(8)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(V1(ND)-XZ(8)))
 2750 IF(V1(IP).EQ.XZ(9)) GOTO 2850
     ZSUM(9)=ZSUM(9)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(V1(IP)-XZ(9)))
 2850 IF(PHI(MD).EQ.XZ(10)) GOTO 2950
     ZSUM(10)=ZSUM(10)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(PHI(MD)-XZ(10)))
 2950 IF(PHI(ND).EQ.XZ(11)) GOTO 3050
     ZSUM(11)=ZSUM(11)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(PHI(ND)-XZ(11)))
 3050 IF(PHI(IP).EQ.XZ(12)) GOTO 3150
     ZSUM(12)=ZSUM(12)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(PHI(IP)-XZ(12)))
 3150 IF(DI(MD).EQ.XZ(13)) GOTO 3250
     ZSUM(13)=ZSUM(13)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(DI(MD)-XZ(13)))
 3250 IF(DI(ND).EQ.XZ(14)) GOTO 3350
     ZSUM(14)=ZSUM(14)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(DI(ND)-XZ(14)))
 3350 IF(DI(IP).EQ.XZ(15)) GOTO 3450
     ZSUM(15)=ZSUM(15)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(DI(IP)-XZ(15)))
 3450 IF(COAI.EQ.XZ(16)) GOTO 1111
     ZSUM(16)=ZSUM(16)-2*(PMECH1(I)-PT1(I))*ABS(PA(I)/(COAI-XZ(16)))
 1111 continue
c c     DO 1350 I=1,16
c c1350 WRITE(30,*) 'SSSSH',ZSUM(I)
     XZ(1)=VSEC(MD)
     XZ(2)=VSEC(ND)
     XZ(3)=VSEC(IP)
     XZ(4)=SI(MD)
     XZ(5)=SI(ND)
     XZ(6)=SI(IP)
```

```
      XZ(7)=V1(MD)
      XZ(8)=V1(ND)
      XZ(9)=V1(IP)
      XZ(10)=PHI(MD)
      XZ(11)=PHI(ND)
      XZ(12)=PHI(IP)
      XZ(13)=DI(MD)
      XZ(14)=DI(ND)
      XZ(15)=DI(IP)
      XZ(16)=COAI
C     WRITE(30,*) ' ACTUAL ZSUM =  ',ZSUM
 1234 CONTINUE
      RETURN
C
  950 FORMAT(//51X,18HINITIAL CONDITIONS/51X,18(1H-)/)
  951 FORMAT(12X,A4,I3,F9.2,F10.4,3F11.3,4F10.3)
  971 FORMAT(F8.4,',',F9.2,',',F9.2,',',F9.2,',',F9.2,',',F9.2,',',F9.2)
  952 FORMAT(/1X,119(1H-))
  992 FORMAT(12X,A4,3X,F8.4,F9.2,F9.2)
  953 FORMAT(50X,20HSYNCHRONOUS MACHINES//
     * 9X,6HBUSBAR,2X,3HM/C,3X,5HROTOR,5X,5HROTOR,5X,5HMECH.,8X,
     * 12HPOWER OUTPUT,8X,5HTERM.,5X,5HTERM.2(5X,5HFIELD)/
     * 10X,4HNAME,3X,3HNO.,3X,5HANGLE,5X,4HSLIP, 6X,5HPOWER,5X,6HACTIVE,
     * 4X,8HREACTIVE,4X,7HVOLTAGE,3X,7HCURRENT,3X,7HVOLTAGE3X,7HCURRENT/
     * 22X,7HDEGREES,5X,4HP.U.,6X,2HMW,9X,2HMW,8X,5HMVAR ,4(6X,4HP.U.)/)
 2001 FORMAT(//9X,39HRATE OF CHANGE OF KINETIC ENERGY P.U. =,
     *2X,F10.5/50X,10(1H-))
  955 FORMAT(//35X,35HSYNCHRONOUS MACHINE ANGLE LIMIT OF ,F6.1,
     * 9H EXCEEDED)
  957 FORMAT(/11H SYSTEM NO.I3,4X,8HCASE NO.I3,75X,13HMAX. ITS/STEPI3/
     * 38X,6HTIME =,F7.4,6H SECS.,10X,10HSTEP NO.= ,I4/)
  958 FORMAT(1H+,19X,1H*,8X,1H*)
  959 FORMAT(/19X,36HREFERENCE MACHINE DENOTED BY - *    ,
     * 52HTHE ANGLE OF THIS MACHINE IS RELATIVE TO SYSTEM ZERO)
      close (10 , status='keep')
      close (20 , status='keep')
      close (30 , status='keep')
      close (70 , status='keep')
      END

      SUBROUTINE DCINP
      COMMON/U1/NK,NL,NA,NANK,LIMAX,IN,IR
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
      COMMON/U4/JSM,NRBUS,ANGMAX,NO,PINT,PINT2,PTM,IPRE,PRTIME,NOPT,SP41
      COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
      COMMON/U8/TSTIME
      COMMON/BUS1/VKR(50),VKM(50),CKR(50),CKM(50),BUS(50)
      COMMON/BUS2/GG(50),BB(50),PL(50),QL(50)
      COMMON/BRANCH/IL(100),KL(100),GL(100),BL(100)
      COMMON/BLD/XC(50),VD(50),PDS(50),QDS(50)
      COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
      COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
      COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
```

