Supersedes GEI-312608

# INSTRUCTIONS

## CR7931-NA101

# VOLTAGE REGULATOR EQUIPMENT

GENERAL ELECTRIC

## CONTENTS



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# CR7931-NA101
# VOLTAGE REGULATOR EQUIPMENT

## INTRODUCTION

The CR7931-NA101 voltage-regulator equipment is designed to regulate automatically the terminal voltage of alternating-current generators and synchronous condensers. The regulator supplies excitation to a small amplidyne generator which controls the voltage of the a-c machine.

The regulator is normally equipped with an underexcited reactive ampere limit circuit. This circuit prevents the excitation of the a-c machine from being automatically reduced materially below a desired minimum value which is either dependent upon or independent of the load on the a-c machine. The regulator and the underexcited reactive ampere limit components are located in two separate units. In a few cases a fixed minimum exciter voltage limit is supplied. The latter equipment is described in GEI-46943.

An auxiliary maximum excitation limit unit may be provided to reduce the excitation of the a-c machine in the event of excessive a-c machine field voltage of armature current. An equalizing reactor is usually included to permit proper division of reactive current, and to restrict the flow of cross currents between paralleled machines. A line-drop compensator is occasionally provided to facilitate the regulation of voltage at some point remote from the machine terminals. A motor starter for the amplidyne driving motor, a magnetic switch for placing the amplidyne in the exciter-field circuit, an amplidyne voltmeter, and the necessary control switches, relays, and control transformers are usually included with the regulating equipment.

Since both the number and the arrangement of the auxiliary components vary with the requirements of the particular application, all components are described. It is necessary to refer to the material lists and diagrams provided for each individual application to determine what material is included and what connections should be used. Therefore, the diagrams shown in this book are for illustrative purposes; they are not intended to apply to all installations.

## RECEIVING, HANDLING AND STORAGE

### RECEIVING AND HANDLING

Immediately upon receipt, the equipment should be carefully unpacked to avoid damaging the apparatus. Particular care should be exercised to prevent small parts being mislaid or thrown away in the packing material.

As soon as the equipment is unpacked, it should be examined for any damage that might have been sustained in transit. If injury or rough handling is evident, a damage claim should be filed immediately with the transportation company and the nearest General Electric Apparatus Sales Office should be notified promptly.

### STORAGE

If the equipment is not to be used as soon as it is unpacked, it should be stored in a clean, dry place and protected from accidental damage. Particular care should be exercised to avoid storing the equipment in locations where construction work is in progress.

### WEIGHTS

The approximate weight of each of the various units is as follows:

| | EQUIPMENT | APPROX. WEIGHT IN POUNDS |
|---|---|---|
| 1 | Enclosed voltage regulator, consisting of items 2, 3, 4, 5 and 6 in an enclosing case (CR7931-NA) | 1600 |
| 2 | Voltage-regulator panel (CR7930-NA) | 120 |
| 3 | Reactive-ampere limit panel (CR7932-KA) | 135 |
| 4 | Control panel (CR7932-CA) | 170 |
| 5 | Auxiliary panel (CR7932-MA) | 300 |
| 6 | Maximum excitation limit panel (CR7932-JA) | 90 |
| 7 | Manual voltage-adjusting unit (CR7932-HA) | 10 |
| 8 | Control switch (Type SB) | 10 |
| 9 | Voltmeter (Type DD) | 10 |
| 10 | Amplidyne motor-generator set | |
| | 2-kw, 4-bearing | 300 |
| | 3-kw, 4-bearing | 375 |
| | 3-kw, 4-bearing | 500 |
| | 5-kw, 4-bearing | 650 |
| | 7 1/2-kw, 4-bearing | 875 |

# DESCRIPTION

## COMPONENT ARRANGEMENT

The CR7931-NA101 central-station voltage regulator is generally housed in a floor-mounted enclosure that can be opened at both the front and the back. It usually includes the following units:

1. A CR7932-CA control panel, which may contain a transfer contactor, a motor starter, and other relaying devices.

2. A CR7932-MA auxiliary panel which may contain the stabilizers, T-connected transformer, and equalizing reactor, line-drop compensator, and motor-operated voltage adjustor when required.

3. A CR7930-NA voltage-regulator panel.

4. A CR7932-KA reactive-ampere limit panel.

5. A CR7932-JA maximum-excitation limit panel where required.

All of the above panels have steel bases with the exception of the control panel which usually has a base of a compound material. All of the panels are provided with mounting holes so that they may be bolted to the supporting framework.

The front and back of all of the panels contain adjustments. Therefore, the equipment must be so installed that access can be had to both the front and back of all panels.

## VOLTAGE REGULATOR

### GENERAL

As shown in Fig. 21, the regulator can be placed in, or removed from, service by operating the regulator control switch.

With the control switch at OFF, the excitation and terminal voltage of the a-c machine can be manually controlled by adjusting the exciter-field rheostat. Under this condition, the regulator is completely out of service and the amplidyne generator armature is disconnected from the exciter-field circuit.

