EXCITATION CONTROL SYSTEMS

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1. Introduction:

An excitation control system is that system which produces controllable direct current energy and supplies it to the field winding of an alternator.

In the early days of the utility industry, electrical energy was used mainly for lighting lamps. Most of the people were sufficiently impressed by the convenience of being able to switch on an electric light and have not thought of the changes in its brightness as voltage changes. There were no form of excitation control. By the turn of the century, field Reostats were in use to manually adjust the terminal voltage of the generators. As the size of the generators grew bigger and their parallel operation became a must, the need of automatic control became evident.

2: Functions of Excitation Control Systems:

Originally, the main objective of excitation control systems were to keep the voltage levels at different parts of the network at the desired values.

In 1922, a group of engineers undertook solution of the stability problem to determine the factors involved that most affected the ability of a system to transfer power from one point to another. The results of these studies have indicated that the synchronous machine excitation systems are an important factor in the problem of determining the time variation of angle, voltage, and power quantities during transient disturbances. They stressed the theoretical possibility of increasing the steady-state power that could be transmitted over transmission lines through the use of a generator voltage regulator and an excitation system with a high degree of response.

Improvement of the excitation systems, therefore, appeared to be at least one method of increasing the stability limits of power networks. Greater interest in the design of excitation systems and their component parts develcped. More accurate generator voltage regulators were soon introduced to the industry.

3: <u>Development of Excitation Control Systems:</u>

Excitation Control Systems have undergone the following developments.

1- The common bus system.

In this system, the common exciting bus was energized by several exciters driven by motors to provide the needed d.c. supply. This system suffers from the following drawbacks and became abselete.

a- Low reliability; since a fault on the common bus will deprive all the generators of the power station from their excitation source.

b- Low efficiency; since the controlling resistance exists in the alternator field circuit with the full field current passing through it.

c- Less adaptable to automatic control. Therefore, it was not long before it was realized that mounting a seperated exciter on the shaft of each alternator over comes the above mentioned drawbacks.

2- Excitation Control Systems using conventional Rotating D.C. Machines.

3- Excitation Control Systems using Rotating D.C. Amplifiers.

4- Electronic Excitation Control Systems using silicon controlled rectifiers.

The common bus system is not in use any more and the excitation systems utilizing conventional rotating D.C. machines have been replaced by the more advanced systems of categories 3 and 4. Therefore, we shall focus our discussion in the following on categories 3 and 4 only. Category 3, because excitation control systems using rotating d.c. amplifiers are still in operation in many power stations in the world, while category 4 because electronic excitation control systems are the latest and operate already in all the modern power stations and are ordered for any new synchronous generator built.

4: Excitation Systems Using Rotating D.C. Amplifiers:

4.1: Main Exciter, Rotating Amplifier and Static Regulator:

The main exciter is either an ordinary separately excited machine or a shunt wound machine with additional field