```
      COMMON/BL4/TR,TI,TP,BR,BI,BP,CRK,CKI,CKP,CK1,CK2,CK3
      COMMON/BL5/DIX(50),DICN(50),VIC(50),DCX(50)
      COMMON/BL6/TRR,TPP,TII,TRC,TIC,TPC,TKX1,TX1,TKX2,TX2
      COMMON/SW2/TPS(20),SS(20),STM(20),ITYPE(20),STMD(20)
      COMMON/CONTROL/SIG1,SIG2,SP1(10),ANG1(10),Y1DX,Y1DX2,DIS1,DIS2
      COMMON/CONTROL1/PMECH1(10),PT1(10),PA(10)
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
C     COMMON/CNTRL4/VMD,VND,VIP,THM,THN,THP
      DATA END/4HEND /
      open (unit = 10 ,file ='DC3F2.dat',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      open (unit = 30 ,file ='DC3F22.out',status='old')
C     WRITE(30,*)'DCINP'
      WRITE(20,39)
      WRITE(20,40)
      READ(10,555)AD,BD,CD
      CALL COMP8(AD,END,L)
      IF(L.EQ.1)GO TO 556
      IDC=1
      READ(10,*) DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,TR,TI,TP,BR,BI,BP
      DO 3 I=1,NK
      IF(AD.EQ.BUS(I))MD=I
      IF(BD.EQ.BUS(I))ND=I
      IF(CD.EQ.BUS(I))IP=I
    3 CONTINUE
      WRITE(20,41)MD,ND,IP
      READ(10,*)DI(ND),DI(IP),VD(ND),VD(IP)
      WRITE(20,42)DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,TR,TI,TP,BR,BI,BP
      READ(10,*)XC(MD),XC(ND),XC(IP)
      READ(10,*)RDR,RDI,RDP,MAXTR,PDI,PDP
      PDR=PDI+PDP
      WRITE(20,43)RDR,RDI,RDP
      READ(10,*)SI(MD),SI(ND),SI(IP)
      WRITE(20,44)SI(MD),SI(ND),SI(IP)
      READ(10,*)TRR,TII,TPP,TRC,TIC,TPC,TKX1,TX1,TKX2,TX2
      WRITE(6,*)TRR,TII,TPP,TRC,TIC,TPC
      PI=3.14159
      DO 4 I=1,16
      DO 4 J=1,17
      A(I,J)=0.
    4 CONTINUE
      VMD=SQRT(VKR(MD)*VKR(MD)+VKM(MD)*VKM(MD))
      THM=ATAN2(VKM(MD),VKR(MD))
      VND=SQRT(VKR(ND)*VKR(ND)+VKM(ND)*VKM(ND))
      THN=ATAN2(VKM(ND),VKR(ND))
      VIP=SQRT(VKR(IP)*VKR(IP)+VKM(IP)*VKM(IP))
      THP=ATAN2(VKM(IP),VKR(IP))
      VSEC(MD)=TR*VMD
      VSEC(ND)=TI*VND
      VSEC(IP)=TP*VIP
      RAD=PI/180.
      ALSR=ALSR*RAD
```

```
      ALSI=ALSI*RAD
      ALSP=ALSP*RAD
      SI(MD)=SI(MD)*RAD
      SI(ND)=SI(ND)*RAD
      SI(IP)=SI(IP)*RAD
      CK1=PI/6.
      CK2=CK1
      CK3=CK1
      CRK=1./TR
      CKI=1./TI
      CKP=1./TP
      DI(MD)=DI(ND)+DI(IP)
      VD(MD)=VD(ND)+RDR*DI(MD)+RDI*DI(ND)
      PFR=VD(MD)/(CRK*VMD)
      PFI=VD(ND)/(CKI*VND)
      PFP=VD(IP)/(CKP*VIP)
     PHI(MD)=THM-ACOS(PFR)
      PHI(ND)=THN+ACOS(PFI)
      PHI(IP)=THP+ACOS(PFP)
      AIR=PHI(MD)/RAD
      AII=PHI(ND)/RAD
      AIP=PHI(IP)/RAD
      COAR=(VD(MD)+CK1*XC(MD)*DI(MD))/(CRK*VMD)
      COAI=(VD(ND)+DI(ND)*CK2*XC(ND))/(CKI*VND)
      COAP=(VD(IP)+DI(IP)*CK3*XC(IP))/(CKP*VIP)
C       WRITE(30,*)'COAR',COAR,'COAI',COAI,'COAP',COAP
      FIR=ACOS(COAR)/RAD
      FII=ACOS(COAI)/RAD
      FIP=ACOS(COAP)/RAD
     PDS(MD)=VD(MD)*DI(MD)
     PDS(ND)=VD(ND)*DI(ND)
     PDS(IP)=VD(IP)*DI(IP)
     QDS(MD)=0.6*PDS(MD)
     QDS(ND)=0.6*PDS(ND)
     QDS(IP)=0.6*PDS(IP)
      WRITE(20,45)VD(MD),VD(ND),VD(IP)
     WRITE(20,46)DI(MD),DI(ND),DI(IP),AIR,AII,AIP
C     WRITE(30,*)'WAKE UP00',MD,ND,IP,DI(MD),DI(ND),DI(IP)
     WRITE(20,47)FIR,FII,FIP
C************* FORMATS*****************************************************
   39 FORMAT(/50X,'DC LINK INPUT DATA'/
     140X,'---------------------------------------')
   40 FORMAT(/30X,'RECTIFIER',10X,'INVERTOR(I)',10X,'INVERTOR(P)')
   41 FORMAT(10X,'BUSBAR NUMBER',10X,I4,15X,I4,15X,I4)
   42 FORMAT(10X,'SPECFIED CURRENTS IN PU',3X,F6.2,12X,F6.2,14X,F6.2/
     110X,'SPECFIED ANGLES IN DEG',3X,F6.2,10X,F6.2,15X,F6.2/
     210X,'TRAN TAP RATIO IN PU',3X,F6.2,12X,F6.2,15X,F6.2/
     310X,'SYSTEM ADMIT. IN PU',3X,F6.2,12X,F6.2,15X,F6.2)
   43 FORMAT(10X,'DC RESISTANCE=',3X,F9.4,12X,F9.4,13X,F9.4)
   44 FORMAT(10X,'SECONDARY ANGLES',3X,F9.3,12X,F9.3,13X,F9.3)
   45 FORMAT(10X,'DIRECT VOLT$$.IN PU',3X,F6.2,12X,F6.2,17X,F6.2)
   46 FORMAT(10X,'DIRECT CURRENT IN PU',3X,F6.2,12X,F6.2,13X,F6.2/
     110X'CURRENT ANGLES',7X,F12.4,13X,F12.4,15X,F12.4)
   47 FORMAT(10X,'FIRING ANGLES',7X,F6.2,13X,F6.2,16X,F6.2)
```