With the control switch at ON, the regulator will control automatically the excitation and terminal voltage of the a-c machine.

When the a-c machine voltage is higher than normal, the regulator will supply control-field current to the amplidyne, so that the amplidyne voltage will oppose, or "buck," the exciter voltage impressed across the exciter-field circuit. This will tend to reduce the exciter-field current, lower the exciter voltage, and decrease the a-c machine field current and terminal voltage.

When the a-c machine terminal voltage is below normal, the regulator will supply control-field current to the amplidyne which will produce an amplidyne voltage in the opposite direction to raise, or "boost," the exciter voltage impressed across the exciter-field circuit. This will tend to increase the exciter-field current, raise the exciter voltage, increase the a-c machine field current, and raise the terminal voltage of the a-c machine toward normal.

The exciter-field rheostat can be manually adjusted so that at any given load the resistance of the exciter-field circuit will be correct for normal a-c machine voltage, and the amplidyne voltage will be zero. If the load on the a-c machine is increased, the resultant drop in terminal voltage will cause the regulator to produce an amplidyne voltage in the boost direction to raise the a-c machine excitation. As the load on the a-c machine is still further increased, the amplidyne voltage will increase further in the boost direction to continually raise the excitation in an effort to maintain normal terminal voltage. Should the load be decreased to the original load value, the machine excitation requirements will be less, and the amplidyne boost voltage will fall until it becomes zero. Lowering the load on the a-c machine beyond this value will cause the regulator to produce an amplidyne voltage in the buck direction to reduce the a-c machine excitation.

The regulator control switch is provided with a position to be used for test and adjustment of the regulator preparatory to placing it in service. With the control switch at TEST, the regulator is connected to the signal-voltage source and the transfer contactor is so positioned that the amplidyne will operate independently without affecting the excitation of the a-c machine. This permits operation of all regulator equipment for test purposes.

The regulator control switch may also be provided with INTER (intermediate) and POLARIZE positions for correcting the polarity of the exciter armature if the polarity is the reverse of that required by the voltage regulator. With the control switch at INTER, the a-c motor-amplidyne generator set is started. With the control switch at POLARIZE the polarity of the exciter is corrected. In this latter position the regulator is disconnected from the signal-voltage source, the transfer contactor is so positioned that the amplidyne armature is connected in series with the exciter field, and the amplidyne control-field (F3-F4) is energized to provide proper voltage and polarity to the amplidyne.

**Caution**

The polarity of the exciter should be corrected only when the a-c machine is not synchronized with the power system or when the exciter is not connected to the a-c machine field.

## REGULATOR SIGNAL VOLTAGE

When the control switch is at ON, the regulator is connected to the secondaries of potential transformers whose primaries are connected to the a-c machine terminals or bus. If an equalizing reactor is not used, the potential transformers supply the regulator with a signal voltage which is directly proportional to the terminal voltage of the machine.

If the a-c machine is to be operated in parallel with other machines, an equalizing reactor should be connected in one of the transformer secondary lines to the regulator. The equalizing reactor is described in greater detail in a following section, and connections for this device are shown in Fig. 13.

## REGULATOR CIRCUIT

The three-phase signal voltage is supplied to the regulator circuit at the primary of T-transformer 1T which changes the three-phase voltage into a two-phase voltage (Fig. 21). Resistor A1R and linear reactor A1X are used to convert the two-phase voltage into a single-phase voltage which is substantially an average of the three-phase signal voltages supplied to the regulator. One secondary of T-transformer 1T is usually provided with taps for factory adjustment of the single-phase voltage.

The combination of T-transformer 1T, linear reactor A1X, and resistor A1R is generally referred to as the three-phase response circuit. This circuit h .s a positive phase-sequence characteristic, and the gnal voltage supplied to the T-transformer primary .ust have a phase rotation in the order of 1-2-3 at .e correspondingly numbered primary terminals.

Linear reactor A2X and one or more capacitors (A1C1-A1C7 inclusive) are connected in parallel across three-phase response-circuit resistor A1R. These elements form a frequency-sensitive circuit which should be in resonance at the rated signal frequency. Addition or removal of trimming capacitors (A1C2-A1C7 inclusive) permits factory adjustment ›' he circuit to obtain resonance at the proper fre- ncy. Increasing the capacitance will lower the onant frequency and decreasing the capacitance . raise the resonant frequency. Resistor A1R is ›vided with taps for factory adjustment.