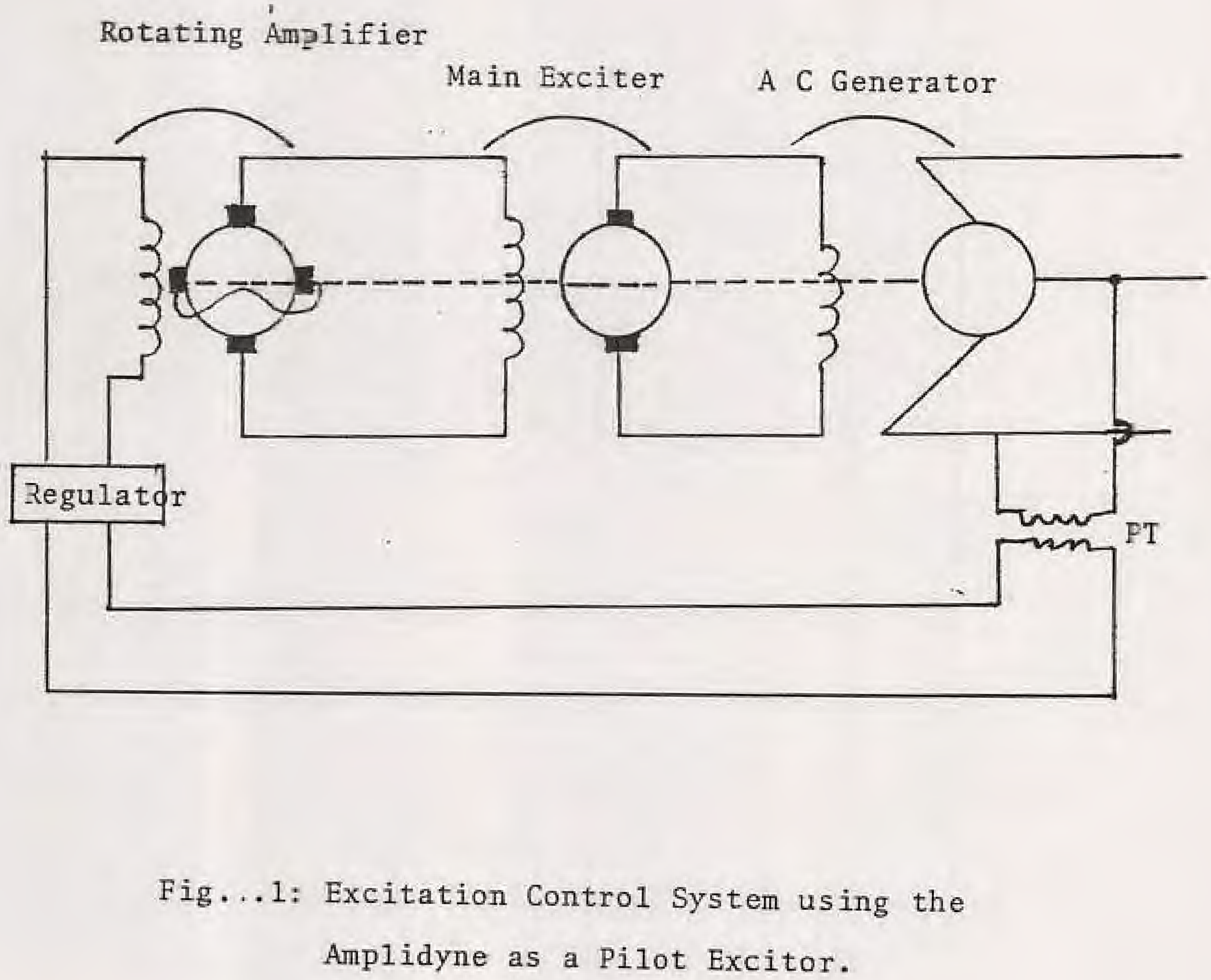

Fig...1: Excitation Control System using the Amplidyne as a Pilot Excitor.

windings. The rotating amplifier is a special dc machine, an amplidyne for example. Such a system is illustrated in Fig .1. The important feature of the rotating amplifiers is that a large output may be controlled by a few watts input which can be supplied by an electronic type voltage regulator. Its function is described in the following.

The electronic regulator compares a constant voltage with the rectified alternating voltage being controlled. The electronic regulator consists mainly of an operational amplifier. The operational amplifier (Op-amp) is an amplifier with a very high gain. Fig.4.2.shows how such an amplifier acts as a regulator.

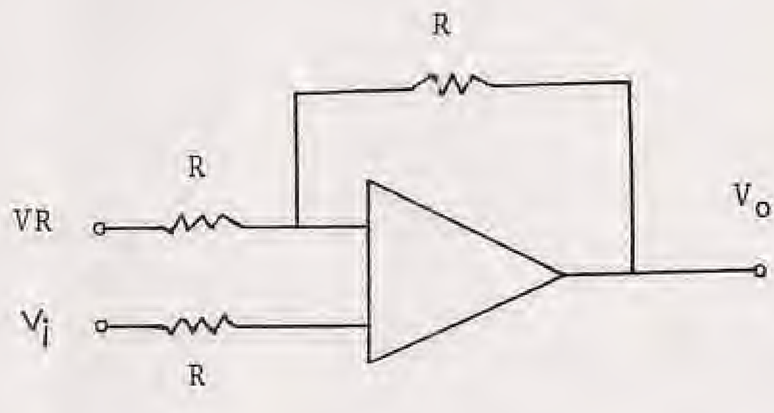

Fig ..2: An Amplifier acting as a regulator.