```
 555  FORMAT(3A4)
 556  CONTINUE
C     IF(TIME.GE.TSTIME)CALL CONINP
      RETURN
      close (10 , status='keep')
      close (20 , status='keep')
      close (30 , status='keep')
      END
      SUBROUTINE DCSOL
      COMMON/U1/NK,NL,NA,NANK,LIMAX,IN,IR
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
      COMMON/U4/JSM,NRBUS,ANGMAX,NO,PINT,PINT2,PTM,IPRE,PRTIME,NOPT,SP41
      COMMON/BUS1/VKR(50),VKM(50),CKR(50),CKM(50),BUS(50)
      COMMON/BUS2/GG(50),BB(50),PL(50),QL(50)
      COMMON/BRANCH/IL(100),KL(100),GL(100),BL(100)
C     COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
      COMMON/BLD/XC(50),VD(50),PDS(50),QDS(50)
      COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
      COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
      COMMON/BL4/TR,TI,TP,BR,BI,BP,CRK,CKI,CKP,CK1,CK2,CK3
      COMMON/BL5/DIX(50),DICN(50),VIC(50),DCX(50)
      COMMON/BL6/TRR,TPP,TII,TRC,TIC,TPC,TKX1,TX1,TKX2,TX2
      COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
      COMMON/SW2/TPS(20),SS(20),STM(20),ITYPE(20),STMD(20)
      COMMON/ADD/VKRL(50),VKMG(50)
C     COMMON/CONTROL/SIG,SP1(10),ANG1(10),SDX
      COMMON/CONTROL/SIG1,SIG2,SP1(10),ANG1(10),Y1DX,Y1DX2,DIS1,DIS2
      COMMON/CONTROL1/PMECH1(10),PT1(10),PA(10)
      COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
      COMMON/YZAHRA/GA,GB,PASS,ALPHA,GU,GLIM,FYU,FYLIM,YY(16),ZZ(16),
     *SPTOT
C     COMMON/CNTRL4/VMD,VND,VIP,THM,THN,THP
c     REAL VMD,VND,VIP,THM,THN,THP
      open (unit = 10 ,file ='DC3F2.dat',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      open (unit = 30 ,file ='DC3F22.out',status='old')
      open (unit = 60 ,file ='ddd.out',status='old')
C     IF(PASS.EQ.1.0) GO TO 2233
C     IF(PASS.EQ.2.0) GO TO 3344
C     WRITE(30,*)'WAKE UP33',MD,ND,IP,DI(MD),DI(ND),DI(IP),TKX,TX
C     CALL CONINP
C     ZSUM=55555.0
C     CALL LNRP
C     WRITE(30,*)'DCSOL'
C     WRITE(30,*)'WAKE UP44 ',DI(MD),DI(ND),DI(IP)
      VMD=SQRT(VKRL(MD)*VKRL(MD)+VKMG(MD)*VKMG(MD))
      VND=SQRT(VKRL(ND)*VKRL(ND)+VKMG(ND)*VKMG(ND))
      VIP=SQRT(VKRL(IP)*VKRL(IP)+VKMG(IP)*VKMG(IP))
      THM=ATAN2(VKMG(MD),VKRL(MD))
      THN=ATAN2(VKMG(ND),VKRL(ND))
```

```
      THP=ATAN2(VKMG(IP),VKRL(IP))
      VSEC(MD)=TR*VMD
      VSEC(ND)=TI*VND
      VSEC(IP)=TP*VIP
      WRITE(60,*)'VSEC(IP)',VSEC(IP)
      WRITE(60,*)'VSEC(ND)',VSEC(ND)
      SI(MD)=THM
      SI(ND)=THN
      SI(IP)=THP
      WRITE(60,*)'SI(IP)',SI(IP)
      DO 4 I=1,16
      DO 4 J=1,17
      A(I,J)=0.
    4 CONTINUE
      IDDV=0
      ITERR=0
      AA=VMD*COS(ALSR)
      BDI=VND*COS(ALSI)
      CC=VIP*COS(ALSP)
C     GO TO 7
      IF(CC.LE.BDI.AND.CC.LE.AA)GO TO 6
      IF(AA.LE.BDI)GO TO 7
      COAI=COS(ALSI)
      LL=1
      VD(ND)=CKI*VND*COAI-CK1*XC(ND)*DI(ND)
      VD(MD)=VD(ND)+RDR*DI(MD)+RDI*DI(ND)
      VD(IP)=VD(MD)-RDR*DI(MD)-RDP*DI(IP)
      COAR=(VD(MD)+CK1*XC(MD)*DI(MD))/(CRK*VMD)
      COAP=(VD(IP)+DI(IP)*CK3*XC(IP))/(CKP*VIP)
      IF(COAR.GT.COS(ALSR))COAR=COS(ALSR)
      IF(COAP.GT.COS(ALSP))COAP=COS(ALSP)
      GO TO 8
    7 CONTINUE
      COAR=COS(ALSR)
      LL=2
      VD(MD)=CRK*VMD*COAR-CK1*XC(MD)*DI(MD)
      VD(ND)=VD(MD)-RDR*DI(MD)-RDI*DI(ND)
      VD(IP)=VD(MD)-RDR*DI(MD)-RDP*DI(IP)
      COAI=(VD(ND)+DI(ND)*CK2*XC(ND))/(CKI*VND)
      COAP=(VD(IP)+DI(IP)*CK3*XC(IP))/(CKP*VIP)
      IF(COAI.GT.COS(ALSI))COAI=COS(ALSI)
      IF(COAP.GT.COS(ALSP))COAP=COS(ALSP)
      GO TO 8
    6 CONTINUE
      COAP=COS(ALSP)
      LL=3
      VD(IP)=CKP*VIP*COAP-CK1*XC(IP)*DI(IP)
      VD(MD)=VD(IP)+RDR*DI(MD)+RDI*DI(IP)
      VD(ND)=VD(MD)-RDR*DI(MD)-RDI*DI(ND)
      COAR=(VD(MD)+CK1*XC(MD)*DI(MD))/(CRK*VMD)
      COAI=(VD(ND)+DI(ND)*CK2*XC(ND))/(CKI*VND)
      IF(COAI.GT.COS(ALSI))COAI=COS(ALSI)
      IF(COAR.GT.COS(ALSR))COAR=COS(ALSR)
    8 CONTINUE
```

```
      PFR=VD(MD)/(CRK*VMD)
      PFI=VD(ND)/(CKI*VND)
      PFP=VD(IP)/(CKP*VIP)
      WRITE(60,*)'VND',VND,'VIP',VIP,'PFR',PFR,'PFI',PFI,'PFP',PFP
      WRITE(60,*)'VD(ND)',VD(ND),'CKI',CKI
     PHI(MD)=THM-ACOS(PFR)
      PHI(ND)=THN+ACOS(PFI)
      PHI(IP)=THP+ACOS(PFP)
   50 CONTINUE
     CPM=COS(PHI(MD))
     CSM=COS(SI(MD))
     SIM=SIN(SI(MD))
     SPM=SIN(PHI(MD))
     CPN=COS(PHI(ND))
     CSN=COS(SI(ND))
     SII=SIN(SI(ND))
     SPN=SIN(PHI(ND))
     CPP=COS(PHI(IP))
     CSP=COS(SI(IP))
     SIP=SIN(SI(IP))
     SPP=SIN(PHI(IP))
C*********************************************************************
C    CHECK WHICH STATION CONTROLS CURRENT
C
C**********************************************************************
     R(1)=DI(MD)*CPM-BR*(TR*VSEC(MD)*SIM-VMD*SIN(THM))
     R(2)=DI(ND)*CPN-BI*(VND*SIN(THN)-TI*VSEC(ND)*SII)
     R(3)=DI(IP)*CPP-BP*(VIP*SIN(THP)-TP*VSEC(IP)*SIP)
     R(4)=DI(MD)*SPM-BR*(VMD*COS(THM)-TR*VSEC(MD)*CSM)
     R(5)=DI(ND)*SPN-BI*(TI*VSEC(ND)*CSN-VND*COS(THN))
     R(6)=DI(IP)*SPP-BP*(TP*VSEC(IP)*CSP-VIP*COS(THP))
     R(7)=VD(MD)-CRK*VMD*COAR+CK1*XC(MD)*DI(MD)
     R(8)=VD(ND)-CKI*VND*COAI+CK2*XC(ND)*DI(ND)
     R(9)=VD(IP)-CKP*VIP*COAP+CK3*XC(IP)*DI(IP)
     R(10)=VD(MD)-CRK*VMD*COS(THM-PHI(MD))
     R(11)=VD(ND)-CKI*VND*COS(THN-PHI(ND))
     R(12)=VD(IP)-CKP*VIP*COS(THP-PHI(IP))
     R(13)=DI(MD)-DI(ND)-DI(IP)
     R(14)=CRK*VMD*COAR-CKI*VND*COAI-DI(MD)*(RDR+CK1*XC(MD))-
    1DI(ND)*(RDI-CK2*XC(ND))
     R(15)=CRK*VMD*COAR-CKP*VIP*COAP-DI(MD)*(RDR+CK1*XC(MD))-
    1DI(IP)*(RDP-CK3*XC(IP))
     GO TO (11,12,13)LL
  11 R(16)=COAI-COS(ALSI)
     A(16,16)=-1.
     A(8,16)=CKI*VND
     A(14,16)=CKI*VND
     GO TO 14
  12 R(16)=COAR-COS(ALSR)
     A(7,16)=CRK*VMD
     A(14,16)=-CRK*VMD
     A(16,16)=-1.
C      A(15,16)=-CRK*VMD
     GO TO 14
```

