MODELLING AND ANALYSIS OF STATIC EXCITATION SYSTEM

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
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MEASUREMENT AND INSTRUMENTATION)

By

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CERTIFICATE

This is to certify that dissertation entitled "MODELLING AND ANALYSIS OF STATIC EXCITATION SYSTEM" which is being submitted by Shri Dhananjay Kumar Chaturvedi in partial fulfilment for the award of the degree of Master of Engineering in Electrical Engineering (Measurement and Instrumentation) of University of Roorkee, Roorkee is a record of student's own work carried out under our guidance. The matter embodied in this dissertation has not been submitted for the award of any degree or diploma.

This is further certify that he has worked for a period of 15 months (fifteen months) from February, 1984 to May 1985 for preparing this dissertation.

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CONTENTS

CHAPTER - 1

1.0 INTRODUCTION

Excitation system of turbogenerator plays a vital role in power system. It basically controls the reactive power output of a generator. The aims of excitation system are [1]:

(i) to control the terminal voltage of machine so that operation is possible nearer to the steady state stability limit.

(ii) to maintain voltage under system fault conditions to ensure rapid operation of protective gear and

(iii) to facilitate sharing of the reactive load between machines operating in parallel.

IEEE standards [2] defines excitation system as source of field voltage for a synchronous machine. The generator excitation system is employed to maintain the generator terminal voltage at a preset value. This is accomplished by the use of a voltage regulator whose output is fed into the exciter field. The excitation system provides field current to the generator.

In 1960's it was recognised that for unit connected turbogenerator having increased MVA rating, a serious problem would arise with the conventional dc excitation system due to limitations in commutating ever increasing excitation energy and in delivering it through sliprings to the generator field.

Commutators, collector rings and brushes - all are being highly maintained in them - poses serious problems and forced outages of generating units. These considerations leads to the manufacturer to search for an excitation system which can handle effectively high energy input to generators field with a high speed of response.

In order to have fast response and high performance excitation system to improve the transient stability of synchronous machine the Brushless Excitation System [5] have been developed.

Subsequently, generators (especially hydroelectric) that have to cope with difficult stability requirement due to large amount of power to be transmitted over long distance, have equipped with control rectifiers.

The application of solid state exciter made it possible to apply very effective positive damping of the machine oscillations with suitable supplemental signals. In fact the electronic exciters have low time constant, so in their case more effective damping with faster response can be obtained.

In recent years the application of faster excitation system to steam turbine generators has developed at a slower pace. Generally in case of steam turbine generators the excitation energy is derived from the shaft with a direct connected rotating exciter.

The alternator type brushless excitation system employ a shaft driven alternator rectifier exciter with rotating rectifiers, whose output is fed to the generator field. This scheme retains the concept of a shaft power source, independent of power system disturbances and provide better reliability and reduce maintenance by eliminating all commutators, collector rings and associated brushes.

The faster response is achieved by means of replacing the rotating diodes by controlled rectifiers.

Development of mathematical model of the system during the transient is the first step in a stability study [4,5]. The elements included in the model are those affecting the acceleration (or deceleration) of the machine rotors.

Power system dynamic simulation and stability studies are possible with the help of mathematical model of the following:

(I) The network before and after the disturbance,
(II) The loads and their characteristics,
(III) The parameters of the synchronous machine,
(IV) The turbine and speed governor,
(V) The excitation system of the synchronous machine and
(VI) Other supplementary components and controls such as d.c line, inverter and converter or controls, deemed necessary in the mathematical description of the system.

This dissertation describes an approach to develop mathematical model of static excitation system and method for determining the typical values of various parameters of the system so that it will try to remain stable when subjected to the [6] following disturbances:

(i) Step input disturbance
(ii) Tie line disturbance
(iii) Terminal voltage reference disturbance and
(iv) Short circuit.

The mathematical modeling of excitation system is applicable in stability analysis of large electric power system [7]. Presently computer simulation remain the only practical and effective approach for studying the system dynamic behaviour. Simulation implies the existence of mathematical model for the system to be analysed, data files which contains parameters for specific power system and computer program.

This dissertation describes mathematical modeling and analysis of static excitation system. Chapter-1 gives the introduction to the system. Chapter-2 deals with the various types of excitation systems and AVR presently available. It describes the transfer function model for each type of excitation system. Chapter-3 describes the salient features of static excitation system. Function of each equipment is elaborated. The performance and characteristics of the system is also discussed. Chapter-4 elaborates details of AVR, limiters and slip stabilizer. It also discusses the effect of limiters and slip stabilizer on AVR. Chapter-5 describes the mathematical modeling of different major blocks of AVR, limiters and slip stabiliser developed here. A combined model is also presented to study the effect of limiters and slip stabiliser on AVR. In Chapter-6 response of AVR for step input is calculated and discussed. Effect of limiters and slip stabiliser on AVR is determined and the results are discussed. The conclusions drawn are elaborated in Chapter-7.

The program structure is elaborated in Appendix-I. It also describe the program development and its functions. Appendix-II describe the step by step integration method. The rectifier regulation and commutating reactance is discussed in Appendix-III.

Main Contribution Includes

(i) Development of mathematical model of AVR with limiters and slip stabiliser.

(ii) Response of AVR for step and sinusoidal input.

(iii) Effect of limiters and slip stabiliser. The results have been compared with available data. Optimal values of system parameters were calculated for the minimum response time.

CHAPTER - 2

2.0 EXCITATION SYSTEM AND AVR

2.1 Types of Excitation Systems:

Excitation systems are of the following types [8,9]:

2.1.1 Conventional Type DC Excitation Systems:

In this type turbogenerator obtain excitation supply from the power station dc distribution system. Each with its field winding to permit adjustment of the terminal voltage and reactive load. This method was suitable for machines, which need small field power. DC excitation systems are described below:

2.1.1.1 Type DC 1 Excitation System Model:

Figure 2.1 describes the type DC1 excitation system. It shows a Field Controlled DC Commutator Exciter with continuously acting voltage regulator (direct acting rheostatic type).

The input to this model is given as difference between a reference signal VREF and output of load compensator unit V_C is expressed as VERR = VREF - V_C.

The input to the control amplifier is derived from the error signal (VERR), power system stabilizing signal (V_S) and stabilizing feedback signal (VF). The input to amplifier unit is

$$V_{IN} = V_{ERR} + V_S - V_F \qquad \ldots (2.1)$$

In steady state condition the stabilizing feedback (V_F) and power system stabilizer output (V_S) are zero. The resulting signal is amplified in the regulator. The time constant and gain of regulator unit are represented by T_A and K_A. T_B and T_C represents equivalent time constants inherent in the voltage regulators. These two time constants are normally very small and can be considered equal to zero.

The voltage regulator output (V_R) is used to control exciter, which can be either separately or shunt excited. When a self excited shunt field is used, K_E represents the setting of the shunt rheostat.

Exciter saturation (S_E) is defined as ratio of change in field current (DEL IF) and exciter output voltage (Ex). The signal V_F derived from field voltage (E_{FD}) is normally used to provide stabilization to the excitation system. K_F and T_F are the gain and time constants of the stabilizing network.

2.2.1.2 Type DC2 Excitation System:

The type DC2 represents Field Controlled DC Commutator Exciter with continuously acting voltage regulator. This type of systems obtain their power supplies from the generator termin (in case of self excited) or auxiliary bus. The only difference exist as compared to Type DC1 model is that the voltage regulator output limits are proportional to the terminal voltage (V_T). The system is shown in Fig. 2.2. This type of system employs solid state, controlled rectifiers.

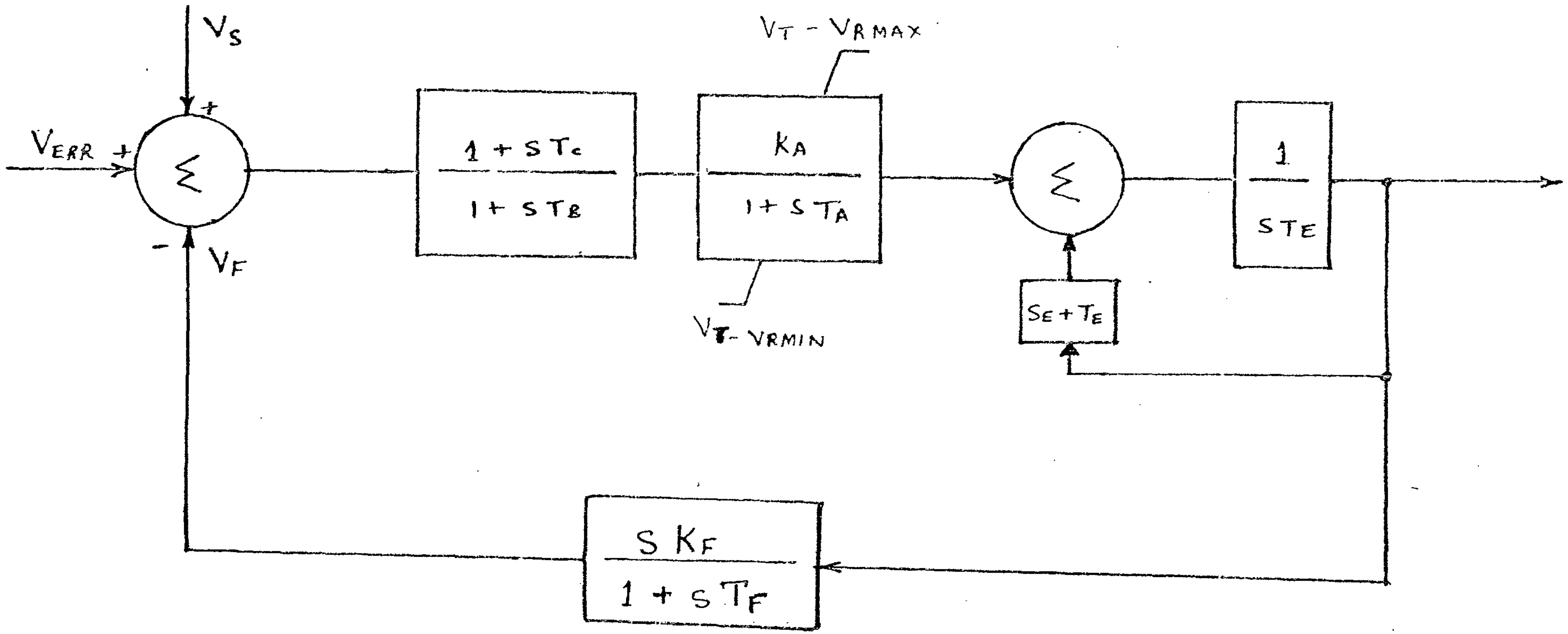


FIG. 2.2 TYPE DC 2, DC COMMUTATOR EXCITER

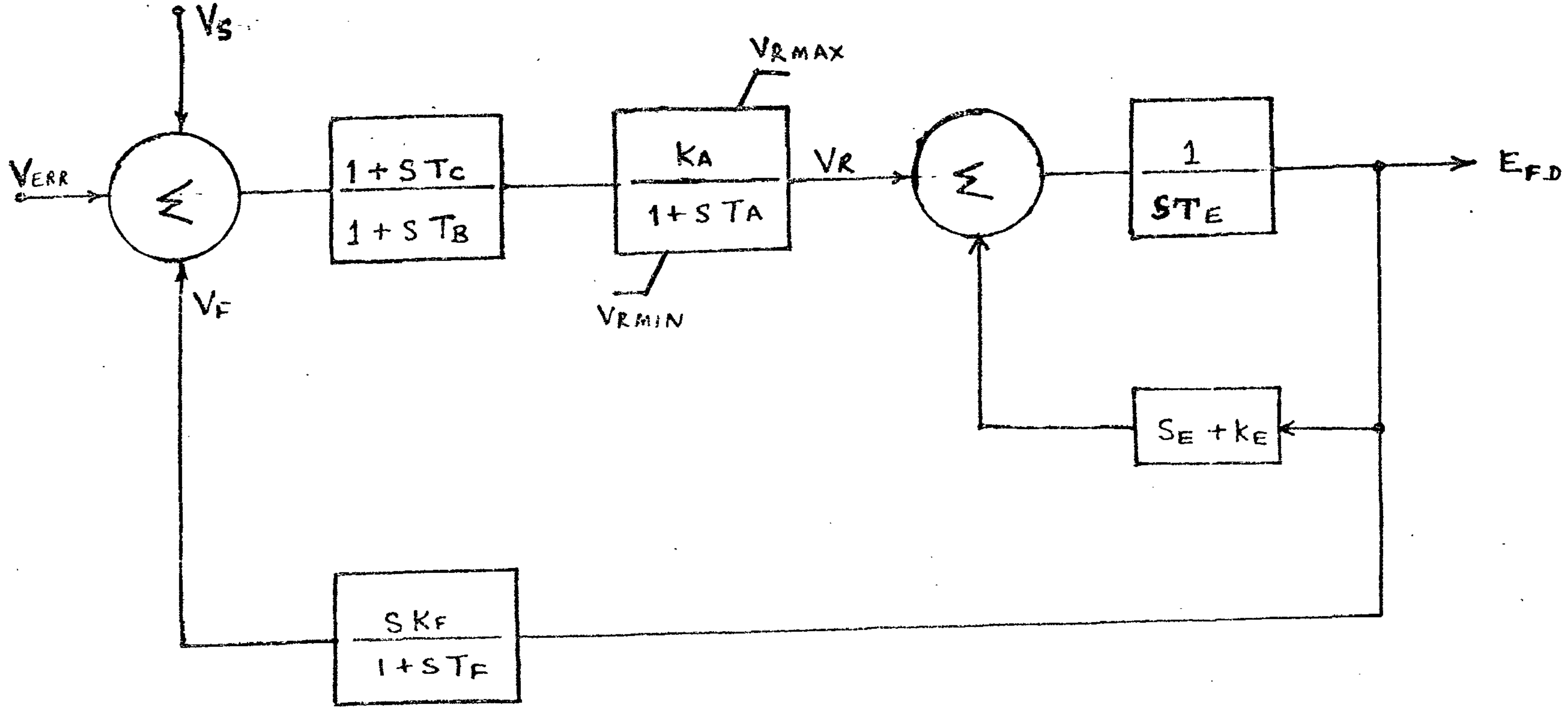


FIG 2.1 TYPE DC-1 DC COMMUTATOR EXCITER

2.1.2 A.C. High Frequency Excitation System [9]:

Supply of high current by means of slip rings involves considerable operational problems and it requires suitable design of slip rings and brushgear. In case of brushless excitation system, the diode rectifiers are mounted on the generator shaft and their output is directly connected to the field of the alternator, thus eliminating brushes and slip rings. This arrangement requires the use of a rotating armature and stationary field system for the main a.c. exciter.

A permanent magnet generator (PMG) is used to provide a high frequency AC to three phase thyristor bridge. The thyristor bridge is controlled by the output of AVR and inturn the dc supply to main exciter field is controlled. The rotating armature of main exciter generates a three phase output which is given to rectifier wheel mounted on the rotating shaft. The dc output of rectifier is fed to generator field.

The response ratio [10] of excitation system can be expressed as

$$\text{Response Ratio} = \frac{\text{Change in exciter field voltage in 0.5 second}}{\text{nominal exciter voltage x 0.5 second}} \quad \ldots (2.2)$$

In case of brushless excitation a response ratio of around two can be achieved.

The a.c. excitation systems are of the following types:

2.1.2.1 Type AC1 Excitation System Model

Figure 2.3 shows the Type AC1 excitation system. This system is called Field Controlled Alternator rectifier excitation system. Here the exciter is not self-excited. The voltage regulator derives power from a source which is not affected by the external transients. The load current (I_{FD}) has the demagnetizing effect on the exciter output voltage V_E. That can be accounted by the constant K_D (demagnetizing factor - function of exciter alternator reactance) in the feedback path. The constant K_C is a function of commutating reactance [22] (Refer Appendix-III) accounts for the exciter output voltage drop due to rectifier regulation (Refer Appendix-III). I_N represents the normalized exciter load current and E_{FD} represents the generator field voltage.

A feedback signal V_{FE}, which is proportional to exciter field current is derived from the summation of signals from exciter output voltage V_E and load current I_{FD}. The V_{FE} can be expressed as

$$V_{FE} = V_E \times (K_E + S_E) + K_D \times I_{FD} \qquad \ldots (2.3)$$

where K_E = represents exciter constant,

S_E represents saturation and

K_D represents demagnetizing factor (Refer Appendix-III).

The exciter field current signal (V_{FE}) is used as the input to the excitation system stabilizer in the Type AC-1 model.

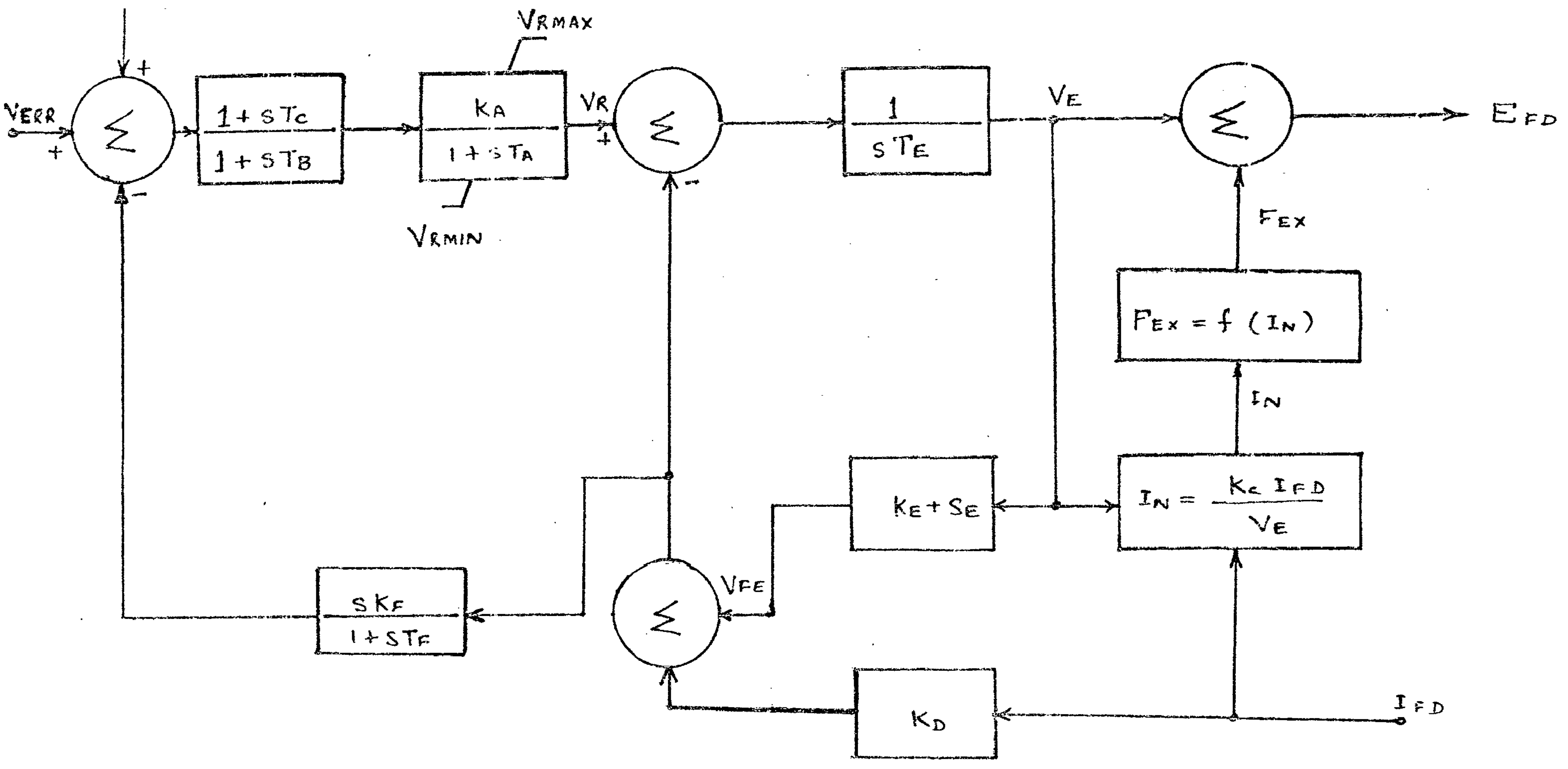


FIG. 2.3 TYPE AC-1 , Alternator - Rectifier Excitation System

2.1.2.2 Type AC2 Excitation System Model:

The Type AC2 represents a High Initial Response Field Controlled Alternator Rectifier Excitation System. The alternator main exciter is used with non-controlled rectifiers. The Type AC2 model is different from Type AC1 due to two additional feedback loops. One feedback loop accounts for exciter time constant compensation and other for exciter field current limitation. Fig. 2.4 shows Type AC-2 Excitation System. The model is applicable for simulating the performance of High Initial Response (HIR) Brushless Excitation System.

The excitation time constant compensation is done by negative feedback (V_H = exciter field current feedback signal). It reduces the effective value of exciter field time constant and thereby increases the bandwidth of the system response. The time constant is reduced by the gain ($1 + K_B K_H$) of the compensation loop.

In order to obtain high initial response with this system, a very high forcing voltage (V_{RMAX}) is applied to the exciter. A limiter is there to limit the exciter field current during field forcing [2] . The exciter output voltage (V_E) is limited to a preset value (V_{FE}) by limiting the exciter field current. The voltage regulator output V_A is fed to a summing point, where a negative feedback signal V_H from the time constant compensation circuitry is present. The error signal will be fed to LV gate (whose output is equal to the low value input)

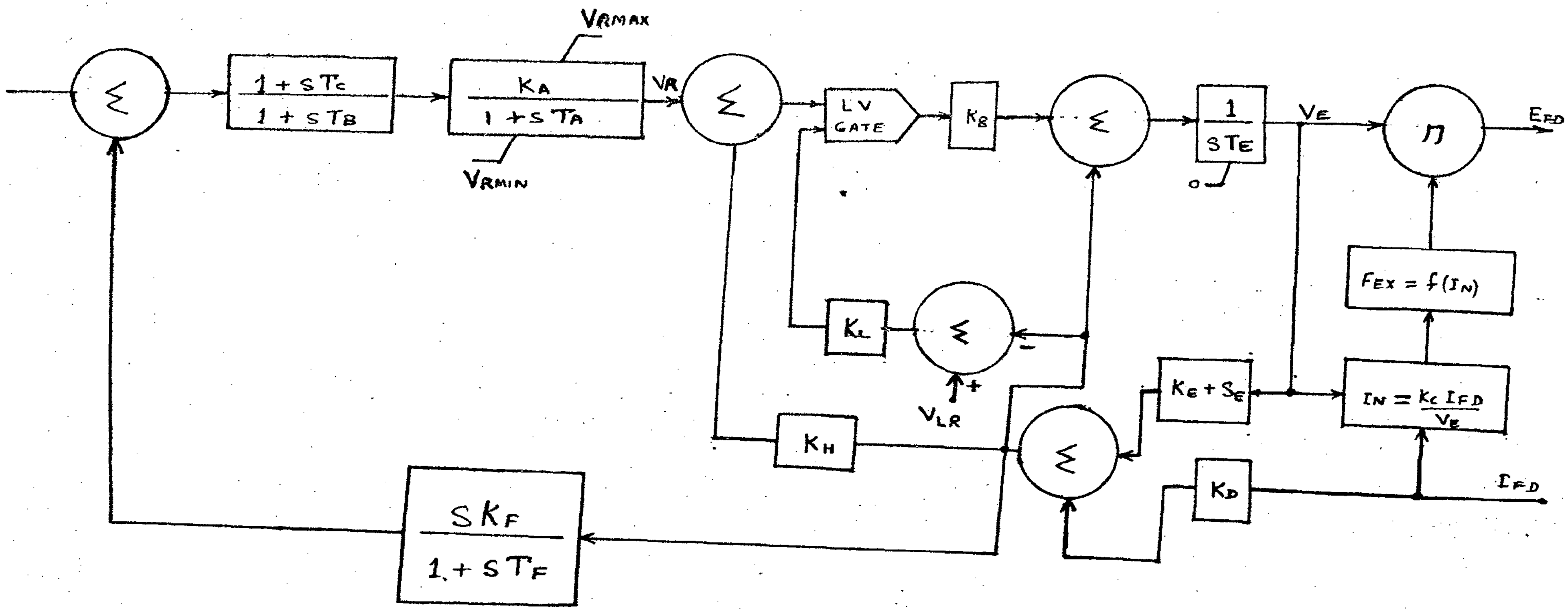


FIG.2.4 TYPE AC-2 HIGH INITIAL RESPONSE TYPE EXCITATION SYSTEM

and compared with the output signal (V_2) from the limiter circuitry. The excitation is controlled by the more negative of the two incoming signals.

2.3.9 Static Excitation System:

In order to maintain system stability, it is necessary to have fast excitation for large synchronous machines. It means the field current must be adjusted extremely fast in respond to the changing operational conditions. Besides maintaining the field current and steady state stability the excitation system is required to increase stability limits. Thus, the static excitation system is preferred to conventional excitation system.

In this system the a.c. power is tapped off from the generator terminals stepped down and rectified by fully controlled thyristor bridge and then fed to the generator field, thereby controlling the generator voltage output.

The fast response of the system is achieved by using a PID controller and power electronic systems. Signal output of the error detector causes the voltage regulator to advance or retard the firing angle of the thyristors, thereby controlling the field excitation of the alternator [9].

2.3.9.1 Type ST1 Static Excitation System:

The Fig. 2.9 shows the Type ST1 static Excitation System. This type of system is known as Potential Source Controlled Rectifier Excitation System. It represents all systems in which

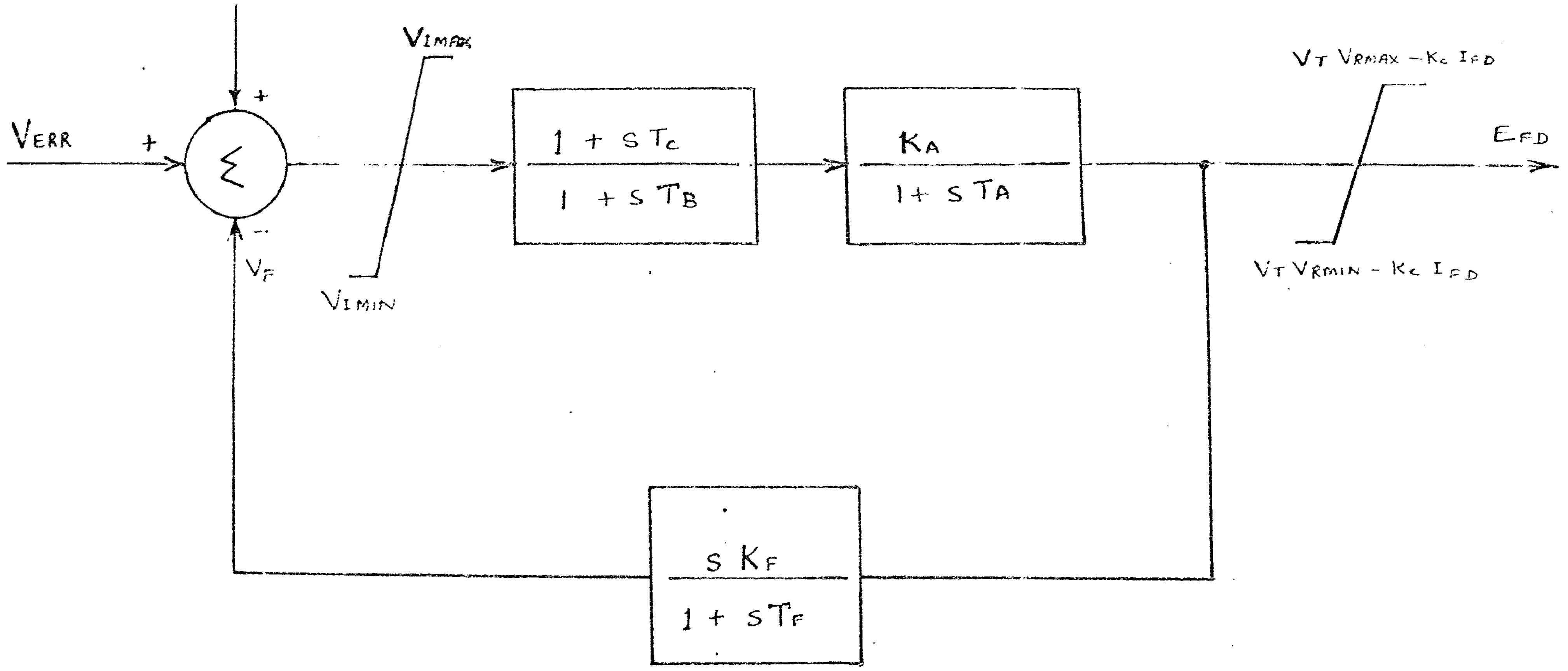


FIG 2.5 TYPE ST1 : POTENTIAL SOURCE CONTROLLED RECTIFIER EXCITER

excitation power is derived through a rectifier transformer from the generator output. The thyristors used to convert ac power (derived from terminal) to dc output (fed to field winding) are controlled. The maximum exciter voltage available from such system is directly related to the generator terminal voltage.

In such systems, the inherent exciter time constant T_E is very small and exciter stabilization is normally not required. The transient gain reduction is implemented by either (a) the time constants T_B and T_C (in case when stabilizing circuitry gain K_F is set to zero), or (b) by suitable choice of rate feedback parameters K_F and T_F in the feedback path. K_A and T_A represents the voltage regulator gain and inherent excitation system time constant. V_{RMAX} and V_{RMIN} represents the upper and lower limits of inherent limiter. The field voltage limits can be represented as linear function of generator field current I_{FD}, because the operation of thyristor bridge is in mode 1. (described in Appendix-III).

In case of static excitation system employing rectifier transformer, K_C (rectifier loading factor related to commutating reactance) is very small and so it can be neglected for many studies.

2.1.9.2 Type ST2 - Static Excitation System:

In this type of excitation system the excitation power is delivered by a generator output voltage and current. These systems are called compound source Rectifier Excitation System. The Fig. 2.6 shows the transfer function block diagram for type ST2 system. The excitation power source can be represented as a phasor combination of terminal voltage VT and terminal current I_T. The normalized exciter load current I_N is function of exciter output voltage V_E and generator field current I_{FD}. The I_N can be expressed as

$$I_N = K_C \times (I_{FD}/V_E) \qquad \ldots (2.4)$$

where K_C is the rectifier loading factor related to the commutating reactance.

The rectifier loading factor and commutating effects are explained in a Appendix-III.

E_{FDMAX} represents the limit of exciter output voltage due to saturation of the magnetic components.

K_E represents the rectifier exciter constant.

T_E is the integration rate associated with the inductance of the control winding. Example of such type system is the General Electric static excitation system referred as SCPT system.

2.1.3.3 <u>Type ST-3 Static Excitation System</u>:

This type of static excitation system utilizes terminal voltage and current to form the source of excitation power. This type of system employing controlled rectifiers in the exciter output circuit are referred as compound source

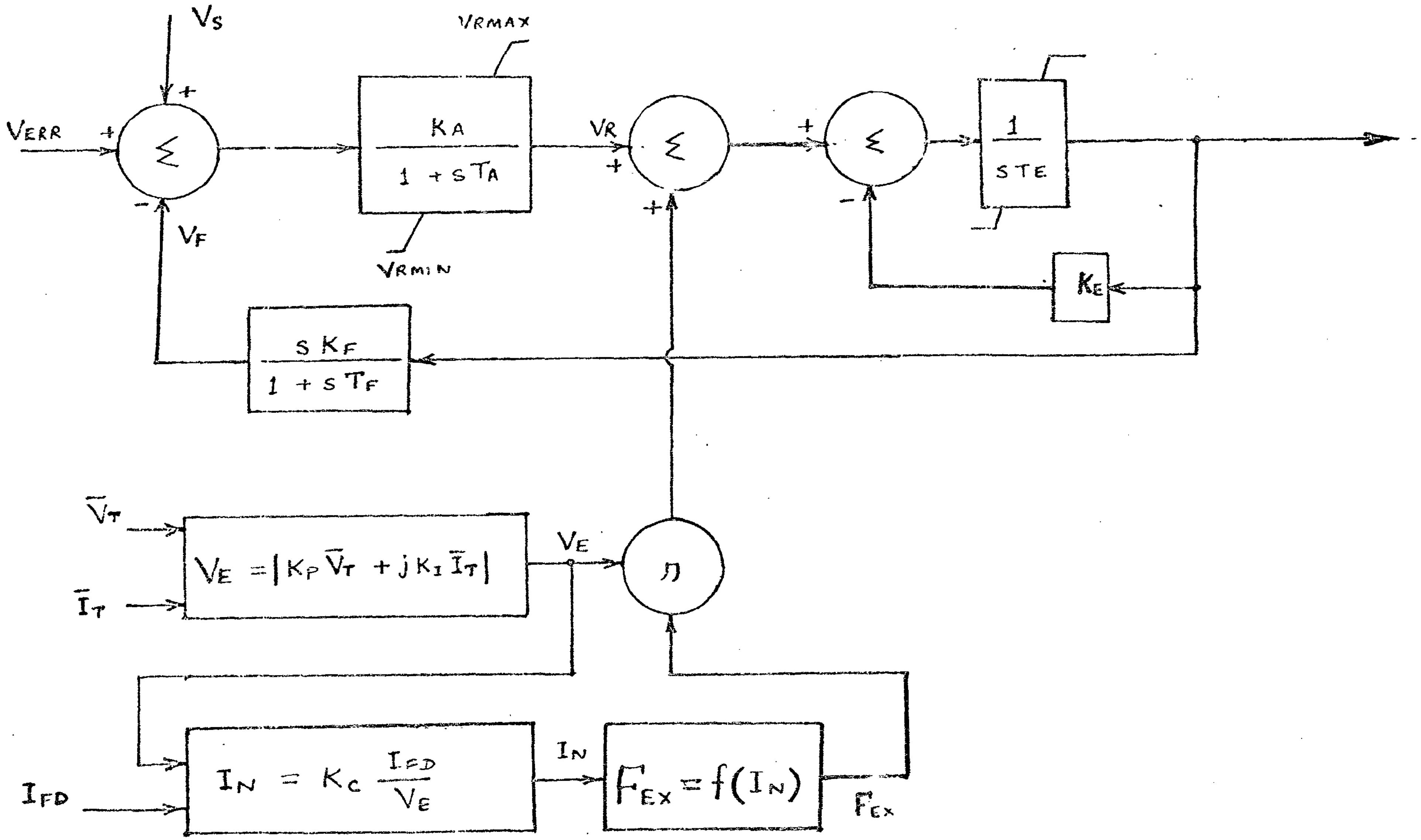


FIG 2.6 TYPE ST2 COMPOUND SOURCE RECTIFIER EXCITER

Controlled Rectifier Excitation Systems. The Fig. 2.7 shows the transfer function block diagram for such system.

The excitation system stabilizer in these systems is provided by a series lag-lead element, represented by the time constants T_B and T_C. An inner loop field voltage regulator is comprised of the gain K_A and K_F (inner loop feedback constant) and the time constant T_A. The E_{FDMAX} limit is established by the saturation level of power components. K_J represents the first stage regulator gain. V_{GMAX} represents the maximum limit of inner loop voltage feedback. This type of system includes the General Electric GENERREX excitation system.

2.2 Types of Voltage Regulators:

The voltage regulators may be classified as continuous acting or non-continuous acting [1,12]:

2.2.1 A non-continuous acting regulator is one that requires a sustain finite change in the controlled variable to initiate corrective action.

Early voltage regulators where predominantly non-continuous acting i.e. indirect acting rheostat regulators. These regulators accomplished the regulating function by varying the resistance in the output of a pilot exciter.

2.2.2 Continuous acting voltage regulators were introduced in 1940's and quickly become the predominant type. Today, continuous acting regulators employing all static components are normally used for application to turbine generators.