From Fig .2.V_i is the rectified voltage from the alternator output.

V_R is the reference voltage.

$V_o = -(V_i + V_R) = -V_i - V_R$

(if V_R is negative)

$\therefore V_o = V_R - V_i$

At the normal voltage of the alternator output, $V_i = V_R$. Any change of the voltage V_i will appear at the output of the operational amplifier as a + ve or - ve voltage. This voltage is connected to a first stage power amplifier feeding the control winding of a rotating amplifier.

Electronic voltage regulators find also their use with silicon controlled excitation systems as will be seen later. In this case the output of the operational amplifier is fed to a pulse generating circuit which will in turn control the firing angle of the silicon controlled rectifier.

Several different methods of exciting the main exciter separately from the output of the rotating amplifier are available. However, it is generally better to use some combination of self and separate excitation of the main exciters.

4.4.2: Rotating Amplifiers

There are quite a variety of machines that are entitled to be rotating amplifiers. As a matter of fact the conventional d-c generator is considered to be a power amplifier in the sence that few field watts produce large armature output. Out of the most important rotating amplifiers, the following commercial types are used in excitation control systems.

1- The Amplidyne

2- The Rotorol

3- The Regulex.

Sufficient information about these types, their construction, principle of operation and dynamical analysis can be found in reference .

5: Electronic Excitation Using Silicon Controlled Rectifiers.

5.1: General:

Electronic excitation systems based on higher power mercury arc rectifiers were introduced in the year 1960. However, they were not generally accepted by the industry due to complexity and inherent short comings. They were also designed to work only as static exciters. With the advent of reliable semiconductor high power devices such as sillicon diodes and controlled rectifiers during the last twenty years, the semiconductor electronic excitation systems have found a significant place in the industry. They have the following specific advantages:

1- Higher ratio of response.

2- Greater reliability.

3- Probable lower cost.

4- Better compatability with remote supervisory control.

Two basic types have been developed:

a- Brushless Excitation System.

b- Static Excitation System.

5.2: Brushless Excitation System:

With the development of the silicon diode, which is a small rugged simiconductor rectifier unit, the stage was set for a revolution in the manufacture of ac exciters. Since for the first time it was possible to rotate the rectifier at high speed, and the rectifier was not subject to contamination, aging or arcing . The excitation-rectification system most commonly used at present is a 3-phase a-c exciter armature with the output rectified by a 3-phase full-wave bridge.

Elimination of the commutator, collector rings and brushes opened the new era of brushless generator, a major step toward simplicity, compactness, minimum maintenance and freedom from sparking (Fig .3).

The system is most suitable for high speed turbo-alternators, where the brush maintainence is a greater problem. It consists of:

1- A small 3-phase a-c pilot exciter which has a permanent magnet rotor.
2- An a-c rotating generator exciter with a 3-phase rotor and a stationary field structure.
3- The alternator field structure.