The combination of linear reactor A2X and capaci- 's A1C1-A1C7 inclusive, is called the frequency-

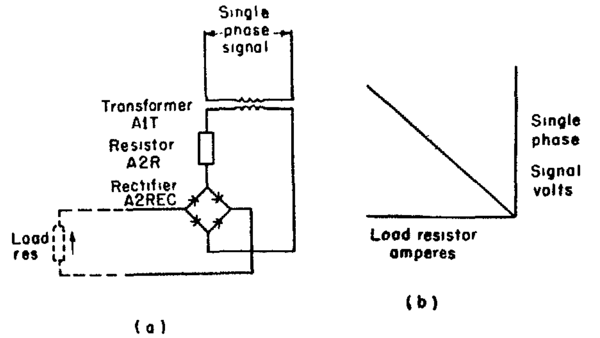



*Fig. 1. Linear circuit and its signal voltage—load current characteristic*

compensation circuit. This circuit is provided to vary the single-phase voltage output of the three-phase response network as a function of the signal frequency. Thus, the frequency-compensation circuit acts to raise or to lower the single-phase output voltage with corresponding increases or decreases in frequency. This is necessary as important elements in the remainder of the regulator circuit are frequency sensitive.

The frequency-compensated single-phase voltage is impressed upon the major components of the regulator. These components may be divided into three groups: the linear circuit, the nonlinear circuit, and the comparison circuit.

The linear circuit consists of transformer A1T, resistor A2R, and full-wave selenium rectifier A2REC. If this circuit were connected across a resistor representing the load offered by the comparison circuit, it would appear as shown in Fig. 1(a). As the single-phase voltage is increased, the current passed through the load resistor will increase in direct proportion, and will flow in the direction indicated by the arrow.

The characteristic of this circuit is represented in graphical form in Fig. 1(b) in which the current to the left along the abscissa represents the current passing through the load resistor in the direction shown by the arrow.

The second, or nonlinear circuit, consists of resistor A4R, capacitor A2C, saturable reactor A1-SX, variable transformer 1VT, and selenium rectifier A1REC. If this circuit were connected across a resistor representing the load offered by the comparison circuit, it would appear as shown in Fig. 2(a).

The characteristic of this circuit is represented graphically in Fig. 2(b) and 2(c). As the single-phase voltage increases from zero, the characteristic is linear until reactor A1SX begins to saturate. The voltage at which reactor A1SX will begin to saturate may be raised by effectively increasing the number of turns in reactor A1SX, as shown in Fig. 2(b). This

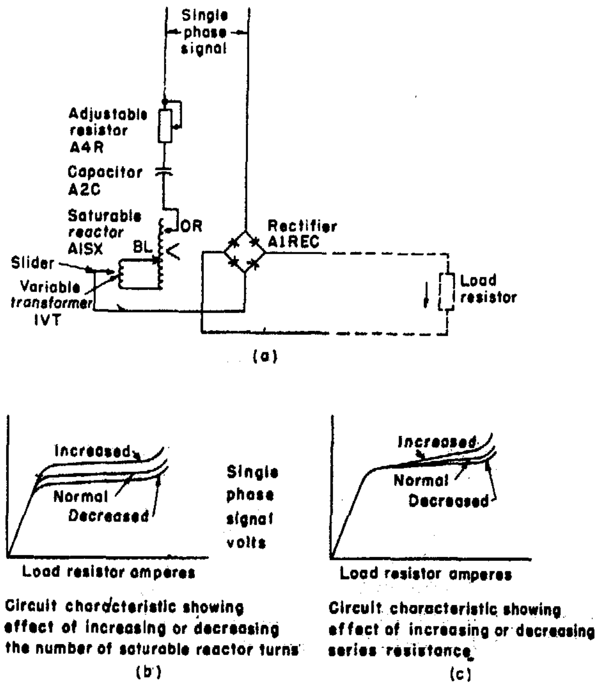



*Fig. 2. Nonlinear circuit and its signal voltage—load current characteristic*

is accomplished by moving the slider on variable transformer 1VT (down in Fig. 2(a)) toward the end of reactor A1SX opposite capacitor A2C. The saturating voltage may be lowered by moving the slider on variable transformer 1VT (up in Fig. 2(a)) to reduce the effective number of reactor turns.

When reactor A1SX begins to saturate, its reactance decreases and it will pass a relatively large current with a very small increase in voltage. The series combination of resistor A4R, capacitor A2C, and reactor A1SX then has a very flat characteristic over an appreciable current range. At the limit of this range, however, the capacitive reactance begins to predominate and the characteristic again slopes sharply upward. The slope of the flat portion of the curve may be increased as shown in Fig. 2(c), by increasing the resistance of adjustable resistor A4R in the nonlinear circuit, and decreased by decreasing this resistance.

Therefore, the nonlinear circuit provides a means of obtaining a very large change in current with only a small change in signal voltage over a given useful range. Variable transformer 1VT makes it possible to select the level of the given voltage range, and the adjustable resistance may be used to determine the sensitivity of the circuit.

The respective outputs of the linear and nonlinear circuits are compared by a comparison circuit. This circuit consists of resistor A3R, linear reactor A3X, and amplidyne field F1-F2. The circuit is represented in Fig. 3(a). The impedance presented to the linear circuit consists of comparison-circuit resistor A3R and reactor A3X in series with the parallel combination of amplidyne field F1-F2 and nonlinear-circuit rectifier A1REC. The impedance presented to the nonlinear circuit will be amplidyne field F1-F2 in parallel with the series combination of linear-circuit rectifier A2REC, comparison-circuit resistor A3R, and comparison circuit reactor A3X.