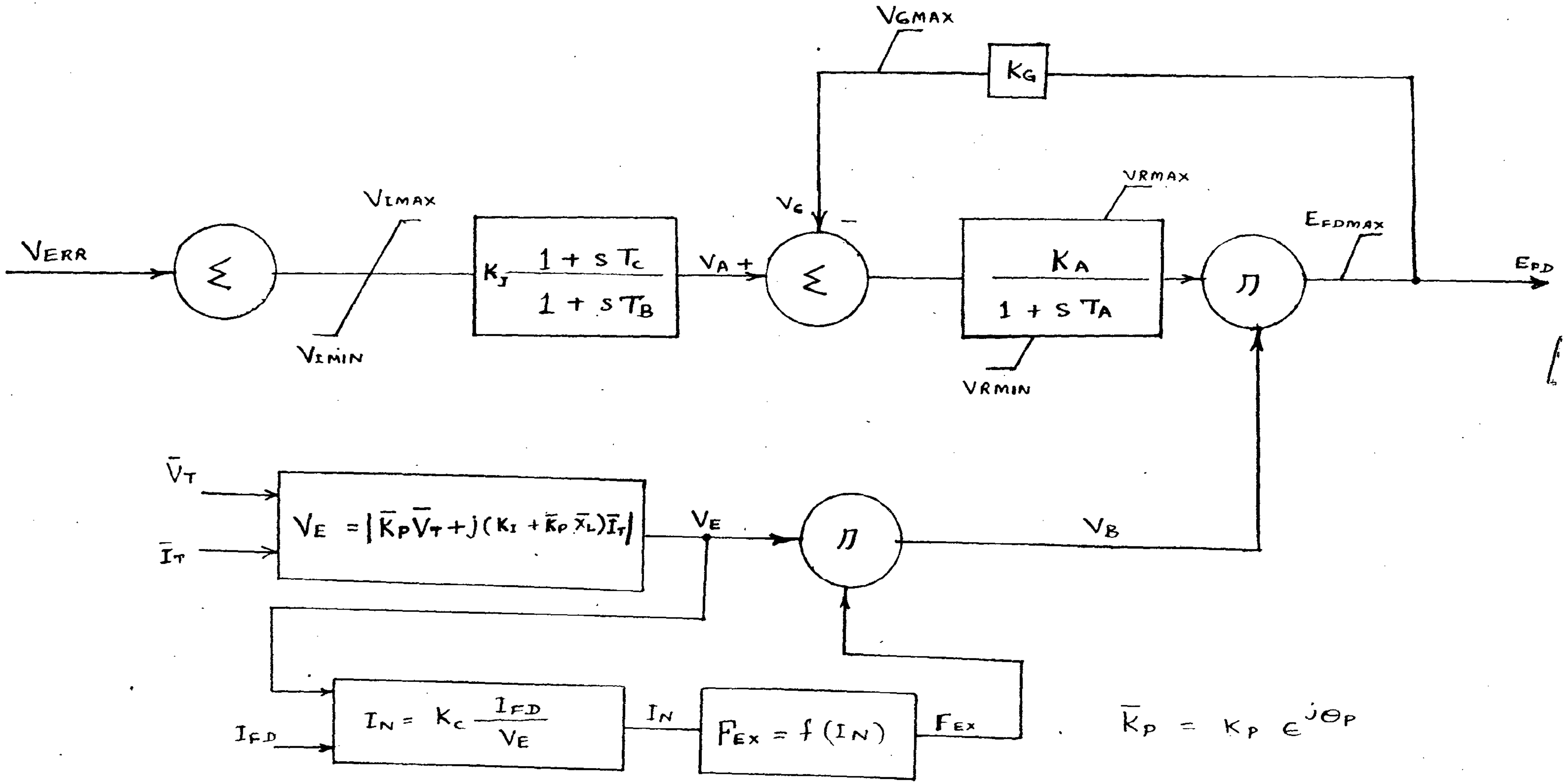


FIG.2.7 TYPE ST3 COMPOUND SOURCE CONTROLLED RECTIFIER EXCITER

In a modern excitation system continuously acting regulators provide a number of functions to improve machine performance in the power system. These include:

(a) Supply d.c. to the field winding.

(b) Maintain constant generator voltage.

(c) Contribute to and improve the steady state and dynamic stability of the generator through its high response ratio.

(d) Improve transient stability.

(e) Excitation system must possess a sufficient reserve to ensure the power capability of the generator within its entire working range and under all operating conditions without any restriction.

(f) It should contain optimal protective facilities for the generator and the excitation system.

(g) Increase short time reactive output.

(h) Limit underexcited operation to maintain stability.

(i) Limit overexcited operation to a safe value.

(j) Control over voltage and/or volts/Hz ratio to protect other equipment associated with the machine.

(k) Supply synchronisation and automation, either alone or in conjunction with computer.

While designing regulator the following points are to be considered:

(a) The regulator should be continuous acting,

(b) It should have fast response,

(c) It should be easy to stabilise,

(d) It should have reliable components,

(e) It should have good excitation limiters.

2.9 Features of Excitation System:

The excitation system must possess the following features:

(a) Very high response,

(b) It should be capable of providing negative excitation by operating as inverter.

(c) High availability as the necessary redundancy is incorporated.

(d) Easy replacement by advanced design,

(e) Integrated local indication facilities, enabling faults to be located rapidly,

(f) Minimum maintenance requirements,

(g) Provision for additional inputs to accommodate stabilising signals.

CHAPTER - 3

3.0 STATIC EXCITATION SYSTEM:

3.1 Salient Features:

Figure 3.1 shows the functional block diagram of static excitation system [2]. The static excitation system consist of the following:

(i) Rectifier Transformer,
(ii) Thyristor bridge,
(iii) Excitation start-up and field flashing equipment,
(iv) Regulator and operational control circuits.

3.1.1 Rectifier Transformer:

The excitation power is taken from generator output. The rectifier transformer steps down voltage level suitable for the SCR bridges and the power is transferred through field breaker to the generator field.

The rectifier transformer ([illegible]) should have high reliability as failure of this will cause shutdown of power station. The transformer is selected such that it supplies rated excitation current at rated voltage continuously and is capable of supplying ceiling current at the ceiling excitation for a short period of 10 seconds.

3.1.2 Thyristor Bridge:

It consist of a suitable number of bridges connected in parallel. Each thyristor bridge comprises of six thyristors, working as fully controlled bridges. Current carrying capacity of each bridge depends on the rating of individual thyristor.

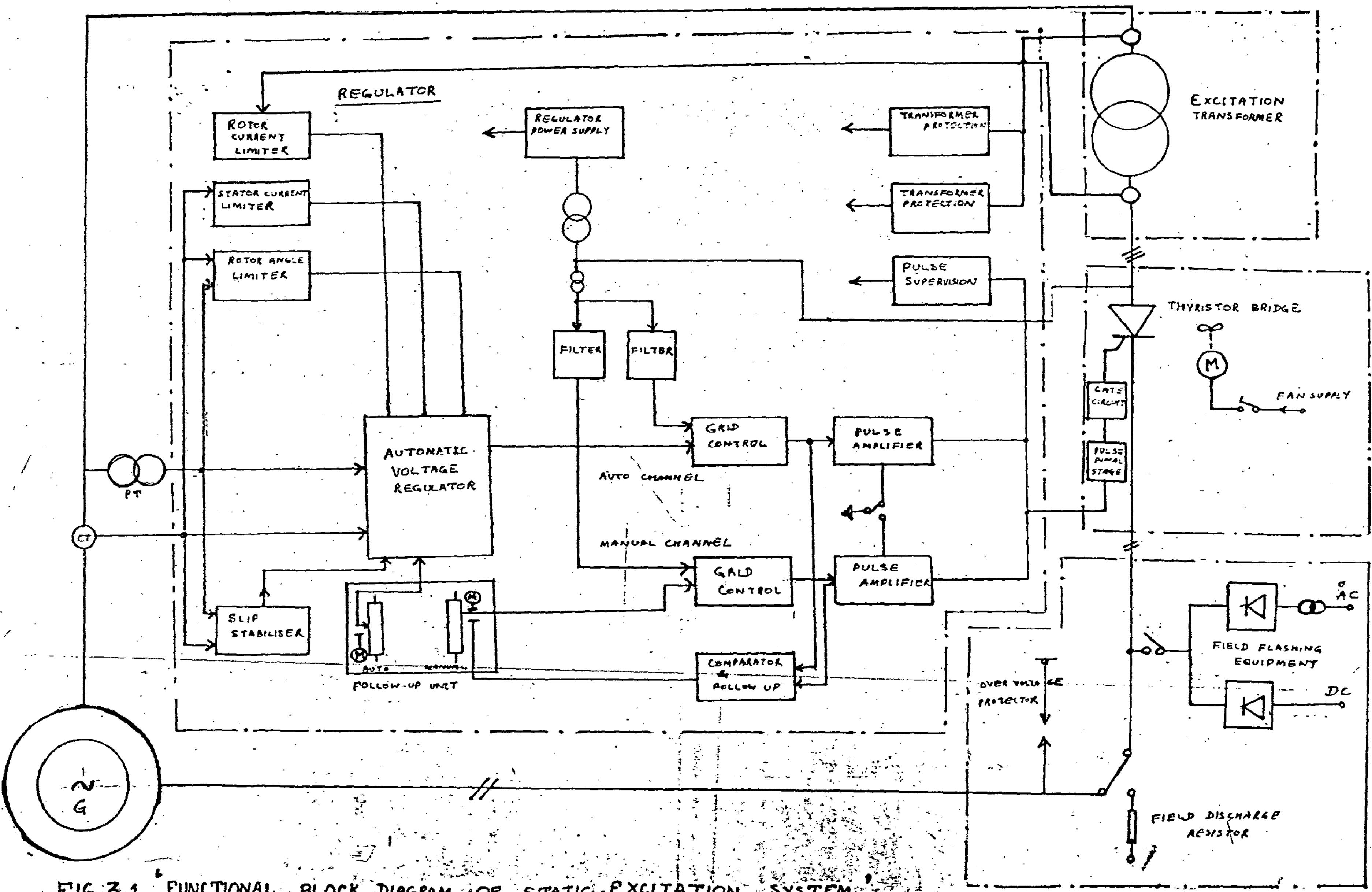


FIG 3.1 FUNCTIONAL BLOCK DIAGRAM OF STATIC EXCITATION SYSTEM

Thyristors are designed such that their junction temperature rise is well within its specified rating. By changing the firing angle of the thyristors, variable output is obtained. Each bridge is controlled by one pulse and cooled by a fan.

These bridges are equipped with protection devices and failure of one bridge cause alarm. If there is a failure of two thyristor bridges, the excitation current will be limited to a predetermined value lesser than the normal current. However, failure of the third bridge result in tripping and rapid de-excitation of the generator.

3.1.3 Excitation Build-Up and Field Discharge Equipment:

For the initial build up of the generator voltage, a field flashing equipment is required. The rating of this equipment depends upon the no-load excitation requirement and field time constant of the generator. From the reliability point of view, provision for both the AC and DC field flashing are provided.

The field breaker is selected such that it carries the full load excitation current continuously and also it breaks the maximum field current when the three phase short circuit occurs at the generator terminals.

The field discharge resistor is normally of non-linear type for medium and large machines, i.e. voltage dependent resistor.

To protect the field winding of generator against overvoltages, an overload protector alongwith a current limiting resistor is used to limit the overvoltage across the field winding. The over-voltage protector operates on the insulation breakover principle. The voltage level at which over-voltage protector should operate is selected based on insulation level of field winding of the generator.

3.1.4 Regulator and Operational Control Circuits:

Regulator is the heart of static excitation system. This regulates the generator voltage by controlling the firing pulses to the thyristors. It consist of the following:

(a) Error Detector and Amplifier:

The generator terminal voltage stepped down by a 3ø P.T. is fed to the AVR. The a.c. input thus obtained is rectified, filtered and compared against a highly stabilized reference value and the difference is amplified in different stages of amplification. The AVR is designed with highly stable elements so that variation in ambient temperature does not cause any drift or change in the output level. Three CT's sensing the output current of the generator feed proportional current across variable resistor in the AVR. The voltage thus obtained across the resistor, can be added vectorially either for compounding or for transformer drop compensation.

(b) Pulse Generator Unit:

The output of AVR is fed to a grid control unit (pulse generator), it gets its synchronous a.c. reference through a filter circuit and generates a double pulse spaced 60° (3.3 ms duration) apart whose position depends on the output of the AVR, i.e. the pulse position varies continuously as a function of the control voltage. Two relays are provided, by energising the relays, the pulses can be either blocked completely or shifted to inverter mode of operation.

(c) Pulse Amplifier:

The pulse output of the 'Grid Control Unit' is amplified further at intermediate stage amplification. This is also known as pulse intermediate stage. The unit has a d.c. power-supply, which operates from a three phase 380 V supply and delivers +15 V, -15 V, +5 V and a coarse stabilised voltage V_Z.

A built-in relay is provided which can be used for blocking the six pulse channels. In a two channel system (like Auto and Manual), the changeover is effected by energising/de-energising the relay.

(d) Pulse Final Stage:

This unit receives input pulses from the pulse amplifier and transmits them through pulse transformers to the gates of the thyristors.

A build in power supply provides the required d.c. supply to the final stage amplifier. Each thyristor bridge has own final pulse stage. Therefore, even if thyristor bridge fails with its final pulse stage, the remaining thyristor bridges can continue to cater the full load requirement of the machine and thereby ensure (n-1) operation.

(c) Manual Control Channel:

A separate manual control channel is provided where the controlling d.c. signal is taken from a stabilised d.c. voltage through a motor operated potentiometer. The d.c. signal is fed to a separate grid control unit whose output pulses after being amplified at an intermediate stage can be fed to the final pulse stage. When one channel is working, generating the required pulses, the other remaining blocked. Therefore, a changeover from 'auto' to 'manual' control or vice versa is effected by blocking or releasing the pulses of the corresponding intermediate stage.

(d) Follow-up Unit:

To ensure a smooth changeover from 'Auto' to 'Manual' control, it is necessary that the position of the pulses on both channels should be identical. A pulse comparison unit detects any difference in the position of the pulses and with the help of a follow-up unit actuates the motor operated potentiometer on the 'Manual' channel to turn in a direction so as to eliminate the difference.

However, while transferring control from 'Manual' to 'Auto' mode any difference in the two control levels can be visually checked on a balanced meter and adjusted to obtain null before changeover.

(e) Field Controllers:

When a generator is running in parallel with the power network, it is essential to maintain it in synchronism without exceeding the setting of the machine and also without the protection system tripping. The automatic voltage regulator by itself can't ensure this. It is necessary to supplement the basic voltage regulator by limiters to limit overexcitation and underexcitation. Limiters do not replace the protection system but only prevent the protection system from tripping unnecessarily under extreme transient conditions.

The AVR also has a built-in-frequency sensing circuit so that when the machine is running below the rated frequency, the regulator reference voltage should be reduced proportional to frequency. With the help of a potentiometer provided in the AVR, the circuit can be made to respond proportionally to voltage above a certain frequency (fo) and proportional to frequency below this frequency. The range of adjustment of this cut off frequency , lies between 40 and 60 Hz.

3.2 Performance and Characteristics:

The steady state and transient behaviours of a synchronous machine coupled to an infinite system must be matched to the desired operating conditions by suitable selection of control functions in the entire excitation system [39].

The basic requirements of a closed loop excitation control system is to hold the terminal voltage of a generator at a predetermined value independent of the change in loading conditions. In addition to this, the excitation system has to contribute the following functions also:

(a) Maintain machine operation stable, under steady state, dynamic and transient conditions.

(b) Satisfactory operation with other machines connected in parallel.

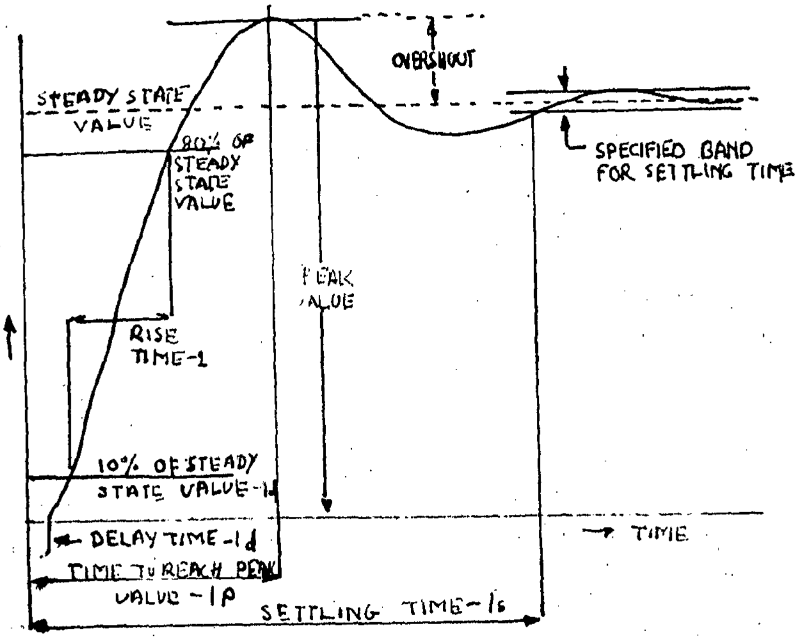
(c) Effective utilisation of machine capabilities without exceeding machine operating limits.

3.2.1 Response of the System : (Refer Figure 3.2)

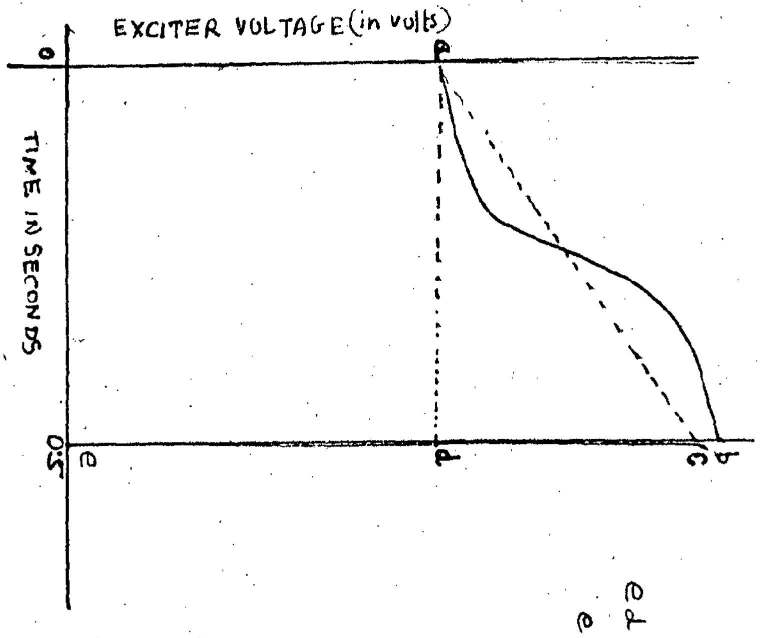
The fastness of action of an excitation system is measured/expressed by the term 'Response ratio of the system'. Earlier response of the system was calculated by measuring the rise of exciter voltage in first 0.5 seconds. With the advent of very fast acting and high initial response excitation system, like static systems the term 'High Initial Response System' is defined (in IEEE standard 421-A (8)) as those system which attain 95% of the ceiling voltage level in 0.1 second or less. Static Excitation System comes in this category, which is considered good enough for power system stability point of view. Typical response time for static excitation system is 20 ms.

3.2.2 Capability Diagram:

The capability diagram of generator is shown in Fig. 3.3. It gives the operating zone of the machine and the limitations imposed. This is of great importance in setting the limiting zones of operation for the various limiters in AVR. Capability curve gives information regarding the full load rotor current (excitation) and maximum rotor angle during steady state loading



TIME RESPONSE OF SYSTEM FOR STEP INPUT



$$\text{RESPONSE RATIO} = \frac{ce - de}{(de)(oe)}$$

ed = Rated voltage
ec = Ceiling voltage

FIG 3.2 RESPONSE RATIO OF EXCITATION SYSTEM

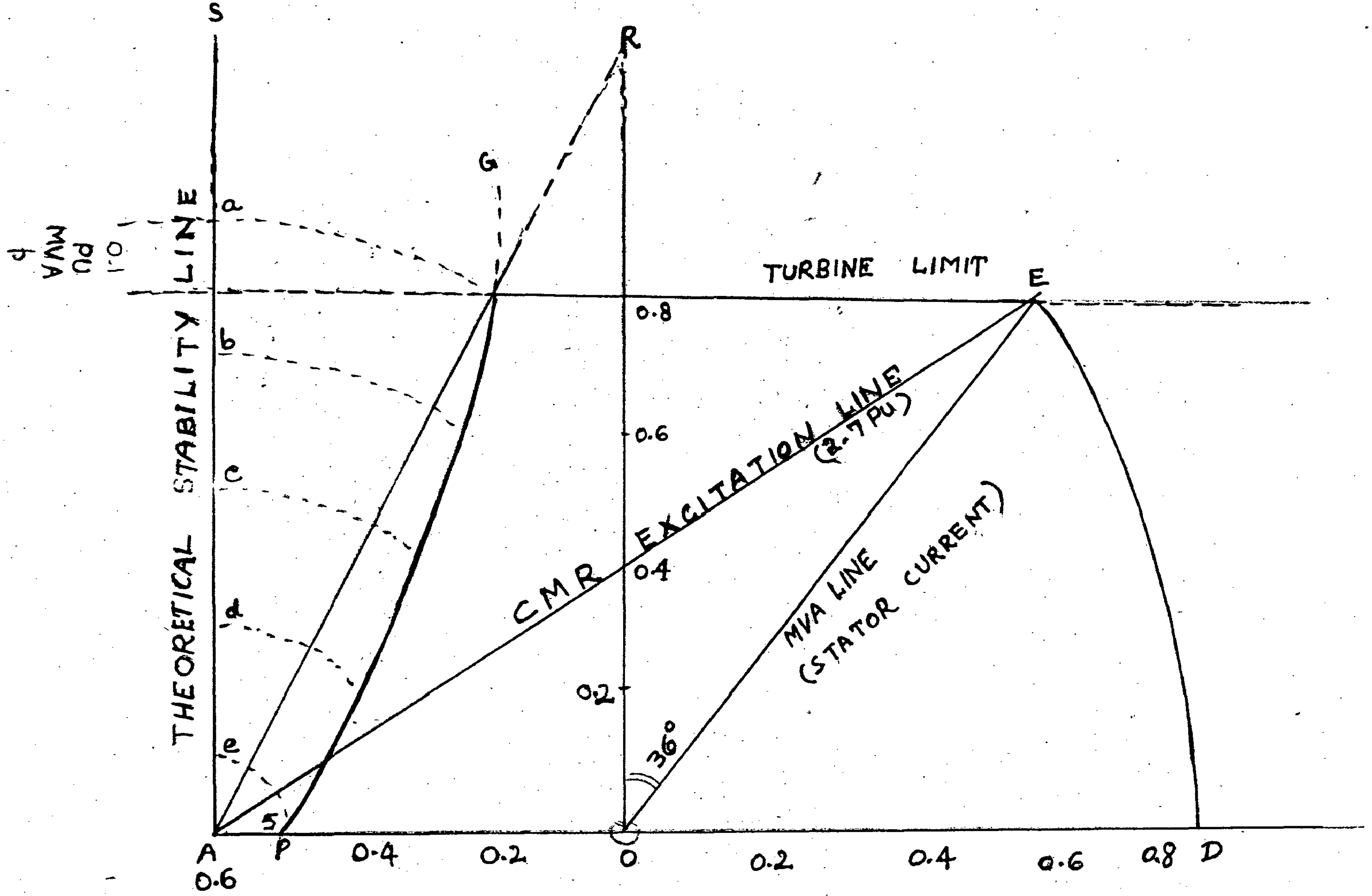


FIG-3.3 CAPABILITY DIAGRAM OF SYNCH. M/C

P.F. and operating conditions. This is essential for proper setting of the various limiters in the exciter control system.

3.2.3 Transient and Dynamic Stability Limit:

Fast response of excitation helps during disturbance and contributes to power system stability by allowing the required transfer of power even during the disturbance [3]. In transient stability the machine is subjected to a severe disturbance (during fault etc.) for a short time. This results in a dip in the machine terminal voltage and power transfer. Taking one machine connected to infinite bus, the equation for power transfer can be written as

$$P = \frac{V_t \times V}{X} \sin\delta \qquad \ldots (3)$$

where V_t = Machine terminal voltage,

V = Infinite bus voltage

X = Interconnected reactance

δ = Load angle.

In this equation power transfer 'P' is proportional to terminal voltage 'V_t', so if 'V_t' is reduced then 'P' will also reduce. In order to maintain power transfer 'P', the excitation should be fast acting enough to boost up the field voltage to ceiling and then maintaining the 'V_t' at desired value. Thus, it is advantageous to have higher speed and ceiling values in excitation control circuitry.

Similarly in case of faulty condition, after the fault is removed, the reactance 'X' suddenly changes thereby causing unbalance conditions due to power swings. This needs fast corrective action through a excitation system to bring the machine to normal operating condition.

Modern fast and high response excitation system [24] helps in two ways by reducing the severity of the machines first swing during transient disturbances and also ensuring that the subsequent swings are smaller than the first one. Thus, it helps in increasing the transient stability limits. With a typical static excitation system, ceiling level can be achieved within 20 ms due to which it offers an improved transient stability limit.

Following a disturbance, the group of machines operating in the same control group experience smaller oscillations. Moreover the oscillating control group of machines react with each other reinforcing these oscillations. Here the change in excitation may not result in stable operation, because by the time corrective action being taken by the excitation (due to inherent time delay) the oscillating system changes, causing opposite excitation requirement to be met. Though fast excitation system avoids this problem to certain extent. Power system stabilizers as mentioned earlier are employed alongwith the AVR to damp out inter area oscillations and local machine system oscillations.

In addition to the above, limiters are generally built in the excitation system for large generators connected to the grid. This helps in optimal utilization of machine's capability without jeopardising its stability. These limit controllers prevent the tripping by keeping the system parameters well within the safe limits.

3.2.4 Effect of Excitation System on Transient Stability:

Since the transient stability problems deal with the performance of power system when subjected to sudden disturbances, some times leads to sudden loss of synchronism. It is worthwhile to study the behaviour during the first swing as the period is of very short duration.

It is assumed that the mechanical power supplied by the prime mover remains constant during the disturbance. Therefore the effect of excitation control on this type of transient depends on its ability to help the generator to maintain its power output in the above period. The main factors that affect the performance during severe transients are:

(i) The disturbing influence of impact, this includes the type of disturbance, its location and duration.

(ii) The ability of transmission system to maintain synchronising force during the transients.

(iii) Turbine and generator parameters.

These factors mainly affect the first swing of the machine.

CHAPTER - 4

4.0 AVR, DESIGN AND [illegible]

The heart of AVR is the control amplifier and PID network. It will be discussed below:

4.1 Control Amplifier and PID Network:

Automatic voltage regulator basically consist of a control Amplifier with PID network [1]. The input to control amplifier (error signal) is the difference of reference signal and actual input voltage at the terminal. The main features of AVR modules are listed below:

(a) The AVR comprises an input circuit which accept 3-phase voltage signals of 110 V a.c. and 3-phase current signal of 5A or 1 A a.c. It is thus necessary to use intermediate PT's and CT's to transform the generator voltage and current to the above mentioned values. This module itself contains PT's and CT's which further step down the signals to make them compatible with electronic circuits.

(b) An actual input value converting circuit for converting the a.c. input signal to d.c. signal with minimum ripple.

(c) It has a reference value circuit (using temperature compensated zener diodes). The output of this is taken to an external potentiometer that provides 90 - 110% range of operation of the generator voltage.

(d) A control amplifier which compares the reference and actual value and provides an output proportional to the deviation is also there. Apart from this, it has the facility to accept other inputs for operation in conjunction with various limiters and power system stabilizer.

(c) A voltage signal proportional to frequency is generated which reduces the excitation current when frequency falls below the set level, thus keeping the air gap flux constant. This prevents saturation of connected transformer and possible overvoltages.

4.2 Role of PID Network:

The objective of the closed loop control system is to keep the following parameters under control [15].

(i) The overshoot due to a step change in controlled variable (in this case the terminal voltage) should be within acceptable limits for the system to be stable.

(ii) The response time should be as small as possible so that the correction in the controlled variable is done by the controller without any appreciable lapse of time.

(iii) Steady state error should be as small as possible.

(iv) The settling time should be as small as possible.

(v) The system should remain stable for a wide range of operating points. The PID characteristic is shown in Fig. 4.1.

It is not possible for the control amplifier alone to take care of all the above mentioned points. Hence to improve the performance, compensation network are provided in the control amplifier.

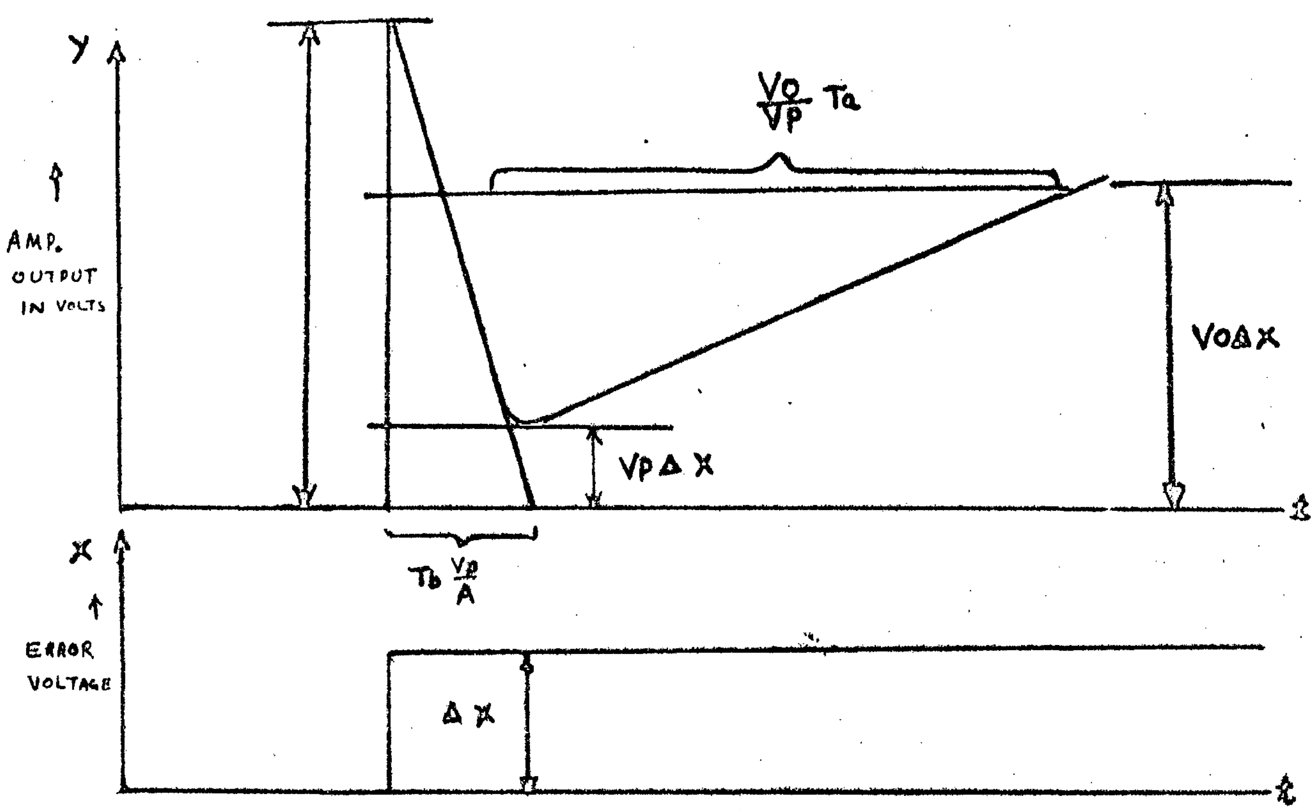


FIG. 4.1 PID CHARACTERISTICS

A → Natural Gain

V_o → STATIC GAIN (1 — 100)

V_P → DYNAMIC PROPORTIONAL GAIN (1 — 50)

T_A → 0·1 - 10 SEC.

T_B → 0·03 — 3.3 SEC.

Three compensating network are proportional, Integral and Derivative feedback circuits. The characteristics of these networks are discussed below:

The proportional controller provides an output which is proportional to the error signal at the input of amplifier. In such circuits a finite steady state error always exists as the output depends on this value. This steady state error can be decreased by having higher gains but there is a risk of the system becoming unstable as the overshoot are likely to be large. On the contrary with the purely integral feedback the output is proportional to the time integral of the error signal, here it is theoretically possible to achieve zero steady state error. However such systems are sluggish and have very large settling time. With a Proportional Integral (PI) feedback it is possible to have small response time and small steady state error. However, if the proportional gain is increased beyond a limit or the integral time constant is reduced, it will cause oscillations and make the system unstable.

With PID network in the feedback path stable operation over a very wide range of gain is possible. In this case, response time, settling time and steady state error is also small.

4.3 Voltage Proportional to Frequency Signal:

It is likely that under low frequency conditions, saturation of transformers, PT's and unintended tripping due to over-voltage may occur if the excitation is maintained corresponding to rated frequency condition. A circuit is provided to sense frequency. It reduces the reference value when the frequency falls below a cut off value. This reduction in excitation will reduce the terminal voltage.

4.4 Limiters in Static Excitation System:

An automatic voltage regulator alone can't ensure stable operation under dynamic and transient conditions. Optimum utilization of the generator can be ensured only if the basic AVR is influenced by additional signal to limit the under excitation and overexcitation of the machine. Thus, limit controllers working in conjunction with the AVR ensure:

(a) Optimum utilization of the machine,
(b) Security of parallel operation.

The following parameters are to be limited in the static excitation system [1]:

(i) Stator current under condition of overexcitation and underexcitation,
(ii) Rotor current,
(iii) Rotor angle or the load angle.

During overexcitation, the rotor current and stator current limiters intervene to bring about a reduction in excitation. On the other hand during under excitation, limitation of rotor angle and stator current increases the excitation. Rotor and stator current limiters must be designed to intervene after a certain delay so as to permit temporary over/ceiling excitation.

limiters don't impair the control behaviour of the AVR as over excitation condition can exist in the event of load surge or because of the short lived faults in the power supply network.

In case of distant fault (i.e. 3-phase short circuit) the AVR senses and commands ceiling excitation to be applied. This results in increase of synchronising torque of machine and thereby prevents it from losing synchronism. If the short circuit persists and has not been cleared by the system protection after a set time, delayed rotor current limiter comes into operation preventing the generator and excitation equipment from being subjected to thermal overloads.

4.4.2 Rotor Angle Limiter:

Figure 4.8 shows the functional block diagram of rotor angle limiter. As shown in capability curve (Fig. 3.3) line AB represents the range of influence of the rotor angle limiter, the maximum angle of which has been taken as 85°. Although stable operation can be ensured even beyond 85° with the fast acting load angle limiter in action and achieve greater possible reactive power absorption capability. The load angle is limited for practical purposes to 85° because of the following considerations:

In the event of a short circuit in the system, the generators may accelerate owing to abrupt partial removal of the electrical load and as the turbine governor can't act fast,

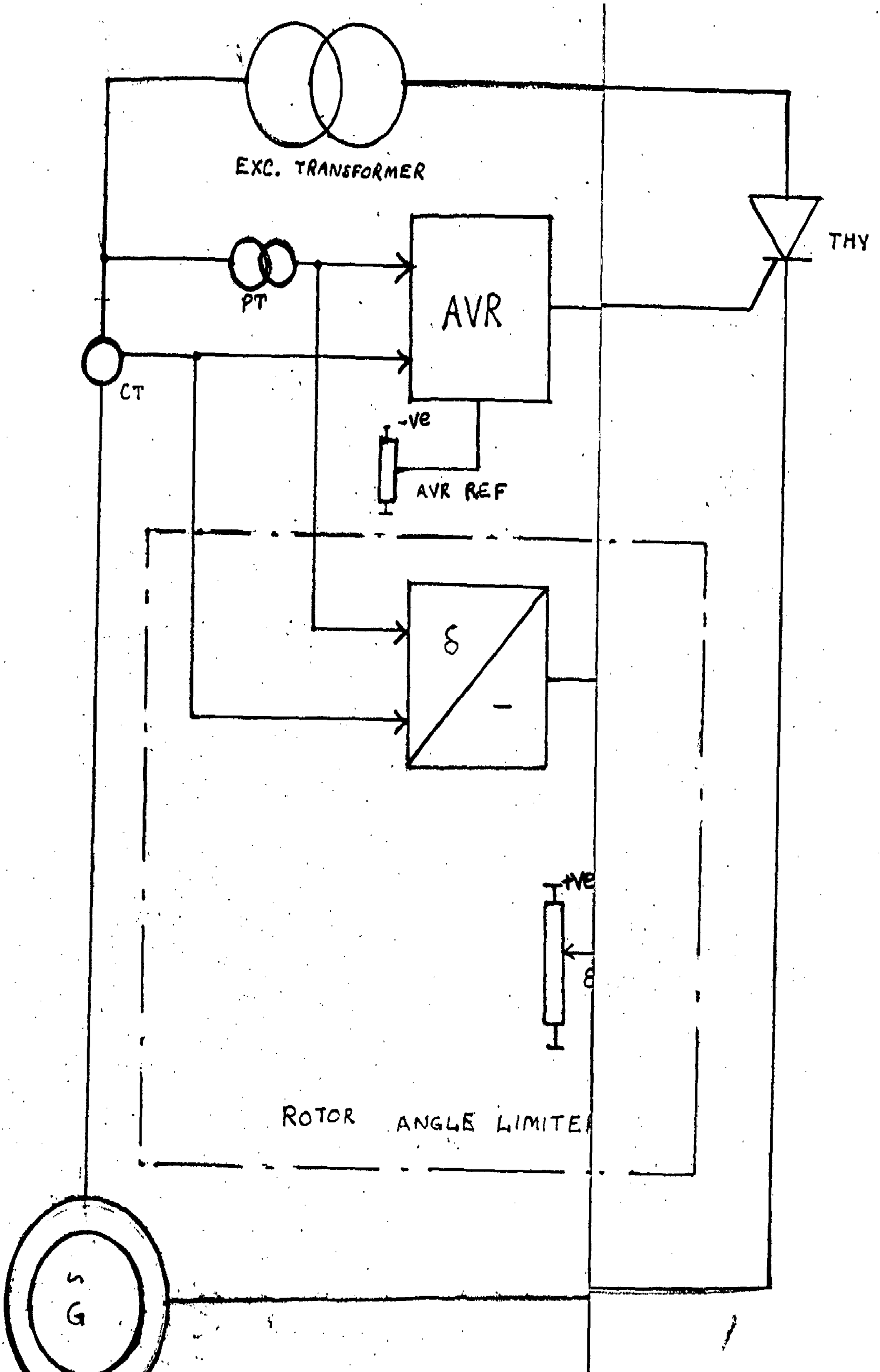


FIG 4.2 BLOCK DIAGRAM OF

OPERATING IN CONJU

the rotor angle increases and it becomes so large relative to the system vector that the machine may fall out of step.