5.3: Static Excitation System:

This system is most suitable of hydro-generators. It is of extremely high response. A schematic diagram of

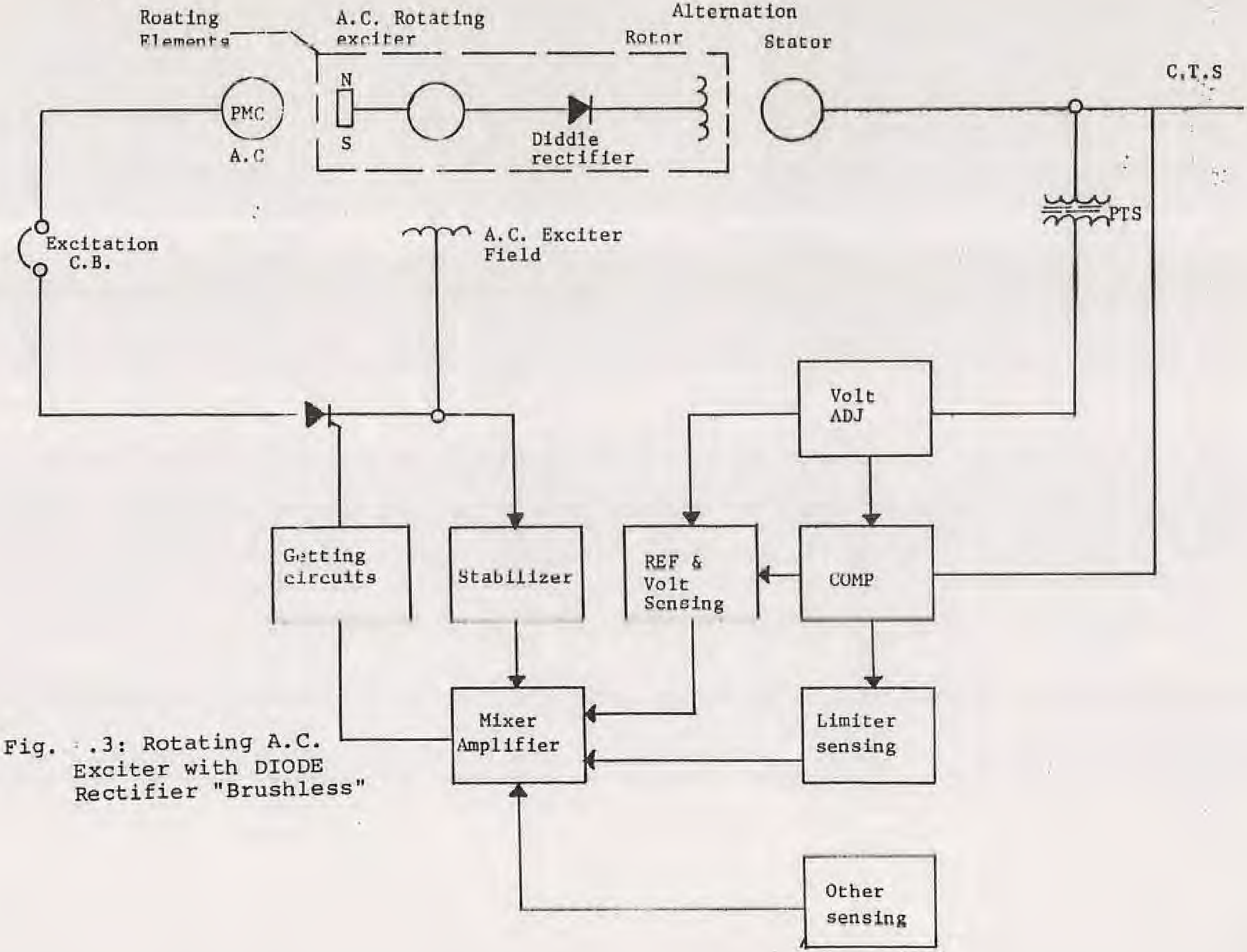

Fig. .3: Rotating A.C. Exciter with DIODE Rectifier "Brushless" such a system is given in Fig .4.

The static excitation system uses a stationary controlled rectifier to provide d-c for the alternator field. The regulator is designed to provide a gain in the order of 200. In some cases, the self-excited A.C. generator (exciter) is replaced by a power supply tapped off the generator terminals as illustrated in Fig. .5.

6: Mathematical Representation of Excitation Control Systems:

6.1: Dynamic Simulation:

Dynamic simulation of power systems is of atmost importance in nowdays technology. The development of sound mathematical models that describe correctly the dynamic behaviour of a system under steady state and transient conditions have proved to be very helpfull.