If the outputs of the two circuits are equal, the voltage at F1 will equal the voltage at F2. If, however, the output of the nonlinear circuit is greater than that of the linear circuit, the voltage at F2 will be greater than at F1 and current will flow downward through the field. When the linear circuit output is greater, current will flow upward through the field. The amplidyne armature voltage will boost to raise the a-c machine excitation if current flows through the field from F1 to F2, and will buck to lower the a-c machine excitation if field current flows from F2 to F1. Thus, as F1 on the amplidyne field becomes increasingly positive, C2 on the amplidyne armature becomes increasingly positive.

## REGULATOR OPERATION

The characteristic of the complete regulator circuit is shown in Fig. 3(b). This characteristic is a combination of the linear and nonlinear characteristics shown in Fig. 1 and 2.

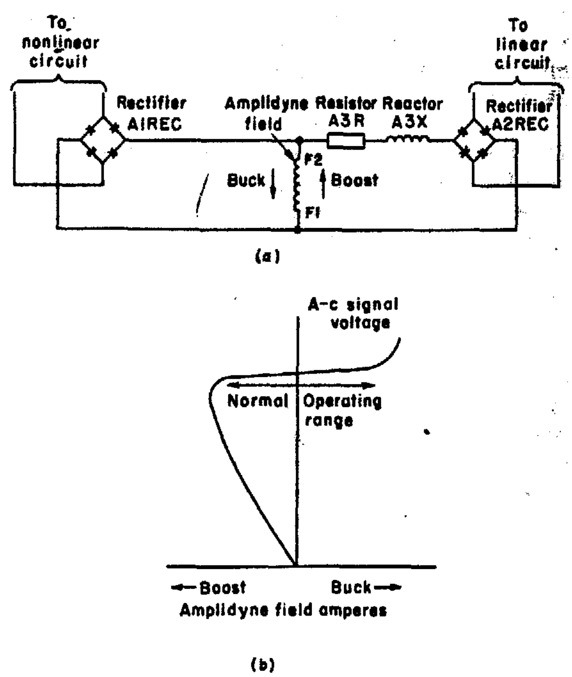



*Fig. 3. Comparison circuit and its signal voltage—amplidyne field current characteristic*

As the a-c signal voltage is increased from zero, the linear-circuit output will continually increase and will be greater than the nonlinear-circuit output, which increases at a much less rapid rate due to its high impedance. Boost current will, therefore, flow through the amplidyne field and the amplidyne armature voltage will be of such polarity as to increase the a-c machine excitation. This will further increase the machine terminal voltage and the a-c signal voltage. As the a-c machine terminal voltage, and consequently the signal voltage, approach normal, nonlinear-circuit reactor A1SX, Fig. 2(a), will begin to saturate, its impedance will rapidly decrease, and the output of the nonlinear-circuit will rapidly increase. Thus at normal voltage the outputs of the linear and nonlinear circuits will be equal. As a result, no current will flow through amplidyne field F1-F2. The amplidyne armature voltage will then be zero and will not affect the a-c machine excitation.

If the signal voltage should increase above normal, due to a corresponding increase in the terminal voltage of the a-c machine, the nonlinear circuit output will increase rapidly to overcome the linear-circuit output. Current will pass through amplidyne field F2-F1 in the buck direction to cause the amplidyne armature voltage to oppose the increase in a-c machine terminal voltage by acting to reduce machine excitation.

The normal operating range of the regulator is along the flat portion of the curve shown in Fig. 3(b). It is evident that a small change in a-c voltage will produce proportionally large changes in amplidyne field current, and therefore large changes in amplidyne terminal voltage. The regulator is consequently quite sensitive, and will act to raise the a-c voltage if it is slightly less than normal and lower it if it is slightly greater than normal.

## REGULATOR ADJUSTMENTS

The normal voltage level which the regulator will operate to maintain may be increased by increasing the number of active turns in saturable reactor A1SX, or may be decreased by decreasing the number of active turns. Variable transformer 1VT, called the voltage-adjusting unit, which is connected across part of the saturable-reactor winding (Fig. 2), may be used for this purpose. It will usually permit adjustment of the voltage level over a fairly wide range. Larger changes in normal voltage level may be made by using lead OR to reconnect capacitor A2C to any of the several taps provided at one end of the saturable-reactor winding. The actual range of voltage-level adjustment by voltage-adjusting unit 1VT can be set by using lead BL to connect the voltage-adjusting unit to appropriate taps at the other end of the saturable-reactor winding.

Regulation, or regulator sensitivity, may be varied with adjustable resistor A4R. Increasing the resistance will make the slope of the flat portion of the curve greater and will make the regulator less sensitive, thereby increasing voltage regulation; decreasing the resistance will have the opposite effect.