The rotor angle limiter limits the load angle of the machine to an acceptable preset value. The angle δ is sensed and converted into a proportional dc voltage. The actual value is compared with an adjustable reference and fed to the input of an operational amplifier. In case the angle exceeds the set value, the output signal immediately takes over the control of the thyristor network to build up the generator air gap flux fast enough to avoid slipping.

The output of the limiter acts directly over AVR output to avoid any loss of time due to filter time constant in the AVR.

4.4.2 Field Current Limiter:

Figure 4.5 shows the field current limiter. The AVR may drive the field (or the thyristor network) into overload due to one or more of the following reasons:

(a) Faulty handling,
(b) System voltage reduction,
(c) Loss of sensing voltage to AVR and
(d) Failure within the controller.

The excitation limiter must prevent this overload from persisting. On the other hand, during dynamic disturbances in the system the excitation should not be reduced at once but ceiling excitation should be possible for a limited time.

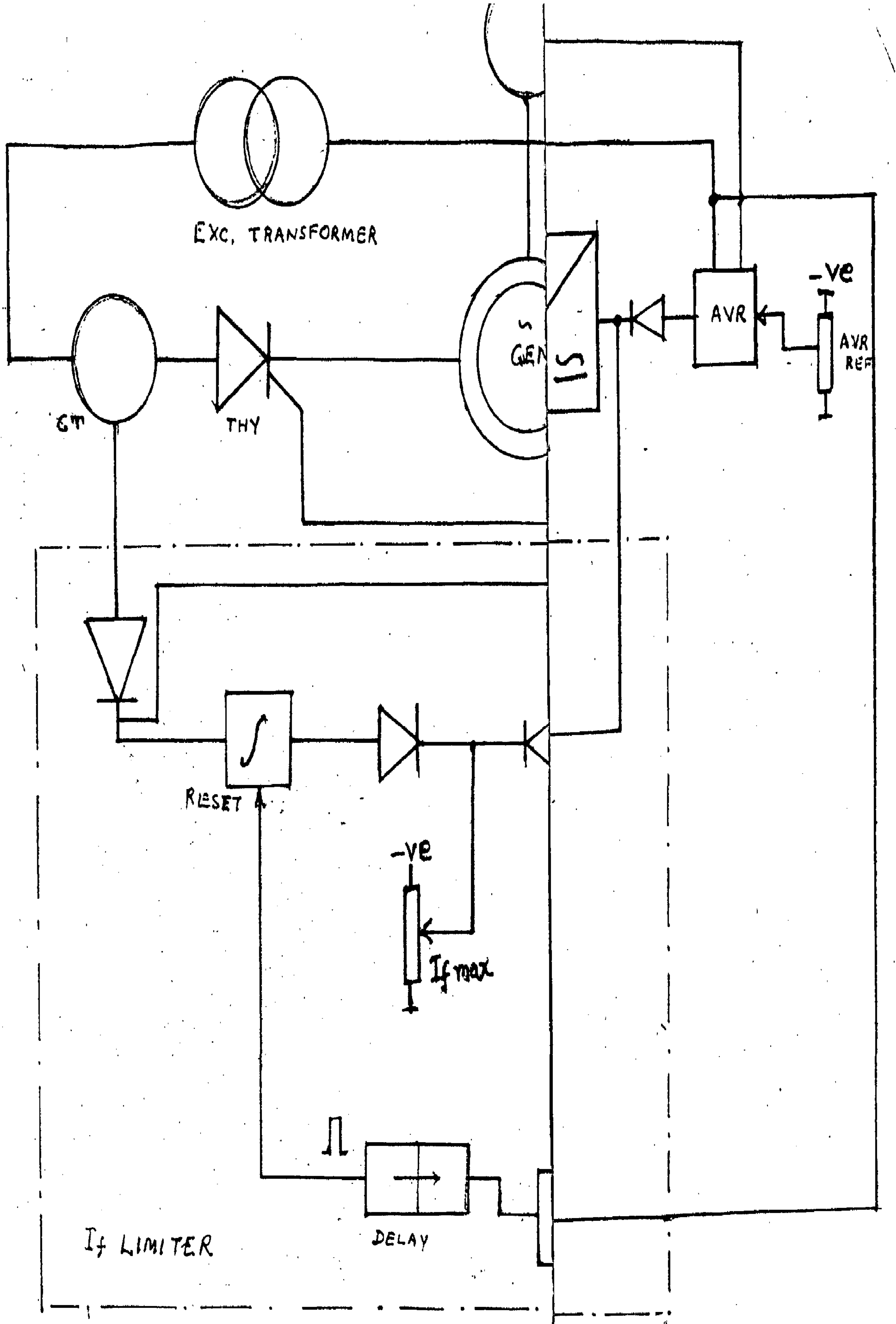


FIG 4.3 BLOCK DIAGRAM OF FIELD CURRENT

CONJUNCTION WITH AVR

The limiter can be operated in three different modes as explained to cater the above requirements.

(1) Single mode:

In this mode the excitation current is limited to a preset maximum value. The limiter intervenes with a time delay which is inversely proportional to the magnitude of the overload. While the limiter is operation the field current is limited steadily to the rated value.

(2) Fixed mode:

If during the above mentioned period of limitation, the generator voltage dips steeply for any reason, the ceiling excitation limit is validated again. The ceiling excitation current helps in increasing the short circuit current in the fault zone and hence aid selective tripping of the faulted section.

(3) Switching mode:

In the switching mode the excitation is limited to the thermal or rated current value. Only in case of sharp dip in the machine voltage, the ceiling limit is enabled momentarily. After the set time, the limit switches return to the rated value.

4.4.3 Stator Current Limiter:

Figure 4.4 shows the block diagram of stator current limiter. The stator current limiter has to influence the AVR differently depending on whether the machine is overexcited or underexcited. The excitation current is to be suitably reduced to limit the inductive stator current.

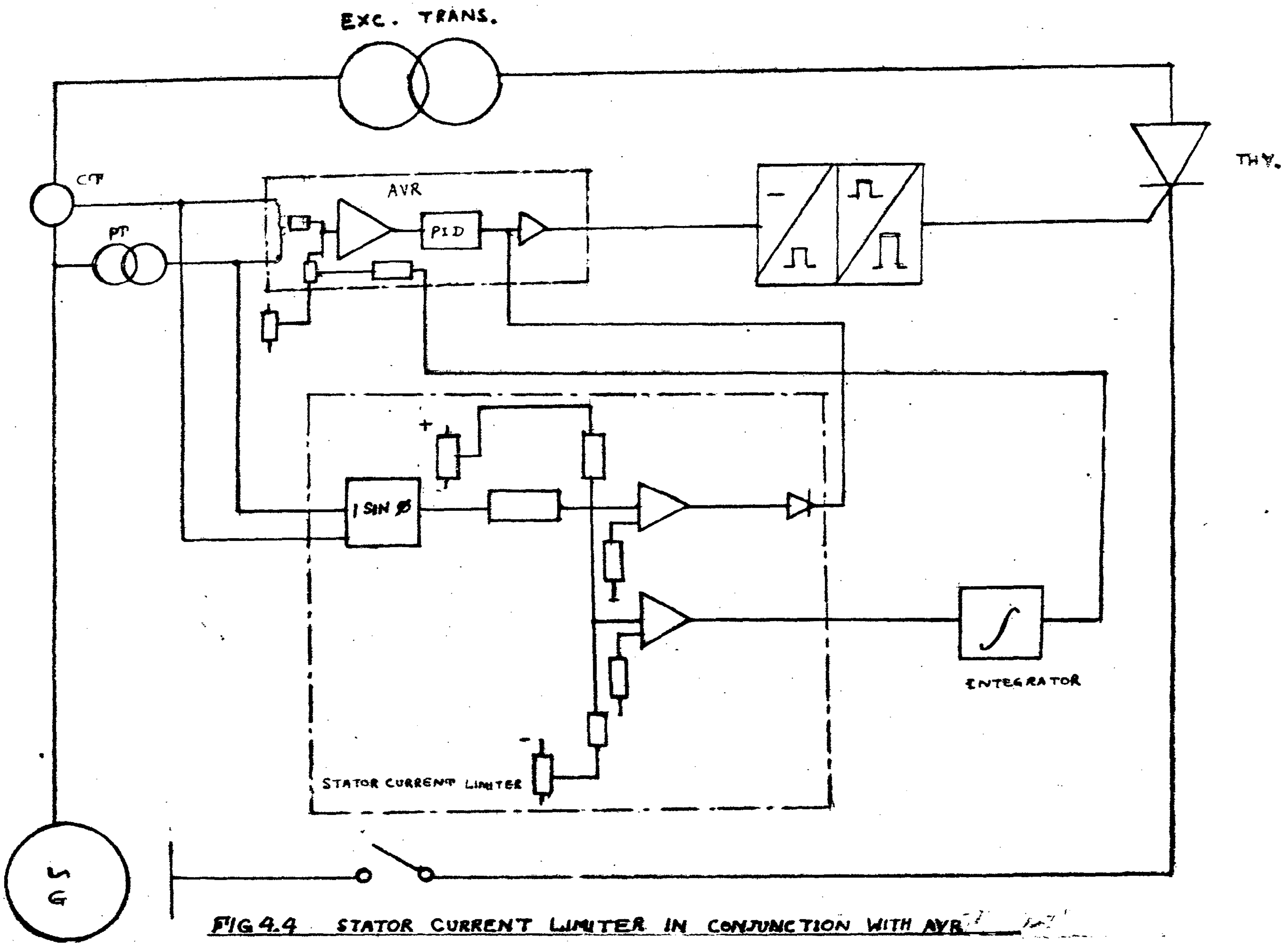


FIG 4.4 STATOR CURRENT LIMITER IN CONJUNCTION WITH AVR

The rotor angle limiter provides a more definite protection in preventing the machine from falling out of step. Capacitive stator current limitations come into play only with synchronous condensers which are to some extent negatively excited with generators. It prevents excessive leading MVAR loading corresponding to any given MW load.

The generator stator current is converted into polarised dc signal +ve or -ve, depending upon whether the machine is overexcited or underexcited. The voltage forms the actual input value for the controller which process each of the bipolar signal independently. One of the controller compares the capacitive stator current against its reference and acts directly on the regulator via a decoupling diode circuitry to increase the field current. The action of second controller which limits the inductive stator current is delayed by means of an integrator before it influences the control input of the AVR so as to reduce the excitation. The time lag offered is perfectly acceptable as far as stator overheating is concern because the integrator time constant is set one order less than the stator thermal time constant.

4.5 Slip Stabilisation Equipment

The AVR is provided with a slip stabilising equipment [20] to dampen the power oscillations. The damping torque in a typical system with a single machine connected to infinite bus through a reactance is directly proportional to two factors namely:

1. The gain in the excitation system and
2. The change on the generator terminal voltage for small change in rotor angle at constant flux linkages.

Interestingly several cases studies have revealed that the second factor can assume negative values in large and weakly connected power systems. As added to this, the high gain of excitation system worsens the situation, the net result being either sustain oscillations in the active power or machine getting out of step in extreme cases.

In order to improve system damping more active power should be given off at the generator terminal when the rotor is accelerated and less when it is deccelerated. The slip stabiliser performance characteristic is shown in Fig. 4.5.

The slip stabiliser unit is required to provide the 'supplementary signals' for controlling the active power. The signal can be derived from speed and the output of 'slip stabiliser' is fed to the AVR. The rotor speed would be ideal for deriving stabilising signal, but it is generally avoided since the design of suitable speed transducer and the associated filters calls for complecated mechanical and electrical equipment. The simple and direct method involved in using active power as stabilising signal make it advantageous and preferable over any other method. The gain setting of the slip stabiliser should be properly selected for effective use of the same. Since the damping present in a system depends on the operating conditions, the theoretically determined gain

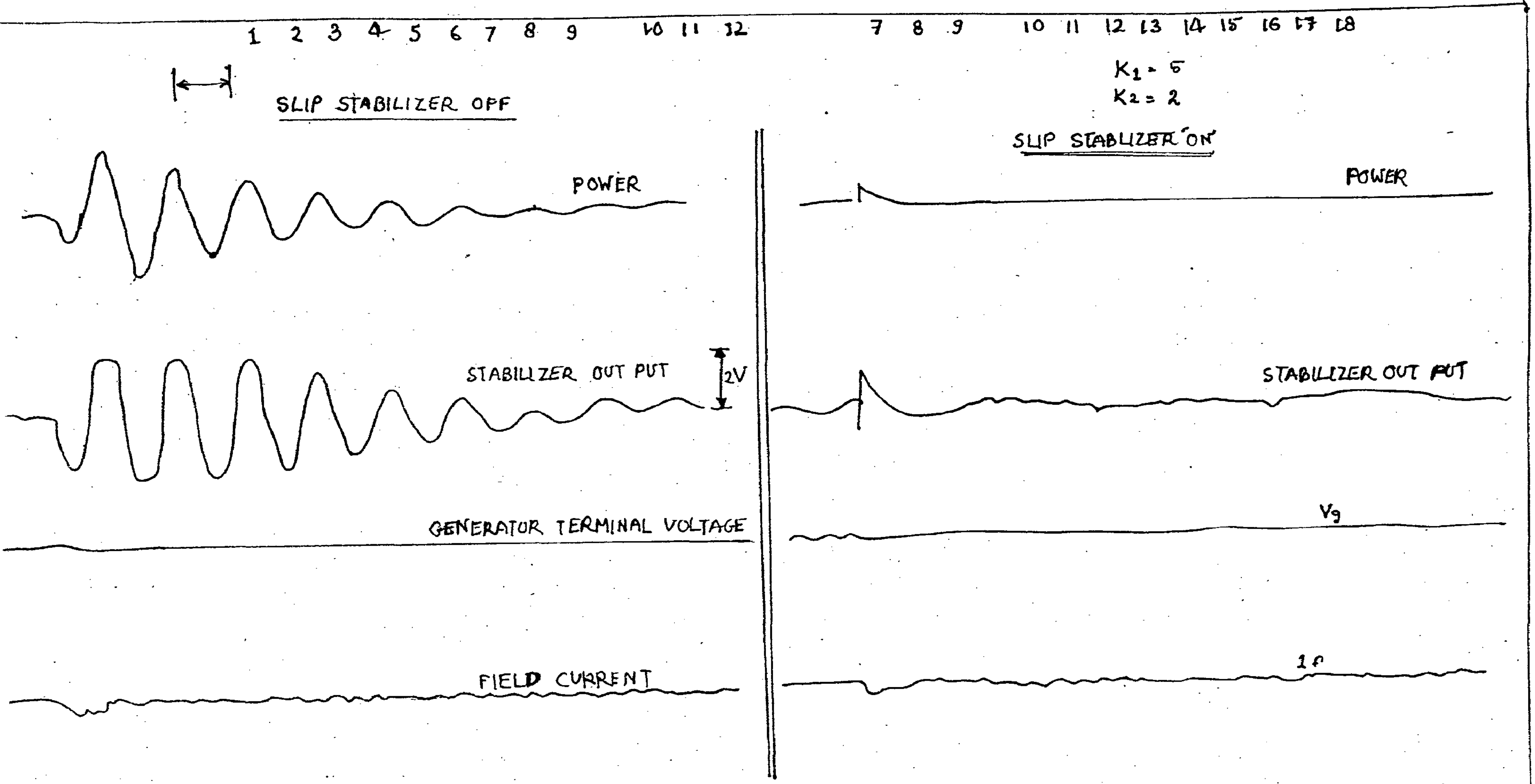


FIG. 4.5 SLIP STABILIZER PERFORMANCE

S.N.A

settings of the only stabiliser equipment should be suitable for a wide range of generator operating conditions.

4.9.2 Reasons for Accepting Accelerating Power as Auxiliary Signal:

(i) First and foremost is its very advantageous than phase position. To obtain the phase position with a velocity signal, a careful signal differentiation is required to avoid unacceptable noise level.

(ii) The advantage is that accelerating power senses relative motion of the generator voltage w.r.t. system voltage and the same is required for control. Speed or velocity deviations from normal value may not represent exact changes relative to the system.

(iii) Accelerating power may be approximated by the change in electrical power and is relatively easy to measure.

CHAPTER - 9

9.0 DEVELOPMENT OF ANALOG COMPUTER MODEL:

Presently computer simulation is the only effective means available for stability analysis of large electric power system. Computer simulation consist of mathematical model of the system to be analysed, data files of which contains parameters for specific power system and computer programme [6,17].

Here we have analysed STATIC EXCITATION SYSTEM. The effect of limiters and slip stabiliser on AVR is studied. The analog computer model of the system is developed with the aid of transfer functions block diagram (shown in Fig. 9.1).

9.1 Comparison With State Space Model:

The analog computer technique possess the following advantages [19] as compared with state space technique:

(a) Development of analog computer model is easier in comparison with state space model, since it involves less manipulations over the original model.

(b) The state at various intermediate points like integrator outputs, summing junction output or limiter output can be determined w.r.t. time, following a disturbance.

(c) Variables defined at different points are susceptible for signal processing operations like saturation and switching conditions.

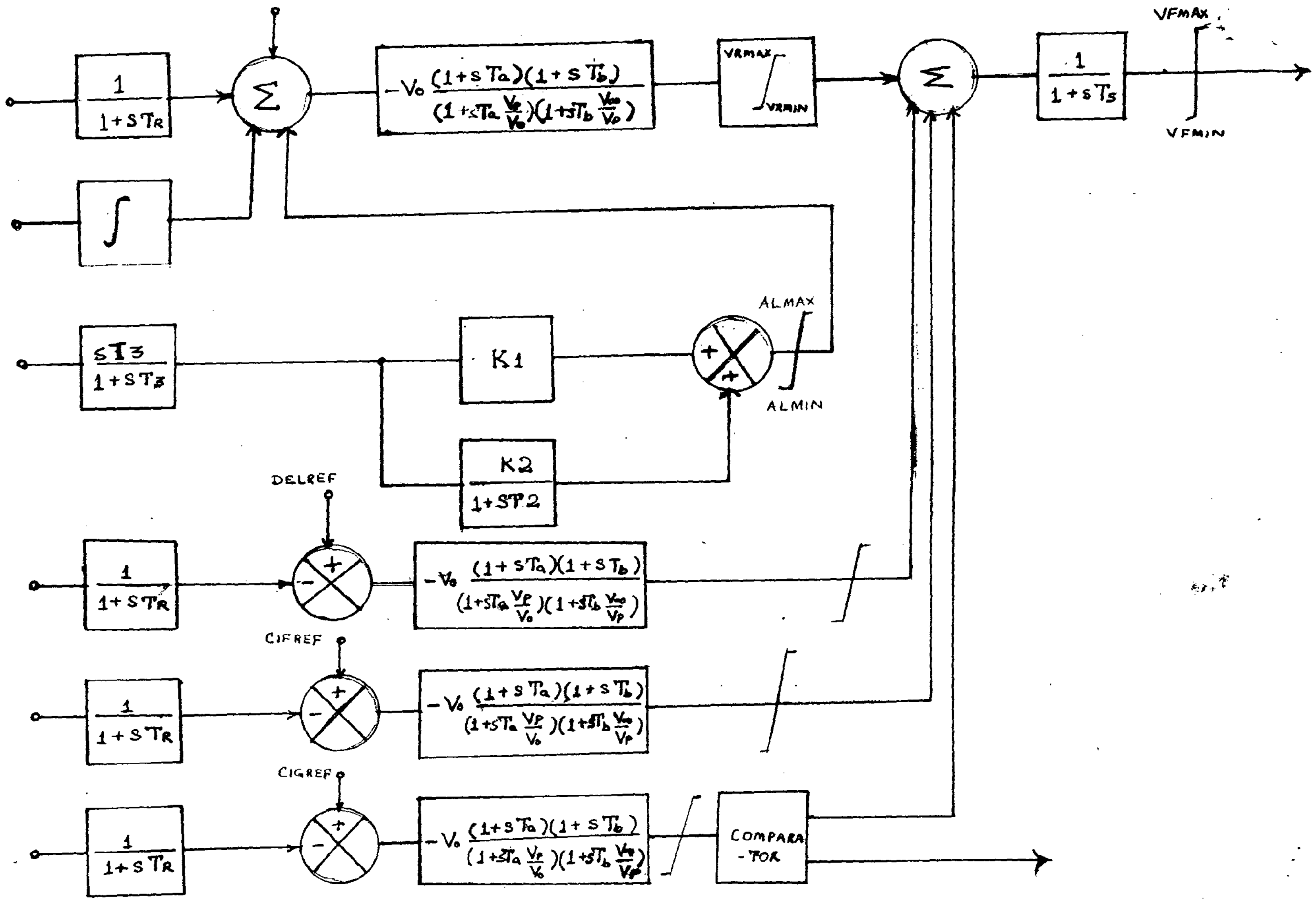


FIG. 5.1 'FUNTIONAL BLOCK DIAGRAM OF STATIC EXCITATION SYSTEM' (TRANSFER FUNCTION)

(d) The solution is calculated in terms of variables which have physical meaning.

(e) The variables are readily available for complex operations like non-linear function generation, time delays and variable differentiation.

(f) In case of analog computer approach, changes to the model can be isolated in the analog computer diagram and included very easily in the program. On the other hand in case of state space model, a simple change to the model involves wide spread program change.

(g) The approach being simple in nature makes it quite easy to develop program.

5.2 Method of Development:

The transfer function of static excitation system comprises of filters, lead-lag networks, limiters (saturation circuits), comparators and integrators. The analog computer model from the transfer function block diagram is developed as follows:

(a) The elements of static excitation system are individually considered for system modelling.

(b) Set of linear equations, showing input - output relationship of individual elements are derived from the transfer function.

(c) Signal flow graph for each element is formed, that have the following properties:

(i) The nodes represents variables of a system. It adds the incoming signals and transmit the sum to all outgoing branches.

(ii) A branch indicates the functional dependence of one variable on others.

(iii) A mixed node which has both incoming and outgoing branches, may be treated as an output node by additing an outgoing branch of unity gain.

(iv) For a given system signal flow graph is not unique. Many different signal flow graphs can be drawn for a given system by writting the system equation differently.

(d) The branches showing gains are replaced by amplifiers, while others having 1/s factor (s is the Laplace operator) are replaced by integrators. It will be further elaborated in the following discussion.

5.2.5 The limiters have a linear input-output relation between the preset lower and upper limits. These limits represents the saturation of the function.

5.2.6 The comparator used is a zero crossing detector, whose output switches from one terminal point to other, as the input changes from a positive value to a negative. The expression for input-output relation are as follows:

If $x < 0$ $y1 = f(x)$ and

$y2 = 0$.

If $x \geqslant 0$ $y1 = 0$ and

$y2 = f(x)$

where x is the input to the comparator,
y1 and y2 are two outputs.

5.3 Description:

The development of the analog computer model for each individual is described below:

5.3.1 Input Filtering Circuit:

The transfer function of input filtering unit is given by expression,

$$y(t)/x(t) = 1/(1 + s\,T_R) \qquad \ldots (5.1)$$

where $y(t)$ is the output,
$x(t)$ is the input and
T_R is the time constant of the circuit. It can also be written as

$$(1 + s\,T_R)\,y(t) = x(t)$$

or

$$y(t) + T_R\,\dot{y}(t) = x(t)$$

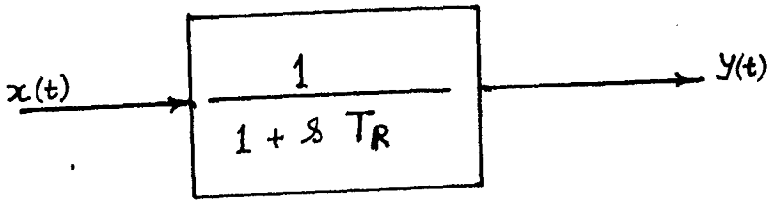
$$\dot{y}(t) = (x(t) - y(t)/T_R \qquad \ldots (5.2)$$

where, $\dot{y}(t) = dy(t)/dt$

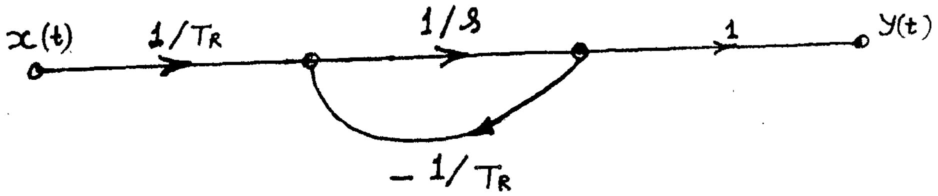
The signal flow graph and analog computer model is determined as shown in Fig. 5.2(b) and Fig. 5.2(c) respectively.

5.3.2 PID Controller:

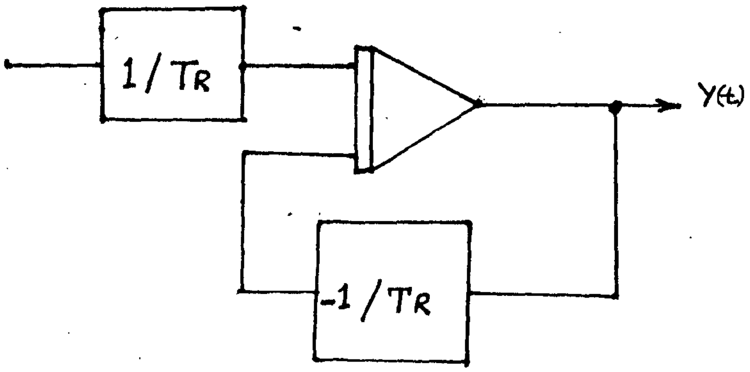
The PID network is consist of an amplifier and lead-log network. The error signal at input of AVR is fed to the lead lag



(a) Block diagram



(b) Signal flow graph



(c) Analog Computer Diagram

FIG. 5.2 INPUT FILTERING NETWORK

circuitry having adjustable lead and lag time constants. The lead time constants serves to compensate for the time delay inherent in the excitation system. The lag time constant are necessary for practical noise considerations and should not be set less than 1/20th of the lead time constant. The restriction on the lag time constant lower limit is imposed by the integration time step. It should be atleast 5 times of the integration time step.

5.3.2.1 Modeling Network:

The transfer function of the lead lag network is given by the expression:

$$Z(s)/X(s) = [(1 + sT_1)/(1 + sT_1 \times V_S/V_D)]$$
$$\times [(1 + sT_2)/(1 + sT_2 \times V_D/V_S)] \quad \ldots (5.3)$$

where, T_1 is the lead time constant,

T_2 is the lag time constant,

V_S is the static gain,

V_D is the dynamic gain and

V_{TR} is the open loop natural gain of the PSS network.

The transfer function for the lead-lag network can also be expressed as

$$Z(s)/X(s) = [Z(s)/Y(s)] \times [Y(s)/X(s)] \quad \ldots (5.4)$$

where lead network output is Y(s) and

lag network output is Z(s).

$$y(s)/x(s) = (1 + s\ T1)/(1 + s\ T1/V5) \quad \ldots (5.5)$$

$$u(s)/y(s) = (1 + s\ T2)/(1 + s\ T2/V6) \quad \ldots (5.6)$$

where $V5 = V_p/V_o$ and
$V6 = V_\infty/V_p$.

Equation (5.5) can also be written as

$$y(s)(1 + s\ T1/V5) = x(s)(1 + s\ T1)$$

or $y(s) + s(T1/V5)y(s) = x(s) + s\ T1\ x(s)$

or $y(s) = (V5/T1)x(x(s) - y(s))/s + V5\ x\ x(s) \quad \ldots (5.7)$

The Fig. 5.3 shows the transfer function block diagram, signal flow graph and the analog computer model for the lead network.

Similarly the analog computer model for the lag network can be determined by replacing S_a by S_b and V5 by V6 in Fig. 5.3(c). The analog computer model for the lag circuit is shown in Fig. 5.4.

5.3.3 Slip Stabilizer Lead Circuit:

The transfer function of the slip stabilizer lead circuit (washout circuit) is expressed as

$$y(s)/x(s) = s\ T9/(1 + s\ T9) \quad \ldots (5.8)$$

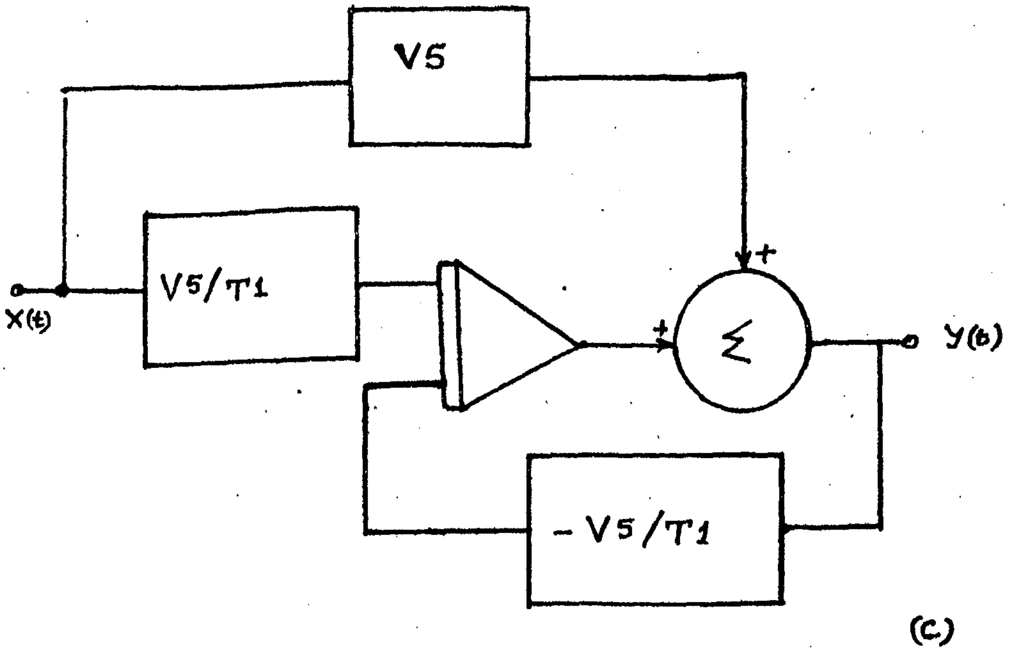
which can be written as

$$y(s)/x(s) = (1 - 1/(1 + s\ T9))$$

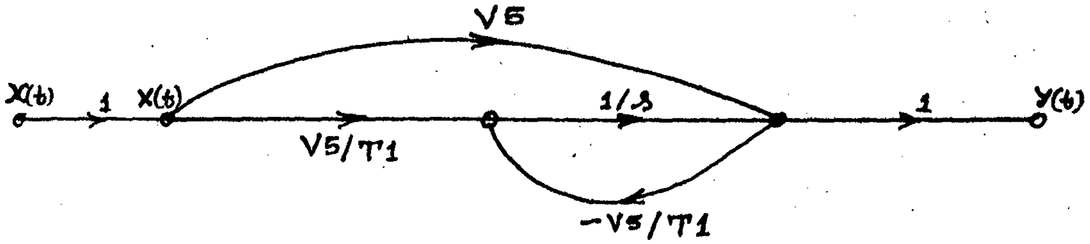
$$y(s) = x(s) - x(s)/(1 + s\ T9)$$

$$y(s) = x(s) - u(s) \quad \ldots (5.9)$$

where $u(s) = x(s)/(1 + s\ T9) \quad \ldots (5.10)$



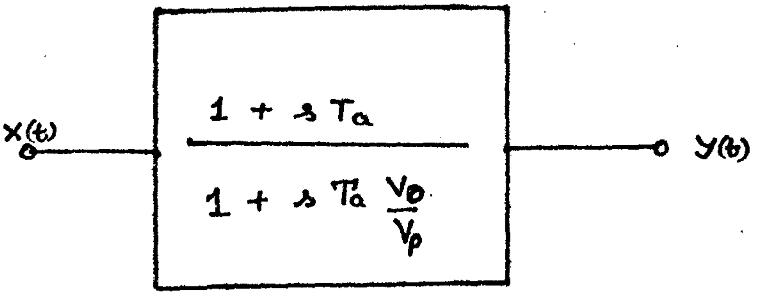
(C) ANALOG COMPUTER MODEL



$V5 = V_P / V_0$

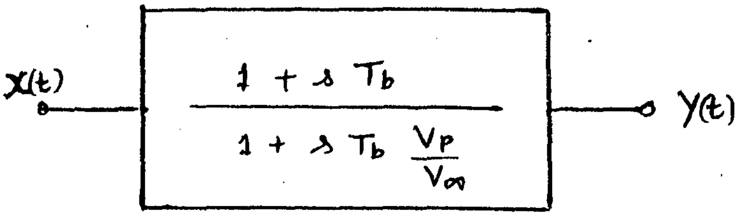
$T1 = T_a$

(b) SIGNAL FLOW GRAPH

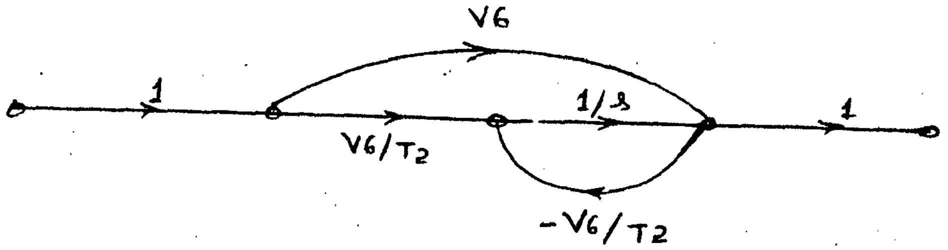


(a) TRANSFER FUNCTION BLOCK DIAGRAM

FIG. 5.3 LEAD NETWORK OF PID



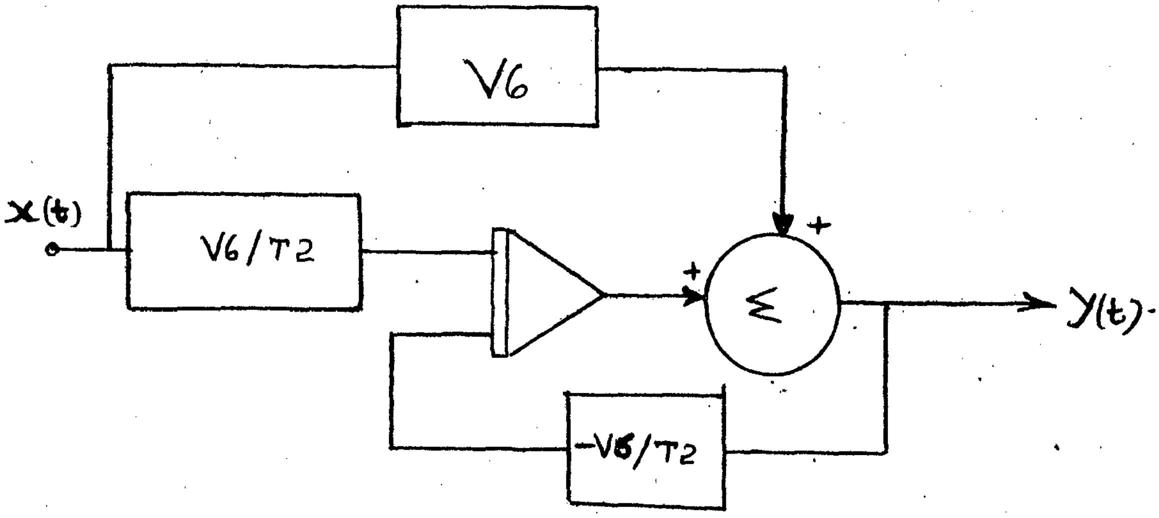
(a) Tranfer function Block Diagram



$V6 = V\infty / VP$

$T2 = T_b$

(b) Signal Flow Graph



(c) Analog Computer Model

FIG 5.4 LAG NETWORK OF PID

$$u(t) + s\,T5\,u(t) = x(t)$$

or $$u(t) = (x(t) - u(t))/s\,T5 \qquad \ldots (5.11)$$

The signal flow graph and analog computer model is derived from these equations, as shown in Fig. 5.5.