Transfer functions and block diagram approach has been realized as an effective and comprehensive method of dynamic simulation of control systems. This technique will be followed in carrying out the study presented here in this project.

6.2: Block Diagrams of the Different Components.

1- Electronic amplifiers are normally fast acting compared with the other elements in excitation systems and therefore are considered as pure gain devices.

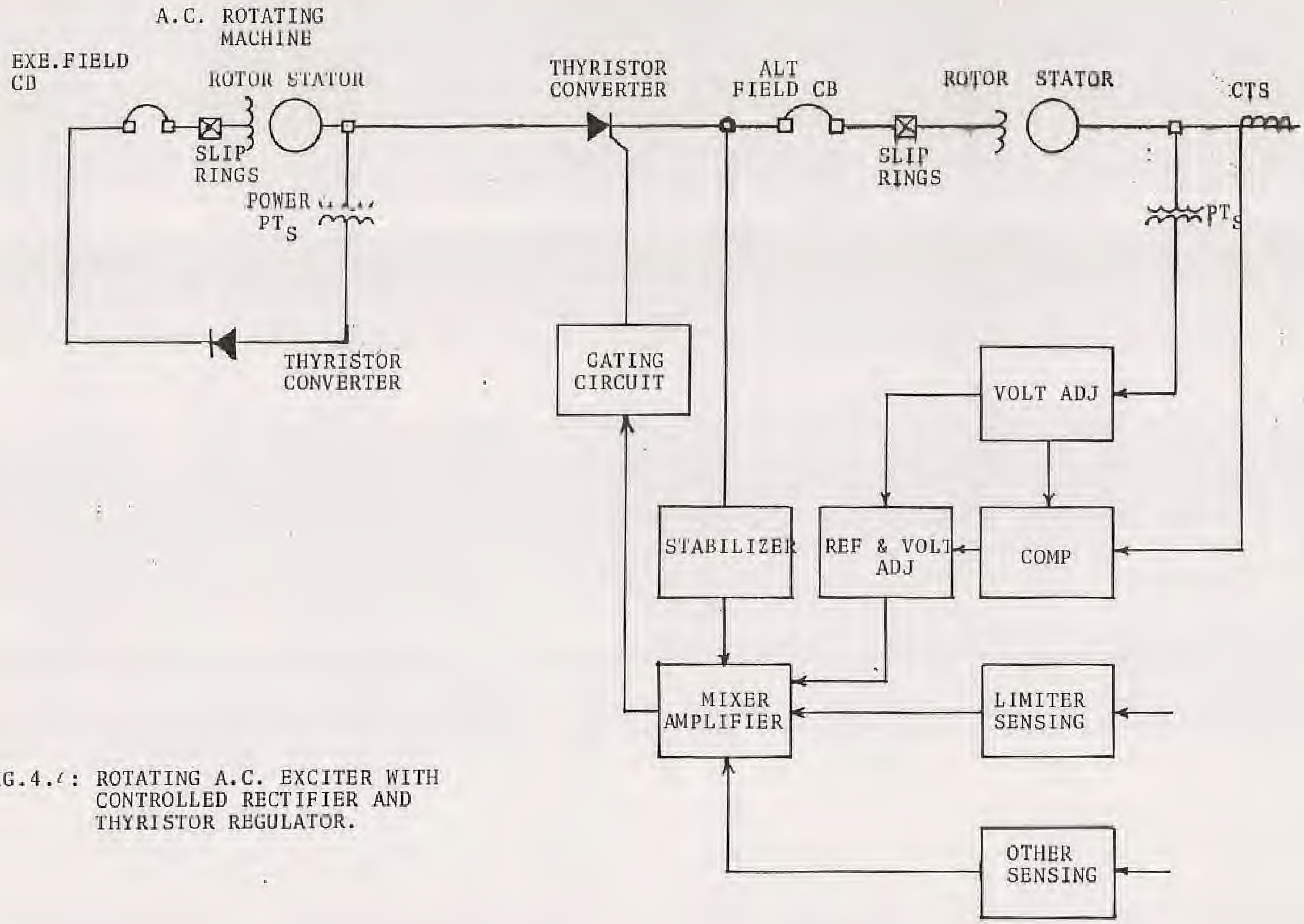

FIG.4.[illegible]: ROTATING A.C. EXCITER WITH CONTROLLED RECTIFIER AND THYRISTOR REGULATOR.