```
 13 R(16)=COAP-COS(ALSP)
    A(9,16)=CKP*VIP
    A(15,16)=CKP*VIP
    A(16,16)=-1.
 14 CONTINUE
    DO 1 I=1,16
    IF(ABS(R(I)).GT.0.001)GO TO 16
  1 CONTINUE
    ANG=180./3.14159
    WRITE(60,*)'COAR',COAR,'COAI',COAI,'COAP',COAP

    FIR=ACOS(COAR)*ANG
    FII=ACOS(COAI)*ANG
    FIP=ACOS(COAP)*ANG
    PDS(MD)=VD(MD)*DI(MD)
    PDS(ND)=VD(ND)*DI(ND)
    PDS(IP)=VD(IP)*DI(IP)
    QDS(MD)=0.6*PDS(MD)
    QDS(ND)=0.6*PDS(ND)
    QDS(IP)=0.6*PDS(IP)
    CKR(MD)=-DI(MD)*CPM
    CKR(ND)=DI(ND)*CPN
    CKR(IP)=DI(IP)*CPP
    CKM(MD)=-DI(MD)*SPM
    CKM(ND)=DI(ND)*SPN
    CKM(IP)=DI(IP)*SPP
    RETURN
 16 CONTINUE
C  FORM JACOBIAN MATRIX ELEMENTS
    A(1,17)=R(1)
    A(2,17)=R(2)
    A(3,17)=R(3)
    A(4,17)=R(4)
    A(5,17)=R(5)
    A(6,17)=R(6)
    A(7,17)=R(7)
    A(8,17)=R(8)
    A(9,17)=R(9)
    A(10,17)=R(10)
    A(11,17)=R(11)
    A(12,17)=R(12)
    A(13,17)=R(13)
    A(14,17)=R(14)
    A(15,17)=R(15)
    A(16,17)=R(16)
    A(2,14)=-CPN
    A(5,14)=-SPN
    A(3,15)=-CPP
    A(6,15)=-SPP
    A(8,14)=-CK2*XC(ND)
    A(9,15)=-CK3*XC(IP)
    A(14,14)=RDI-CK2*XC(ND)
    A(13,14)=1.0
    A(13,15)=1.0
```

```
      A(1,13)=-CPM
      A(4,13)=-SPM
      A(7,13)=-CK1*XC(MD)
      A(14,13)=RDR+CK1*XC(MD)
      A(13,13)=-1.0
      A(1,1)=BR*TR*SIM
      A(1,4)=BR*TR*VSEC(MD)*CSM
      A(1,10)=DI(MD)*SPM
      A(2,2)=-BI*TI*SII
      A(2,5)=-BI*TI*VSEC(ND)*CSN
      A(2,11)=DI(ND)*SPN
      A(4,1)=-BR*TR*CSM
      A(4,4)=BR*TR*VSEC(MD)*SIM
      A(4,10)=-DI(MD)*CPM
      A(5,2)=TI*BI*CSN
      A(5,5)=-BI*TI*VSEC(ND)*SII
      A(5,11)=-DI(ND)*SPN
      A(7,7)=-1.0
      A(8,8)=-1.0
      A(10,7)=-1.
      A(11,8)=-1.
      A(10,10)=CRK*VMD*SIN(THM-PHI(MD))
      A(11,11)=CKI*VND*SIN(THN-PHI(ND))
      A(3,3)=-BP*TP*SIP
      A(3,6)=-BP*TP*VSEC(IP)*CSP
      A(3,12)=DI(IP)*SPP
      A(6,3)=BP*TP*CSP
      A(6,6)=BP*TP*VSEC(IP)*SIP
      A(6,12)=-DI(IP)*CPP
      A(9,9)=-1.0
      A(12,9)=-1.0
      A(12,12)=CKP*VIP*SIN(THP-PHI(IP))
      A(15,15)=RDP-CK3*XC(IP)
      A(15,13)=RDR+CK1*XC(MD)
CSTART ITERATION BY GAUS ELIMINATION
   51 CONTINUE
      ITERR=ITERR+1
      IF(ITERR.GE.MAXTR) GO TO 81