5.3.4 Slip Stabiliser Network:

The proportional channel of PI network has a gain K1 and the transfer function of Integral channel can be expressed as

$$y(t)/x(t) = K2/(1 + s\,T4) \qquad \ldots (5.12)$$

The two channels are in parallel. The equation (5.12) can be written as

$$y(t)(1 + s\,T4) = K2\,x(t)$$

or $$y(t) + s\,T4\,y(t) = K2\,x(t)$$

or $$y(t) = (K2\,x(t) - y(t))/s\,T4 \qquad \ldots (5.13)$$

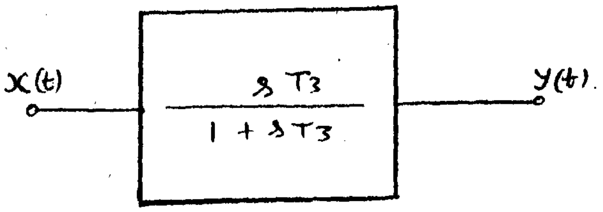
Fig. 5.6 shows the transfer function block diagram, signal flow graph and analog computer model of the PI network.

From the combination of above the following analog computer models have been developed from the following three cases:

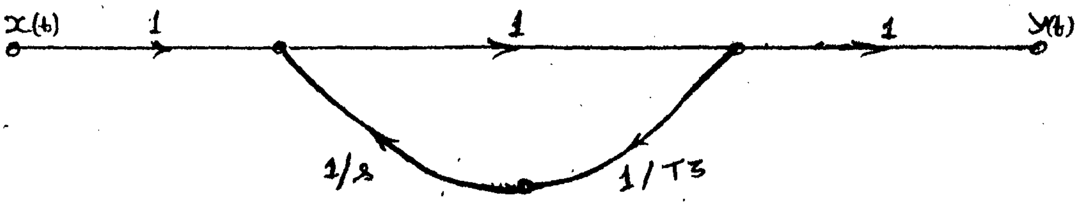
(i) AVR without limiters shown in Fig. 5.7,

(ii) AVR with limiters shown in Fig. 5.8 and

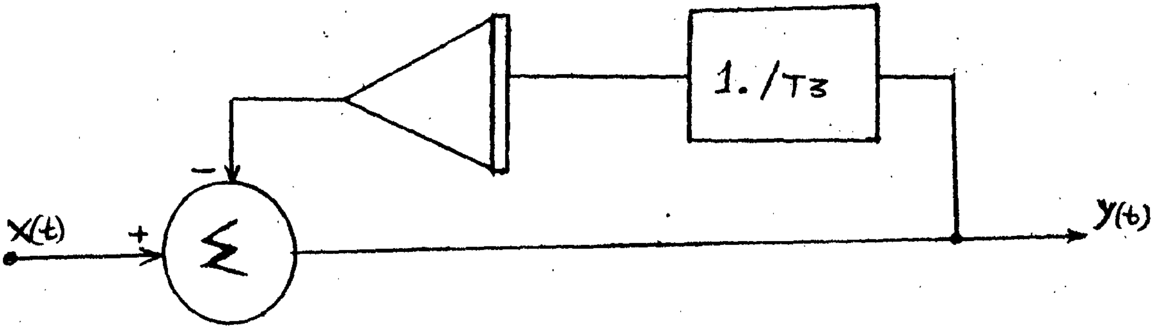
(iii) AVR with limiters and slip stabiliser shown in Fig. 5.9.



(a) Functional Block Diagram (T. F.)

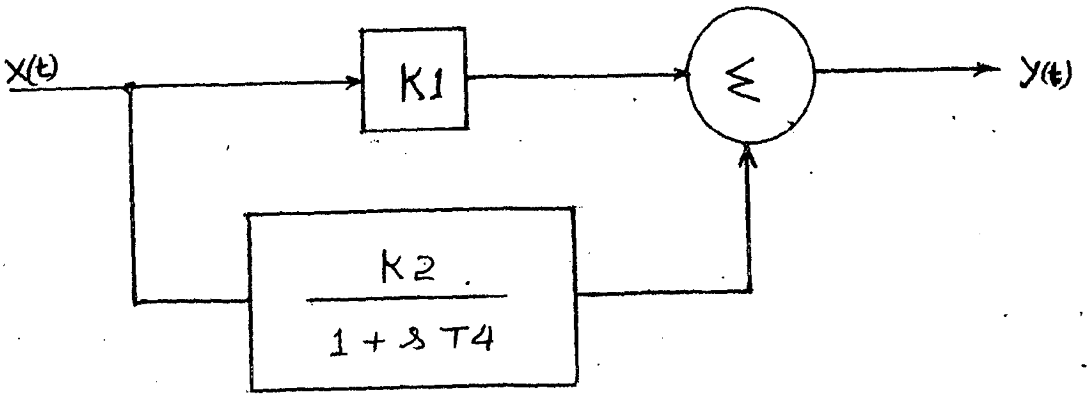


(b) Signal Flow Graph

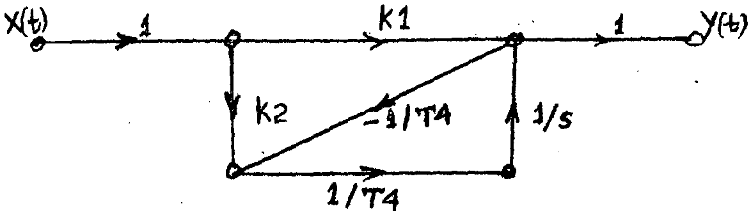


(c) Analog Computer Model

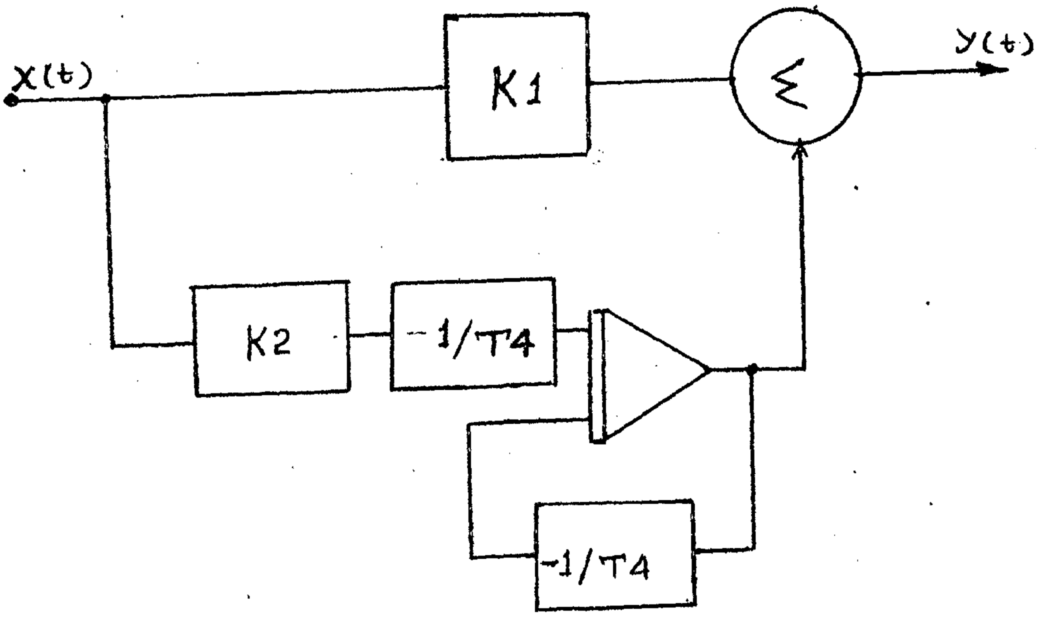
FIG 5.5 WASHOUT CIRCUIT OF SLIP STABILISER



(a) TRANFER FUNCTION BLOCK DIAGRAM



(b) SIGNAL FLOW GRAPH



(c) ANALOG COMPUTER DIAGRAM

FIG 5.6 PI NETWORK OF SLIP STABILISER

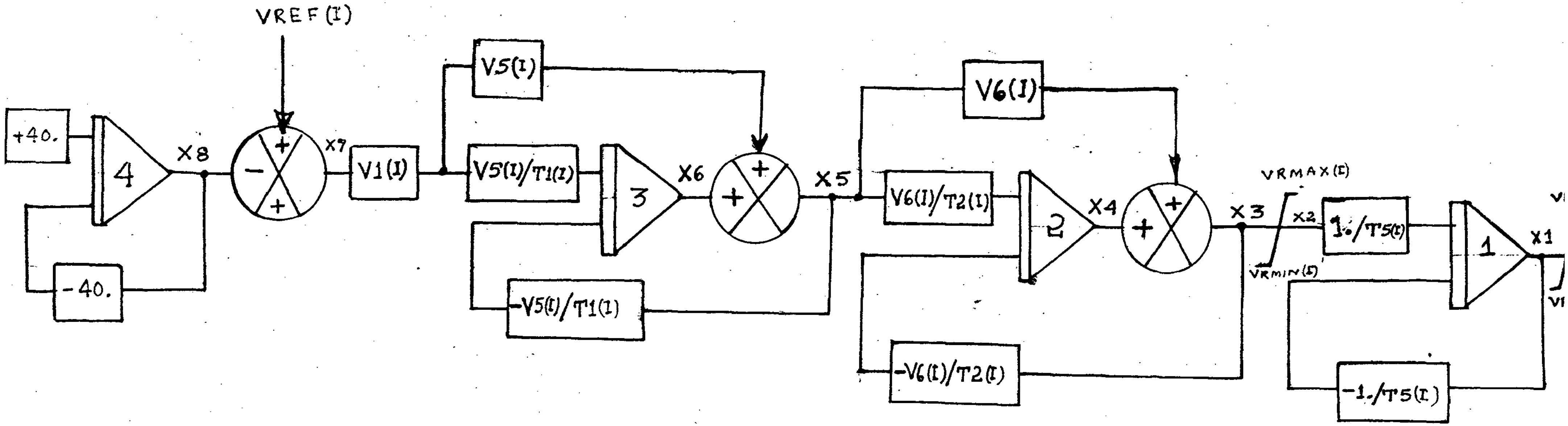


FIG 5.7 'ANALOG COMPUTER MODEL OF S.E.E. WITHOUT LIMITERS'

FIG. 5.8 'ANALOG COMPUTER MODEL OF AVR WITH LIMITERS'

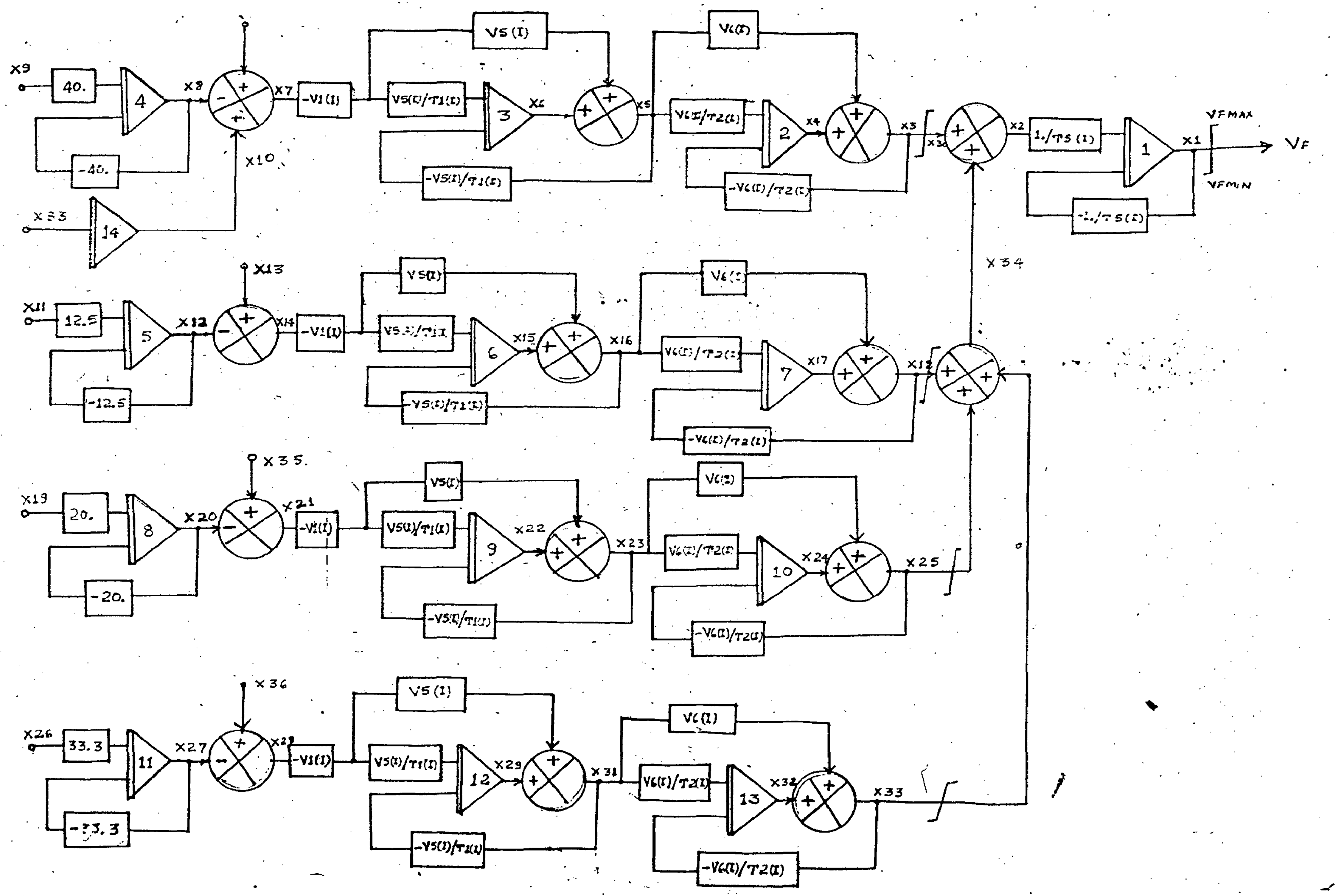
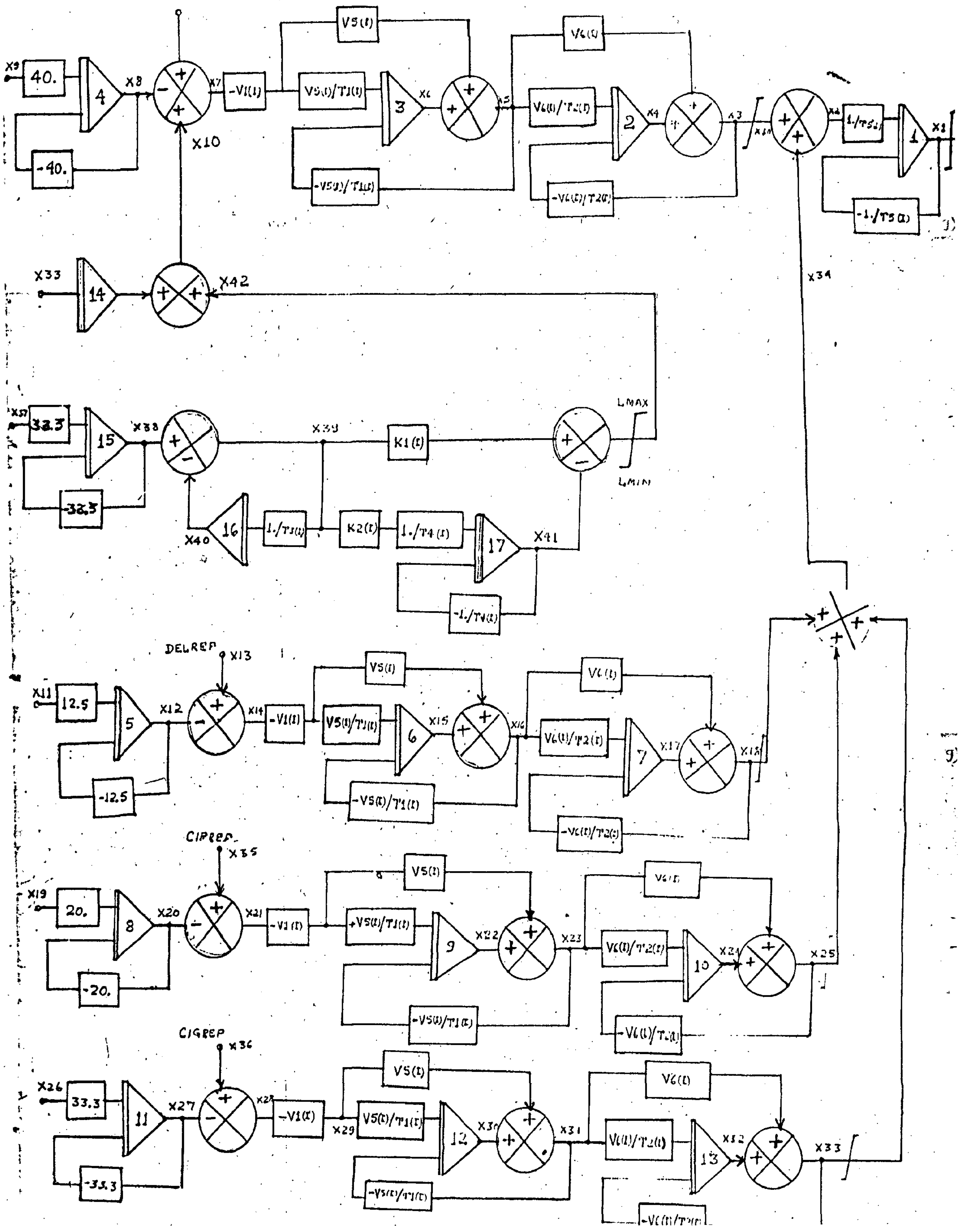


FIG.5.9 ANALOG COMPUTER MODEL FOR S.E.E. WITH SLIP STABILISER AND LIMITERS'



CHAPTER - 6

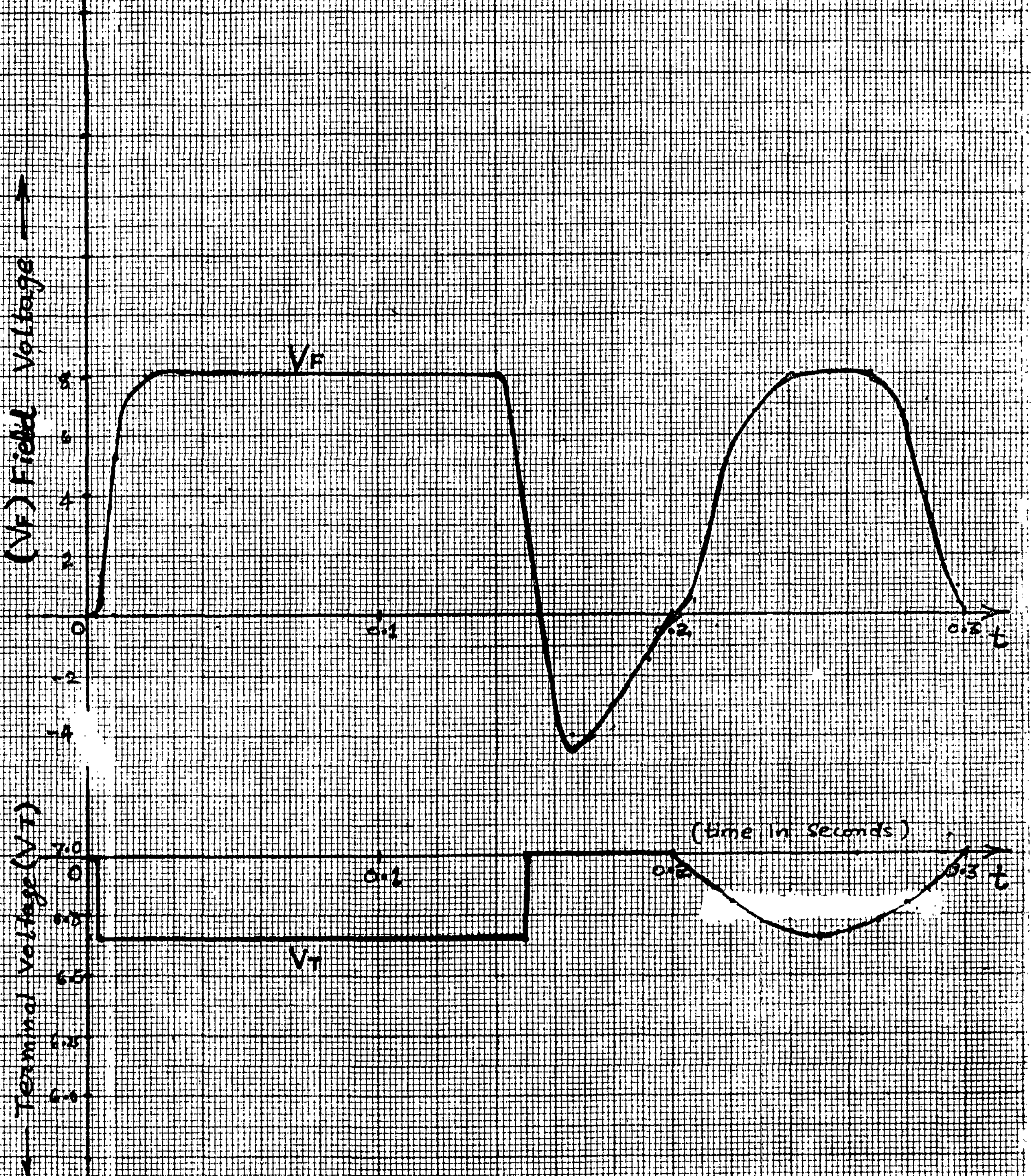
6.0 RESULTS AND DISCUSSIONS:

Computer program is developed to determine the performance and characteristics of static excitation system. The program consist of fifteen subroutines. Details of each subroutine and main program are given in Appendix-I. Program listing, input datas and results for each case is attached at the end of dissertation.

6.1 AVR Characteristics:

Figure 5.7 shows the analog computer model of the AVR (without limiters). The response of AVR is determined for a step and sinusoidal input at the machine terminal voltage. The normal value of terminal voltage corresponding to 7.0 volts d.c. at AVR input. A dip of approximately five percent of terminal voltage (0.35 volts) is given to the AVR input and response is observed.

Fig. 6.1 shows the variation of field voltage (V_F) w.r.t. terminal voltage (V_T). The value of field voltage (V_F) is determined as a function of time for step and sinusoidal input. (0.35 volts in magnitude) so that it will drive the field voltage to ceiling value in a minimum possible time. Initially the input V_T takes a constant value for 0.002 seconds duration thereafter it changes (in one step) to another value, lower than the normal value. As the dip is observe the field voltage increases at a very fast rate. The field voltage reaches to its



RESPONSE TO A STEP INPUT AND SINUSOIDAL DIP

FIG. 6.1 AVR CHARACTERISTIC

ceiling value in 0.008 seconds. The AVR is of high initial response type (Excitation system having a response time less than 50 mS are called high initial response type).

The system response is also observed for a sinusoidal dip. At time 0.2 second the input again changes and a dip is observed at terminal voltage. The nature of dip is sinusoidal and described by the function

$$\text{dip} = \text{DIP} \times \text{SIN}\ (31.4 \times (\text{TIME} - 0.02)) \qquad \ldots (6.1)$$

where DIP is the maximum value of dip.

The Fig. 6.1 also shows the response of AVR to a sinusoidal dip. The system takes 40 mS to increase field voltage from its nominal value to the ceiling value. The results were compared with the characteristics available in the literature [3,12].

6.2 Determination of AVR Parameters:

The program is developed to determine the optimal values of AVR parameters. Initially each variable is assigned suitable values based on field results available [3,12,16,18]. Then parameters are varied (in suitable steps) in specified ranges. The initial values of parameters and constants are selected so that these values are within desirable limits. The variable T1 (time constant of lead network) is varied in step of 0.5 seconds and response is calculated. In case, the field voltage reaches to its ceiling value V_{Fmax} (8.0 volts), then the response time and corresponding parameters values are noted.

The different parameters are varied within specified limits by giving a small increment and the response time in each case is calculated for a step input. At one time only one parameter is considered as a variable and all other parameters are taken as constant.

The parameter value for which the response time is minimum is considered as optimal value, which will be used in further calculations. Thus, the minimum response time and corresponding parameter values are determined.

Similar steps are involved in determining the optimal values of T, V1, V5 and V6 (these parameters are defined in Appendix-I). The parameters of PID network for rotor angle limiter, field current limiter and stator current limiter are considered same as discussed above. The following assumptions are made:

The lead network have two independent time constant. The lead time constant is adjustable from 0.5 to 10.0 second and the lag time constant is adjustable from 0.03 to 0.6 second. The lead time constant serve to compensate for the time delay inherent in the excitation system. The lag time constant are necessarily small for practical noise considerations. The lag time constant should not be less then 1/10th of the lead time constant. The minimum time constant should be at least five of times the integration time step. The allowable gain settings are limited by the stability of the control loop and noise considerations.

6.3 Effect of Limiter on AVR:

Figure 9.0 shows analog computer model of AVR with limiters. A program is developed to see the effect of limiters on AVR. Keeping the terminal voltage (V_g) constant suitable input signals are provided to different limiters and response observed. The effect of rotor angle limiter, field current limiter and stator current limiter is as follows.

6.3.1 Effect of Rotor Angle Limiter on AVR:

The response of AVR is determined for a sinusoidal input at rotor angle limiter. Such input may arise due to transient disturbance on the system. The input is simulated for a condition which may persist on the system and results in sinusoidal increase (or decrease) in rotor angle w.r.t. its nominal value. During normal conditions, the rotor angle limiter input takes a constant value of -3.3 volts, this will remain constant for 0.02 second. Then the input changes sinusoidally (corresponding to a faulty condition) and reaches a maximum value of -3.05 volts. The frequency of signal is suitably chosen to match with the practical conditions [2]. The frequency in this case is taken equal to 1 Hz. The variation in field current (V_F) is observed w.r.t. time, which changes from its normal value of 6.0 volts to ceiling value 8.0 volts in 30 ms. The response is shown in Fig. 6.2.

6.3.2 Effect of Field Current Limiter on AVR:

The effect of field current limiter on AVR is determined for a step input at field current limiter. A sharp increase in

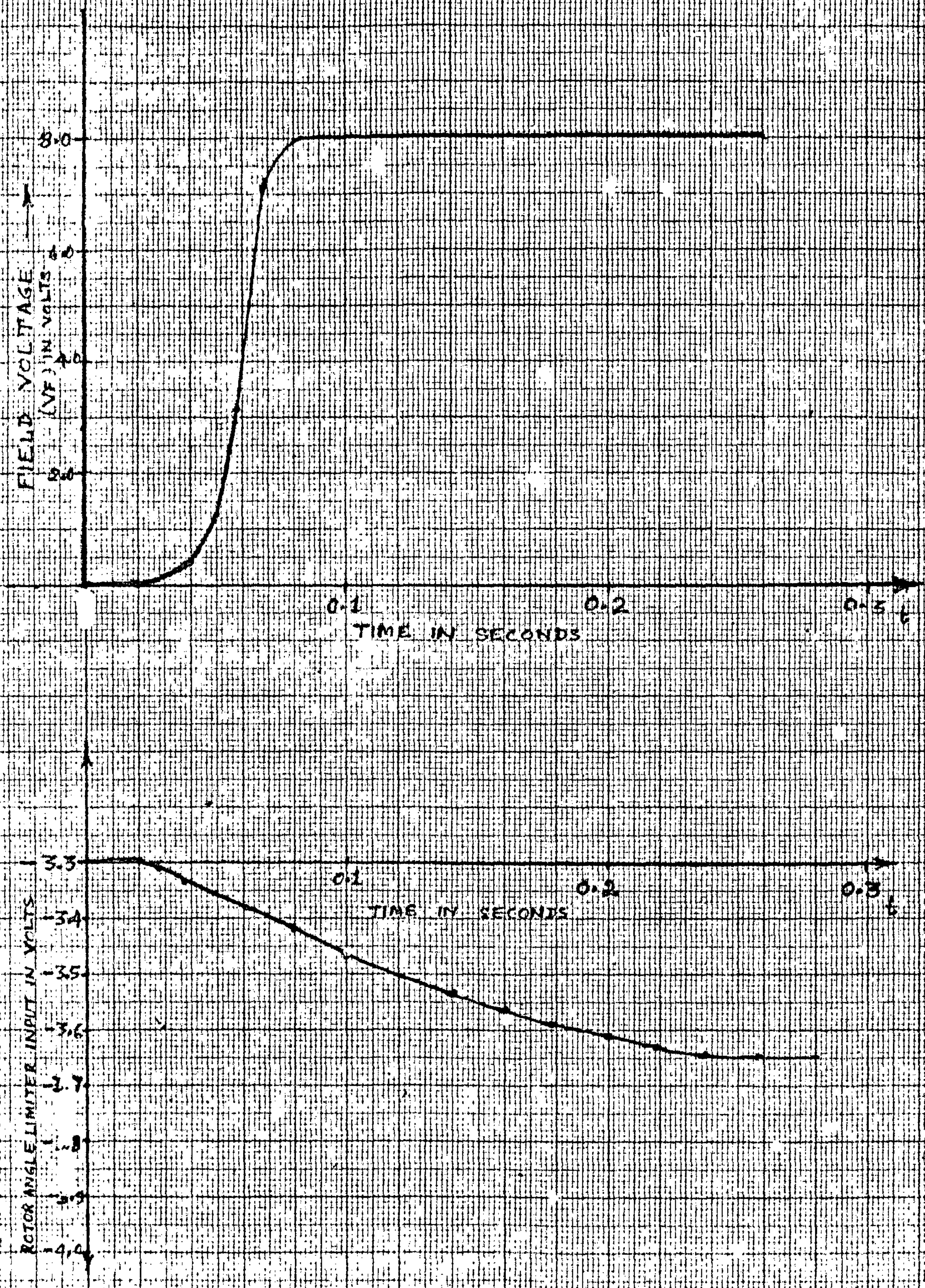


FIG 6.2 ROTOR ANGLE LIMITER RESPONSE

field current during a faulty condition results in change in input to field current limiter (considered as step change). The normal value of input to field current limiter remains constant (i.e. -3.55 volts) for initial 50 ms. A step change occurs at this time and input changes from its normal value of -3.35 volts to -2.65 volts, corresponding to an increase in field current. The limiter action takes place and it decreases the field voltage (V_F) from its normal value of 0.0 volts to another value -6.0 volts (V_{FMIN} defined in Appendix-3). This results in decrease in excitation current during the field forcing [9]. This will continue till the faulty condition persists on the system. The effect of field current limiter on AVR is shown in Fig. 6.3.

6.3.3 Effect of Stator Current Limiter on AVR:

Figure 6.4 shows the effect of stator current limiter on AVR. The AVR response is calculated for a step input at stator current limiter. The behaviour of stator current limiter in lagging and leading mode of machine operation is different. In leading mode the limiter action is instantaneous and in lagging mode of operation, the action is delayed (explained in Chapter - 4). The stator current limiter prevents the excessive overheating of machine and limits the stator current. During initial 20 ms, the stator current limiter senses a normal input value of -3.5 volts. A sudden rise in stator current is caused and correspondingly the input

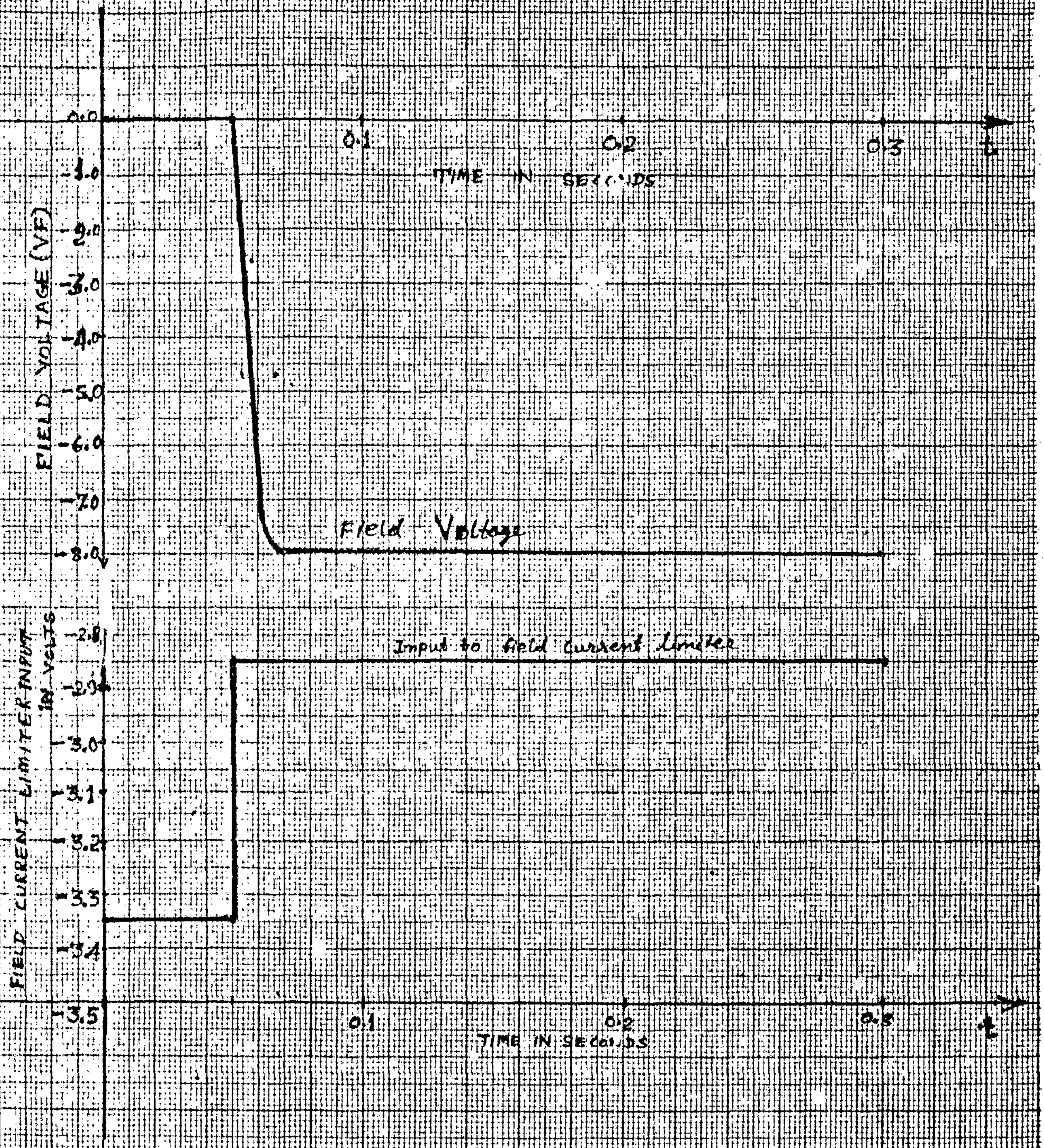


FIG 6.3 FIELD CURRENT LIMITER RESPONSE

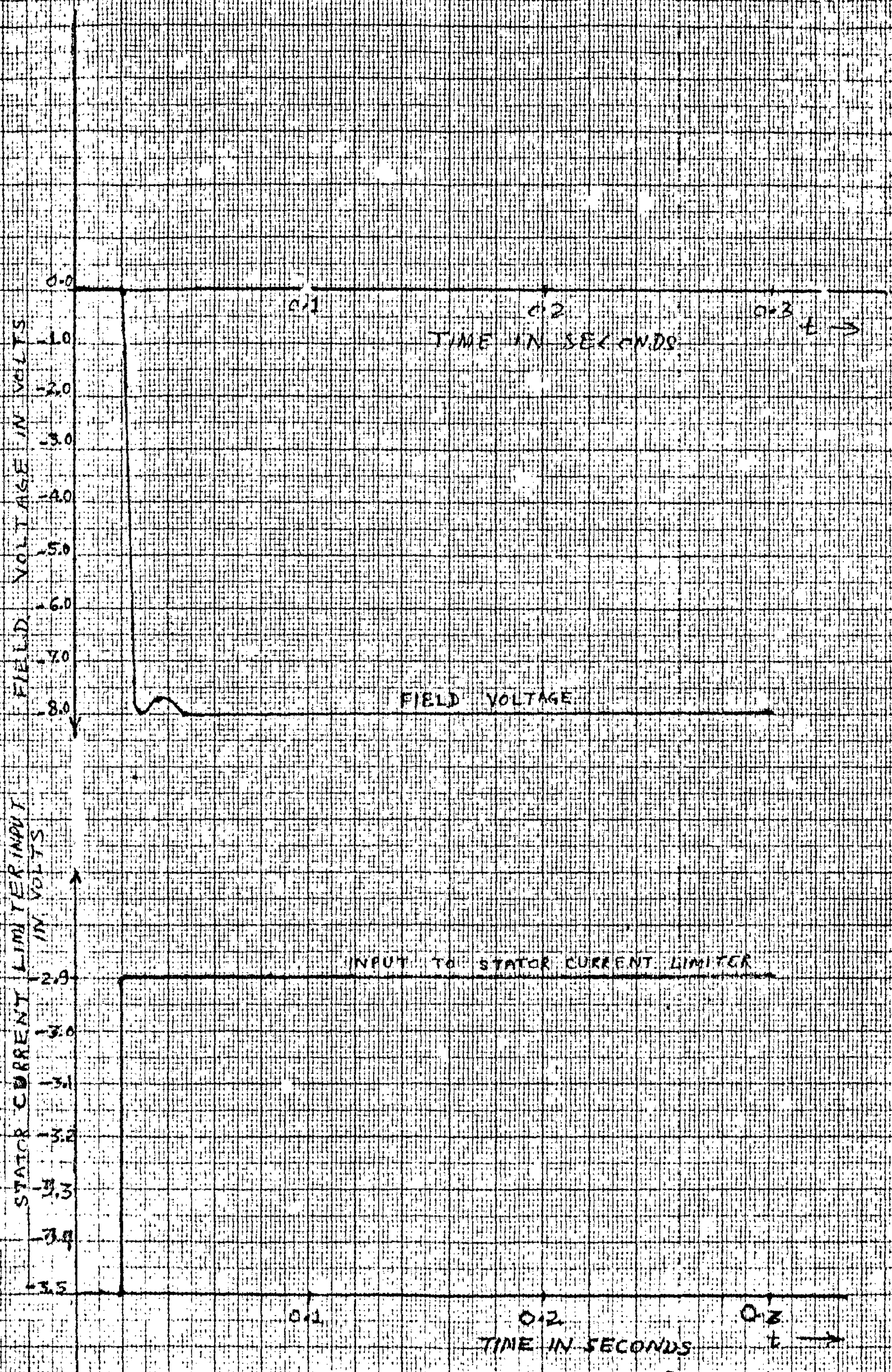


FIG.6.4 STATOR CURRENT LIMITER RESPONSE

changes from normal value of -9.5 volts to -3.0Volts in one step. The change is sensed by the stator current limiter and instantaneous action (in case of machine operating in leading mode) or delayed action (in case of lagging mode operation) takes place. The output field voltage changes from its normal value of 0.0 volts to -3.0 volts (V_{Fmin}). The new value of input will remain constant till the fault persist on the system.