Adjustments for frequency compensation, ratio of T-transformer 1T, voltage-adjustment range, voltage level, and sensitivity are the only adjustments provided in the regulator. Frequency compensation and ratio of T-transformer 1T are properly adjusted at the factory and should require no further attention. Voltage-adjustment range, voltage level, and sensitivity are also adjusted at the factory, but further adjustment may be required at the time of installation.

## STABILIZING TRANSFORMER

To prevent excessive overshooting of the a-c machine voltage and to obtain voltage stability, one or more stabilizing transformers are used. Three stabilizing transformers (1ST, 2ST, 5ST) are shown in Fig. 21 with primary and secondary windings connected in series. The primaries of stabilizing transformers 1ST, 2ST and 5ST are connected to the exciter armature lines with the B (black) lead of 1ST on the positive line, and the G (green) lead of 5ST on the negative line. The secondaries of the stabilizing transformers are connected in series with the amplidyne field F3-F4 with the R (red) lead of 5ST connected to F3.

The stabilizers will act as transformers during changes in exciter voltage, and are therefore effective only during transient conditions when needed. They are ineffective under steady-state conditions when stabilizer action is not required.

Neglecting the voltage drops due to winding resistances, and with the exciter voltage increasing, the B lead will become increasingly positive with respect to the G lead, and by transformer action the O (orange) lead will become increasingly positive with respect to the R lead. This effect causes current to flow in the amplidyne field F3-F4 from F4 to F3 producing an amplidyne armature voltage in such a direction as to oppose an increase in exciter voltage to prevent overshooting and instability. With the exciter voltage falling, the opposite action takes place to oppose this decrease in exciter voltage.

Resistor 6R is connected in series with the primaries of stabilizing transformers 1ST, 2ST and 5ST and permit adjustment of the primary-circuit resistance. This resistor is called the stabilizer resistor and should normally be adjusted to provide a 90-volt maximum continuous voltage drop across the primary of each stabilizer when the exciter is operating at rated full-load voltage. Special adjustments may

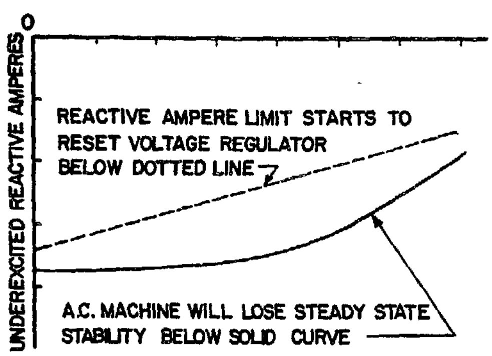



*Fig. 4. Typical a-c machine pull-out and reactive-ampere limit-start characteristics*

be made in individual cases to obtain optimum stability.

In some cases, special stabilizing-transformer connections may be employed, but since these will vary with the requirements of the particular installation, they are not described.

## MINIMUM EXCITATION LIMIT

### UNDEREXCITED REACTIVE AMPERE LIMIT

#### General

The function of the underexcited reactive ampere limit circuit, shown in Fig. 21 is to prevent the regulator from reducing the a-c machine excitation to such a low value that the machine would lose steady-state stability. It operates by limiting the underexcited reactive current of the a-c machine

Under normal operating conditions, with the regulator and the limit in service, the underexcited reactive current of the a-c machine is less than the value at which the limit functions, and the limit is inoperative; however, if the regulator reduces the machine excitation to a sufficiently low value, the limit immediately becomes operative and prevents the underexcited reactive current from rising materially above the value for which the limit is adjusted. The output from the limit circuit is applied to a voltage resetting circuit which recalibrates the voltage regulator to hold a higher machine voltage. Consequently, the limit will prevent appreciable increases in a-c machine underexcited reactive current beyond a predetermined value.

Since in many cases the magnitude of the underexcited reactive current at which the a-c machine would lose steady-state stability, is a function of a-c machine active current, the limit can be adjusted so that the value of underexcited reactive current at which the limit will become operative (the limit start point) will decrease as the machine active current increases. Therefore, it is possible to arrange the limit so that its starting point is automatically changed as machine active current varies. Active current is the in-phase or watt component of the machine armature current.

Figure 4 illustrates the loss of stability characteristic of a typical a-c machine, as well as a typical setting of the underexcited reactive ampere limit. The solid curve represents the limit of stable operation of the a-c machine while the dotted line indicates a particular setting of the underexcited reactive ampere limit. The loss of stability characteristic is a function of the a-c machine and the power system and must be determined for each case.

The solid curve demonstrates that with no load on the a-c machine the underexcited reactive current which is allowable, without exceeding the steady-state stability limit, is greater than the allowable underexcited current at full load. To prevent loss of steady-state stability, the underexcited reactive ampere limit acts to prevent the generator from operating below the solid curve, and therefore must be adjusted to become effective at lower values of underexcited reactive current than those shown on the solid curve. This results in a setting as indicated by the dotted characteristic curve in Fig. 4. The distance between the curves represents a margin between the underexcited reactive ampere limit operating point and the steady-state stability characteristic.