      CALL GAUS(A,X,16,16,17,DET,IND)
      IF(IND.EQ.1)GO TO 84
C UPDATE VARIABLES
   27 CONTINUE
      VSEC(MD)=VSEC(MD)+X(1)
      VSEC(ND)=VSEC(ND)+X(2)
      VSEC(IP)=VSEC(IP)+X(3)
      SI(MD)=SI(MD)+X(4)
      SI(ND)=SI(ND)+X(5)
      SI(IP)=SI(IP)+X(6)
      VD(MD)=VD(MD)+X(7)
      VD(ND)=VD(ND)+X(8)
      VD(IP)=VD(IP)+X(9)
      PHI(MD)=PHI(MD)+X(10)
      PHI(ND)=PHI(ND)+X(11)
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```
      PHI(IP)=PHI(IP)+X(12)
      DI(MD)=DI(MD)+X(13)
      DI(ND)=DI(ND)+X(14)
      DI(IP)=DI(IP)+X(15)
      IF(LL.EQ.1)COAI=COAI+X(16)
      IF(LL.EQ.2)COAR=COAR+X(16)
      IF(LL.EQ.3)COAP=COAP+X(16)
      CALL LNRP
      GO TO 50
 84   WRITE(20,85)
      RETURN
 81   WRITE(20,82)
C
C
C************************FORMATS***********************************
 82   FORMAT(10X,'SYSTEM NOT CONVERGED')
 85   FORMAT(10X,'*****SYSTEM NOT SOLVABLE*****')
      IF(PASS.EQ.0.0) GO TO 2233
 3344 CONTINUE
2233 CONTINUE
      RETURN
      close (10 , status='keep')
      close (20 , status='keep')
      close (30 , status='keep')
      close (60 , status='keep')
      END
      SUBROUTINE DCINC
      COMMON/U1/NK,NL,NA,NANK,LIMAX,IN,IR
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
      COMMON/U4/JSM,NRBUS,ANGMAX,NO,PINT,PINT2,PTM,IPRE,PRTIME,NOPT,SP41
      COMMON/BUS1/VKR(50),VKM(50),CKR(50),CKM(50),BUS(50)
      COMMON/BUS2/GG(50),BB(50),PL(50),QL(50)
      COMMON/BRANCH/IL(100),KL(100),GL(100),BL(100)
      COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
      COMMON/BLD/XC(50),VD(50),PDS(50),QDS(50)
      COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
      COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
      COMMON/BL4/TR,TI,TP,BR,BI,BP,CRK,CKI,CKP,CK1,CK2,CK3
      COMMON/BL5/DIX(50),DICN(50),VIC(50),DCX(50)
      COMMON/BL6/TRR,TPP,TII,TRC,TIC,TPC,TKX1,TX1,TKX2,TX2
      COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
      COMMON/SW2/TPS(20),SS(20),STM(20),ITYPE(20),STMD(20)
      COMMON/ADD/VKRL(50),VKMG(50)
C     COMMON/CONTROL/SIG,SP1(10),ANG1(10),SDX
      COMMON/CONTROL/SIG1,SIG2,SP1(10),ANG1(10),Y1DX,Y1DX2,DIS1,DIS2
      COMMON/CONTROL1/PMECH1(10),PT1(10),PA(10)
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
C     COMMON/CNTRL4/VMD,VND,VIP,THM,THN,THP
      open (unit = 10 ,file ='DC3F2.dat',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      open (unit = 30 ,file ='DC3F22.out',status='old')
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```
      open (unit = 60 ,file ='DDD.out',status='old')
C       WRITE(30,*)'DCINC'
C       WRITE(30,*)'WAKE UP8888',DI(MD),DI(ND),DI(IP)
      VMD=SQRT(VKR(MD)*VKR(MD)+VKM(MD)*VKM(MD))
c       RETURN
      THM=ATAN2(VKM(MD),VKR(MD))
      VND=SQRT(VKR(ND)*VKR(ND)+VKM(ND)*VKM(ND))
      THN=ATAN2(VKM(ND),VKR(ND))
      VIP=SQRT(VKR(IP)*VKR(IP)+VKM(IP)*VKM(IP))
      THP=ATAN2(VKM(IP),VKR(IP))
       VSEC(MD)=TR*VMD
       VSEC(ND)=TI*VND
       VSEC(IP)=TP*VIP
      WRITE(60,*)'VSEC(IP) 1 ',VSEC(IP)
      WRITE(60,*)'VSEC(ND) 1 ',VSEC(ND)
       SI(MD)=THM
       SI(ND)=THN
       SI(IP)=THP
       DO 4 I=1,16
       DO 4 J=1,17
       A(I,J)=0.
    4  CONTINUE
      IDDV=0
      ITERR=0
      AA=VMD*COS(ALSR)
      BDI=VND*COS(ALSI)
      CC=VIP*COS(ALSP)
C       GO TO 7
      IF(CC.LE.BDI.AND.CC.LE.AA)GO TO 6
      IF(AA.LE.BDI)GO TO 7
      COAI=COS(ALSI)
      LL=1
      VD(ND)=CKI*VND*COAI-CK1*XC(ND)*DI(ND)
       VD(MD)=VD(ND)+RDR*DI(MD)+RDI*DI(ND)
       VD(IP)=VD(MD)-RDR*DI(MD)-RDP*DI(IP)
       COAR=(VD(MD)+CK1*XC(MD)*DI(MD))/(CRK*VMD)
       COAP=(VD(IP)+DI(IP)*CK3*XC(IP))/(CKP*VIP)
       IF(COAR.GT.COS(ALSR))COAR=COS(ALSR)
       IF(COAP.GT.COS(ALSP))COAP=COS(ALSP)
      GO TO 8
    7 CONTINUE
      COAR=COS(ALSR)
      LL=2
      VD(MD)=CRK*VMD*COAR-CK1*XC(MD)*DI(MD)
       VD(ND)=VD(MD)-RDR*DI(MD)-RDI*DI(ND)
       VD(IP)=VD(MD)-RDR*DI(MD)-RDP*DI(IP)
       COAI=(VD(ND)+DI(ND)*CK2*XC(ND))/(CKI*VND)
       COAP=(VD(IP)+DI(IP)*CK3*XC(IP))/(CKP*VIP)
       IF(COAI.GT.COS(ALSI))COAI=COS(ALSI)
       IF(COAP.GT.COS(ALSP))COAP=COS(ALSP)
      GO TO 8
    6 CONTINUE
      COAP=COS(ALSP)
      LL=3
```

```
      VD(IP)=CKP*VIP*COAP-CK1*XC(IP)*DI(IP)
      VD(MD)=VD(IP)+RDR*DI(MD)+RDI*DI(IP)
      VD(ND)=VD(MD)-RDR*DI(MD)-RDI*DI(ND)
      COAR=(VD(MD)+CK1*XC(MD)*DI(MD))/(CRK*VMD)
      COAI=(VD(ND)+DI(ND)*CK2*XC(ND))/(CKI*VND)
      IF(COAR.GT.COS(ALSR))COAR=COS(ALSR)
      IF(COAI.GT.COS(ALSI))COAI=COS(ALSI)
    8 CONTINUE
      PFR=VD(MD)/(CRK*VMD)
      PFI=VD(ND)/(CKI*VND)
      PFP=VD(IP)/(CKP*VIP)
      PHI(MD)=THM-ACOS(PFR)
      PHI(ND)=THN+ACOS(PFI)
      PHI(IP)=THP+ACOS(PFP)
      RETURN
      close (10 , status='keep')
      close (20 , status='keep')
      close (30 , status='keep')
      close (60 , status='keep')
      END
      SUBROUTINE DCCON
      COMMON/U1/NK,NL,NA,NANK,LIMAX,IN,IR
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
      COMMON/U4/JSM,NRBUS,ANGMAX,NO,PINT,PINT2,PTM,IPRE,PRTIME,NOPT,SP41
      COMMON/BUS1/VKR(50),VKM(50),CKR(50),CKM(50),BUS(50)
      COMMON/BUS2/GG(50),BB(50),PL(50),QL(50)
      COMMON/BRANCH/IL(100),KL(100),GL(100),BL(100)
      COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
      COMMON/BLD/XC(50),VD(50),PDS(50),QDS(50)
      COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
      COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
      COMMON/BL4/TR,TI,TP,BR,BI,BP,CRK,CKI,CKP,CK1,CK2,CK3
      COMMON/BL5/DIX(50),DICN(50),VIC(50),DCX(50)
      COMMON/BL6/TRR,TPP,TII,TRC,TIC,TPC,TKX1,TX1,TKX2,TX2
      COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
      COMMON/U8/TSTIME
      COMMON/SW2/TPS(20),SS(20),STM(20),ITYPE(20),STMD(20)
      COMMON/ADD/VKRL(50),VKMG(50)
C     COMMON/CONTROL/SIG,SP1(10),ANG1(10),SDX
      COMMON/CONTROL/SIG1,SIG2,SP1(10),ANG1(10),Y1DX,Y1DX2,DIS1,DIS2
      COMMON/CONTROL1/PMECH1(10),PT1(10),PA(10)
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
C     COMMON/CNTRL4/VMD,VND,VIP,THM,THN,THP
      open (unit = 10 ,file ='DC3F2.dat',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      open (unit = 30 ,file ='DC3F22.out',status='old')
C     WRITE(30,*)'DCCON'
C     WRITE(30,*)'WAKE UP7777',DI(MD),DI(ND),DI(IP)
      VMD=SQRT(VKR(MD)*VKR(MD)+VKM(MD)*VKM(MD))
      VND=SQRT(VKR(ND)*VKR(ND)+VKM(ND)*VKM(ND))
      VIP=SQRT(VKR(IP)*VKR(IP)+VKM(IP)*VKM(IP))
```