6.4 Effect of Slip Stabilizer on AVR:

The Fig. 9.9 shows analog computer model of AVR with limiters and slip stabilizer. A program has been developed to determine the effect of slip stabilizer on AVR. The program simulates a faulty condition due to which the accelerating power (mechanical input to turbine - electrical output of the generator) varies sinusoidally at a low frequency. The frequency of signal corresponds to practical conditions which may persist on the system [2,20]. The input to slip stabilizer remains constant initially (equal to 0.0) for 8 ms and then varies sinusoidally w.r.t. time. The maximum value of signal is 4.5 volts. The actual signal at slip stabilizer input can be expressed as

$$P_{act} = P_{max} \sin (10x (time - 0.008)) \quad \ldots (6.2)$$

where P_{act} is the actual power input to slip stabilizer and P_{max} represents its maximum value. A constant input is given to AVR corresponding to normal terminal voltage, i.e. 7.0 volts.

Fig. 6.3 shows the effect of slip stabilizer on AVR. Initially the P_{acc} remains zero for 0 m seconds and the corresponding field current output observed is zero. At time 0 ms the P_{acc} signal starts varying sinusoidally and as a result the field current increases. The field current reaches to its ceiling value 8.0 volts at 60 ms. The results showing variation of field current, terminal voltage and actual power input to the slip stabilizer w.r.t. time are attached at the end of dissertation. The Fig. 6.5 describes the variation of field voltage w.r.t. power input to slip stabilizer. The response is compared with the practical results available [1].

6.5 Determination of Slip Stabilizer Parameters:

A program has been developed to determine optimal values of slip stabilizer parameters [10]. The initial values of parameters and constants are chosen so that they will remain in desirable limits. The lead network time constant (T3), integral channel time constant (T4), gain of proportional (K1) and integral (K2) channel are taken 1.5, 12.0, 0.5 and 5.0 respectively based on field results. The lead time constant is varied 0.25 to 1.5 in step of 0.25 and response is observed. In case the field voltage reaches to its ceiling value (8.0 V) then the values of response time and corresponding parameters are noted. The value of lead network time constant (T3) corresponding to fastest response is considered as optimal value. This value is taken for further calculations for determining

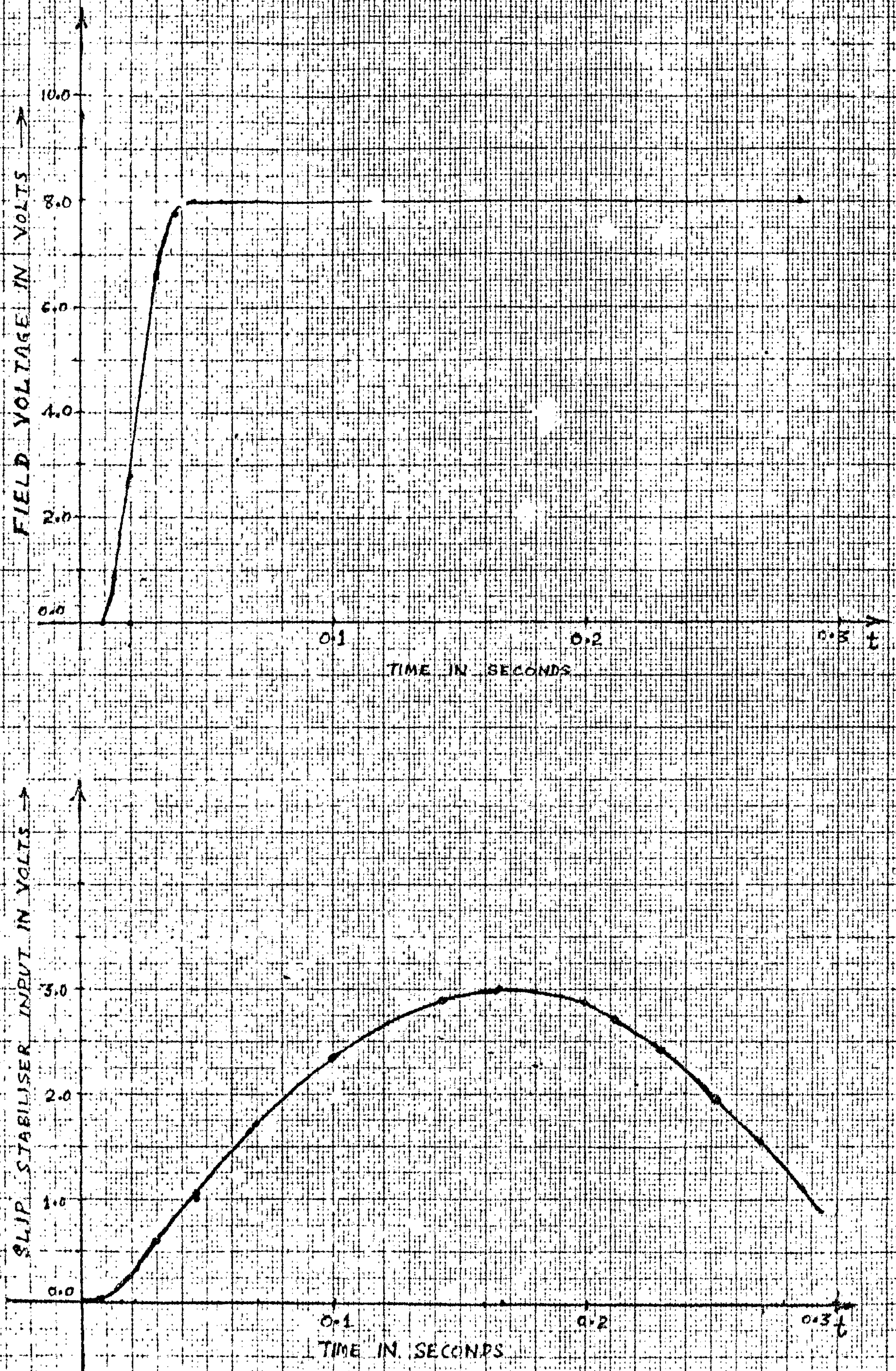


FIG. 6.5 AVR RESPONSE WITH SLIP STABILISER

optimal values of other parameters (T4, K1 and K2). Similar steps are involve in determining the optimal value of other slip stabiliser parameters.

CHAPTER - 7

7.0 CONCLUSIONS:

Computer simulation is the only effective means presently available for studying system problem and transient stability. The development of mathematical model of static excitation system provides a means of studying AVR response for a disturbance which may persist on the system. This program is designed to provide sufficient details for representing the system with different features (i.e. limiters and slip stabilizer). The model is flexible in nature so that further improvements (addition of new devices) can be made without much of changes involve in the program.

This developed program can analyse (i) AVR without limiters (ii) AVR with limiters and (iii) AVR with limiters and slip stabilizer. The following studies have been conducted:

(a) AVR response for a step input.

(b) Determination of optimal values of AVR parameters.

(c) Effect of (I) rotor angle limiter (II) field current limiter (III) stator current limiter on AVR.

(d) Effect of slip stabilizer on AVR.

(e) Determination of optimal values of slip stabilizer parameters.

Further work can be done to minimize the effect of voltage oscillations and to ensure the dynamic stability of the system. Model can be modified for studying the adaptive control of excitation system.

APPENDIX - I

(A) PROGRAM DEVELOPMENT:

The development of computer program [19] for analysing static excitation system involves the following steps:

(i) The analog computer model of the system consist of various integrators, amplifiers and limiters. Sufficient numbers of variables like integrator outputs, summer outputs and limiter outputs are defined so that relations between them are quite obvious, means variable at a node will be function of the preceeding variables.

(ii) Intermediate variables are defined as function of input signal, reference signal and integrator outputs at various relevent points.

(iii) Expressions for input to integrators (PLUG) are defined as function of intermediate variables and integrator output.

(iv) Expression for the initial integrator outputs are determined considering input to integrator as zero during steady state of the system.

(v) The program for the solution of controller model are developed for all the three cases (i) AVR alone, (ii) AVR with limiters and (iii) AVR with limiters and slip stabiliser.

The response of the system is determined in two steps -

(a) Determination of initial conditions at various relevent points of the system and

(b) then integrate over a fixed time step.

(B) MAIN PROGRAM FUNCTIONS:

A main program is developed, to perform the following functions:

(i) It calculates the AVR characteristics for a step and sinusoidal dip at machine terminal voltage (V_T).

(ii) It calculates the optimal values of AVR parameters to give a minimum rise time.

(iii) It determines the effect of (a) Rotor Angle Limiter, (b) Field Current Limiter and (c) Stator Current Limiter on AVR performance.

(iv) It provides information regarding the effect of slip stabiliser on AVR.

(v) It determines the optimal values of slip stabiliser parameters.

Programs have been developed for calculating the initial conditions of the variables prior to simulation and then determining the time derivative of the state variable at each integration step during the simulation. Listing of the program and results are given at the end of dissertation. The variables and constants used are defined below:

The value of time - TIME
Time step size - TSTEP
Initial value of stator current limiter input - VC
Initial value of rotor angle limiter input - VD
Initial value of field current limiter input - VE
[illegible]

Maximum change in rotor angle limiter input from the nominal value = E1

Maximum change in stator current limiter input from the nominal value = E2

Maximum increase in field current limiter input from the nominal value = E3

Maximum change in slip stabilizer input = E4

Static gain of PID network = V1

Dynamic gain of PID network = V_D

Integral gain of PID network = V_I

V2 = Dynamic gain/Static gain

V3 = Integral gain/Dynamic gain

The reference signal at input of AVR = VREF

Maximum value of AVR output = VRMAX

Minimum value of AVR output = VRMIN

Field voltage = VF

Maximum value of field voltage = VFMAX

Minimum value of field voltage = VFMIN

Time constant of lead network = T1

Time constant of lag network = T2

Time constant of thyristor = T3

Input to integrator = DEVO

Output of integrator = OUT

Previous value of input to integrator = DAVI

Reference value of rotor angle limiter input = DELREF

Reference value of stator current limiter input = CICREF

Reference value of field current limiter input = CIFREF

Actual value of rotor angle limiter input = DELACT

Actual value of stator current limiter input = CICACT

Actual value of field current limiter input = CIFACT

Maximum value of slip stabilizer output = ALMAX

Minimum value of slip stabilizer output = ALMIN

Time constant of washout circuit = T3

Time constant of integrator network = T4

Gain of proportional channel = AK1

Gain of integrator channel = AK2

Actual input to slip stabilizer = XIACT

The maximum value of slip at AVR input voltage = DXP

Nominal AVR input voltage = VTR

Actual input voltage to AVR = VT

The final value of time = TFIN

The number of step = NSTEP

The number of type = NTYPE

Response time = TTIME

Minimum value of response time = TOM

Optimal value of lead time constant of PID = TLD

Optimal value of lag-time constant of PID = TLG

Optimal value of static gain = VR1

Optimal value of ratio of dynamic gain to static gain = VR2

Optimal value of ratio of natural gain to dynamic gain = VR3

Optimal value of rudder circuit time constant of ship stabilizer = ST3

Optimal value of integral channel time constant of ship stabilizer = ST4

Optimal value of proportional channel gain of ship stabilizer = AKP1

Optimal value of integral channel gain of ship stabilizer = AKP2

The following subroutines have been used for program development:

(1) <u>MAIN PROGRAM</u>:

It controls the entire functioning of the program.

```
DIMENSION SAVE (10)
COMMON/BLOCK1/TIME, TSTOP
COMMON/BLOCK2/VO, VD, VA, D1, D2, D3, D4
COMMON/BLOCK3/V1(90), V5(90), V6(90, VREF(90), VRMAX(90)
VRMIN(90), VP(90), E1(90), E2(90), E5(90), VPMAX(90)
VPMIN(90)
COMMON/BLOCK4/PESO(90), CUR(90), SAVD(90)
COMMON/BLOCK5/DHEADY(90), OIPHIT(90), OSCHET(90), DELAGE(90)
OEPAGE(90), OSCAGE(90)
COMMON/BLOCK6/ALMAX(90), ALMIN(90), S3(90), S4(90), AK1(90,AK2(90)
EVAGE(90)
COMMON/BLOCK7/DED(90), VR(90), VRA(90)
COMMON/BLOCK8/NTEN, LREAD, LEVEL
COMMON/BLOCK9/EXTRE(90), TRA(10,90), TRE(10,90), VRA(10,90),
VRE(10,90), VRI(10,90), ST1, ST3(10,90), ST4(10,90), AKP1(10,90)
AKP2(10,90).
```

(2) INT

This subroutine is developed to perform integration. The method has been described in Appendix-II.

```
COMMON/BLOCK1/TIME STEP
COMMON/BLOCK2/V0, VB, VA, E1, E2, E3, E4
COMMON/BLOCK3/TAUO(90), OUT(90), SAVD(90)
COMMON/BLOCK4/NTIM, NSTEP, NTYPE
```

(3) AVRA

This determines the initial conditions at various points of AVR having no limiter.

```
COMMON/BLOCK1/TIME, STEP
COMMON/BLOCK2/V0, VB, VD, E1, E2, E3, E4
COMMON/BLOCK4/NTIM, NSTEP, NTYPE
COMMON/BLOCK5/V1(90, V5(90), V6(90), VINF(90), VRMAX(90)
VRMIN(90), V7(90), S1(90), S2(90), S5(90), V7MAX(90), V7MIN(90)
COMMON/BLOCK3/TAUO(90), OUT(90), SAVD(90)
COMMON/BLOCK6/DEP(90), V2(90), V21(90)
COMMON/BLOCK7/EXMIN(90), SEA(10,90), SE2(10,90), VE1(10,90)
VE2(10,90), VE3(10,90), TON, SE3(10,90), SE4(10,90), AKE1(10,90)
AKE2(10,90).
```

(4) AVRB

This determines the initial conditions of various points of AVR with limiters.

```
COMMON/BLOCK1/TIME, STEP
COMMON/BLOCK2/V0, VB, VA, E1, E2, E3, E4
```

```
COMMON/BLOCK8/WTH, HSTEP, IXYZ
COMMON/BLOCK2/V1(90), V5(90), V6(90, VREF(90), VRMAX(90),VRMIN(90)
V7(90), S2(1), S1(2), S5(1), VPMAX(90), VPMIN(90)
COMMON/BLOCK3/PHIO(90), CUT(90), SAVE(90)
COMMON/BLOCK4/DELRIF(90), QXDRIF(90), QZQRIF(90), DELAGT(90)
QXDAGT(90), QZQAGT(90)
COMMON/BLOCK7/DXP(90), VX(90), VXL(90)
COMMON/BLOCK6/TXIMZ(90), SH1(10,90), SH2(10,90), VH1(10,90),
VH5(10,90), VH6(10,90), SOH, SH3(10,90), SH4(10,90), AKH1(10,90)
AKH2(10,90)
```

(5) AVRI

This determines the initial integrator outputs of analog computer model of AVR with limiters and slip stabilizer.

```
COMMON/BLOCK1/TIME, TSTEP
COMMON/BLOCK0/VC, VD, VQ, E1, E2, E3, E4
COMMON/BLOCK8/WTH, HSTEP, IXYZ
COMMON/BLOCK2/V1(90), V5(90), V6(90), VREF(90), VRMAX(90),
VRMIN(90), V7(90), S1(90), S2(90), S3(90), VPMAX(90), VPMIN(90)
COMMON/BLOCK3/PHIO(90), CUT(90), SAVE(90)
COMMON/BLOCK4/DELRIF(90), QXDRIF(90), QZQRIF(90), DELAGT(90),
QXDAGT(90), QZQAGT(90)
COMMON/BLOCK5/AMAX(90), AMIN(90), S3(90), S4(90), AL1(90,AL2(90)
FLAGS(90)
COMMON/BLOCK7/DXP(90), VX(90), VXL(90)
COMMON/BLOCK6/TXIMZ(90), SH1(10,90), SH2(10,90), VH1(10,90),
VH5(10,90), VH6(10,90), SOH, SH3(10,90), SH4(10,90), AKH1(10,90)
AKH2(10,90).
```

(6) [illegible]:

To calculate the input to AVR as function of time.

```
COMMON/BLOCK17/DEP(90), VT(90), VTA(90)
COMMON/BLOCK12/TIME, TSTEP
COMMON/BLOCK18/STXN, DCYCP, [illegible]
```

(7) [illegible]:

To calculate the optimal values of various parameters (S3, S4, AK1, AK2) of ship stabilizer.

```
COMMON/BLOCK9/VC, VD, VL, R1, R2, R3, R4
COMMON/BLOCK5/[illegible](90), SR1(10,90), SR2(10,90), VR1(10,90),
VR5(20,90), VR6(20,90), ZGM, SR9(20,90), SR6(20,90), AMR(20,90)
AMP(20,90)
COMMON/BLOCK12/TIME, TSTEP
COMMON/BLOCK13/V1(90), V5(90), V6(90), VREF(90), VRMAX(90)
VRMIN(90), VT(90), S1(90), S2(90), S5(90), VFMAX(90),
VFMIN(90)
COMMON/BLOCK19/DIFQ(90) OUT(90), DAVR(90)
COMMON/BLOCK14/AMAXF(90), OMAXF(90), OMINF(90), DMAG2(90),
OMAG2(90), OMAG1(90)
COMMON/BLOCK15/AMAX(90), AMIN(90), S3(90), S4(90), AK1(90),AK2(90)
FMAG2(90)
COMMON/BLOCK17/DEP(90), VT(90), VTA(90)
COMMON/BLOCK18/STXN, DCYCP, [illegible].
```

(8) [illegible]:

To provide the input to rotor angle limiter to determine the effect of rotor angle limiter on AVR.

```
COMMON/BLOCK1/VC, VD, VR, D1, D2, D3, D4
COMMON/BLOCK2/TIME, TSTEP
COMMON/BLOCK3/DELREF(90), OUTREF(90), CTREF(90), DELAGR(90).
```

(9) [illegible].

To provide a step input to the stator current limiter to determine effect of stator current limiter on AVR.

```
COMMON/BLOCK1/VC, VD, VR, D1, D2, D3, D4
COMMON/BLOCK2/TIME, TSTEP
COMMON/BLOCK3/DELREF(90), OUTREF(90), CTREF(90), DELAGR(90).
```

(10) [illegible]:

Corresponding to a sharp increase in field current it gives suitable input to field current limiter.

```
COMMON/BLOCK1/VC, VD, VR, D1, D2, D3, D4
COMMON/BLOCK2/TIME, TSTEP
COMMON/BLOCK3/DELREF(90), OUTREF(90), CTREF(90), DELAGR(90).
```

(11) [illegible]:

For oscillations in electrical power output generator, to provide a suitable sinusoidal input to the slip stabilizer.

```
COMMON/BLOCK1/VC, VD, VR, D1, D2, D3, D4
COMMON/BLOCK2/TIME, TSTEP
COMMON/BLOCK3/AMAX(90), AMIN(90), T3(90), T4(90), AT1(90),AT2(90)
DLAGR(90).
```

(12) [illegible]:

This determines the effect of slip stabilizer on AVR for a sinusoidal input of slip stabilizer, considering the AVR input a constant.

```
COMMON/[illegible]/[illegible](90), SIA(10,90), SIB(10,90),VIA(10,90),
VIB(10,90), VIJ(10,90), [illegible], SIJ(10,90), SI4(10,90),ANGA(10,90)
ANGB(10,90)
COMMON/[illegible]/[illegible], [illegible]
COMMON/[illegible]/VC, VD, VL, S1, S2, S3, S4
COMMON/[illegible]/V1(90), V5(90), V6(90), VREF(90), VRMAX(90)
VRMIN(90), V7(90), S1(90), S2(90), S3(90), V7MAX(90)
V7MIN(90)
COMMON/[illegible]/[illegible](90), OUT(90), [illegible](90)
COMMON/[illegible]/[illegible](90), [illegible](90), [illegible](90), [illegible](90)
[illegible](90), [illegible](90)
COMMON/[illegible]/ASMIN(90), ASMAX(90), S5(90), S4(90), AS1(90),AS2(90)
[illegible](90)
COMMON/[illegible]/[illegible], [illegible], [illegible]
COMMON/[illegible]/DXP(90), VT(90), VT1(90)
```

(25) [illegible]:

It provides a constant input to AVR while studying the effect of limiters and slip stabilizer.

```
COMMON/[illegible]/[illegible]
COMMON/[illegible]/DXP(90), VT(90), VT1(90).
```

(26) [illegible]:

This calculates the effect of rotor angle limiter, stator current limiter and field current limiter on AVR assuming the input to AVR a constant value.

```
COMMON/BLOCK[illegible]/[illegible], [illegible]
COMMON/BLOCK[illegible]/VO, VD, VB, D1, D2, D3, D4
COMMON/BLOCK[illegible]/ZLIBN(90), ZH1(10,90), ZH2(10,90), VH1(10,90)
VH2(10,90), VH3(10,90), ZHI, ZH3(10,90), ZH4(10,90), ARH1(10,90)
ARH2(10,90)
COMMON/BLOCK[illegible]/WTH, ISTEP, ITYPE
COMMON/BLOCK[illegible]/V1(90), V5(90), VC(90, VREF(90), VRMAX(90)
VRMIN(90), V[illegible](90), S1(90), S2(90), S3(90), VPMAX(90)
VPMIN(90)
COMMON/BLOCK[illegible]/PRIC(90), OUT(90), [illegible](90)
COMMON/BLOCK[illegible]/[illegible](90), O[illegible](90), O[illegible](90), [illegible](90),
O[illegible]AGE(90), [illegible]AGE(90)
COMMON/BLOCK[illegible]/A[illegible](90), A[illegible](90), Z3(90), Z4(90), AR1(90),
AR2(90), [illegible](90)
COMMON/BLOCK[illegible]/[illegible](90), VT(90), VZ1(90).
```

(28) AVR[illegible]:

It determines the optimal values of various parameters (V1, V5, VC, [illegible], ZB) of PID network of AVR.

```
COMMON/BLOCK[illegible]/VO, VD, VB, D1, D2, D3, D4
COMMON/BLOCK[illegible]/WTH, ISTEP, ITYPE
COMMON/BLOCK[illegible]/[illegible], ISTEP
COMMON/BLOCK[illegible]/V1(90), V5(90), VC(90), VREF(90), VRMAX(90),
VRMIN(90), VW(90), Z1(90), Z2(90), Z3(90), VPMAX(90),
VPMIN(90)
COMMON/BLOCK[illegible]/PRIC(90), OUT(90), [illegible](90)
```

```
COMMON/BLOCK4/DALDEF(90), OXYDEF(90), OXCDEF(90), DELAGE(90),
OXYAGE(90), OXCAGE(90)
COMMON/BLOCK5/ALMAX(90), ALMIN(90), Z3(90), Z4(90), AK1(90),
AK2(90), [illegible](90)
COMMON/BLOCK7/DIP(90), V8(90), V21(90)
COMMON/BLOCK8/[illegible](90), ZK1(10,90), ZK2(10,90), VK1(10,90),
VK2(10,90), VK3(10,90), [illegible], ZK3(10,90), ZK4(10,90), AKK1(10,90)
AKK2(10,90).
```

(16) READ:

This subroutine has been developed to read the values of different variables and constant to perform various functions.

```
COMMON/BLOCK1/ZIN, TOTEP
COMMON/BLOCK2/VG, VD, VH, Z1, Z2, Z3, Z4
COMMON/BLOCK3/V1(90), V5(90), V6(90), VDIF(90), VHMAX(90)
VHMIN(90), V7(90), Z1(90), Z2(90), Z5(90), VPMAX(90)
VPMIN(90)
COMMON/BLOCK3/ZMAX(90), CUR(90), SAVE(90)
COMMON/BLOCK4/DALDEF(90), OXYDEF(90), OXCDEF(90), DELAGE(90),
OXYAGE(90), OXCAGE(90)
COMMON/BLOCK5/ALMAX(90), ALMIN(90), Z3(90), Z4(90), AK1(90),
AK2(90), [illegible](90)
COMMON/BLOCK7/DIP(90), V8(90), V21(90)
COMMON/BLOCK9/SPZN, [illegible], [illegible].
```

APPENDIX - II

STEP BY STEP INTEGRATION

The step by step integration method is used for calculating various integrator outputs with respect to time. This process involves a simple integration procedure which is flexible and easily programmed.

Consider a general set of differential equations with state variables Y and assume that the time derivatives of state variables can be calculated at any instant, then the variable before and after a time interval is given by expression

$$Y_{t+\Delta t} = Y_t + \int_t^{t+\Delta t} \dot{y}\, dt \qquad \ldots \text{(i)}$$

The figure II-a shows graphical representation of the formula used.

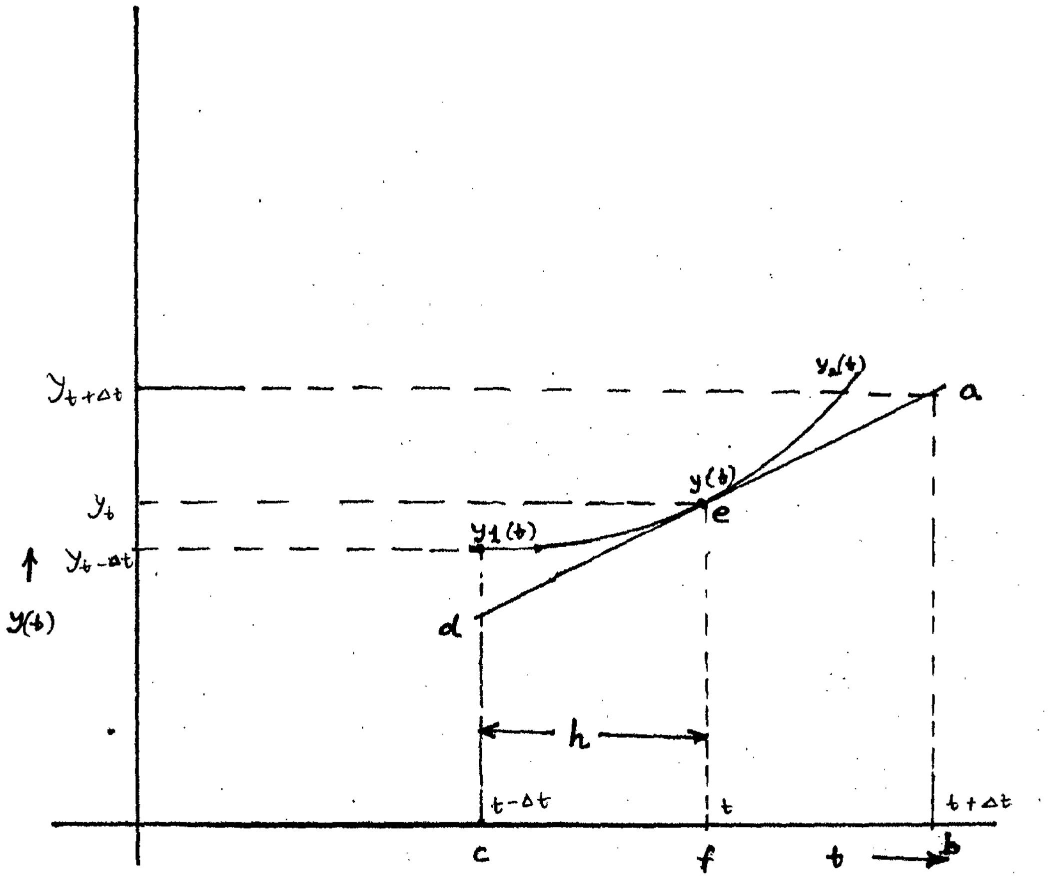
In the approximation we assume that the function $\dot{y}(t)$ for time interval t to t + Δt is equal to the slope of the previous interval t − Δt to t.

$$y_{t+\Delta t} = \dot{y}(t)\, \Delta t + (\dot{y} - \dot{y}_t - \Delta t)\, \Delta t/2 + y(t) \qquad \ldots \text{(ii)}$$

Equation (ii) express the solution of state variable and their derivatives in the preceding time steps.

Restriction :

The solution of dynamic equation will be stable only if the integration time step follow the condition



h = step size.

FIG II-(a) Step by step Method.

$$\Delta t < \tau_{min}/5$$

where τ_{min} is the period of highest frequency, which is present in the solution.

Since τ_{min} is usually not known before the solution, so satisfactory response can be achieved by selecting the time interval as

$$\Delta t < \tau_{c\ min}/5$$

where $\tau_{c\ min}$ is the smallest time constant in the system. Otherwise instability will occur in the solution.

APPENDIX - III

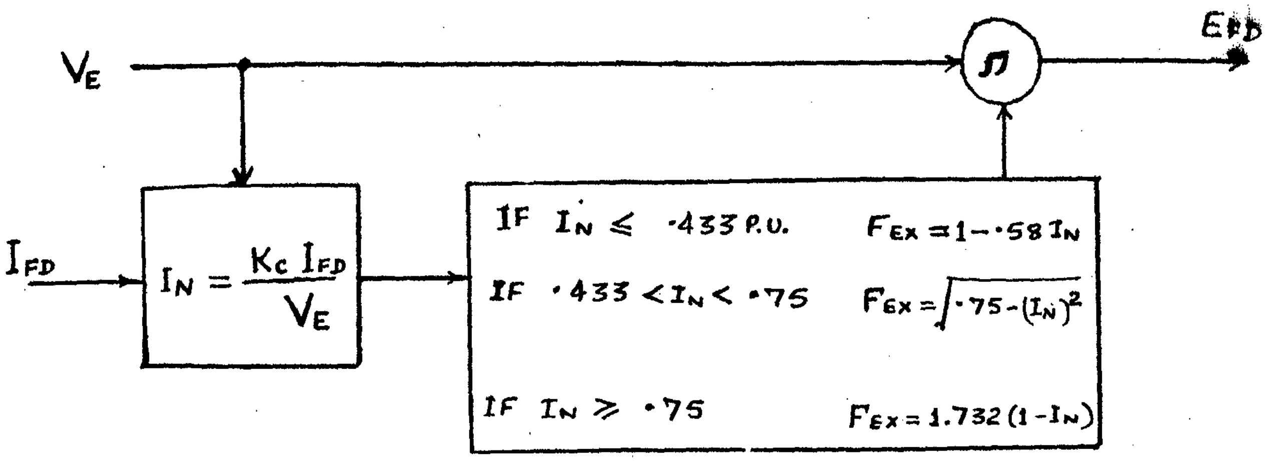
The inherent impedance of all a.c. sources is predominantly inductive. When an a.c. source is used to feed power to rectifiers, this impedance will effect the commutation process. It results in a decrease in rectifier average output voltage as rectifier load current is increased.

Commutating reactance is defined as the source reactance from phase to neutral which opposes the transfer of current from one rectifier to another. The commutation process requires a finite time, which is defined as commutating angle (μ).

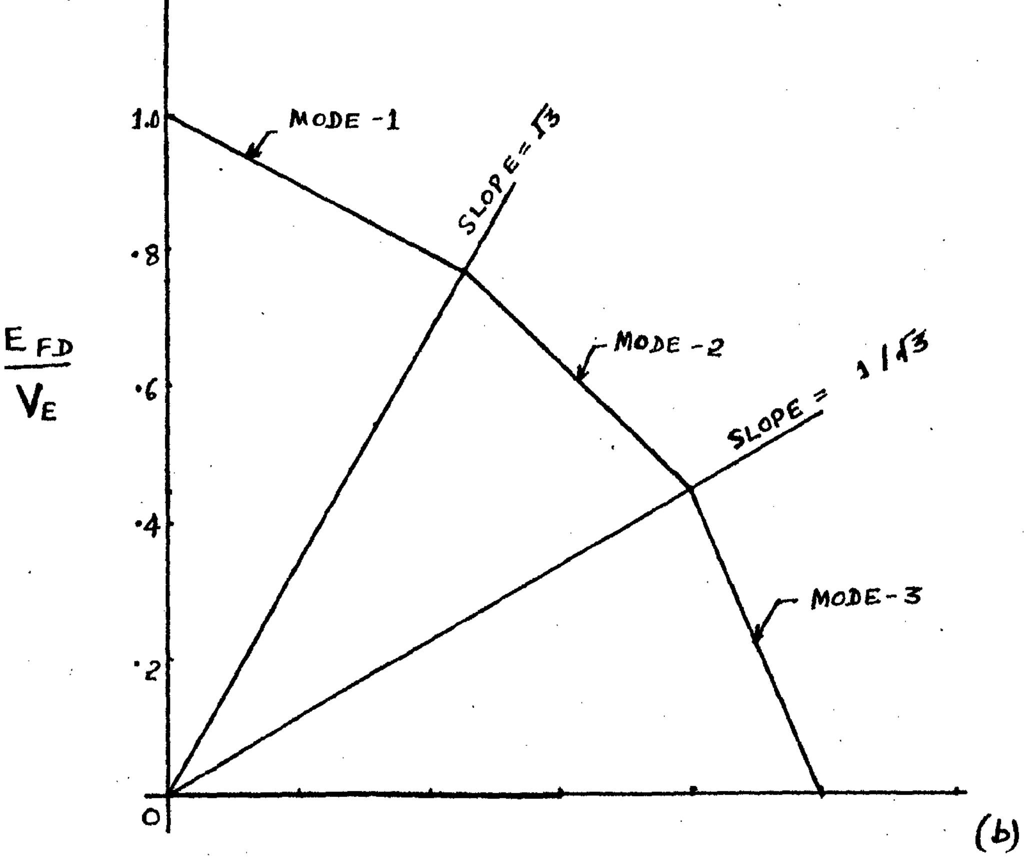
Another term inherent delay is defined by an angle (α) which represents the delay at the start of commutation process. This delay depends upon the magnitude of load current.