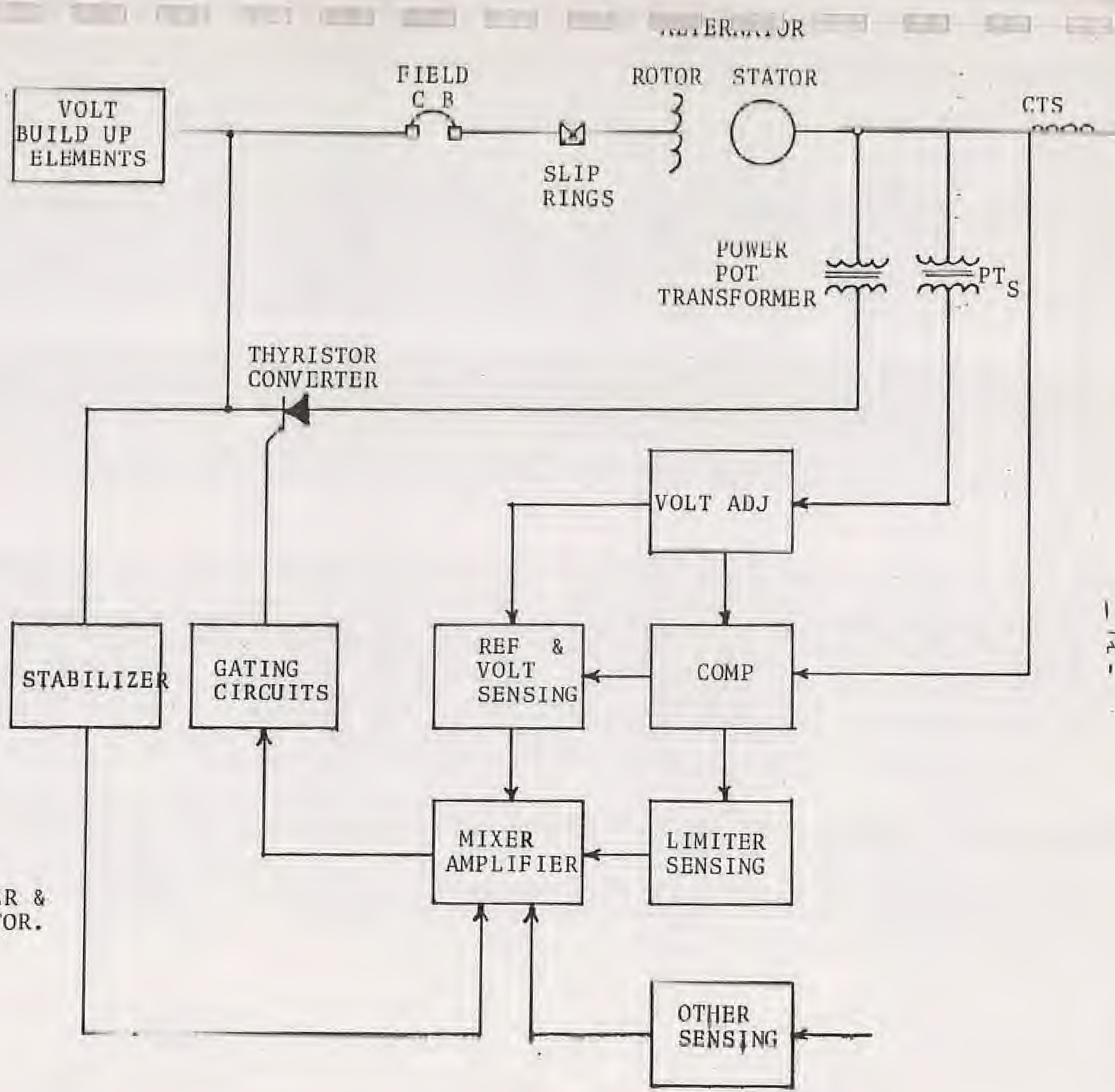

Fig. 5: STATIC EXCITER
THYRISTOR CONVERTER &
ELECTRONIC REGULATOR.

2. Conventional D.C. Generators. (Fig .6)

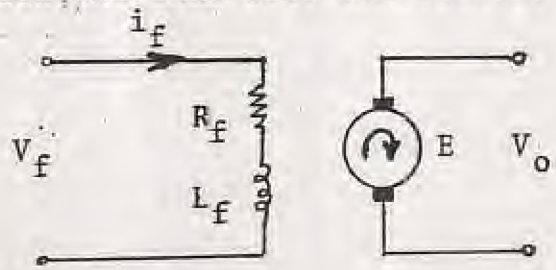

Fig .6: Schematic Diagram of a separately excited dc machine.

$$V_f = i_f R_f + L_f \frac{di_f}{dt}$$

$$V_f = I_f R_f + L_f SI_f$$

$$V_f = (R_f + L_f S) \; I_f$$

$$V_{out} = E_1 i_f = \frac{K_1 V_f}{R_f + L_f S}$$

$$\therefore \frac{V_o}{V_f} = \frac{E_1}{R_f + L_f S} = \frac{K_1/R_f}{1 + \frac{L_f}{R_f} S}$$

$$\therefore \frac{V_o}{V_f} = \frac{K}{1 + T_f S}$$

Where T_f = time constant $= \frac{L_f}{R_f}$ and it is of the order of 0.8 sec.

3. Amplidyne:

The amplidyne is a normal d.c. machine with two sets of brushes. Two of these are located on q.axis (interpolar-axis) of the rotor. While the other two are located on the d-axis (Pole-axis) of the rotor as shown in Fig .7.

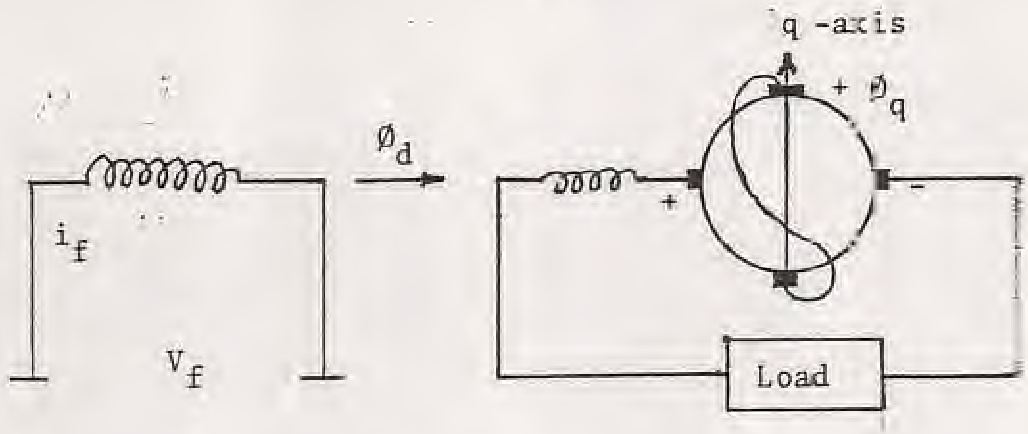

Fig .7. Schematic Diagram of an amplidyne.

$$e_q = \emptyset_d \propto i_f$$

$$e_q = K_1 \frac{V_f}{1+T_p P}$$

$$i_q = e_q \frac{1}{r_f(1+T_{aq}.P)} \quad K_1 V_f \frac{1}{r_f(1+T_{aq}P)(1+T_f P)}$$

$$e_d \propto \emptyset_q \propto i_q$$

$$\therefore \frac{e_d}{V_f} = \frac{K_1 . K_2}{(1+T_{aq}P)(1+T_f . P)}$$

The amplification is of the order of 20,000:1 compared with values in the range of 100 :1 for conventional generators. The principle time lag is that of the q-axis time constant and is in the range from 0.02-0.25 seconds.