```
 10  CONTINUE
     B1=TSTEP/(2.*TII+TSTEP)
     XXR=(VD(MD)-VD(ND))/RDI
     DIX(ND)=B1
     DICN(ND)=DI(ND)*(1.-2.*B1)+B1*XXR
     B1=TSTEP/(2.*TPP+TSTEP)
     XXR=(VD(MD)-VD(IP))/RDP
     DIX(IP)=B1
     DICN(IP)=DI(IP)*(1.-2.*B1)+B1*XXR
C     WRITE(20,*)DICN(ND),DICN(IP)
C      GO TO 14
     GO TO (11,12,13),LL
 11  CONTINUE
     V1=CRK*VMD*COAR
     B1=TSTEP/(2.*TRC+TSTEP)
     XXR=DIRS-DI(MD)
     VIC(MD)=V1*(1.-2.*B1)+B1*XXR
     DCX(MD)=B1
     V1=CKP*VIP*COAP
     B1=TSTEP/(2.*TPC+TSTEP)
     XXR=DIPS-DI(IP)
     VIC(IP)=V1*(1.-2.*B1)+B1*XXR
     DCX(IP)=B1
     V1=CKI*VND*COAI
     B1=TSTEP/(2.*TIC+TSTEP)
     XXR=DIIS-DI(ND)
     VIC(ND)=V1*(1.-2.*B1)+B1*XXR
c    GO TO 14
 12  CONTINUE
     V1=CKI*VND*COAI
     B1=TSTEP/(2.*TIC+TSTEP)
     XXR=DIIS-DI(ND)
     VIC(ND)=V1*(1.-2.*B1)+B1*XXR
     DCX(ND)=B1
     V1=CKP*VIP*COAP
     B1=TSTEP/(2.*TPC+TSTEP)
     XXR=DIPS-DI(IP)
     VIC(IP)=V1*(1.-2.*B1)+B1*XXR
     DCX(IP)=B1
     GO TO 14
 13  CONTINUE
     V1=CRK*VMD*COAR
     B1=TSTEP/(2.*TRC+TSTEP)
     XXR=DIRS-DI(MD)
     VIC(MD)=V1*(1.-2.*B1)+B1*XXR
     DCX(MD)=B1
     V1=CKI*VND*COAI
     B1=TSTEP/(2.*TIC+TSTEP)
     XXR=DIIS-DI(ND)
     VIC(ND)=V1*(1.-2.*B1)+B1*XXR
     DCX(ND)=B1
 14  CONTINUE
C     IF(TIME.GE.TSTIME)CALL CONCON
     RETURN
```

```
      close (10 , status='keep')
      close (20 , status='keep')
      close (30 , status='keep')
      END
      SUBROUTINE DCTRA
      COMMON/U1/NK,NL,NA,NANK,LIMAX,IN,IR
      COMMON/U2/KG,NR,NG,NM,KP,KO,IA,IG,IML,IPC,MAXIT,ITS,F,VA,IDC
      COMMON/U3/KM,KMM,MS,MSS,STEPF,TSADJ,MC,KBF1,KBF3,SP31,SP32,SP33
      COMMON/U4/JSM,NRBUS,ANGMAX,NO,PINT,PINT2,PTM,IPRE,PRTIME,NOPT,SP41
      COMMON/BUS1/VKR(50),VKM(50),CKR(50),CKM(50),BUS(50)
      COMMON/BUS2/GG(50),BB(50),PL(50),QL(50)
      COMMON/BRANCH/IL(100),KL(100),GL(100),BL(100)
      COMMON/BL1/VSEC(50),SI(50),PHI(50),DI(50)
      COMMON/BLD/XC(50),VD(50),PDS(50),QDS(50)
      COMMON/BL2/LL,DIRS,DIIS,DIPS,ALSR,ALSI,ALSP,RDR,RDI,RDP
      COMMON/BL3/COAR,COAI,COAP,ITERR,MAXTR,MD,ND,IP,PDR,PDI,PDP
      COMMON/BL4/TR,TI,TP,BR,BI,BP,CRK,CKI,CKP,CK1,CK2,CK3
      COMMON/BL5/DIX(50),DICN(50),VIC(50),DCX(50)
      COMMON/BL6/TRR,TPP,TII,TRC,TIC,TPC,TKX1,TX1,TKX2,TX2
      COMMON/SW2/TPS(20),SS(20),STM(20),ITYPE(20),STMD(20)
      COMMON/U5/JJ,LF,TSTEP,TIME,TMAX,ISWD,IDDV
      COMMON/U8/TSTIME
      COMMON/ERRORS/ERRVOL,ERRDEL,ERRPOW,ERRAVR,ERRMOT,ERRDC,ERRCON
      COMMON/ADD/VKRL(50),VKMG(50)
C     COMMON/CONTROL/SIG,SP1(10),ANG1(10),SDX
      COMMON/CONTROL/SIG1,SIG2,SP1(10),ANG1(10),Y1DX,Y1DX2,DIS1,DIS2
      COMMON/CONTROL1/PMECH1(10),PT1(10),PA(10)
      COMMON/CNTRL2/A(16,17),X(16),R(16),EC(50,100), BC(100),
     *CJ(100), NXI(100), KODE(100),CF(50,100),DD(100), EN(100),IS(100,2)
      COMMON/CNTRL3/XZ(20),ZSUM(20)
C     COMMON/CNTRL4/VMD,VND,VIP,THM,THN,THP
      open (unit = 10 ,file ='DC3F2.dat',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      open (unit = 20 ,file ='DC3F2.out',status='old')
      open (unit = 60 ,file ='DDD.out',status='old')
C     WRITE(30,*)'DCTRA'
C     WRITE(30,*)'WAKE UP55',DI(MD),DI(ND),DI(IP)
      VMD=SQRT(VKR(MD)*VKR(MD)+VKM(MD)*VKM(MD))
      VND=SQRT(VKR(ND)*VKR(ND)+VKM(ND)*VKM(ND))
      VIP=SQRT(VKR(IP)*VKR(IP)+VKM(IP)*VKM(IP))
C     WRITE(60,*)'VSEC(IP) 2 ',VSEC(IP)
C     WRITE(60,*)'VSEC(ND) 2 ',VSEC(ND)
      FIRMX=30.*3.14159/180.
      XXR=(VD(MD)-VD(ND))/RDI
      DII=DICN(ND)+DIX(ND)*XXR
      IF(DII.GT.DIIS)DII=DIIS
      ERR=ABS(DII-DI(ND))
      IF(ERR.GT.ERRDC)ERRDC=ERR
      DI(ND)=DII
      XXR=(VD(MD)-VD(IP))/RDP
      DII=DICN(IP)+DIX(IP)*XXR
      IF(DII.GT.DIPS)DII=DIPS
      ERR=ABS(DII-DI(IP))
      IF(ERR.GT.ERRDC)ERRDC=ERR
```