The rectifier regulation characteristic is shown in Fig. III-(a). In mode-I operation the commutating angle increases from 0 to 60° and the inherent delay angle (α) is zero with increasing load current.

In mode-II operation, the commutating angle (μ) is fixed at 60° but start of commutation is delayed by the inherent delay angle (α) which varies from 0 to 30°. In mode-III operation the inherent delay angle (α) is fixed at 30° and the commutating angle (μ) varies from 60° to 120°. The rectifier regulation equations are shown in Fig. III-(b).



RECTIFIER REGULATION EQUATIONS(a)



RECTIFIER REGULATION CHARACTERISTICS

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MAIN PROGRAM

```
DIMENSION INVE(10)
COMMON /BLOCK1/TIME,TSTEP
COMMON /BLOCK3/VC,VD,VF,D1,D2,D3,D4
COMMON /BLOCK2/ V1(30),V5(30),V6(30),VREF(30),VMAX(30)
, [illegible](30),VF(30),T1(30),T2(30),T5(30),VFMAX(30)
,VF[illegible](30)
COMMON /BLOCK4/ PLUG(30),OUT(30),SAVE(30)
COMMON /BLOCK[illegible]/ELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
CIFACT(30),CIGACT(30)
COMMON /BLOCK5/ALMAX(30),ALMIN(30),T3(30),T4(30),AK1(30),AK2(30)
,[illegible]ACT(30)
COMMON /BLOCK7/DIP(30),VT(30),VT1(30)
COMMON /BLOCK8/TFIN,NSTEP,NTYPE
COMMON /BLOCK9 /TIME(30),TN1(10,30),TN2(10,30),VN1(10,30),
VN5(10,30),VN6(10,30),TS[illegible],TN3(10,30),TN4(10,30),AKN1(10,30)
,AKN2(10,30)
OPEN (UNIT=1,DEVICE='DSK',FILE='DKC4.DAT')
INVE(I)=1
CALL READ(1)
TYPE 5
FORMAT(72('=')/5X,'AVR RESPONSE TO STEP AND SINE INPUT'/72('=')//)
TIME=0.
AVR RESPONSE FOR STEP AND SIN INPUT
TYPE 12
FORMAT(5X,'TIME              VT(I)                    VF(I)'/)
N=
CALL EQUIPMENT SUBROUTINE TO CALCULATE INITIAL COND
CALL INPUT(I)
CALL AVR1(I)
LOOP HERE FOR EACH NEW NETWORK CONDITIONS
PERFORM INTEGRATION STEP
CALL INT(I)
N=N+1
IF (N.LT.4) GO TO 109
TYPE *,TIME,VT(I),VF(I)
N=0
IF(TIME.GT.TFIN)GO TO 111
NSTEP=NSTEP+1
TIME=NSTEP*TSTEP
NTYPE=NTYPE+1
CHECK FOR NEW NETWORK CONDITIONS
IF(TIME.LT.TFIN) GO TO 70
LOOP BACK FOR NEW NETWORK CONDITIONS
```

```
CALL SUBROUTINE TO CALCULATE PARAMETERS
CALL AVRP S(I)
CALL LI (I)
CALL SS(I)
CALL SSFNS(I)
STOP
END

..........................................................

SUBROUTINE TO CALCULATE STATE VARIABLES FOR NEXT INC IN TIME
SUBROUTINE INT(I)
COMMON/BLOCK1/TIME,TSTEP
COMMON /BLOCK9/VC,VD,VE,D1,D2,D3,D4
COMMON/BLOCK3/PLUG(30),OUT(30),SAVE(30)
COMMON/BLOCK8/TFIN,NSTEP,NTYPE
IF(TIME.GT.0.0) GO TO 20
DO 10 II= 1,30
SAVE(II)=PLUG(II)
NFLG=1
CONTINUE
DO 25 II=1,30
OUT(II)=OUT(II)+PLUG(II)*TSTEP+(PLUG(II)-SAVE(II))*0.5*TSTEP
SAVE(II)=PLUG(II)
RETURN
END
..........................................................
S.E.E.E. COMPUTER MODEL WITHOUT LIMITERS
SUBROUTINE AVR1(I)
COMMON /BLOCK1/TIME,TSTEP
COMMON /BLOCK9/VC,VD,VE,D1,D2,D3,D4
COMMON/BLOCK8/TFIN,NSTEP,NTYPE
COMMON/BLOCK2/ V1(30),V5(30),V6(30),VREF(30),VRMAX(30),
VRMIN(30),VF(30),T1(30),T2(30),T5(30),VFMAX(30),VFMIN(30)
COMMON /BLOCK3/ PLUG(30),OUT(30),SAVE(30)
COMMON/BLOCK7/DIP(30),VT(30),VT1(30)
COMMON/BLOCK6 /TIME1(30),TM1(10,30),TM2(10,30),VM1(10,30),
VM5(10,30),VM6(10,30),TSM,TM3(10,30),TM4(10,30),AMV1(10,30)
,AMV2(10,30)
CALCULATE INITIAL INTEGRATOR OUTPUTS
IF(TIME.GE.TSTEP)GO TO 110
OUT(1)=VF(I)
OUT(2)=VF(I)*(1.-V6(I))
OUT(3)=VF(I)*(1.-V5(I))
```

```
          [illegible]
C         CALCULATE VOLTAGE REF SET POINT
          VREF(I)=VT(I)-VF(I)/V1(I)
C         DEFINE INTEGRATOR OUTPUT FOR AVR
110       X1=OUT(1)
          X2=OUT(2)
          X6=OUT(3)
          X4=OUT(4)
C         DEFINE INTERMEDIATE VARIABLES
          X7=VREF(I)-X6
          X5=X6-V1(I)*V5(I)*X7
          X3=V6(I)*X5+X4
          X3 =X3
          IF(X3.GE.VRMAX(I))    X3 =VRMAX(I)
          IF(X3.LT.VRMIN(I))    X3 =VRMIN(I)
          X2=X3
          VF(I)=X1
          IF (X1.GE.VFMAX(I)) VF(I)=VFMAX(I)
          IF (X1.LE.VFMIN(I)) VF(I)=VFMIN(I)
          X9=VT(I)
C         DEFINE INTEGRATOR INPUTS
          PLUG(4)=1 .*(X9-X4)
          PLUG(3)=-(V5(I)/T1(I))*(V1(I)*X7+X5)
          PLUG(2)=(V6(I)/T2(I))*(X5-X3)
          PLUG(1)=(1./T5(I))*(X2-X1)

          RETURN
          END
C.....................................................................
C
C
C       . 3...2. CONVERTER MODEL WITH LIMITERS
          SUBROUTINE AVR2(I)
          COMMON/BLOCK1/TIME,TSTEP
          COMMON /BLOCK5/VC,VD,VE,D1,D2,D3,D4
          COMMON/BLOCK6/TFIN,NSTEP,NTYPE
          COMMON/BLOCK2/V1(30),V5(30),V6(30),VREF(30),VRMAX(30),VRMIN(30)
     1    ,VF(30),T1(30),T2(30),T5(30),VFMAX(30),VFMIN(30)
          COMMON /BLOCK3/ PLUG(30),OUT(30),SAVE(30)
          COMMON/BLOCK4/DELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
     1    CIFACT(30),CIGACT(30)
          COMMON /BLOCK7/DIP(30),VT(30),VT1(30)
          COMMON/BLOCK8 /TIME1(30),TA1(10,30),TA2(10,30),VA1(10,30),
     1    VA2(10,30),VA3(10,30),TS ,TA3(10,30),TA4(10,30),AA1(10,30)
```

```
      2 [illegible](  ,3 )
        IF(TIME.GE.TSTOP)GO TO 610
C       CALCULATE INITIAL INTEGRATOR OUTPUTS
        OUT(5)=DELACT(I)
        OUT(6)=0.
        OUT(7)=0.
C       CALCULATE VOLTAGE REF SET POINT
        X13=DELACT(I)-VF(I)/V1(I)
C       DEFINE INTEGRATOR OUTPUTS FOR ROTOR ANGLE LIMITER
610     X17=OUT(7)
        X15=OUT(6)
        X12=OUT(5)
C       DEFINE INTERMEDIATE VARIABLES
        X14=X13-X12
        X16=X15-V5(I)*V1(I)*X14
        X18=X17+V6(I)*X16
        X118=X18
        IF(X18.GE.VRMAX(I)) X118=VRMAX(I)
        IF(X18.LE.VRMIN(I)) X118=VRMIN(I)
        X11=DELACT(I)
C       DEFINE INTEGRATOR INPUTS
        PLUG(5)=12.5*(X11-X12)
        PLUG(6)=-(V5(I)/T1(I))*(V1(I)*X14+X16)
        PLUG(7)=(V6(I)/T2(I))*(X16-X18)
        IF(TIME.GE.TSTOP)GO TO 710
C       CALCULATE INITIAL INTEGRATOR OUTPUTS
        OUT(8)=CIFACT(I)
        OUT(9)=0.
        OUT(10)=0.
C       CALCULATE VOL REF SET POINT
        X35=CIFACT(I)-VI(I)/VT(I)-VF(I)/V1(I)
C       DEFINE INTEGRATOR OUTPUTS FOR FIELD CURRENT LIMITER
710     X2[illegible]=OUT([illegible])
        X22=OUT(9)
        X24=OUT(10)
C       DEFINE INTERMEDIATE VARIABLES
        X21=X35-X22
        X23=X2[illegible]-V5(I)*V1(I)*X21
        X25=X2[illegible]+V6(I)*X23
        X125=X25
        IF(X25.GE.VRMAX(I)) X125=VRMAX(I)
        IF(X25.LE.VRMIN(I)) X125=VRMIN(I)
        X1[illegible]=CIFACT(I)
C       DEFINE INTEGRATOR INPUTS
```

```
      P[illegible]( )=[illegible].*(X[illegible]-X[illegible])
      [illegible]3( )=-(V5(I)/V[illegible](I))*(V1(I)*X21+X23)
      [illegible]( )=(V[illegible](I)/T2(I))*(X23-X25)
      IF( [illegible].G[illegible].[illegible])GO TO 11[illegible]
C     [illegible] INTEGRATOR OUTPUTS
      [illegible]( )=CIG[illegible]C2(I)
      GI[illegible]( 2)= .
      GI[illegible]( 3)= .
C     [illegible] SET POINT
      X36=CIG[illegible]C1(I)
C     [illegible] OUTPUTS FOR STATOR CURRENT LIMITER
110   X27=GI[illegible]( )
      X2[illegible]=GI[illegible]( )
      X32=GI[illegible](3)
      X[illegible]=GI[illegible](4)
C     [illegible] VARIABLES
      X28=X36-X27
      X31=-V1(I)*V5(I)*X2[illegible]+X29
      X33=X32+V5(I)*X31
      X133=X33
      IF(X33.GT.VRMAX(I))X133=VRMAX(I)
      IF(X33.LT.VRMIN(I))X133=VRMIN(I)
      X26=CIG[illegible]C2(I)
      IF(X133.GE. . )GO TO 88
      IF(X133.LT. . )GO TO 99
88    X5 =X133
      X15=0.
      GO TO 105
99    X5 = .
      X15=X133
C     [illegible] PUTS
105   P[illegible]( 1)=33.3*(X2[illegible]-X27)
      P[illegible]( 2)=-(V5(I)/V[illegible](I))*(V1(I)*X24+X31)
      P[illegible](13)=(V3(I)/T2(I))*(X31-X33)
      P[illegible]( )=X1[illegible]
      IF( [illegible].[illegible].[illegible]P)GO TO [illegible]1
C     [illegible] INITIAL INTEGRATOR OUTPUTS
      G[illegible]( )=[illegible](I)
      G[illegible]( )=[illegible](I)*(1.-V5(I))
      G[illegible]( 3)=[illegible](I)*(1.-V5(I))
      G[illegible]( )=[illegible](I)
C     [illegible] SET POINT
      [illegible]( )=[illegible](I)-V[illegible](I)/V[illegible](I)+X1
C     [illegible] OUTPUT FOR [illegible]VR
```

```
 410      [illegible] = [illegible]( )
          [illegible] = [illegible]( )
          X = [illegible](I)
          X = [illegible]( )
C         [illegible] FOR [illegible] VARIABLES
          X2= [illegible](I)
          X7=X[illegible] +[illegible]F(I)-X3
          X5=X6-V[illegible](I)*V5(I)*X7
          X[illegible]=V[illegible](I)*X5+X[illegible]
          X3 =X3
          IF(X3.GT.VRMAX(I))     X3=VRMAX(I)
          IF(X3.LT.VRMIN(I))     X3=VRMIN(I)
          X3[illegible]=X[illegible]+X[illegible]25+X5[illegible]
          X[illegible]=X2 +X3[illegible]
          VF(I)=X[illegible]
          IF(VF(I).GT.VFMAX(I)) VF(I)=VFMAX(I)
          IF(VF(I).LT.VFMIN(I)) VF(I)=VFMIN(I)
C         [illegible] GENERATOR INPUTS
          FDPG(1)=[illegible].*(X3-X[illegible])
          FDPG(3)=-(V5(I)/T5(I))*(V1(I)*X7+X5)
          FDPG(2)=(VF(I)/T2(I))*(X5-X3)
          FDPG(4)=(1./T5(I))*(X2-X1)
          RETURN
          END
C...................................................................
C
C
C         [illegible] POWER MODEL WITH SLIP STABILISER AND LIMITERS
          DIMENSION [illegible],VF3(I)
          COMMON /[illegible]/[illegible],ISTEP
          COMMON /BLOCK9/VC,VE,V[illegible],D1,D2,D3,D4
          COMMON /BLOCK8/TF1 ,NSTEP,ITYPE
          COMMON /BLOCK2/ V1(30),V5(30),V6(30),VREF(30),VRMAX(30),
       1  VRMIN(30),VF(30),T1(30),T2(30),T5(30),VFMAX(30),VFMIN(30)
          COMMON /BLOCK3/ FDPG(30),OUT(30),SAVE(30)
          COMMON /BLOCK4/[illegible]REF(30),CIFREF(30),CIGREF(30),DELACT(30),
       1  CIF[illegible]( ),CIGACT(30)
          COMMON /BLOCK5/[illegible]X(30),A[illegible]IN(30),T3(30),T4(30),AK1(30),AK2(30)
       1  ,[illegible]( )
          COMMON /BLOCK7/[illegible]( ),VX(30),VT1(30)
          COMMON /[illegible]/T[illegible]( ),T[illegible]1( ,30),T[illegible]2(10,30),V[illegible](10,30),
       1  V[illegible]( , ),V[illegible](1 ,30),T[illegible],T[illegible]3( ,30),T[illegible](1 ,30),AK[illegible]1(10,30)
       2  ,[illegible]( , )
          IF( [illegible] . [illegible] )GO TO 19
```

```
C     [illegible] INITIAL INTEGRATOR OUTPUTS
      [illegible](I)=0.
      [illegible](I)=0.
      [illegible](I)=[illegible]C3(I)
C     [illegible] VOLTAGE REF SET POINT
      X[illegible]=[illegible](I)-VF(I)/V1(I)
C     [illegible] OUTPUTS FOR ROTOR ANGLE LIMITER
1[illegible] X17=[illegible](I)
      X[illegible]=[illegible](I)
      X[illegible]=[illegible](I)
C     [illegible] VARIABLE
      X[illegible]=[illegible](I)
      X[illegible]=X[illegible]-X12
      X[illegible]=X15-V1(I)*V2(I)*X1[illegible]
      X[illegible]=X17+V[illegible](I)*X16
      X[illegible]=X[illegible]
      [illegible](X[illegible].GT.V[illegible]X(I)) X118=VRMAX(I)
      [illegible](X[illegible].LT.V[illegible](I)) X11[illegible]=VRMIN(I)
C     [illegible]
      [illegible](I)=[illegible]*(X11-X12)
      [illegible](I)=-(V[illegible](I)/T1(I))*(V1(I)*X14+X16)
      [illegible]3(I)=(V[illegible](I)/T2(I))*(X1[illegible]-X1[illegible])
      [illegible]GO TO 210
C     [illegible] INITIAL INTEGRATOR OUTPUTS
      [illegible](I)=0.
      [illegible](I)=0.
      [illegible](I)=[illegible](I)
C     [illegible] VOLTAGE REF SET POINT
      X3[illegible]=[illegible](I)-V[illegible](I)/V1(I)
C     [illegible] OUTPUTS FOR FIELD CURRENT LIMITER
210   X2[illegible]=[illegible](I)
      X2[illegible]=[illegible](I)
      X[illegible]=[illegible](I)
C     [illegible] VARIABLES
      X[illegible]=X3[illegible]-X[illegible]
      X[illegible]=X[illegible]-V[illegible](I)*V5(I)*X21
      X[illegible]=X[illegible]+V[illegible](I)*X23
      X[illegible]=X[illegible]
      [illegible](X[illegible].[illegible].V[illegible]AX(I)) X[illegible]=VRMAX(I)
      [illegible](X[illegible].[illegible].V[illegible](I)) X[illegible]5=VRMIN(I)
      X[illegible]=[illegible](I)
C     [illegible] INPUTS
      [illegible](I)=[illegible]*(X19-X2[illegible])
      [illegible](I)=-(V[illegible](I)/T1(I))*(V1(I)*X[illegible]1+X23)
```

```
      .  .(  )=(V (I)/T (I))*(X2 -X25)
      IF(   .GT.TSTP)GO TO  1
C     I    I ITIAL INTEGRATOR OUTPUTS
      (  )= .
      (  )= .
      (  )= .
      (  )=CIGAC (I)
C     CALCULATE VOLTAGE FOR SET POINT
      X  =CIGAC (I)-VF(I)/V (I)
C     ...INTEGRATOR OUTPUTS FOR SIAT OR CURRENT LIMITER
310   X32=OUT( 3)
      X29=OUT(12)
      X27=OUT( 1)
      X 3=OUT(1 )
C     CALCULATE INTERMEDIATE VARIABLES
      X26=CIGAC (I)
      X28=X26-X27
      X31=X29-V (I)*V5(I)*X28
      X33=X32+V6(I)*X31
      X  =X33
      IF(X33.GT.VRMAX(I))X133=VRMAX(I)
      IF(X33.LT.VRMIN(I))X133=VRMIN(I)
      IF(X  .LT.  .)GO TO 98
      IF(X  .GE.  . )GO TO 99
98    X   =
      X  =  .
      G         
99    X  = .
      X  =X
C     CALCULATE INTEGRATOR INPUTS
1.5   FNOG(  )=  . *(X26-X27)
      FNOG(  )=-(V (I)/ (I))*(V1(I)*X28+X31)
      FNOG(12)=(V (I)/T (I))*(X31-X33)
      FNOG(  )=X 5
      IF(    .GT.TSTP)GO TO  1
C     ...INITIAL INTEGRATOR OUTPUTS
      OUT(15)= .
      OUT(16)= .
      OUT(17)= .
C     ...INTEGRATORS FOR SLIP STABILIZER
  1   X  =OUT(1 )
      X  =   (  )
      X  =   ( 7)
C     ...         INTERMEDIATE VARIABLES
```

```
      [illegible]7=[illegible](I)
      [illegible]
      X[illegible] =[illegible]( )*X[illegible]+X[illegible]
      IF((X[illegible](I)+X[illegible]).[illegible].[illegible]I[illegible](I))   X2=[illegible]L[illegible](I)
      IF((X[illegible](I)+X[illegible]).G[illegible].[illegible]X(I))   X2=[illegible]AX(I)
C     [illegible]
      [illegible](I)=33.2*(X7-X5)
      [illegible](I)=-(1./[illegible](I))*X[illegible]
      [illegible](I7)=(1./[illegible](I))*([illegible](I)*X3+X[illegible])
      IF([illegible].G[illegible].[illegible])[illegible]
C     CALC[illegible] OUTPUTS
      [illegible](I)=[illegible](I)
      [illegible](I)=[illegible](I)*(1.-[illegible](I))
      [illegible](I)=[illegible](I)*(1.-[illegible](I))
      [illegible](I)=[illegible](I)
C     [illegible]
      V[illegible](I)=V[illegible](I)-VF(I)/V[illegible](I)
C     [illegible] AV.
810   X[illegible]=[illegible](I)
      X[illegible]=[illegible](I)
      X[illegible]=[illegible](I)
      X[illegible]=[illegible](I)
C     [illegible]S
      X[illegible]=[illegible](I)
      X[illegible]=X[illegible]+X[illegible]5
      X7=[illegible]+[illegible](I)-X[illegible]
      X5=X[illegible]-[illegible](I)*[illegible](I)*X7
      X[illegible]=[illegible](I)*X[illegible]+[illegible]
      X5 =X[illegible]
      IF(X5.G[illegible].[illegible]X(I))   X3 =V[illegible]AX(I)
      IF(X5.L[illegible].V[illegible](I))   X3 =V[illegible]I[illegible](I)
      X3 =X[illegible]+X[illegible]5+X[illegible]
      X2=X3 +X[illegible]
      V[illegible](I)=X[illegible]
      I[illegible](X[illegible].G[illegible].V[illegible]X(I)) VF(I)=VF[illegible]AX(I)
      I[illegible](X[illegible].L[illegible].VF[illegible](I)) VF(I)=VF[illegible]I[illegible](I)
C     [illegible]
      [illegible](I)=[illegible]*(X[illegible]-X[illegible])
      F[illegible](I)=-([illegible](I)/[illegible](I))*(V1(I)*X7+X5)
      F[illegible](I)=(V[illegible](I)/[illegible](I))*(X5-X3)
      F[illegible](I)=(1./[illegible](I))*(X2-X[illegible])
      [illegible]
      -

C.......................................................................
```

```
                [illegible] (..)
          / [illegible] 7/[illegible]P(3 ),V[illegible](  ),V[illegible](3 )
          / [illegible] C, 1/ I  7,[illegible]
          / I  C  /[illegible]I , S[illegible], DIP
        IF(    -,   )1,1,2
 1      V (I)=  (I)
        [illegible]
 2      IF(     -.  )3, , 
 3      V (I)=V (I)+ IP(I)
        GO     17
 4      IF( I   -.?  )5, ,6
 5      V (I)=V  (I)
        G  [illegible]
 6      IF(     -.  )7,7,12
 7      V (I)=V (I)+DIP(I)*ST (2). *(I    -.7 ))
   12   [illegible]
        [illegible]
C.......................................................................
```

```
C       SUBROUTINE TO CALCULATE AVR PARAMETERS
        SUBROUTINE AVRPMS(I)
        COMMON/BLOCK9/VC,VD,VE,D1,D2,D3,D4
        COMMON/BLOCK8/TFIN,NSTEP,NTYPE
        COMMON/BLOCK1/TIME,TSTEP
        COMMON/BLOCK2/ V1(30),V5(30),V6(30),VREF(30),VRMAX(30)
     1  ,VRMIN(30),VF(30),T1(30),T2(30),T5(30),VFMAX(30)
     2  ,VFMIN(30)
        COMMON/BLOCK3/ PLUG(30),OUT(30),SAVE(30)
        COMMON/BLOCK4/DELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
     1  CIFACT(30),CIGACT(30)
        COMMON/BLOCK5/ALMAX(30),ALMIN(30),T3(30),T4(30),AK1(30),AK2(30)
     1  ,PWACT(30)
        COMMON/BLOCK7/DIP(30),VT(30),VT1(30)
        COMMON/BLOCK6 /TIMEN(30),TN1(10,30),TN2(10,30),VN1(10,30),
     1  VN5(10,30),VN6(10,30),TSM,TN3(10,30),TN4(10,30),AKN1(10,30)
     2  ,AKN2(10,30)
        I=1
        CALL READ(I)
        DO 113 J=1,20
        TIMEN(J)=0.0
 113    CONTINUE
        TSM=0.0
        T1(I)=0.0
        TYPE 112
 112    FORMAT(3X,'SUBROUTINE FOR CALCULATING AVR PARAMETERS').
        DO 10 J=1,20
        T1(I)=T1(I)+.5
        TIME=0.0
        TN1(I,J)=T1(I)
 111    CALL INPUT(I)
        CALL AVR1(I)
        IF(TIME.GE.TFIN)GO TO 10
C       PERFORM INTEGRATION STEP
        CALL INT(I)
        TIME=NSTEP*TSTEP
        NSTEP=NSTEP+1
        NTYPE=NTYPE+1
C       CHECK FOR NEW NETWORK CONDITIONS
        IF((VFMAX(I)-VF(I)).GT.1E-03)GO TO 111
        TIMEN(J)=TIME
        TN1(I,J)=T1(I)
 110    TYPE501,TIMEN(J),VF(I),TN1(I,J)   ,T2(I),V1(I),V5(I),V6(I)
 501    FORMAT(1X,'TIMEN(J)=',F8.4,X,'VF(I)=',F8.4,X,'TN1(I,J)=',F8.4,X,
```

```
     1 'T2(I)=',F8.4,X,/,2X,'V1(I)=',F8.4,X,'V5(I)=',F8.4,X,'V6(I)='
     2 ,F8.4//)
10      CONTINUE
        TSM=TIMEN(1)
        DO 15 J=1,20
        IF(TIMEN(J)-TSM)3,3 ,15
3       TSM=TIMEN(J)
        K=J
15      CONTINUE
        TYPE61,K,TIMEN(K),TN1(I,K)
61      FORMAT(3X,'K=',I5,X,'TIMEN(K)=',F8.4,X,'TN1(I,K)=',F8.4//)
        CALL READ(I)
        DO 213 J=1,20
        TIMEN(J)=0.0
213     CONTINUE
        TSM=0.0
        TYPE17,TN1(I,K)
  17    FORMAT(10X,'TN1(I,K)=',F10.4/)
        T1(I)=TN1(I,K)
        T2(I)=0.0
        DO 20 J=1,20
        T2(I)=T2(I)+.03
        TIME=0.0
        TN2(I,J)=T2(I)
222     CALL INPUT(I)
        CALL AVR1(I)
        IF(TIME.GE.TFIN)GO TO 20
C       PERFORM INTEGRATION STEP
        CALL INT(I)
        TIME=NSTEP*TSTEP
        NSTEP=NSTEP+1
        NTYPE=NTYPE+1
C       CHECK FOR NEW NETWORK CONDITIONS
        IF((VFMAX(I)-VF(I)).GT.1E-03)GO TO 222
        TN2(I,J)=T2(I)
        TIMEN(J)=TIME
120     TYPE502,TIMEN(J),VF(I),T1(I),TN2(I,J),V1(I),V5(I),V6(I)
502     FORMAT(1X,'TIMEN(J)=',F8.4,X,'VF(I)=',F8.4,X,'T1(I)=',F8.4,X,
     1 'TN2(I,J)=',F8.4,X,/,2X,'V1(I)=',F8.4,X,'V5(I)=',F8.4,X,'V6(I)='
     2 ,F8.4//)
  20    CONTINUE
        TSM=TIMEN(1)
        DO 115 J=1,20
        IF(TIMEN(J)-TSM)13, 13,115
```

```
   13 TSM=TIMEN(J)
      KK=J
  115 CONTINUE
      TYPE62,KK,TIMEN(KK),TN2(I,KK)
   62 FORMAT(3X,'KK=',I5,X,'TIMEN(KK)=',F8.4,X,'TN2(I,KK)=',F8.4//)
      CALL READ(I)
      DO 313 J=1,20
      TIMEN(J)=0.0
  313 CONTINUE
      TSM=0.0
      TYPE27,TN2(I,KK)
   27 FORMAT(10X,'TN2(I,KK)=',F10.4/)
      T1(I)=TN1(I,K)
      T2(I)=TN2(I,KK)
      V1(I)=-200.
      DO 30 J=1,9
      V1(I)=V1(I)+20.
      TIME=0.0
      VN1(I,J)=V1(I)
  333 CALL INPUT(I)
      CALL AVR1(I)
      IF(TIME.GE.TFIN)GO TO  30
C     PERFORM INTEGRATION STEP
      CALL INT(I)
      TIME=NSTEP*TSTEP
      NSTEP=NSTEP+1
      NTYPE=NTYPE+1
C     CHECK FOR NEW NETWORK CONDITIONS
      IF((VFMAX(I)-VF(I)).GT.1E-03)GO TO 333
      TIMEN(J)=TIME
      VN1(I,J)=V1(I)
  130 TYPE503,TIMEN(J),VF(I),T1(I),T2(I),VN1(I,J)   ,V5(I),V6(I)
  503 FORMAT(1X,'TIMEN(J)=',F8.4,X,'VF(I)=',F8.4,X,'T1(I)=',F8.4,X,
     1'T2(I)=',F8.4,X,/,2X,'VN1(I,J)=',F9.3,X,'V5(I)=',F8.4,X,'V6(I)='
     2,F8.4//)
   30 CONTINUE
      TSM=TIMEN(1)
      DO 215 J=1,9
      IF(TIMEN(J)-TSM)23,23 ,215
   23 TSM=TIMEN(J)
      LL=J
  215 CONTINUE
      TYPE63,LL,TIMEN(LL),VN1(I,LL)
   63 FORMAT(3X,'LL=',I5,X,'TIMEN(LL)=',F8.4,X,'VN1(I,LL)=',F9.3//)
```

```
      CALL READ(I)
      DO 413 J=1,20
      TIMEN(J)=0.0
413   CONTINUE
      TSM=0.0
      TSM=0.0
      TYPE37,VN1(I,LL)
37    FORMAT(10X,'VN1(I,LL)=',F10.4/)
      T1(I)=TN1(I,K)
      T2(I)=TN2(I,KK)
      V1(I)=VN1(I,LL)
      V5(I)=0.0
      DO 40 J=1,20
      V5(I)=V5(I)+.02
      TIME=0.0
      VN5(I,J)=V5(I)
444   CALL INPUT(I)
      CALL AVR1(I)
      IF(TIME.GE.TFIN)GO TO 40
C     PERFORM INTEGRATION STEP
      CALL INT(I)
      TIME=NSTEP*TSTEP
      NSTEP=NSTEP+1
      NTYPE=NTYPE+1
C     CHECK FOR NEW NETWORK CONDITIONS
      IF((VFMAX(I)-VF(I)).GT.1E-03)GO TO 444
      VN5(I,J)=V5(I)
      TIMEN(J)=TIME
140   TYPE504,TIMEN(J),VF(I),T1(I),T2(I),V1(I),VN5(I,J)   ,V6(I)
504   FORMAT(1X,'TIMEN(J)=',F8.4,X,'VF(I)=',F8.4,X,'T1(I)=',F8.4,X,
     1'T2(I)=',F8.4,X,/,2X,'V1(I)=',F9.3,X,'VN5(I,J)=',F8.4,X,'V6(I)='
     2,F8.4//)
40    CONTINUE
      TSM=TIMEN(1)
      DO 315 J=1,20
      IF(TIMEN(J)-TSM)93, 93,315
93    TSM=TIMEN(J)
      MM=J
315   CONTINUE
      TYPE64,MM,TIMEN(MM),VN5(I,MM)
64    FORMAT(3X,'MM=',I5,X,'TIMEN(MM)=',F8.4,X,'VN5(I,MM)=',F8.4//)
      CALL READ(I)
      DO 513 J=1,20
      TIMEN(J)=0.0
```

```
 513    CONTINUE
        TYPE 47,VN5(I,MM)
 47     FORMAT(10X,'VN5(I,MM)=',F10.4/)
        T1(I)=TN1(I,K)
        T2(I)=TN2(I,KK)
        V1(I)=VN1(I,LL)
        V5(I)=VN5(I,MM)
        V6(I)=0.0
        DO 50 J=1,20
        V6(I)=V6(I)+5.
        TIME=0.0
        VN6(I,J)=V6(I)
 555    CALL INPUT(I)
        CALL AVR1(I)
        IF(TIME.GE.TFIN)GO TO 50
 C      PERFORM INTEGRATION STEP
        CALL INT(I)
        TIME=NSTEP*ISTEP
        NSTEP=NSTEP+1
        NTYPE=NTYPE+1
 C      CHECK FOR NEW NETWORK CONDITIONS
        IF((VFMAX(I)-VF(I)).GT.1E-03)GO TO 555
        VN6(I,J)=V6(I)
        TIMEN(J)=TIME
 150    TYPE505,TIMEN(J),VF(I),T1(I),T2(I),V1(I),V5(I),VN6(I,J)
 505    FORMAT(1X,'TIMEN(J)=',F8.4,X,'VF(I)=',F8.4,X,'T1(I)=',F8.4,X,
      1 'T2(I)=',F8.4,X,/,2X,'V1(I)=',F8.4,X,'V5(I)=',F8.4,X,'VN6(I,J)='
      2 ,F8.4//)
 50     CONTINUE
        TSM=TIMEN(1)
        DO 415 J=1,20
        IF(TIMEN(J)-TSM)43, 43,415
 43     TSM=TIMEN(J)
        NN=J
 415    CONTINUE
        TYPE65,NN,TIMEN(NN),VN6(I,NN)
 65     FORMAT(3X,'NN=',I5,X,'TIMEN(NN)=',F8.4,X,'VN6(I,NN)=',F8.4//)
        V6(I)=VN6(I,NN)
        TYPE57,VN6(I,NN)
 57     FORMAT(10X,'VN6(I,NN)=',F10.4/)
        RETURN
        END
 C.....................................................................
        SUBROUTINE READ(I)
```

```
      COMMON/BLOCK1/TIME,TSTEP
      COMMON/BLOCK9/VC,VD,VE,D1,D2,D3,D4
      COMMON/BLOCK2/ V1(30),V5(30),V6(30),VREF(30),VRMAX(30)
     1 ,VRMIN(30),VF(30),T1(30),T2(30),T5(30),VFMAX(30)
     2 ,VFMIN(30)
      COMMON/BLOCK3/ PLUG(30),OUT(30),SAVE(30)
      COMMON/BLOCK4/DELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
     1 CIFACT(30),CIGACT(30)
      COMMON/BLOCK5/ALMAX(30),ALMIN(30),T3(30),T4(30),AK1(30),AK2(30)
     1 ,PWACT(30)
      COMMON/BLOCK7/DIP(30),VT(30),VT1(30)
      COMMON/BLOCK8/TFIN,NSTEP,NTYPE
      OPEN(UNIT=1,DEVICE='DSK',FILE='DKC4.DAT')
      I=1
C     CLEAR INTEGRATOR ARRAYS
      DO 5 I=1,30
      PLUG(I)=0.0
      OUT(I)=0.0
      SAVE(I)=0.0
    5 CONTINUE
      TIME=0.0
      NSTEP=0
      NTYPE=0
      READ (1,*) TSTEP,TTYPE
      TYPE 591,TSTEP,TTYPE
  591  FORMAT(1X, 'TIME STEP ',T20,F6.3/1X,'TYPE INTERVAL=',T20,F6.3)
      TYPE 592
 592   FORMAT(' EXCITATION SYSTEM PARAMETERS ')
C     READ EXCITATION SYSTEM PARAMETERS
C     READ AVR PARAMETERS
      READ(1,*) V1(I),V5(I),V6(I),VREF(I),VRMAX(I),VRMIN(I)
     1 ,VF(I),VT1(I),T1(I),T2(I),T5(I),VFMAX(I),VFMIN(I)
      TYPE 593,V1(I),V5(I),V6(I),VREF(I),VRMAX(I),VRMIN(I),VF(I),VT1(
     1 I),T1(I),T2(I),T5(I),VFMAX(I),VFMIN(I)
593    FORMAT(3X,'V1(I)=',F8.4,2X,'V5(I)=',F8.4,2X,'V6(I)=',F8.4,2X
     1  ,'VREF(I)',F8.4,/,2X,'VRMAX(I)',F8.4,2X,'VRMIN(I)=',F8.4,2X,
     2 'VF(I)=',F8.4,/,2X,'VT1(I)=',F8.4,2X,'T1(I)=',F8.4,2X,'T2(I)='
     1 ,F8.4,/,X,'T5(I)=',F8.4,X,'VFMAX(I)=',F8.4,X,'VFMIN(I)='F8.4/)
C     READ LIMITER PARAMETERS
      READ (1,*),DELREF(I),CIFREF(I),CIGREF(I),DELACT(I),CIFACT(I),
     1 CIGACT(I)
      TYPE594,DELREF(I),CIFREF(I),CIGREF(I),DELACT(I),CIFACT(I),
     1 CIGACT(I)
594   FORMAT(2X,'DELREF(I)=',F8.4,2X,'CIFREF(I)=',F8.4,2X,'CIGREF(I)=',
```

```
     1F8.4,/,2X,'DELACT(I)=',F8.4,2X,'CIFACT(I)=',F8.4,2X,'CIGACT(I)='
     1,F8.4/)
      READ (1,*),ALMAX(I),ALMIN(I),T3(I),T4(I),AK1(I),AK2(I),PWACT(I)
      TYPE 595,ALMAX(I),ALMIN(I),T3(I),T4(I),AK1(I),AK2(I),PWACT(I)
595   FORMAT(2X,'AKMAX(I)',F8.4,2X,'ALMIN(I)=',F8.4,2X,'T3(I)=',F8.4,/
     1,2X,'T4(I)=',F8.4,2X,'AK1(I)=',F8.4,2X,'AK2(I)=',F8.4,/,
     12X,'PWACT(I)=',F8.4//)
C      READ (1,*), IAVR(I)
      READ(1,*),TFIN,TIME
      READ(1,*),DIP(I)
      READ(1,*),VC,VD,VE,D1,D2,D3,D4
      TYPE 598,VC,VD,VE,D1,D2,D3,D4
598   FORMAT(2X,'VC=',F8.4,2X,'VD=',F8.4,2X,'VE=',F8.4,2X,'D1=',F8.4,/
     1,2X,'D2=',F8.4,2X,'D3=',F8.4,2X,'D4=',F8.4/)
      TYPE596,TFIN,TIME
596   FORMAT(10X,'TFIN='F10.4,10X,'TIME='F10.4)
      TYPE597,DIP(I)
597   FORMAT(10X,'DIP(I)='F10.4)
      RETURN
      END
C............................................................
```

```
C      SUBROUTINE TO CALCULATE SLIP STAB PARAMETERS
       SUBROUTINE SSPMS(I)
       COMMON/BLOCK9/VC,VD,VE,D1,D2,D3,D4
       COMMON/BLOCK6 /TIMEN(30),TN1(10,30),TN2(10,30),VN1(10,30),
     1 VN5(10,30),VN6(10,30),TSM,TN3(10,30),TN4(10,30),AKN1(10,30)
     2 ,AKN2(10,30)
       COMMON/BLOCK1/TIME,TSTEP
       COMMON/BLOCK2/ V1(30),V5(30),V6(30),VREF(30),VRMAX(30)
     1 ,VRMIN(30),VF(30),T1(30),T2(30),T5(30),VFMAX(30)
     2 ,VFMIN(30)
       COMMON/BLOCK3/ PLUG(30),OUT(30),SAVE(30)
       COMMON/BLOCK4/DELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
     1 CIFACT(30),CIGACT(30)
       COMMON/BLOCK5/ALMAX(30),ALMIN(30),T3(30),T4(30),AK1(30),AK2(30)
     1 ,PWACT(30)
       COMMON/BLOCK7/DIP(30),VT(30),VT1(30)
       COMMON/BLOCK8/TFIN,NSTEP,NTYPE
        I=1
       CALL READ(I)
       DO 113 J=1,10
       TIMEN(J)=0.0
113    CONTINUE
       TSM=0.0
       TYPE 19
19      FORMAT(10X,'RESPONSE TO CHANGE IN T3(I)'//)
       T3(I)=0.0
       DO 10 J=1,10
       T3(I)=T3(I)+.15
       TIME=0.0
111    CALL SSINP(I)
       CALL VTINP(I)
       CALL AVR3(I)
       IF(TIME.GE.TFIN)GO TO 10
C      PERFORM INTEGRATION STEP
       CALL INT(I)
       TIME=NSTEP*TSTEP
       NSTEP=NSTEP+1
       NTYPE=NTYPE+1
       IF((VFMAX(I)-VF(I)).GT.1E-03)GO TO 111
       TIMEN(J)=TIME
       TN3(I,J)=T3(I)
110    TYPE501,TIMEN(J), VF(I),TN3(I,J)  ,T4(I),AK1(I),AK2(I)
501    FORMAT(3X,'TIMEN(J)=',F8.4,5X,'VF(I)=',F8.4,5X,'TN3(I,J)=',F8.4,/
     1 ,5X,'T4(I)=',F8.4,5X,'AK1(I)=',F8.4,5X,'AK2(I)=',F8.4//)
```

```
10    CONTINUE
      TSM=TIMEN(1)
      DO 15 J=1,10
      IF(TIMEN(J)-TSM)3,3,15
3     TSM=TIMEN(J)
      K=J
15    CONTINUE
      TYPE61,K,TIMEN(K),TN3(I,K)
61    FORMAT(3X,'K=',I4,5X,'TIMEN(K)=',F8.4,5X,'TN3(I,K)=',F8.4//)
      CALL READ(I)
      TYPE 199
199    FORMAT(10X,'RESPONSE TO CHANGE IN T4(I)'//)
      DO 213 J=1,10
      TIMEN(J)=0.0
213   CONTINUE
      TSM=0.0
      T3(I)=TN3(I,K)
      TYPE57,TN3(I,K)
57    FORMAT(10X,'TN3(I,K)=',F10.4/)
      T4(I)=0.0
      DO20J=1,10
      T4(I)=T4(I)+.75
      TIME=0.0
222   CALL SSINP(I)
      CALL VTINP(I)
      CALL AVR3(I)
      IF(TIME.GE.TFIN)GO TO 20
C     PERFORM INTEGRATION STEP
      CALL INT(I)
      TIME=NSTEP*TSTEP
      NSTEP=NSTEP+1
      NTYPE=NTYPE+1
C     CHECK FOR NEW NETWORK CONDITIONS
      IF((VFMAX(I)-VF(I)).GT.1E-03)GO TO 222
      TIMEN(J)=TIME
      TN4(I,J)=T4(I)
120   TYPE502,TIMEN(J),VF(I),T3(I),TN4(I,J)   ,AK1(I),AK2(I)
502   FORMAT(3X,'TIMEN(J)=',F8.4,5X,'VF(I)=',F8.4,5X,'T3(I)=',F8.4,/
     1,5X,'TN4(I,J)=',F8.4,5X,'AK1(I)=',F8.4,5X,'AK2(I)=',F8.4//)
   20 CONTINUE
      TSM=TIMEN(1)
      DO 115 J=1,10
      IF(TIMEN(J)-TSM)13,13,115
13    TSM=TIMEN(J)
```

```
      KK=J
115   CONTINUE
      TYPE62,KK,TIMEN(KK),TN4(I,KK)
62    FORMAT(3X,'KK=',I4,5X,'TIMEN(KK)=',F8.4,5X,'TN4(I,KK)=',F8.4//)
      TYPE 189
189    FORMAT(10X,'RESPONSE TO CHANGE IN AK1(I)'//)
      CALL READ(I)
      DO 313 J=1,10
      TIMEN(J)=0.0
313   CONTINUE
      TSM=0.0
      T3(I)=TN3(I,K)
      T4(I)=TN4(I,KK)
      TYPE67,TN4(I,KK)
67    FORMAT(10X,'TN4(I,KK)=',F10.4/)
      AK1(I)=0.0
      DO 30 J=1,10
      AK1(I)=AK1(I)+.1
      TIME=0.0
333   CALL SSINP(I)
      CALL VTINP(I)
      CALL AVR3(I)
      IF(TIME.GE.TFIN)GO TO  30
C     PERFORM INTEGRATION STEP
      CALL INT(I)
      TIME=NSTEP*TSTEP
      NSTEP=NSTEP+1
      NTYPE=NTYPE+1
C     CHECK FOR NEW NETWORK CONDITIONS
      IF((VFMAX(I)-VF(I)).GT.1E-03)GO TO 333