Both the loss of steady-state stability characteristic illustrated in Fig. 4, and the underexcited reactive ampere limit start point, are functions of terminal voltage of the a-c machine. Therefore, a setting of the underexcited reactive ampere limit establishes the limit start curve for a particular terminal voltage on the machine which will protect against loss of steady-state stability for normal variations in the terminal voltage of the a-c machine.

The underexcited reactive ampere limit circuits include the following:

1. Reactive ampere sensitive circuit.
2. Comparison circuit.
3. Voltage-resetting circuit.

These are shown with the voltage-regulator circuits in Fig. 21.

#### Reactive Ampere Sensitive Circuit

The reactive ampere sensitive circuit obtains its input from one phase of the output of the alternator potential transformers, and one alternator current transformer. It is the function of this circuit to detect an increase of the reactive current in the alternator beyond a predetermined value in the underexcited direction, and to send a signal into the comparison circuit which ultimately acts to limit this increase of reactive current. Referring to Fig. 21, the reactive ampere sensitive circuit consists of transformer B3T with a multitapped secondary, limit-start variable transformer B1VT, resistor B3R, reactive-ampere limit power recalibration tap switch B1SW, reactor B3X, and isolating transformers B1T and B2T. The secondary of B3T has four terminals numbered 3, 4, 5 and 6. Terminal 4 is the midpoint between 3 and 5.

With limit-start variable transformer B1VT connected across terminals 4 and 6 of transformer B3T secondary, the limit start is adjustable in the underexcited reactive current region. With the variable transformer B1VT connected across terminals 3 and 4 of transformer B3T, the limit start is adjustable in the overexcited reactive current region. Since this latter connection is not normally used, it will not be discussed in detail. However, limit operation with this connection is similar to that for underexcited operation. When the POWER RECALIBRATION switch is at zero, the reactance in the circuit from reactor B3X is zero ohms, and the setting of LIMIT START variable transformer B1VT determines the reactive current at which the limit functions regardless of the power loading on the alternator.

The output voltages of the reactive ampere sensitive circuit are impressed on the primaries of isolating transformers B1T and B2T. It is an inherent property of the reactive ampere limit circuit that when the reactive current reaches the predetermined value where the limit action starts (the limit-start point) the voltages across B1T and B2T are equal in magnitude. An increase in reactive current in the underexcited direction above this predetermined value causes the voltage across B1T to exceed that across B2T.

A vector diagram of the reactive ampere sensitive circuit input quantity is shown in Fig. 5. At unity power factor, the vector position of $I_2$ and hence the voltage drop across resistor B3R (in phase with and proportional to machine phase 2 current) is in quadrature with the secondary voltage of B3T (in phase with and proportional to generator line 1 to line 3 voltage).

A vector diagram of reactive ampere sensitive circuit voltages for the case when the reactance from reactor B3X in the circuit is zero ohms, is shown in Fig. 6. At unity power factor the voltage across B3R is represented by the vector Mb. For given overexcited and underexcited conditions, it is Ma and Mc, respectively. Under these conditions, the voltages on transformer B1T are 5b, 5a and 5c, respectively, and the voltages on transformer B2T are 3b, 3a and 3c, respectively.

In all these cases, the voltage on B2T exceeds that on B1T and the reactive ampere limit will be

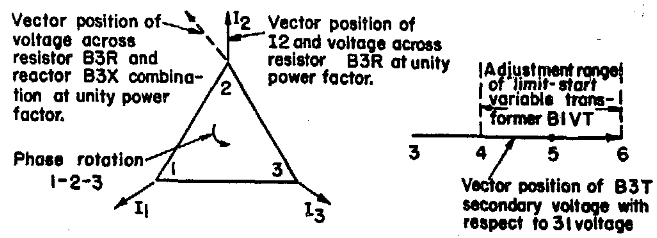



*Fig. 5. Vector positions of input quantities of reactive-ampere sensitive circuit*

inoperative. When the current vector swings further in the underexcited direction so that the voltage across resistor B3R is Md, the voltage on B1T (5d) equals that on B2T (3d). Now any increase in underexcited reactive current will cause the voltage on B1T to exceed that on B2T which will cause the comparison circuit to excite the voltage resetting circuit and oppose further increases in underexcited reactive current. Therefore, the reactive ampere limit will operate to prevent vector Md from extending materially beyond the vertical limit line 4d. Thus, the underexcited reactive current tends to be limited proportionally to the vector length M4. By varying the position of M between 4 and 6 by moving the slider on variable transformer B1VT, it is possible to change the maximum value of underexcited reactive current at which the limit will operate. Since the active power component of current is in quadrature with the reactive current, the reactive current limited is independent of the amount of active power.