```
      DI(IP)=DII
      DI(MD)=DI(ND)+DI(IP)
C     GO TO 14
      GO TO(11,12,13),LL
 11   XXR=DIRS-DI(MD)
      V1=VIC(MD)+DCX(MD)*XXR
      DOAR=V1/(CRK*VMD)
      IF(DOAR.LT.COS(FIRMX))DOAR=COS(FIRMX)
      IF(DOAR.GT.COS(ALSR))DOAR=COS(ALSR)
      ERR=ABS(COAR-DOAR)
      IF(ERR.GT.ERRDC)ERRDC=ERR
      COAR=DOAR
      XXR=DIPS-DI(IP)
      V1=VIC(IP)+DCX(IP)*XXR
      DOAR=V1/(CRK*VIP)
      IF(DOAR.LT.COS(FIRMX))DOAR=COS(FIRMX)
      IF(DOAR.GT.COS(ALSP))DOAR=COS(ALSP)
      ERR=ABS(COAP-DOAR)
      IF(ERR.GT.ERRDC)ERRDC=ERR
      COAP=DOAR
      XXR=DIIS-DI(ND)
      V1=VIC(ND)+DCX(ND)*XXR
      DOAR=V1/(CRK*VND)
      IF(DOAR.LT.COS(FIRMX))DOAR=COS(FIRMX)
      IF(DOAR.GT.COS(ALSI))DOAR=COS(ALSI)
      ERR=ABS(COAI-DOAR)
      IF(ERR.GT.ERRDC)ERRDC=ERR
      COAI=DOAR
      GO TO 14
 12   XXR=DIIS-DI(ND)
      V1=VIC(ND)+DCX(ND)*XXR
      DOAR=V1/(CRK*VND)
      IF(DOAR.LT.COS(FIRMX))DOAR=COS(FIRMX)
      IF(DOAR.GT.COS(ALSI))DOAR=COS(ALSI)
      ERR=ABS(COAI-DOAR)
      IF(ERR.GT.ERRDC)ERRDC=ERR
      COAI=DOAR
      XXR=DIPS-DI(IP)
      V1=VIC(IP)+DCX(IP)*XXR
      DOAR=V1/(CRK*VIP)
      IF(DOAR.LT.COS(FIRMX))DOAR=COS(FIRMX)
      IF(DOAR.GT.COS(ALSP))DOAR=COS(ALSP)
      ERR=ABS(COAP-DOAR)
      IF(ERR.GT.ERRDC)ERRDC=ERR
      COAP=DOAR
      GO TO 14
 13   XXR=DIRS-DI(MD)
      V1=VIC(MD)+DCX(MD)*XXR
      DOAR=V1/(CRK*VMD)
      IF(DOAR.LT.COS(FIRMX))DOAR=COS(FIRMX)
      IF(DOAR.GT.COS(ALSR))DOAR=COS(ALSR)
      ERR=ABS(COAR-DOAR)
      IF(ERR.GT.ERRDC)ERRDC=ERR
      COAR=DOAR
```

```
      XXR=DIIS-DI(ND)
      V1=VIC(ND)+DCX(ND)*XXR
      DOAR=V1/(CRK*VND)
      IF(DOAR.LT.COS(FIRMX))DOAR=COS(FIRMX)
      IF(DOAR.GT.COS(ALSI))DOAR=COS(ALSI)
      ERR=ABS(COAI-DOAR)
      IF(ERR.GT.ERRDC)ERRDC=ERR
      COAI=DOAR
 14   CONTINUE
c       CALL LNRP
RETURN
      close (10 , status='keep')
      close (20 , status='keep')
      close (30 , status='keep')
      close (60 , status='keep')
      END
```

APPENDIX II.A

SYSTEM # 1 DATA

```
  20   BUS SYSTEM  STUDY
 TEST SYSTEM
FOR   THE    PC VERSION

BURS 1.0     -12.860  4.0     2.021    0.0     0.0
BURD 1.0     -14.365  1.991    7.614    7.0     4.0
BURM 0.9923   -13.749  0.0     0.0     13.0    10.0
SWSN 0.9889   -13.495  0.0     0.0     20.0    20.0
KILM 1.052    -13.813  0.0     0.0     8.0     6.0
KUKM 0.9941   -13.432  0.0     0.0     12.0    10.0
KUKI 1.0652   -11.208  0.0     0.0     0.0     0.0
KILH 1.1141   -9.292   0.0     0.0     0.0     15.0
KILI 1.071    -10.794  0.0     0.0     0.0     0.0
MERH 1.1343   -7.847   0.0     0.0     0.0     15.0
ROSH 1.113    -3.481   0.0     0.0     0.0     0.0
ROSL 1.05     -0.277   22.0    -1.72   0.0     20.0
ROLL 1.04     0.0      47.34   -9.811  0.0     40.0
HASI 1.0953   -9.998   0.0     0.0     0.0     0.0
HASL 1.1177   -11.713  0.0     0.0     6.0     4.0
MERM 1.1159   -9.187   0.0     0.0     0.0     0.0
WADM 1.03     -11.664  2.99    -3.765  7.0     5.0
SENM 1.10     -9.355   0.0     0.0     0.0     0.0
RABK 1.0935   -9.9117  0.0     0.0     3.0     2.0
SENL 1.0      -9.359   12.0    1.718   12.0    8.0
END
BURSBURM0.0    0.384   0.0    0.0
BURDBURM0.0    0.213   0.0    0.0
BURMKILM0.213  0.358   0.0    0.0
BURMKUKM0.04   4.900   0.0    0.0
SWSNKUKM0.02   4.900   0.0    0.0
BURMSWSN0.04   0.029   0.0    0.0
KUKMKUKI0.0    0.1106  0.0    -5.0
KUKIKILI0.0047 0.0233  0.01   0.0
KILIKILM0.0    0.4025  0.0    -5.0
KILIKILH0.0    0.065   0.0    -2.0
KILHMERH0.024  0.141   0.2362 0.0
KILHMERH0.024  0.141   0.2362 0.0
MERHROSH0.0442 0.26    0.432  0.0
MERHROSH0.0442 0.26    0.432  0.0
ROSHROLL0.0    0.1485  0.0    0.0
ROSHROSL0.0    0.297   0.0    0.0
MERHMERM0.0    0.156   0.0    0.0
MERMHASI0.14   0.186   0.0175 0.0
```