      AKN1(I,J)=AK1(I)
      TIMEN(J)=TIME
130   TYPE503,TIMEN(J),VF(I),T3(I),T4(I),AKN1(I,J),AK2(I)
503   FORMAT(3X,'TIMEN(J)=',F8.4,5X,'VF(I)=',F8.4,5X,'T3(I)=',F8.4,/
     1,5X,'T4(I)=',F8.4,5X,'AKN1(I,J)=',F8.4,5X,'AK2(I)=',F8.4//)
30    CONTINUE
      TSM=TIMEN(1)
      DO 215 J=1,10
      IF(TIMEN(J)-TSM)23,23,215
23    TSM=TIMEN(J)
      LL=J
215   CONTINUE
      TYPE63,LL,TIMEN(LL),AKN1(I,LL)
63    FORMAT(3X,'LL=',I4,5X,'TIMEN(LL)=',F8.4,5X,'AKN1(I,LL)=',F8.4//)
```

```
         TYPE 179
179       FORMAT(10X,'RESPONSE TO CHANGE IN AK2(I)'//)
         CALL READ (I)
         DO 413 J=1,10
         TIMEN(J)=0.0
413      CONTINUE
         TSM=0.0
         T3(I)=TN3(I,K)
         T4(I)=TN4(I,KK)
         AK1(I)=AKN1(I,LL)
         TYPE77,AKN1(I,LL)
77       FORMAT(10X,'AKN1(I,LL)=',F10.4/)
         AK2(I)=0.0
         DO 40 J=1,10
         AK2(I)=AK2(I)+2.5
         TIME=0.0
444      CALL SSINP(I)
         CALL VTINP(I)
         CALL AVR3(I)
         IF(TIME.GE.TFIN)GO TO 40
C        PERFORM INTEGRATION STEP
         CALL INT(I)
         TIME=NSTEP*TSTEP
         NSTEP=NSTEP+1
         NTYPE=NTYPE+1
C        CHECK FOR NEW NETWORK CONDITIONS
         IF((VFMAX(I)-VF(I)).GT.1E-03)GO TO 444
         AKN2(I,J)=AK2(I)
140      TYPE504,TIMEN(J),VF(I),T3(I),T4(I),AK1(I),AKN2(I,J)
504      FORMAT(3X,'TIMEN(J)=',F8.4,5X,'VF(I)=',F8.4,5X,'T3(I)=',F8.4,/
     1   ,5X,'T4(I)=',F8.4,5X,'AK1(I)=',F8.4,5X,'AKN2(I,J)=',F8.4//)
         TIMEN(J)=TIME
40       CONTINUE
         TSM=TIMEN(1)
         DO 315 J=1,10
                             93
         IF(TIMEN(J)-TSM)93,~~315~~,315
93       TSM=TIMEN(J)
         MM=J
315      CONTINUE
         TYPE64,MM,TIMEN(MM),AKN2(I,MM)
64       FORMAT(3X,'MM=',I4,5X,'TIMEN(MM)=',F8.4,5X,'AKN2(I,MM)=',F8.4//)
         T3(I)=TN3(I,K)
         T4(I)=TN4(I,KK)
         AK1(I)=AKN1(I,MM)
```

```
      AK2(I)=AKN2(I,MM)
      TYPE88,AKN2(I,MM)
88    FORMAT(10X,'AKN2(I,MM)=',F10.4/)
      RETURN
      END
C...............................................................F
      SUBROUTINE DELINP(I)
      COMMON/BLOCK9/VC,VD,VE,D1,D2,D3,D4
      COMMON/BLOCK1/TIME,TSTEP
      COMMON/BLOCK4/DELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
     1 CIFACT(30),CIGACT(30)
      COMMON/BLOCK7/DIP(30),VT(30),VT1(30)
      IF(TIME-.02)1,1,2
1     DELACT(I)=VD
      GO TO 5
2     DELACT(I)=VD-D1*SIN(6.28*(TIME-.02))
5     RETURN
      END
C...............................................................F
      SUBROUTINE SCLINP(I)
      COMMON/BLOCK9/VC,VD,VE,D1,D2,D3,D4
      COMMON/BLOCK1/TIME,TSTEP
      COMMON/BLOCK4/DELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
     1 CIFACT(30),CIGACT(30)
      IF(TIME-.02)1,1,2
1     CIGACT(I)=VC
      GO TO 3
2     CIGACT(I)=VE-D2
3     RETURN
      END
C...............................................................F
      SUBROUTINE FCLINP(I)
      COMMON/BLOCK9/VC,VD,VE,D1,D2,D3,D4
      COMMON/BLOCK1/TIME,TSTEP
      COMMON/BLOCK4/DELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
     1 CIFACT(30),CIGACT(30)
      IF(TIME-.05)1,1,2
1     CIFACT(I)=VE
      GO TO 5
2     CIFACT(I)=VE-D3
5     RETURN
      END
C...............................................................F
      SUBROUTINE SSINP(I)
```

```
      COMMON/BLOCK9/VC,VD,VE,D1,D2,D3,D4
      COMMON/BLOCK1/TIME,TSTEP
      COMMON/BLOCK5/ALMAX(30),ALMIN(30),T3(30),T4(30),AK1(30),AK2(30)
     1 ,PWACT(30)
      IF(TIME-.008)1,1,2
1     PWACT(I)=0.0
      GO TO 3
2     PWACT(I)=D4*SIN(10.*(TIME-.008))
3     RETURN
      END
C...............................................................F
C     SUBROUTINE TO SEE EFFECT OF SLIP STAB
      SUBROUTINE SS(I)
      COMMON/BLOCK6 /TIMEN(30),TN1(10,30),TN2(10,30),VN1(10,30),
     1 VN5(10,30),VN6(10,30),TSM,TN3(10,30),TN4(10,30),AKN1(10,30)
     2 ,AKN2(10,30)
      COMMON/BLOCK1/TIME,TSTEP
      COMMON/BLOCK9/VC,VD,VE,D1,D2,D3,D4
      COMMON/BLOCK2/ V1(30),V5(30),V6(30),VREF(30),VRMAX(30)
     1 ,VRMIN(30),VF(30),T1(30),T2(30),T5(30),VFMAX(30)
     2 ,VFMIN(30)
      COMMON/BLOCK3/ PLUG(30),OUT(30),SAVE(30)
      COMMON/BLOCK4/DELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
     1 CIFACT(30),CIGACT(30)
      COMMON/BLOCK5/ALMAX(30),ALMIN(30),T3(30),T4(30),AK1(30),AK2(30)
     1 ,PWACT(30)
      COMMON/BLOCK8/TFIN,NSTEP,NTYPE
      COMMON/BLOCK7/DIP(30),VT(30),VT1(30)
      CALL READ(I)
      TYPE 10
10    FORMAT(10X,'AVR RESPONSE WITH SLIP STAB'//)
C     AVR RESPONSE WITH SLIP STAB
41    CALL VTINP(I)
      CALL SSINP(I)
      CALL AVR3(I)
C     PERFORM INTEGRATION STEP
      IF(TIME.GE.TFIN)GO TO 11
      CALL INT(I)
      TIME=NSTEP*TSTEP
      NSTEP=NSTEP+1
      NTYPE=NTYPE+3
      TYPE88,TIME,PWACT(I),VF(I),VT(I)
88    FORMAT(3X,'TIME=',F8.4,5X,'PWACT(I)=',F8.4,5X,/,'VF(I)=',
     1 F8.4,5X,'VT(I)=',F8.4/)
```

```
C       CHECK FOR NEW NETWORK CONDITIONS
        IF(TIME.LT.TFIN)GO TO 41
11      RETURN
        END
C...........................................................F
        SUBROUTINE VTINP(I)
        COMMON/BLOCK1/TIME,TSTEP
        COMMON/BLOCK7/DIP(30),VT(30),VT1(30)
        IF(TIME-.3)58,58,59
58      VT(I)=VT1(I)
59      RETURN
        END
C...........................................................F
C       SUBROUTINE TO SEE EFFECT OF LIMITERS ON AVR
        SUBROUTINE LIM(I)
        COMMON/BLOCK1/TIME,TSTEP
        COMMON/BLOCK9/VC,VD,VE,D1,D2,D3,D4
        COMMON/BLOCK6 /TIMEN(30),TN1(10,30),TN2(10,30),VN1(10,30),
     1  VN5(10,30),VN6(10,30),TSM,TN3(10,30),TN4(10,30),AKN1(10,30)
     2  ,AKN2(10,30)
        COMMON/BLOCK8/TFIN,NSTEP,NTYPE
        COMMON/BLOCK2/ V1(30),V5(30),V6(30),VREF(30),VRMAX(30)
     1  ,VRMIN(30),VF(30),T1(30),T2(30),T5(30),VFMAX(30)
     2  ,VFMIN(30)
        COMMON/BLOCK3/ PLUG(30),OUT(30),SAVE(30)
        COMMON/BLOCK4/DELREF(30),CIFREF(30),CIGREF(30),DELACT(30),
     1  CIFACT(30),CIGACT(30)
        COMMON/BLOCK5/ALMAX(30),ALMIN(30),T3(30),T4(30),AK1(30),AK2(30)
     1  ,PWACT(30)
        COMMON/BLOCK7/DIP(30),VT(30),VT1(30)
        CALL READ(I)
        TYPE 10
10      FORMAT(10X,'ROTOR ANGLE LIMITER RESPONSE'//)
C       RESPONSE TO CHANGE IN ROTOR ANGLE
        TIME=0.0
41      CALL DELINP(I)
        CALL VTINP(I)
        CALL AVR2(I)
C       PERFORM INTEGRATION STEP
        IF(TIME.GE.TFIN)GO TO 11
        CALL INT(I)
        TIME=NSTEP*TSTEP
        NSTEP=NSTEP+1
        NTYPE=NTYPE+3
```

```
      TYPE99,TIME,DELACT(I),VF(I),VT(I)
99    FORMAT(3X,'TIME=',F8.4,5X,'DELACT(I)=',F8.4,5X,/,'VF(I)=',
     1F8.4,5X,'VT(I)=',F8.4/)
C     CHECK FOR NEW NETWORK CONDITIONS
      IF(TIME.LT.TFIN)GO TO 41
11    CALL READ(I)
      TYPE 20
20    FORMAT(10X,'FIELD CURRENT LIMITER RESPONSE'//)
C     RESPONSE TO STEP CHANGE IN FIELD CURRENT
51    CALL FCLINP(I)
      CALL VTINP(I)
      CALL AVR2(I)
      IF(TIME.GE.TFIN)GO TO 22
C     PERFORM INTEGRATION STEP
      CALL INT(I)
      TIME=NSTEP*TSTEP
      NSTEP=NSTEP+1
      NTYPE=NTYPE+3
      TYPE77,TIME,CIFACT(I),VF(I),VT(I)
77    FORMAT(3X,'TIME=',F8.4,5X,'CIFACT(I)=',F8.4,5X,/,'VF(I)=',
     1F8.4,5X,'VT(I)=',F8.4/)
C     CHECK FOR NEW NETWORK CONDITIONS
      IF(TIME.LT.TFIN)GO TO 51
22    CALL READ(I)
      TYPE30
30    FORMAT(10X,'STATOR CURRENT LIMITER RESPONSE'//)
C     RESPONSE TO CHANGE IN STATOR CURRENT
      TIME=0.0
61    CALL SCLINP(I)
      CALL VTINP(I)
      CALL AVR2(I)
      IF(TIME.GE.TFIN)GO TO 55
C     PERFORM INTEGRATION STEP
      CALL INT(I)
      TIME=NSTEP*TSTEP
      NSTEP=NSTEP+1
      NTYPE=NTYPE+3
      TYPE66,TIME,CIGACT(I),VF(I),VT(I)
66    FORMAT(3X,'TIME=',F8.4,5X,'CIGACT(I)=',F8.4,5X,/,'VF(I)=',
     1F8.4,5X,'VT(I)=',F8.4/)
C     CHECK FOR NEW NETWORK CONDITIONS
      IF(TIME.LT.TFIN)GO TO 61
55    RETURN
      END
```

```
           PSI<  .  =     T=  >  .C.L.
           PSI<  .  =(     J=  > .L G
                  TIL       STEP:YES        :LOG

                  VELOCITY  LOAD  AS  OUTPUT  C      TOPS=2          3 (2 ??)
                  R=(GRAPHS)J=     16 13
                  SYY216 2  =    5 16: 3:03

           C        PSI<F . =C  ATURV LI= 2>1
                   I   =LIMIT S?
             X   FC.FC ,FC1.FCF,FC  .FO
             :   LOG
           EXECUTION
```

```
XCAT     SYSTEM  PARAMETERS

  V     1.
VI(I)= -?   .      V5(I)=   .1     V6(I)= 1 .          VP F(I)   (.
  (I)    .         VR I (I)= -8.      VF(I)=    .
  (I)=  7.         T1(I)=  1.         T2(I)=    .
  (I)=    .  3   VF AX(I)=  8.       VF J (I)= -8.

  F(I)=   .     CIFRSF(I)=   .      CIGR F(I)=    .
  C (T)= -3.3   CIFACT(I)= -3.35    CI  CT(I)= -3.5

  A(I)    .     AB T (I)= - .5      T3(I)=  1.5
  (I)= 1 .      AK1(I)=  .5         AK2(I)=   .
  C (I)=    .

V = -3.5      VD= -3.5      V = -3.35     D1=    .5
D2=   .5      D3=   .5      D4=  3.

        T  =     0.3            IIII=     .
        TP(I)=    - .35
```

```
V      S  SE  TO STEP AND SINE INPUT

   T                  V (I)                      VF(I)

          = ?,        6.65             ,     .       E+   ,
 .        = 1,        6.65             ,    5.333333      ,
 .        = 1,        6.65             ,    8.            ,
 .        = 1,        6.65             ,    7.9  1235     ,
 .        = 1,        6.65             ,    8.0           ,
 .3       = 1,        6.65             ,    7.996342      ,
 .        = 1,        6.65             ,    8.0           ,
 .        = 1,        6.65             ,    7.999865      ,
 .        = 1,        6.65             ,    8.0           ,
 .        = 1,        6.65             ,    7.990995      ,
 .        = 1,        6.65             ,    8.            ,
 .7       = 1,        6.65             ,    8.            ,
 .7       = 1,        6.65             ,    8.            ,
 .        = 1,        6.65             ,    8.            ,
 .        = 1,        6.65             ,    8.            ,
 .        =  ,        6.65             ,    8.            ,
 .1                 , 6.65             ,    8.            ,
 .1                 , 6.65             ,    8.            ,
 .1                 , 6.65             ,    8.            ,
 .1                 , 6.65             ,    8.            ,
 .1                 , 6.65             ,    8.            ,
 .13                , 6.65             ,    8.            ,
 .136               , 6.65             ,    8.            ,
 .1                 , 6.65             ,    8.            ,
 .14                , 6.65             ,    8.            ,
 .1                 , 7.               ,   -1.6           ,
 .1                 , 7.               ,   -2.55 16       ,
 .1                 , 7.               ,   -4.55 762      ,
 .17                , 7.               ,   -3. 11 1       ,
 .17                , 7.               ,   -3.15          ,
```

```
 [illegible]    ,   7.[illegible]       ,  -1.7 [illegible]    ,
 [illegible]    ,   7.[illegible]       ,  -1.1[illegible]     ,
 [illegible]    ,   6.97[illegible]3    ,  - .72 [illegible]7  ,
 [illegible]    ,   6.[illegible]3[illegible] ,  [illegible].[illegible]757[illegible]35 ,
 [illegible]    ,   6.851 [illegible]   ,   3.[illegible]7[illegible] ,
 [illegible]    ,   6.79[illegible]365  ,   [illegible].5[illegible]25[illegible]9 ,
 [illegible]    ,   6.7[illegible]      ,   7.6[illegible]57[illegible] ,
 [illegible]    ,   6.7[illegible]1     ,   7.8[illegible]72   ,
 [illegible]    ,   6.674[illegible]5[illegible] ,   7.9[illegible]51 ,
 [illegible]    ,   6.6[illegible]      ,   7.995795  ,
 [illegible]5   ,   6.65[illegible]     ,   7.9[illegible]     ,
 [illegible]    ,   6.656[illegible]    ,   7.9[illegible]     ,
 .[illegible]6  ,   6.674[illegible]    ,   7.[illegible]2     ,
 [illegible]    ,   6.7 4[illegible]    ,   7.999[illegible]   ,
 .[illegible]7[illegible] , 6.744579    ,   7.6[illegible] 775 ,
 [illegible]    ,   6.793915  ,   [illegible].1[illegible] 16  ,
 .[illegible]8[illegible] , 6.85 5      ,   4.25[illegible]    ,
 .[illegible]   ,   6.912[illegible]6[illegible] , 2.1[illegible]755[illegible] ,
 .29[illegible] ,   6.977[illegible]7[illegible] , [illegible].[illegible]12 [illegible]55E-[illegible]1,


--------------------------------------------------------------------------------
[illegible] SYSTEM PARAMETERS

[illegible]                 [illegible]
[illegible] L=              1.[illegible]
 V[illegible](I)= -2[illegible]  V5(I)= [illegible].1[illegible]  V6(I)= 12.[illegible]  VREF(I)  0.000[illegible]
 V[illegible](I)  8.[illegible]  VR[illegible](I)= -8.[illegible]   VF(I)= [illegible].000[illegible]
 V[illegible](I)=  7.[illegible]  T1(I)=  1.[illegible]  T2(I)= [illegible].060[illegible]
 [illegible](I)=   .[illegible]3[illegible] VF AX(I)=  8.[illegible] VF I[illegible](I)= -3.[illegible]

 [illegible](I)= [illegible]  CI[illegible]REF(I)= [illegible]  CIGREF(I)= [illegible].0000
 [illegible](I)= -3.3[illegible]  CIFACT(I)= -3.35[illegible]  CIG[illegible]CT(I)= -3.5000

 [illegible]X(I)  [illegible].5000  AL[illegible](I)= -[illegible].5[illegible]  T3(I)=  1.5[illegible]
 [illegible](I)= 1[illegible].[illegible]  AK1(I)=  0.5[illegible]  AK2(I)=  5.[illegible]
 [illegible]CT(I)= [illegible].[illegible]


 VC= -3.5[illegible]    VD= -3.3[illegible]  VE= -3.350[illegible]  D1=  [illegible].35[illegible]
 [illegible]=  [illegible]   D3=  [illegible].5[illegible]  D4=  3.0[illegible]

        [illegible]=   [illegible].3[illegible]          TIME=    0.0000
        DIF(I)=   -[illegible].35[illegible]

--------------------------------------------------------------------------------


--------------------------------------------------------------------------------
  SUBROUTINE FOR CALCULATING AVR PARAMETERS

--------------------------------------------------------------------------------

T[illegible](J)=   . 1[illegible] VF(I)=  8.[illegible] TH1(I,J)=  [illegible].5[illegible] T2(I)=  [illegible].0600
 V[illegible](I)= -[illegible]  .      V5(I)=  [illegible].1[illegible] V6(I)= 12.[illegible]

T[illegible](J)=   . 12[illegible] VF(I)=  8.[illegible] TH1(I,J)=  1.0[illegible] T2(I)=  0.0600
 V1(I)= -[illegible]  .      V5(I)=  [illegible].1[illegible] V6(I)= 12.[illegible]

T[illegible](J)=   . 1[illegible] VF(I)=  8.[illegible] TH1(I,J)=  1.5[illegible] T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .      V5(I)=  [illegible].1[illegible] V6(I)= 12.[illegible]

T[illegible](J)=   . 1[illegible] VF(I)=  8.[illegible] TH1(I,J)=  2.[illegible] T2(I)=  [illegible].0600
 V[illegible](I)= -[illegible]  .      V5(I)=  [illegible].1[illegible] V6(I)= 12.[illegible]

T[illegible](J)=   . [illegible] VF(I)=  8.[illegible] TH1(I,J)=  2.5[illegible] T2(I)=  0.0600
 V1(I)= -[illegible]  .      V5(I)=  [illegible].1[illegible] V6(I)= 12.[illegible]

T[illegible](J)=   . 2[illegible] VF(I)=  8.[illegible] TH1(I,J)=  3.[illegible] T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .      V5(I)=  [illegible].1[illegible] V6(I)= 12.[illegible]

T[illegible](J)=   . 22 VF(I)=  [illegible] TH1(I,J)=  3.5[illegible] T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .      V5(I)=  [illegible].1[illegible] V6(I)= 12.[illegible]

T[illegible](J)=   . 2[illegible] VF(I)=  [illegible] TH1(I,J)=  [illegible] T2(I)=  [illegible].0600
```

```
T[illegible](J)=   .[illegible]   VF(I)=  8.[illegible]  T1(I,J)=  [illegible].5[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible].[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .[illegible]   VF(I)=  8.[illegible]  T1(I,J)=  5.[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible].[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .3[illegible]  VF(I)=  8.[illegible]  T1(I,J)=  5.5[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible].[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .3[illegible]  VF(I)=  8.[illegible]  T1(I,J)=  [illegible].[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .3[illegible]  VF(I)=  8.[illegible]  T1(I,J)=  [illegible].5[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .3[illegible]  VF(I)=  8.[illegible]  T1(I,J)=  7.[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .38[illegible]  VF(I)=  8.[illegible]  T1(I,J)=  7.5[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .[illegible]  VF(I)=  8.[illegible]  T1(I,J)=  8.[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .[illegible]2  VF(I)=  8.[illegible]  T1(I,J)=  8.5[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .4[illegible]  VF(I)=  8.[illegible]  T1(I,J)=  9.[illegible]  T2(I)=  [illegible].0600
 V1(I)= -[illegible]  .[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .[illegible]  VF(I)=  8.[illegible]  T1(I,J)=  9.5[illegible]  T2(I)=  [illegible].0600
 V1(I)= -2  .[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

T[illegible](J)=   .[illegible]  VF(I)=  8.[illegible]  T1(I,J)=  [illegible].[illegible]  T2(I)=  [illegible].0600
 V1(I)= -2  .[illegible]  V5(I)=   .1[illegible]  V6(I)= 12.[illegible]

  [illegible]=   [illegible] T[illegible](M)=  [illegible].[illegible]  T1(J,K)=  [illegible].5

-------------------------------------------------------------------------------
[illegible]

[illegible]
T[illegible] I [illegible]=     1.
 V1(I)= -2[illegible].      V5(I)=  [illegible].[illegible]  V6(I)= 12.[illegible]  VREF(I)  [illegible].[illegible]
 V[illegible](I)   [illegible].     [illegible](I)= -[illegible].[illegible]  VF(I)=  [illegible].[illegible]
 V[illegible](I)=  7.      [illegible](I)=  1.[illegible]  [illegible]2(I)=   .[illegible]
T5(I)=   .[illegible]  [illegible]2(I)=  [illegible].[illegible]  V[illegible](I)= -[illegible].[illegible]

 [illegible](I)=   .[illegible]      [illegible](I)=  [illegible].[illegible]   CIGR[illegible](I)=  [illegible]
 [illegible](I)= -[illegible].[illegible]      [illegible](I)= -3.35    CIGACT(I)= -3.5[illegible]

 [illegible](I)   .[illegible]     [illegible](I)= -[illegible].5     T3(I)=  1.5[illegible]
 [illegible](I)= [illegible].      [illegible](I)=   .5[illegible]   [illegible]2(I)=  5.[illegible]
 [illegible](I)=   .

[illegible]= -3.[illegible]     V[illegible] = -[illegible].[illegible]   V[illegible]= -3.3[illegible]  D1=  [illegible].35[illegible]
[illegible]2=   .[illegible]     [illegible]=   .[illegible]     [illegible]=  3.[illegible]

        [illegible] =    .3            [illegible] =     .[illegible]
        [illegible](I)=   -[illegible].3[illegible]

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        [illegible](I, )=      .5[illegible]

[illegible](I)=   .[illegible]   V[illegible](I)=  [illegible].[illegible]  [illegible](I)=   .[illegible]   [illegible](I,J)=  [illegible].3[illegible]
```

```
     ( )=     .      (I)=   .        (I)=    .        (J,J)=     .
  ( )= -      .     (I)=   .1     V (I)= 12.

 I     ( )=   .   V (I)=   .        (I)=    .      I 2(I,J)=     .
  ( )= -      .     V5(I)=   .1     V (I)= 12.

       (J)=   .   V (I)=   .        (I)=    .5         2(I,J)=    .120
  (I)= -      .     (I)=   .1     V (I)= 12.

       (J)=   .   V (I)=   .        (I)=    .5     I (I,J)=     .15
  (I)= -      .     (I)=   .1     V (I)= 12.

       (J)=   .   V (I)=   .        (I)=    .5      2(I,J)=    .18
  (I)= -      .     (I)=   .1     V (I)= 12.

       (I)=   . 22 V (I)=   .        (I)=    .5     T 2(I,J)=    .21
  (I)= -      .     V5(I)=   .1     V (I)= 12.

       ( )=   .   V (I)=   .        (I)=    .5      2(I,J)=    .24
  ( )= -      .     (I)=   .1     V (I)= 12.

       (J)=   .   VF(I)=   .        (I)=    .5       2(I,J)=    .27
  ( )= -      .     (I)=   .1     V (I)= 12.

       (J)=   . 2  VF(I)=   .       T (I)=    .5     T 2(I,J)=    .300
  ( )= -      .     V5(I)=   .1     V (I)= 12.

       (J)=   .3   V (I)=   .        (I)=    .5     T 2(I,J)=    .33
  (I)= -      .     V (I)=   .1     V (I)= 12.

       (J)=   . 32  VF(I)=   .        (I)=    .5     T 2(I,J)=    .36
  (I)= -      .     V5(I)=   .1     V (I)= 12.

       (J)=   .   VF(I)=   .       T (I)=    .5        (I,J)=    .39
  (I)= -      .     (I)=   .1     V (I)= 12.

       (J)=   . 3  VF(I)=   .        (I)=    .5       2(I,J)=    .42
  ( )= -      .     (I)=   .1     V (I)= 12.

       (J)=   .   V (I)=   .        (I)=    .5        2(I,J)=    .45
  ( )= -      .     (I)=   .1       (I)= 12.

       (J)=   .     (I)=   .         (I)=    .5        (I,J)=   0.480
  ( )= -      .     (I)=   .1     V (I)= 12.

       (J)=   .    V (I)=   .        (I)=    .5     T 2(I,J)=    .51
  ( )= -      .     (I)=   .1     V (I)= 12.

       ( )=   .    V (I)=   .        (I)=    .      T 2(I,J)=    .54
  ( )= -      .     (I)=   .1     V (I)= 12.

       (J)=   .     (I)=   .        (I)=    .      T 2(I,J)=    .57
  (I)= -      .     ( )=   .1     V (I)= 12.

       ( )=   .     (I)=   .        (I)=    .       2(I,J)=    .
  (I)= -      .     (I)=   .1     V (I)= 12.

   =         (   )=   . 1      2(I,K)=    .
```

```
                =         1.
   ( )= -     .        VF(I)=    .1       V (I)=  .          F(I)   .
    (  )      .        V  T (I)= -.          V (I)=    .
   ( )=  7.            (I)=  1.          T (I)=    .
  ( )=    .            A(I)=   .         VF I (I)= -  .

     (I)=     .           CI   F(I)=    .        CI   F(I)=    .
     (I)= -   .           CI   (I)= -3.35        CIGACT(I)= -3.5

     (I)    .           AL   ( )= -  .5         F3(I)=  1.5
   ( )=     .           F1( )=  .5         RK2(I)=  3.
     ( )=     .

  = -3.            = -1.1        V  = -3.35      DI=   .35
  =   .            =   .           )= 3.

        =       .3                 TIM=        .
      (I)=    -  .35

----------------------------------------------------------------------------------------------

          (1,  )=       .3

      (I)=    .      VF(I)=  8.      T1(I)=   .5    T2(I)=   0.0300
      ( , )= -   .       V5(I)=   .1      V6(I)= 12.

      (I)=    .      VF(I)=  8.      T1(I)=   .5    T2(I)=   0.0300
     ( , )= -   .       V5(I)=   .1      V6(I)= 12.

      (I)=    .      VF(I)=  8.      T1(I)=   .5    T2(I)=   0.0300
      ( , )= -   .       V5(I)=   .1      V6(I)= 12.

      (I)=    .      VF(I)=  8.      T1(I)=    .5    T2(I)=     .03
      ( , )= -   .       V5(I)=   .1      V6(I)= 12.

      (I)=    .      VF(I)=  8.      T1(I)=   .5    T2(I)=    .03
      ( , )= -   .       V5(I)=   .1      V6(I)= 12.

      (I)=    .      VF(I)=  8.      T1(I)=  0.50   T2(I)=    .03
     (1,I)= -    .       V5(I)=   .1      V6(I)= 12.

      (I)=    .      VF(I)=  8.      T1(I)=   .50   T2(I)=    .03
      ( , )= -   .       V5(I)=   .1      V6(I)= 12.

      (I)=    .      VF(I)=  8.      T1(I)=   .5    T2(I)=    .030
      ( , )= -   .       V5(I)=   .1      V6(I)= 12.

      (I)=    .      VF(I)=  8.      T1(I)=   .5    T2(I)=    .03
      ( , )= -   .       V5(I)=   .1      V6(I)= 12.

      (I)=    .      VF(I)=  8.      T1(I)=   .5    T2(I)=   0.0300
      ( , )= -   .       V5(I)=   .1      V6(I)= 12.

   I =            (  )=      .       V 1(I,LL)= -2    .




----------------------------------------------------------------------------------------------
                            RS

                          .
                =          .
      ( )= -     .          5(I)=    .1         (I)= 1  .          F(I)     .
        ( )       .         F  T  (T)= -  .           V (I)=    .
      (I)=  7.              (I)=  1.            (I)=     .
    ( )=     .              (I)=    .        VF I  (T)= -  .

      (I)=     .           CI   T(T)=    .        CI    F(I)=    .
      ( )= -   .           CI   (T)= -3.35        CIGACT(I)= -3.5

     ( )    .           L  I  ( )= -  .5         (I)=  1.5
```

```
                                                    ( )=        .
       ( .'=      .

   ( .   .'        '= - .          = -3.3     = .35
   =     .         '=   .        =  3.

         =          .                        =       .
       ( )=        .35

----------------------------------------------------------------------------------------------------

           ( ,  )=-2.  .

      (  )=      .       V (  )=   .          (I)=    .        (  )=    . 3
      ( )= -     .         (I,  )=   .        V6(I)= 12.

      (  )=      .       V (  )=   .          (I)=    .5      T2(I)=    . 3
      ( )= -     .        5(I, )=    .2       V6(I)= 12.

      (  )=      .       V (  )=   .          (I)=    .5      T2(I)=   0.030
      (  )= -    .         ( , )=   .3        V6(I)= 12.

      (  )=      .       VF(I)=   .           (I)=    .5      T2(I)=   0.030
      ( )= -     .         (I, )=   .         V6(I)= 12.

      ( )=       .       VF(I)=   .           (I)=    .5      T2(I)=    .03
      ( )= -     .        (I, )=    .5        V6(I)= 12.

      ( )=       .2      VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .        (I, )=    .6        V6(I)= 12.

      ( )=       .22     VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .       V5(I, )=   .7        V6(I)= 12.

      ( )=       .2      VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .       V5(I, )=   .8        V6(I)= 12.

      ( )=       .26     VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .        (I, )=    .9        V6(I)= 12.

      ( )=       .2      VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .        (I, )=   1.         V6(I)= 12.

      ( )=       .3      VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .        (I, )=   1.1        V6(I)= 12.

      ( )=       .3      VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .        (I, )=   1.2        V6(I)= 12.

      ( )=       .3      VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .        (I, )=   1.3        V6(I)= 12.

      ( )=       .35     VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .       V5(I, )=  1.         V6(I)= 12.

      ( )=       .36     VF(I)=   .           (I)=    .5      T2(I)=    .030
      ( )= -     .        (I, )=   1.5        V6(I)= 12.

      ( )=       .       VF(I)=   .           (I)=    .5      T2(I)=    .03
      ( )= -     .       V5(I, )=  1.6        V6(I)= 12.

      ( )=       .4      VF(I)=   .           (I)=    .5      T2(I)=    .03
      ( )= -     .        (I, )=   1.7        V6(I)= 12.

      ( )=       .       VF(I)=   .           (I)=    .5      T2(I)=    .03
      ( )= -     .        (I, )=   1.8        V6(I)= 12.

      ( )=       .       VF(I)=   .           (I)=    .5      T2(I)=    .03
```

```
 [illegible]( )= -      .      [illegible](I,J)= [illegible].     V6(I)= [illegible].

    =      [illegible]( )=     .1    [illegible]S(I,  )=   [illegible].1

-------------------------------------------------------------------------------------
 [illegible]

 [illegible]
 [illegible](I)= -  .       V5(I)=    .1        V5(I)= 1 .        VREF(I)   [illegible]
 [illegible](I)    .        [illegible](I)= -3.          V7(I)=    .
 [illegible](I)=  7.        [illegible](I)=  1.          [illegible](I)=    .
 [illegible]( )=    .  3    [illegible](I)=  3.          [illegible](I)= -8.

 [illegible](I)=   .        CIG[illegible]F(I)=    .        CIGREF(I)=  [illegible]
 [illegible](I)= -3.3       CIG[illegible]CT(I)= -3.35      CIGFCT(I)= -3.5

 [illegible]( )     .       [illegible](I)= - .5      [illegible]3(I)=  1.5
 [illegible](I)=  .         [illegible](I)=  .5       [illegible]2(I)=  5.
 [illegible]( )=       .

 [illegible]= -3.       V0= -3.3       V1= -3.35       [illegible]=  .35
 [illegible]=   .       V3=  1.5       [illegible]=  3.

          [illegible]=     1.3                   [illegible]=        .
          [illegible](I)=   - .35

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           [illegible](I,  )=       .

 [illegible](J)=     .9    VF(I)=   7.9991 T1(I)=    .5      T2(I)=   0.030
 [illegible]( )= -   .     V5(I)=    .1    V6(I,J)=  5.

 [illegible](J)=     .9    VF(I)=   7.9991 T1(I)=    .5      T2(I)=    .0300
 [illegible]( )= -   .     V5(I)=    .1    V6(I,J)= 1 .

 [illegible](J)=     .     VF(I)=   7.9991 T1(I)=    .5      T2(I)=    .030
 [illegible]( )= -   .     V5(I)=    .     V6(I,J)= 15.

 [illegible]( )=     .     VF(I)=   7.9991 T1(I)=    .5      T2(I)=    .0300
 [illegible]( )= -   .     V5(I)=    .     V6(I,J)= 2 .

 [illegible](J)=     .9    VF(I)=   7.9991 T1(I)=    .5      T2(I)=   0.030
 [illegible]( )= -   .     V5(I)=    .     V6(I,J)= 25.

 [illegible](J)=     .     VF(I)=   7.9991 T1(I)=    .5      T2(I)=   0.030