4. Brushless A.C. System:

The block diagram representing the brushless excitation control system in conjunction with the alternator is shown in Fig .8.

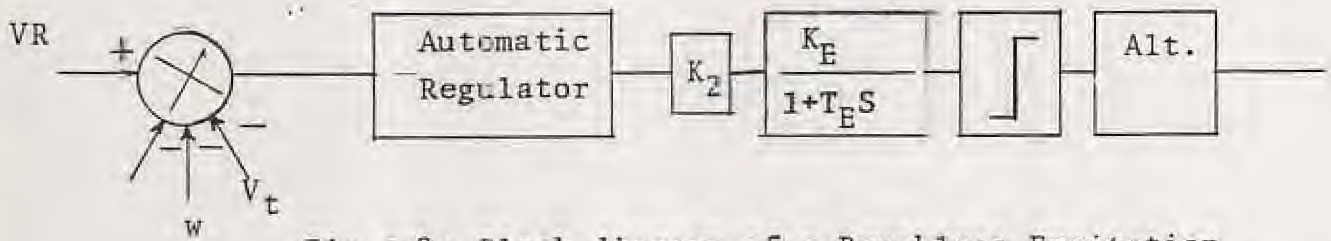

Fig .8 : Block diagram of a Brushless Excitation System.

The alternator of course can be more rigorously represented. The excitation system can be simply represented by a two time constant block diagram (Fig . 9) since no significant time delay is experienced in the sensing circuit and firing control of the S.C.R's (silicon control rectifieres).

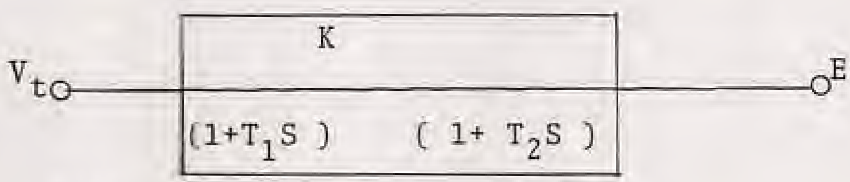

Fig .9:

5. <u>Static Excitation System:</u>

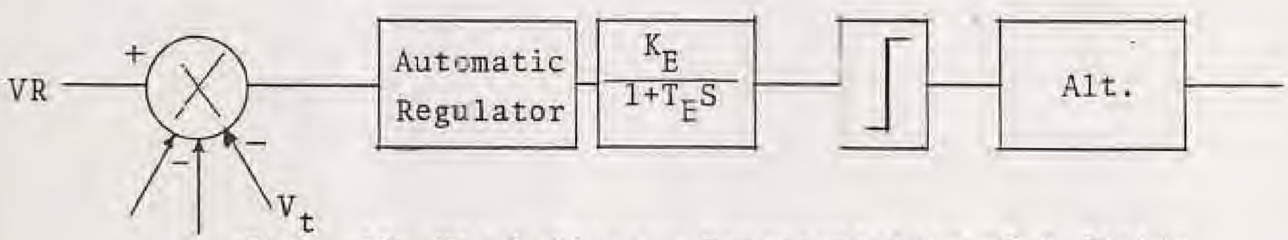

Fig .10. Block Diagram Representation of a Static Excitation System.

The Static excitation system can be reduced also to a single time constant block diagram with a time constant which is even smaller than that of the brushless system as shown in Fig .10.

In general the only significant time constant in S.C.R. excitation system is that of the alternator itself.

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