```
HASIKILI0.307  0.407   0.038  0.0
HASIHASL0.0    0.636   0.0    -4.0
MERMWADM0.0    1.265   0.0    -2.0
MERMSENM0.2505 0.333   0.0312 0.0
SENMRABK0.289  0.378   0.0354 0.0
SENMSENL0.0    1.1     0.0    3.0
KUKMKUKM       -40.
SWSNSWSN       -40.
BURMBURM       -40.
END
BURSBURM0.0    0.384   0.0    0.0
END
ROSL 133.5  4.5  0.28  0.4  0.77  0.4  0.0  4.8  0.00
ROLL 133.5  9.0  0.14  0.2  0.385 0.2  0.0  4.8  0.00
SENL 1 9.9  4.44  0.15  0.295 0.51  0.295 0.0  5.0  0.00
BURS 112.5  10.2  0.073 0.667 0.669 0.667 0.0  6.0  0.00
BURD 1 3.75 5.5  0.072 0.374 0.31  0.374 0.0  4.0  0.00
WADM 1 3.39 2.1  0.138 0.412 0.73250.412 0.0  3.399 0.00
END
ROSL 122.0     -1.72    0.012
ROLL 147.34    -9.811   0.012
SENL 112.0     1.718    0.01
BURS 14.0      2.021    0.01
BURD 11.991    7.614    0.01
WADM 12.99     -3.765   0.01
END
ROSL 1200.00.1  0.1  1.6  6.0  -6.0 1000.
ROLL 1200.00.1  0.1  1.6  6.0  -6.0 1000.
SENL 1124.50.0660.1  0.3756.0  -6.0 1000.
BURS 1300.00.05 0.1  10.0 6.0  -6.0 1000.
BURD 1300.00.05 0.1  10.0 6.0  -6.0 1000.
WADM 1300.00.05 0.1  10.0 6.0  -6.0 1000.
END
KUKMSWSNBURM
.287,0.21,.077,5.0,5.0,5.0,1.,1.,1.,-10.,-10.,-10.
0.21,.077,0.90,0.90
.126,.1260,0.1260
0.024,0.024,0.024,10,0.190,.070
0.,0.,0.
0.1,0.1,0.1,1.0,1.0,1.0,.001,0.1
BURS 10.025    1.0      1000.0    0.00      1 0
SWSNSWSN0.0    0.       0.0    0.0    1 0.0
SWSNSWSN0.0    0.       0.0    0.0   -1 0.05
END
ESUD
END
```

APPENDIX II.B

SYSTEM # 2 DATA

```
  24   BUS SYSTEM  STUDY
 TEST SYSTEM
FOR   THE    PC VERSION

NA01  1.0000   0.000   78.124  40.374
NA02  1.0000   0.926   100.    19.919
NA03  0.9900  -3.474   25.     8.945
NA04  0.9600  -3.138   76.    42.187
NA05  1.0502 -12.645          5.001
NA06  1.0848  -4.31
NA07  1.0784  -5.26
NA08  1.0137 -10.391                 104.978  51.989
NA09  1.0452 -12.645
NA10  1.0443 -12.704                  17.999  13.999
NA11  1.0250 -10.158
NA12  1.0556  -8.848
NA13  1.0574  -8.078                 60.993   31.996
NA14  1.0609  -8.848
NA15  1.0250 -10.158
NA16  1.0556  -8.848
NA17  1.0609  -8.848
NA18  1.0653  -7.104
NA19  0.9992 -12.822                  50.989   9.998
NA20  1.0638  -7.736
NA21  1.0549  -9.756                 11.997   5.999
NA22  1.0629  -7.881
NA23  1.0248 -10.385                  27.995   9.998
NA24  1.0784  -5.26
END
NA06NA02      0.09          10.0
NA06NA070.00476 0.01996 0.0166
NA07NA01      0.1125         12.5
NA07NA24      0.00001
NA08NA240.0719  0.31799 0.061
NA08NA150.0516  0.1062  0.0203
NA08NA09      0.2438         -5.0
NA09NA05      0.106
NA09NA10      0.0062
NA15NA16      0.333          -1.0
NA16NA17      0.1
NA08NA110.0516  0.1062  0.0203
NA11NA12      0.333          -1.0
```

```
NA12NA14        0.1
NA13NA04        0.1             15.0
NA18NA19        0.2              4.0
NA18NA200.0208   0.0807   0.0754
NA20NA21        0.333           -1.0
NA20NA220.0246   0.0967   0.0777
NA22NA23        0.1667           2.0
NA22NA03        0.294           10.0
NA14NA14        -20.0
NA17NA17        -20.0
NA07NA080.0361   0.145    0.13
NA07NA180.0148   0.054    0.0536
END
END
NA01 1      5.08  .2005 .2005 1.305 0.85  .003  5.6    0.4
NA02 1      1.892 .3235 .3235 .9712 .6325 .003  5.6    0.4
NA03 1      1.690 .5230 .5230 4.720 4.700 .010  5.6    0.4
NA04 1      4.400 .2000 .2000 1.970 1.953 .0375 5.6    0.4
NA05 1      0.248 1.550 1.550 5.800 3.750 .0200 9.0    0.4
END
NA01 1  78.124    40.374
NA02 1 100.       19.919
NA03 1  25.       8.945
NA04 1  76.       42.187
NA05 1            5.001
END
NA01 1 200. .05  .05  1.   6.       4.
NA02 1 200. .05  .05  1.   6.       4.
END
NA13NA12NA16
0.018,.0089,.0089,5.0,15.0,15.0,1.,1.,1.,-10.0,-10.00,-10.0
.0089,.0089,0.90,0.90
.126,.1260,0.1260
0.024,0.024,0.024,10,0.190,.070
0.,0.,0.
0.1,0.1,0.1,1.0,1.0,1.0,.1,0.001,.10,0.001
NA01 1 0.025     1.00     1000.       0.00      1
NA03NA03                          -1  0.0
NA03NA03                           1  0.05
END
END
ESUD
END
```