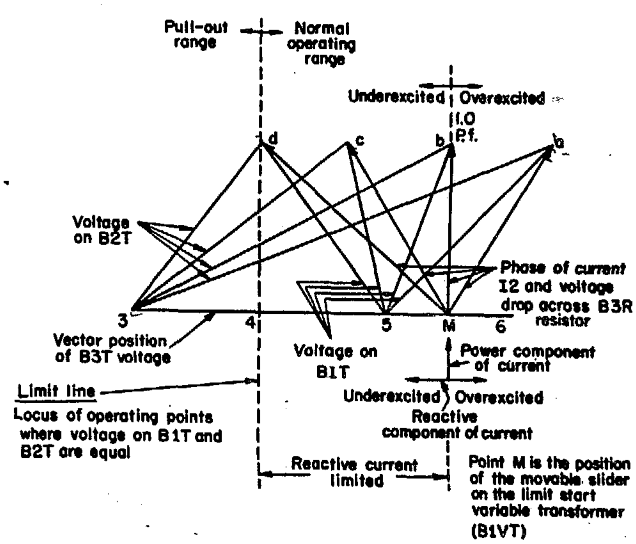



*Fig 6. Vector diagram for reactive-ampere sensitive circuit without power recalibration reactance in circuit*

The purpose of the power recalibrating reactor (B3X) adjustment is to change the limit-start point as a function of the active current delivered by the machine. Figure 7 shows that when the machine is delivering active current, power recalibrating reactor B3X will cause the reactive ampere limit to become operative at a value of underexcited reactive current less than that set by the limit-start adjustment. With zero active amperes, the limit will start to reset the regulator with A underexcited amperes which is determined by the limit-start adjustment. As the active amperes increase, less underexcited reactive amperes are required to reset the voltage regulator.

If some of the reactance of B3X is connected in series with the resistance of B3R, the voltage drop across the resistance and reactance will be shifted in the underexcited direction as shown in Fig. 5. The vector diagram will now be as shown in Fig. 8. Three operating points are shown at b, c, and d, where the limit is ready to start. At point d there is no active power load on the machine. The value of the reactive current limit is proportional to the vector Md and is equal to that limited without the reactance of B3X in the circuit since the impedance in the resistor-reactor (B3R-B3X) circuit has been increased by the ratio of Md to M4. At point c, the power component of voltage across the resistor-reactor combination is Mc′ and the reactive current limited in proportional to cc′. At point b, the power component of voltage across the resistor-reactor (B3R-B3X) combination is Mb′ and the reactive current limited is proportional to bb′. Thus, the reactive current limited decreases as the active current increases. This amounts to a linear decrease of reactive amperes limited as a function of active amperes.

### Comparison Circuit

The voltages from the secondaries of B1T and B2T are applied to the comparison circuit. The function

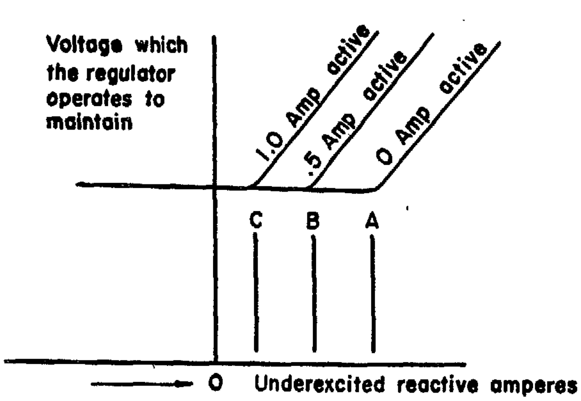



*Fig. 7. Reactive-ampere limit power recalibration characteristic*

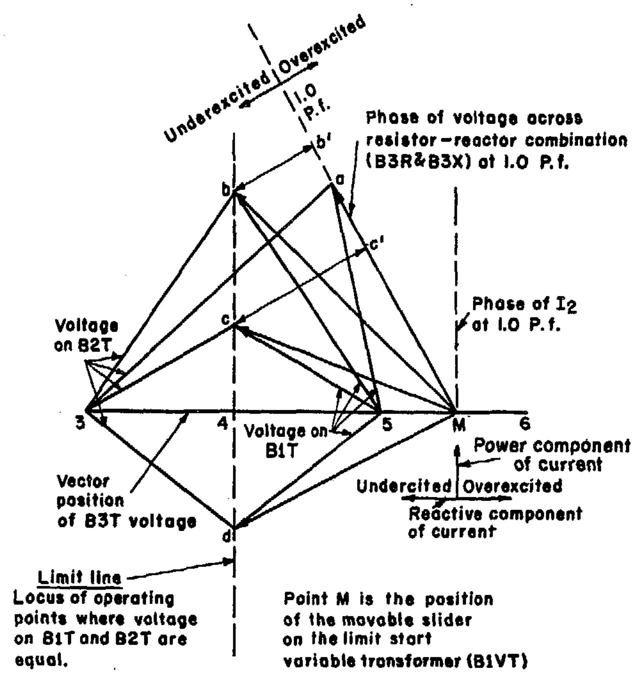



*Fig. 8. Vector diagram for reactive-ampere sensitive circuit with some power recalibration reactance in circuit*

of this circuit is to allow the flow of control direct current into the voltage-resetting circuit, when the voltage across transformer B1T exceeds that across B2T.