 [illegible]( )= -   .     V5(I)=    .1    V6(I,J)= 3 .

 [illegible](J)=     .     VF(I)=   7.9991 T1(I)=    .500    T2(I)=   0.030
 [illegible]( )= -   .     V5(I)=    .1    V6(I,J)= 35.

 [illegible](J)=     .     VF(I)=   7.9991 T1(I)=    .5      T2(I)=   0.030
 [illegible]( )= -   .     V5(I)=    .1    V6(I,J)= 4 .

 [illegible](J)=     .     VF(I)=   7.9991 T1(I)=    .5      T2(I)=    .03
 [illegible]( )= -   .     V5(I)=    .1    V6(I,J)= 45.

 [illegible](J)=     .     VF(I)=   7.9991 T1(I)=    .5      T2(I)=    .03
 [illegible]( )= -   .     V5(I)=    .1    V6(I,J)= 5 .

 [illegible](J)=     .     VF(I)=   7.9991 T1(I)=    .5      T2(I)=    .03
 [illegible]( )= -   .     V5(I)=    .1    V6(I,J)= 55.

 [illegible](J)=     .     VF(I)=   7.9991 T1(I)=    .5      T2(I)=    .3
```

```
     (I)=    .     VF(I)=  7.9991 T1(I)=   .5     T2(I)=    .
 V (I)= -     .      V5(I)=   .3     VF6(I,J)=  F .

     (I)=    .     VF(I)=  7.9991 T1(I)=   .5     T2(I)=    .3
 V (I)= -     .      V5(I)=   .3     VF6(I,J)= 7 .

     (I)=    .     VF(I)=  7.9991 T1(I)=   .5     T2(I)=    .35
 V (I)= -     .      V5(I)=   .3     VF6(I,J)= 75.

     (I)=    .     VF(I)=  7.9991 T1(I)=   .5     T2(I)=    . 3
 V (I)= -     .      V5(I)=   .3     VF6(I,J)= 8 .

     (I)=    . 22  VF(I)=  7.9991 T1(I)=   .5     T2(I)=    . 3
 V (I)= -     .      V5(I)=   .3     VF6(I,J)= 85.

     (I)=    .12   VF(I)=  7.9991 T1(I)=   .5     T2(I)=    .3
 V (I)= -     .      V5(I)=   .      VF6(I,J)= 9 .

     (I)=    . 2   VF(I)=  7.9991 T1(I)=   .5     T2(I)=    . 3
 V (I)= -     .      V5(I)=   .      VF6(I,J)= 95.

     (I)=    .12   VF(I)=  7.9991 T1(I)=   .5     T2(I)=    . 3
 V (I)= -     .      V5(I)=   .1     VF6(I,J)=1  .

   =      T1 F (  )=    . 9   VF6(I,M)=  5.

          VF6(I,I)=     5.

--------------------------------------------------------------------------------
EXCITATION SYSTEM PARAMETERS

 TIME STEP            . 2
 SYS  I  TERVAL=     1.
   V1(I)= -2  .      V5(I)=   .1      V6(I)= 1 .         VFEF(I)    .3
  VF  )(I)    .      VR I (I)= -8.        VF(I)=    .
  V (I)=  7.          T1(I)=  1.          T2(I)=    .
 T (I)=   .  3   VF  X(I)=  8.        VF I (I)= -8.

   I  F(I)=   .         CIEF F(I)=   .           CI  F(I)=   .
 C   C (I)= -3.3         CIFACT(I)= -3.35        CIGACT(I)= -3.5

   X(I)    .5         L I (I)= -1.5          T3(I)=  1.5
   (I)= 1 .            1(I)=   .5           2(I)=  5.
     C (I)=    .

 V = -3.5       V = -3.3       V = -3.35    D1=    .35
   =   .5       D3=   .5       D4=  3.

           T  =      .3                     =      .
           TF(I)=   - .35

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                     S     TI      SPO SE

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    I   =     .       LAC (I)= -3.3         VF(I)=    .     V (I)=   7.

    I   =     . 1     LAC (I)= -3.3         VF(I)=    .     V (I)=   7.

        =     . 2     LAC (I)= -3.3 32      VF(I)=    .3    V (I)=   7.

        =     . 3     LAC (I)= -3.3 5       VF(I)=    .37   V (I)=   7.

        =     .       LAC (I)= -3.3569      VF(I)=  1. 73   V (I)=   7.
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```
TI   =    . [illegible]   DELAC (I)= -3.3755   VF(I)= [illegible]   VT(I)=  7. [illegible]
TI   =    .[illegible]  DELAC (I)= -3.3997   VF(I)=  7.1[illegible]   VT(I)=  7. [illegible]
TI   =    .07[illegible]  DELACT(I)= -3.42[illegible]   VF(I)= [illegible]   VT(I)=  7. [illegible]
TI   =    .0[illegible]  DELACT(I)= -3.44[illegible]9   VF(I)=  8. [illegible]   VT(I)=  7. [illegible]
TI   =    .0[illegible]  DELACT(I)= -3.46[illegible]6   VF(I)=  8. [illegible]   VT(I)=  7.000[illegible]
TI   =    .1[illegible]  DELACT(I)= -3.48[illegible]   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .11[illegible]  DELACT(I)= -3.4[illegible]5   VF(I)=  8. [illegible]   VT(I)=  7.000[illegible]
TI   =    .12[illegible]  DELACT(I)= -3.5162   VF(I)=  8.[illegible]   VT(I)=  7.[illegible]0
TI   =    .13[illegible]  DELACT(I)= -3.533[illegible]   VF(I)=  8.[illegible]   VT(I)=  7.[illegible]0[illegible]
TI   =    .1[illegible]  DELACT(I)= -3.5[illegible]59   VF(I)=  8.   VT(I)=  7.[illegible]0[illegible]
TI   =    .1[illegible]  DELACT(I)= -3.5639   VF(I)=  8.[illegible]   VT(I)=  7.[illegible]0[illegible]
TI   =    .1[illegible]  DELACT(I)= -3.5778   VF(I)=  8.[illegible]   VT(I)=  7.[illegible]0[illegible]
TI   =    .178[illegible]  DELACT(I)= -3.59[illegible]6   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .1[illegible]  DELACT(I)= -3.6[illegible]23   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .1[illegible]  DELACT(I)= -3.6128   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .[illegible]  DELACT(I)= -3.622[illegible]   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .21[illegible]  DELACT(I)= -3.6300   VF(I)=  8.[illegible]   VT(I)=  7.0000
TI   =    .22[illegible]  DELACT(I)= -3.6366   VF(I)=  8.[illegible]   VT(I)=  7.0000
TI   =    .23[illegible]  DELACT(I)= -3.6420   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .24[illegible]  DELACT(I)= -3.646[illegible]   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .25[illegible]  DELACT(I)= -3.6486   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .26[illegible]  DELACT(I)= -3.6499   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .27[illegible]  DELACT(I)= -3.6498   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .2[illegible]  DELACT(I)= -3.6483   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]
TI   =    .2[illegible]  DELACT(I)= -3.6454   VF(I)=  8.[illegible]   VT(I)=  7.000[illegible]



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EXCITATION   SYSTEM   PARAMETERS

TI  [illegible]                .[illegible]2
TYPE [illegible]               1.
 V[illegible](I)= -[illegible] .       V5(I)=   .[illegible]   V6(I)= 12.[illegible]   VREF(I)  0.000[illegible]
 V[illegible](I)   [illegible].        V[illegible](I)= -8.[illegible]   VF(I)=   .[illegible]
 VT[illegible](I)=  7.            T1(I)=  1.[illegible]   T2(I)=  [illegible].[illegible]
T5(I)=   .[illegible]3   VF[illegible](I)=  8.[illegible]   VF[illegible](I)= -[illegible].[illegible]

 [illegible](I)=    .[illegible]       CIFREF(I)=  [illegible].[illegible]   CIGREF(I)=  [illegible].[illegible]
 [illegible]CT(I)= -3.5[illegible]    CIFACT(I)= -3.350[illegible]   CIGACT(I)= -3.5[illegible]

 [illegible](I)    .5[illegible]   AL[illegible](I)= -0.5000   T3(I)=  [illegible].5[illegible]
 [illegible](I)= [illegible].   [illegible]  AK1(I)=  [illegible].5[illegible]   AK2(I)=  5.[illegible]
 [illegible]C[illegible](I)=   .[illegible]


 VC= -[illegible].[illegible]      VI= -3.3[illegible]   VF= -3.35[illegible]   D1=  0.35[illegible]
 [illegible]=   .           D3= [illegible].5[illegible]     D4=  3.5[illegible]

          [illegible] =      .3[illegible]              TIME=      .[illegible]
          [illegible](I)=    -[illegible].35


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          [illegible]
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TIME =    .0080 CIFACT(I)= -3.3500   VF(I)=  0.0000 VT(I)=  7.0000
TIME =    .0180 CIFACT(I)= -3.3500   VF(I)=  0.0000 VT(I)=  7.0000
TIME =    .0280 CIFACT(I)= -3.3500   VF(I)=  0.0000 VT(I)=  7.0000
TIME =    .0380 CIFACT(I)= -3.3500   VF(I)=  0.0000 VT(I)=  7.0000
TIME =    .0480 CIFACT(I)= -3.3500   VF(I)=  0.0000 VT(I)=  7.0000
TIME =    .0580 CIFACT(I)= -2.8500   VF(I)= -5.2274 VT(I)=  7.0000
TIME =    .0680 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .0780 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .0880 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .0980 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1080 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1180 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1280 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1380 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1480 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1580 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1680 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1780 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1880 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .1980 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2080 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2180 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2280 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2380 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2480 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2580 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2680 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2780 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2880 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000
TIME =    .2980 CIFACT(I)= -2.8500   VF(I)= -8.0000 VT(I)=  7.0000



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EXCI[illegible] SYSTEM PARAMETERS

[illegible] STEP            .02
[illegible] V.G=          1.[illegible]
 VI(I)= -[illegible]   V5(I)=  .1000  V6(I)= 12.0000  VREF(I)  0.0000
[illegible](I)  8.[illegible]  VRMIN(I)= -8.0000   VF(I)=  0.0000
VT1(I)=  7.[illegible]  T1(I)=  1.0000  T2(I)=  .0600
TS(I)=  [illegible]3  VFMAX(I)=  3.0000 VFMIN(I)= -9.0000

[illegible](I)=   .[illegible]  CIFREF(I)=  .0[illegible]  CIGREF(I)=  0.0[illegible]
[illegible]CT(I)= -3.3[illegible]  CIFACT(I)= -3.35[illegible]  CIGACT(I)= -3.5[illegible]

[illegible]X(I)   .5[illegible]  AB.I.(I)= -0.5[illegible]  T3(I)=  1.5[illegible]
[illegible](I)= 12.[illegible]  AK1(I)=  .5000  AK2(I)=  5.0000
[illegible]C(I)=  .[illegible]

[illegible]C= -3.5[illegible]  V[illegible]= -3.30[illegible]  VS= -3.35[illegible]  D1=  .35[illegible]
[illegible]=  .5[illegible]  D3=  .5[illegible]  D4=  3.0000

         TFL =     .3[illegible]              TIME=    [illegible]
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        T (I)=    -1.35

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        STATOR CURRENT LIMITER RESPONSE

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    TI(I)=    .0080 CIGACT(I)= -3.5000   VF(I)=  0.0000 VT(I)=  7.0000
    TI(I)=    .0180 CIGACT(I)= -3.5000   VF(I)=  0.0000 VT(I)=  7.0000
    TI(I)=    .0280 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .0380 CIGACT(I)= -3.0000   VF(I)= -7.7937 VT(I)=  7.0000
    TI(I)=    .0480 CIGACT(I)= -3.0000   VF(I)= -8.0500 VT(I)=  7.0000
    TI(I)=    .0580 CIGACT(I)= -3.0000   VF(I)= -7.9988 VT(I)=  7.0000
    TI(I)=    .0680 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .0780 CIGACT(I)= -3.000    VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .0880 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .0980 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .1080 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .1180 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .1280 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .1380 CIGACT(I)= -3.000    VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .1480 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .1580 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .1680 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .1780 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .1880 CIGACT(I)= -3.0000   VF(I)= -8. 0 0 VT(I)=  7.0000
    TI(I)=    .1980 CIGACT(I)= -3.000    VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .2080 CIGACT(I)= -3.000    VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .2180 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .2280 CIGACT(I)= -3.0000   VF(I)= -8. 0 0 VT(I)=  7.0000
    TI(I)=    .2380 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .2480 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .2580 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .2680 CIGACT(I)= -3.0000   VF(I)= -8.0  0 VT(I)=  7.0000
    TI(I)=    .2780 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .2880 CIGACT(I)= -3.0000   VF(I)= -8.0000 VT(I)=  7.0000
    TI(I)=    .2980 CIGACT(I)= -3.0000   VF(I)= -8.0   VT(I)=  7.0000



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   FACILITY'S SYSTEM PARAMETERS

   TI [illegible]           .  2
   TY [illegible] I [illegible] VAL=        1.
     V (I)= -2 [illegible]    V5(I)=  .1000   V6(I)= 12. [illegible]   VREF(I)  [illegible]
    V [illegible](I)   8. [illegible]   VR [illegible](I)= -8.0000   VF(I)=  [illegible]
    V [illegible](I)=  7. [illegible]   T1(T)=  1.0000   T2(I)=  .0600
   [illegible](I)=    . 3   VF AX(I)=  8.0000 VF I (I)= -8.0000

   [illegible](I)=     .   [illegible]   CI [illegible](I)=  ). [illegible]   CIGREF(I)=  . [illegible]
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```
   [illegible](I)= -3.5[illegible]    [illegible](I)= -3.5[illegible]    [illegible](I)= -3.5[illegible]

 [illegible](I)    .5[illegible]   [illegible] (I)= -[illegible].5[illegible]   T3(I)=  1.5
 [illegible](I)= 1[illegible]       XK1(I)=  [illegible].5[illegible]   XK2(I)=  5.[illegible]
 [illegible]C[illegible](I)=    .[illegible]

 V[illegible]= -3.5[illegible]   V1= -3.3[illegible]   V2= -3.35[illegible]   D1=  [illegible].35
 [illegible]=   .5[illegible]   D3=  [illegible].5[illegible]   D4=  3.[illegible]

       CFL =     [illegible].3[illegible]               TI[illegible]=    [illegible]
       [illegible]I[illegible](I)=   -[illegible].35[illegible]

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          [illegible]V[illegible]  [illegible]  [illegible]LIP STAR

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 [illegible] =   .[illegible]    P ACT(I)=   .[illegible] VF(I)=  [illegible] VT(I)=  7.[illegible]

 [illegible] =   .1[illegible]   P ACT(I)=   .1293 VF(I)=  [illegible] VT(I)=  7.[illegible]000

 [illegible] =   .[illegible]2   P ACT(I)=   .3591 VF(I)=  2.8772 VT(I)=  7.0[illegible]0

 [illegible] =   .[illegible]3   P ACT(I)=   .59[illegible] VF(I)=  6.6379 VT(I)=  7.0000

 [illegible] =   .[illegible]3[illegible] P ACT(I)=   .8291 VF(I)=  7.8497 VT(I)=  7.00[illegible]

 [illegible] =   .[illegible]   P ACT(I)=  1.[illegible]558 VF(I)=  7.9832 VT(I)=  7.[illegible]

 TI[illegible] =  .5[illegible]  P ACT(I)=  1.2773 VF(I)=  7.9981 VT(I)=  7.0[illegible]

 [illegible] =   .[illegible]    P ACT(I)=  1.19[illegible]6 VF(I)=  7.9998 VT(I)=  7.[illegible]

 [illegible] =   .7[illegible]   P ACT(I)=  1.[illegible]439 VF(I)=  8.[illegible] VT(I)=  7.[illegible]

 [illegible] =   .7[illegible]   P ACT(I)=  1.[illegible]86[illegible] VF(I)=  8.[illegible] VT(I)=  7.0[illegible]

 [illegible] =   .[illegible]8[illegible]  P ACT(I)=  2.[illegible] VF(I)=  8.[illegible] VT(I)=  7.0[illegible]00

 [illegible] =   .[illegible]   P ACT(I)=  2.2339 VF(I)=  8.[illegible] VT(I)=  7.0[illegible]

 [illegible] =   .1[illegible]   P ACT(I)=  2.3[illegible] VF(I)=  8.[illegible]  VT(I)=  7.0[illegible]

 [illegible] =   .11    P ACT(I)=  2.521[illegible] VF(I)=  8.[illegible]  VT(I)=  7.[illegible]

 [illegible] =   .[illegible]   P ACT(I)=  2.[illegible]55 VF(I)=  8.[illegible] VT(I)=  7.[illegible]

 [illegible] =   .12[illegible]  P ACT(I)=  2.75[illegible] VF(I)=  8.[illegible] VT(I)=  7.[illegible]

 [illegible] =   .13[illegible]  P ACT(I)=  2.837[illegible] VF(I)=  8.[illegible]  VT(I)=  7.[illegible]

 [illegible] =   .1[illegible]  P ACT(I)=  2.9[illegible] VF(I)=  8.[illegible] VT(I)=  7.[illegible]

 [illegible] =   .15   P ACT(I)=  [illegible].95[illegible] VF(I)=  8.[illegible]  VT(I)=  7.[illegible]

 [illegible] =   .[illegible]   P ACT(I)=  2.[illegible]7[illegible] VF(I)=  8.[illegible] VT(I)=  7.[illegible]

 [illegible] =   .1[illegible]  P ACT(I)=  2.[illegible] VF(I)=  8.[illegible]  VT(I)=  7.[illegible]

 [illegible] =   .17    P ACT(I)=  2.9[illegible] VF(I)=  8.[illegible]  VT(I)=  7.[illegible]

 [illegible] =   .1[illegible]  P ACT(I)=  2.9[illegible]7 VF(I)=  8.[illegible]  VT(I)=  7.[illegible]

 [illegible] =   .[illegible]   P ACT(I)=  2.9[illegible]15 VF(I)=  [illegible]  VT(I)=  7.[illegible]

 [illegible] =   .[illegible]   P ACT(I)=  2.[illegible]577 VF(I)=  [illegible]   [illegible](I)=  7.[illegible]

 [illegible] =   .[illegible]   [illegible]ACT(I)=  2.7755 VF(I)=  [illegible]   [illegible](I)=  7.[illegible]

 [illegible] =   .[illegible]   [illegible]ACT(I)=  2.[illegible]7[illegible] VF(I)=  [illegible]   [illegible](I)=  7.[illegible]

 [illegible] =   .[illegible]   [illegible]ACT(I)=  2.[illegible]5[illegible] VF(I)=  [illegible]   [illegible](I)=  7.[illegible]

 [illegible] =   .[illegible]3   [illegible]ACT(I)=  [illegible].[illegible]255 VF(I)=  [illegible]   [illegible](I)=  7.[illegible]

 [illegible] =   .23    [illegible]ACT(I)=  [illegible].[illegible]766 VF(I)=  [illegible]   [illegible](I)=  7.[illegible]

 [illegible] =   .[illegible]   P ACT(I)=  2.[illegible]152 VF(I)=  [illegible]   [illegible](I)=  7.[illegible]
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```
   =    .        (  )=   .  7     (  )=    .          ( )=  7.
   =    .        (I)=    .       V (  )=    .          ( )=  7.
   =   . 7     AC (I)=  1.3301 VF( )=     .            (  )=  7.
   =   .         (  )=    .  7   VF(I)=    .           (I)=  7.
   =   .2      ACT(I)=   .    1  VF( )=    .           (I)=  7.


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          =           .
  V (I)= -      .      V (I)=    .        (I)= 12.        (I)     .
     (I)     .            (I)= -  .       VF(I)=     .
    (I)=  7.           (I)=      .     TZ(I)=   .
   (I)=     .           (I)=  7.        VF  (I)= - .

      (I)=     .         CI   (I)=    .       CIG   (I)=    .
      C (I)= -  .        CI C (I)= -3.35      CIG/C (I)= -3.5

       (I)      .           (I)= -  .5       3(I)=  1.5
     (I)= 1 .              (I)=    .5       K2(I)=  5.
     C (I)=      .

  C= -  .        = -  .        = -3.3        =    .35
   =    .        =    .        =  3.

          F  =      .3                  =      .
          (I)=    -  .

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                                    T3(J)

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        (J)=     . 5      (I)=  7.         3(I,J)=     .15
     (I)=   .             (I)=    .         K2(I)=  5.

        (J)=     .        (I)=  7.          (I,J)=    .3
     (I)=   .             (I)=    .5        K2(I)=  5.

        (J)=     .        (I)=  7.         3(I,J)=    .45
     (I)= 1 .             (I)=    .         2(I)=  5.

        (J)=     .        (I)=  7.         3(I,J)=    .6
     (I)=   .             (I)=    .         2(I)=  5.

   T    (J)=     .      V (I)=  7.         3(I,J)=    .75
     (I)=   .             (I)=    .         K2(I)=  5.

        (J)=     .      V (I)=  7.         3(I,J)=    .9
     (I)= 1 .             (I)=    .         K2(I)=  5.

        (J)=     . 7    VF(I)=  7.       T 2(I,J)=  1. 5
     (I)=   .             (I)=    .         K2(I)=  5.

        (J)=     . 7    VF(I)=  7.         3(I,J)=  1.2
     (I)=   .           K1(I)=    .5        K2(I)=  5.

        (J)=     . 7    VF(I)=  7.         3(I,J)=  1.35
     (I)= 1 .             (I)=    .         K2(I)=  5.

        (J)=     . 7    V (I)=  7.999      3(I,J)=  1.5
     (I)= 1 .           C (I)=    .         K2(I)=  5.

   =            (I)=     . 5        3(I,J)=     .15


------------------------------------------------------------------------------
                  V                  S
```

```
   (I)= -      .           (I)=      .           (I)= 1 .               (I)      .
      (I)      .              I (I)= - .            VF(I)=        .
     (I)=  7.              (I)=   .              (I)=      .
    (I)=       .   3   V     (I)=   .             I (I)= - .

        (I)=       .        (I    F(I)=       .         C1    F(I)=      .
        (I)= - .            (I    CT(I)= -3.35          CI    CT(I)= - .3

          (I)       .            (I)= -  .5          3(I)=  1.
     (I)=     .              A1(I)=    .5           A2(I)=   5.
        (I)=          .

  C= -  .             )= -3.           V = -3.3          I=     .35
   =     .            3=     .         =   3.

              =       .3                        =          .
            (I)=     - .35

---------------------------------------------------------------------------------------


---------------------------------------------------------------------------------------
               8              I  2 (I)

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               (I, )=          .

       (I)=     .      VF(I)=  7.       3(I)=     .15
       (I, )=   .75    A 1(I)=    .5         A2(I)=   5.

 T     (I)=     .      VF(I)=  7.       3(I)=     .15
 1    (T, )=   1.5       1(I)=    .          A 2(I)=   5.

       (I)=     .      VF(I)=  7.       3(I)=     .15
 1    (I, )=    .25      1(I)=    .5           2(I)=   5.

       (I)=     .      VF(I)=  7.       3(I)=     .5
       (I, )=   3.       1(I)=    .5         A 2(I)=   5.

       (I)=     .      VF(I)=  7.  93    3(I)=     .15
       (I, )=   .75    A 1(I)=    .          A (I)=   5.

       (I)=     .      V (I)=  7.    3  3(I)=     .15
       (I, )=   .5          (I)=    .           A 2(I)=   5.

       (I)=     .      VF(I)=  7.   95  3(I)=     .15
       (I, )=   .      A 1(I)=    .          A 2(I)=   5.

       (I)=     .7     V (I)=  7.        3(I)=     .15
      (I, )=     .     A 1(I)=    .5         A 2(I)=   5.

       (I)=     .7     V (I)=  7.   3    3(I)=     .15
      (I, )=    .7        1(I)=    .          A 2(I)=   5.

       (I)=     .      V (I)=  7.        3(I)=     .15
       (I, )=  7.         1(I)=    .          A 2(I)=   5.

  =             (  )=    .           (I, )=    .75


---------------------------------------------------------------------------------------
                 I       G  I   A 1(I)

---------------------------------------------------------------------------------------



---------------------------------------------------------------------------------------
                                   I

               ,=                 .
     (I)= -        .            (I)=      .          (I)= 1 .          VPEF(I)   C.
       (I)        .                 I (I)= - .            VF(I)=     .
     (I)=  7.                  (I)=   .              (I)=    .
      )=        .         VF    (I)=   .             VF I (I)= -8.
```

```
      [illegible]= -[illegible]      CIGACT(I)= -3.35[illegible]   CIGACT(I)= -3.[illegible]

   [illegible]   .        [illegible] (I)= -[illegible].5     T3(I)=  1.5[illegible]
 [illegible]=   .       [illegible](I)=    .5      AK2(I)=  5.[illegible]
  [illegible]=      .

  [illegible]  .        [illegible]= -[illegible].[illegible]     [illegible]= -3.35[illegible]   D1=  [illegible].35[illegible]
   [illegible]  .        [illegible]=  .5        [illegible]=  3.

      [illegible]  =        .[illegible]              [illegible]=      [illegible].[illegible]
      [illegible](I)=     -[illegible].35

------------------------------------------------------------------------------------------

               (  ,  )=         .75

[illegible]   (  )=      .      VF(I)=  7.[illegible]93 T3(I)=    .15[illegible]
[illegible] (  )=     .7       [illegible] 1(I,J)=    .1      AK2(I)=  5.[illegible]

[illegible]   (  )=      .      VF(I)=  7.[illegible]93 T3(I)=  [illegible].15[illegible]
[illegible] (  )=     .7       [illegible] 1(I,J)=    .2      AK2(I)=  5.[illegible]

[illegible]   (  )=      .      VF(I)=  7.[illegible]9[illegible] T3(I)=  [illegible].15[illegible]
[illegible] (  )=     .7       [illegible] 1(I,J)=    .3      AK2(I)=  5.[illegible]

[illegible]   (  )=      .      VF(I)=  7.[illegible]93 T3(I)=  [illegible].15[illegible]
[illegible] (  )=     .7       [illegible] 1(I,J)=    .4      AK2(I)=  5.[illegible]

[illegible]   (  )=      .      VF(I)=  7.[illegible]9[illegible] T3(I)=  [illegible].15[illegible]
[illegible] (  )=     .7       [illegible] 1(I,J)=    .5      AK2(I)=  5.[illegible]

[illegible]   (  )=      .      VF(I)=  7.[illegible]93 T3(I)=  [illegible].15[illegible]
[illegible] (  )=     .75      [illegible] 1(I,J)=    .[illegible]      AK2(I)=  5.[illegible]

[illegible]   (  )=      .      VF(I)=  7.[illegible]93 T3(I)=    .15[illegible]
[illegible] (  )=     .7[illegible]      [illegible] 1(I,J)=    .7      AK2(I)=  5.[illegible]

[illegible]   (  )=      .      VF(I)=  7.9[illegible]9[illegible] T3(I)=  [illegible].15[illegible]
[illegible] (  )=     .7[illegible]      [illegible] 1(I,J)=    .[illegible]      AK2(I)=  5.[illegible]

[illegible]   (  )=      .      VF(I)=  7.[illegible]93 T3(I)=    .15[illegible]
[illegible] (  )=     .7[illegible]      [illegible] 1(I,J)=    .[illegible]      AK2(I)=  5.[illegible]

[illegible]   (  )=      .      VF(I)=  7.[illegible]93 T3(I)=  [illegible].15[illegible]
[illegible] (  )=     .75      [illegible] 1(I,J)=   [illegible].[illegible]      AK2(I)=  5.[illegible]

[illegible]=   [illegible]    (  )=  [illegible].[illegible]    AK 1(I,LL)=  [illegible].[illegible]


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            [illegible] T[illegible] CH[illegible] [illegible] AK2(I)

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[illegible]

[illegible]  [illegible]    V[illegible]=          .  [illegible]
                             [illegible].
   (  )= -[illegible]  .        [illegible](I)=    .[illegible]      [illegible](I)= 12.[illegible]   VRGF(I)  [illegible].[illegible]
   [illegible](  )    .         [illegible] (I)= -[illegible].[illegible]         VF(I)=   [illegible].[illegible]
   [illegible](  )=  7.          T[illegible](I)=  [illegible].        [illegible](I)=  [illegible].[illegible]
 [illegible](  )=     .       [illegible] AA(I)=  8.      VF[illegible] I[illegible](I)= -8.[illegible]

 [illegible]   (  )=    .          CI[illegible](I)=    .          CIGPLF(I)=    .[illegible]
 [illegible](I)= -[illegible].[illegible]      CI[illegible](I)= -3.35     CIGACT(I)= -3.5[illegible]

   [illegible]   (  )     .        [illegible] I (I)= -[illegible].[illegible]       3(I)=  1.5[illegible]
  [illegible] (  )=    .        [illegible](I)=    .5       [illegible]2(I)=  5.[illegible]
     [illegible] (  )=      .

  [illegible]= -  .[illegible]      [illegible]= -[illegible].[illegible]      [illegible] = -3.35[illegible]    D1=    .35
   [illegible]=   .[illegible]       [illegible]=    .[illegible]       [illegible]=  3.

          [illegible] =        .[illegible]              [illegible]=       .  [illegible]
          [illegible](  )=     -[illegible].35
```

```
          (  ,  )=          .1

      (J)=        .           V (J)=  7.9 9   3(I)=     .15
      (J)=      .7            (J)=     .1      AK 2(I,J)=   2.5

      (J)=        .           V (J)=  7.999   3(I)=     .15
      (J)=      .7            (J)=     .1      AK 2(I,J)=   5.

      (J)=        .            (I)=   7.999   3(I)=     .15
      (J)=      .7            (J)=     .1      AK 2(I,J)=   7.5

      (J)=        .            (J)=   7.9     3(I)=     .15
      (J)=      .7            (J)=     .1      AK 2(I,J)=  1 .

      (J)=        .           V (J)=  7.9     3(I)=     .15
      (J)=      .7            (I)=     .1      AK 2(I,J)=  12.5

      (J)=        .           VF(J)=  7.9     3(I)=     .15
      (J)=      .7            (J)=     .1      AK 2(I,J)=  15.

      (J)=        .           VF(J)=  7.9 9   3(I)=     .15
      (J)=      .7            (J)=     .1      AK 2(I,J)=   7.5

      (J)=        .           VF(J)=  7.999  T3(I)=     .15
      (J)=      .75       AK1(J)=     .        AK 2(I,J)=  2 .

      (J)=        .  5        VF(J)=  7.9 9  T3(I)=     .15
      (J)=      .75       AK1(J)=     .        AK 2(I,J)=  22.5

      (J)=        .           VF(J)=  7.999   3(I)=     .15
      (J)=      .75       AK1(J)=     .1       AK 2(I,J)=  25.

   =    1 TI    (  )=       .          2(I,  )=   2.5

             AK 2(I,  )=        .5

S

      TE   X C   I
                :  1 .75      S            :  1:2  .

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AT    [              PRTING J   N  ,  S      793  ,  REQUEST CREATED AT  2  -   Y- 5  1
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