The comparison circuit consists of bridge-type rectifiers B1REC and B2REC together with resistors B1R and B2R, capacitors B1C and B2C and reactors B1X and B2X, necessary for filtering and rectifier preloading. In addition, two inverse voltage-limiting rectifiers (B3REC) are used to allow a unidirectional flow of control current through the d-c winding of saturable reactor B1SX only when the voltage across B1T is greater than the voltage across B2T.

Included in the comparison circuit is limit-sensitivity rheostat B1RH. Increasing the resistance of rheostat B1RH causes the limit to require a greater change of reactive current in the underexcited direction to produce a given change in control direct current to the voltage-resetting circuit. Rheostat B1RH should be set at zero resistance to provide maximum sensitivity. If, however, a less sensitive limit is desired, rheostat B1RH should be turned to insert additional resistance, thus causing the underexcited reactive current to increase further above the limit-start point as the limit becomes increasingly effective. Curve 2 in Fig. 9 shows how the limit operation is affected by decreasing the sensitivity.

### Voltage-resetting Circuit

The control current from the comparison circuit is applied to the d-c control coil of saturable reactor

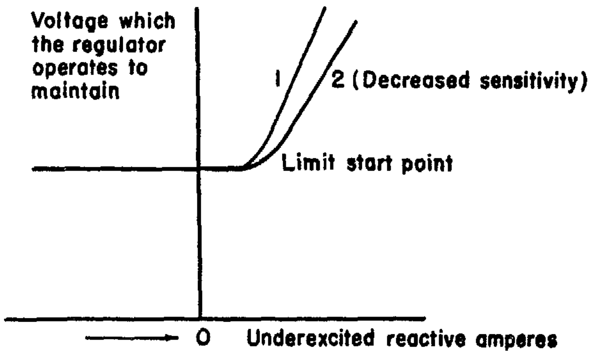



*Fig. 9. Reactive-ampere limit sensitivity adjustment characteristic*

B1SX in the voltage-resetting circuit. The function of this circuit is to cause a linear increase of the voltage which the regulator will operate to maintain as a function of the direct control current of saturable reactor B1SX.

The voltage-resetting circuit consists of saturable reactor B1SX, supplied from transformer B4T and connected to resistor B4R. The reactance of the saturable reactor is an inverse function of its direct control current. The circuit subtracts a voltage from the three-phase response-circuit single-phase output voltage impressed on the voltage-regulator nonlinear circuit. This resetting voltage appears across resistor B4R (through which flows the alternating current from saturable reactor B1SX) and is proportional to the direct current supplied from the limit comparison circuits. The resetting voltage causes an increase in the voltage which the regulator will operate to maintain. Figure 10 shows the relation between the voltage across resistor B4R, the resetting voltage for the voltage regulator, and the direct control current in saturable reactor B1SX, Figure 11 shows the relation between the voltage which the regulator will operate to maintain and the control current in the d-c winding of saturable reactor B1SX for a typical voltage-regulator equipment.

Stabilizing transformers are normally connected in the limit circuit and function in a similar manner to the stabilizers used in the regulator circuit. The secondary windings of the stabilizers are connected in series with the d-c windings of saturable reactor B1SX, while the primary windings are usually connected across the exciter armature as shown in Fig. 21. In some cases other connections may be used.

## RATINGS

### VOLTAGE REGULATOR

The voltage regulator imposes an unbalanced three-phase burden at about 115 volts a-c on the

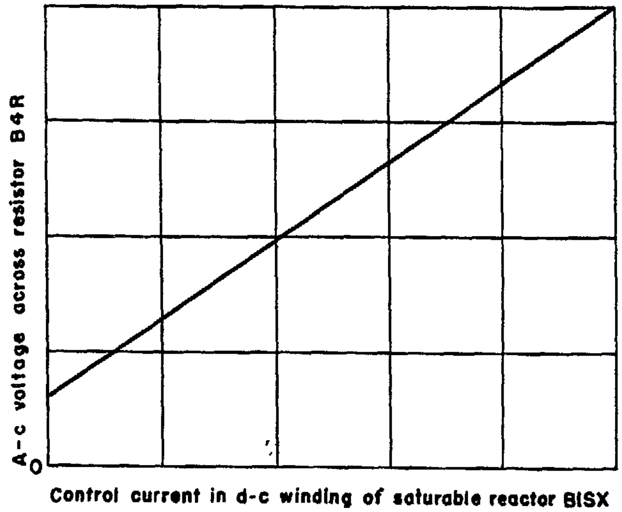



*Fig. 10. Characteristic of voltage-resetting circuit*

generator potential transformers. The regulator will require, from the secondaries of the potential transformers, a maximum of approximately three amperes for phase 1 and two amperes for phases 2 and 3 without the reactive-ampere limit. The current required by the voltage regulator and the re-

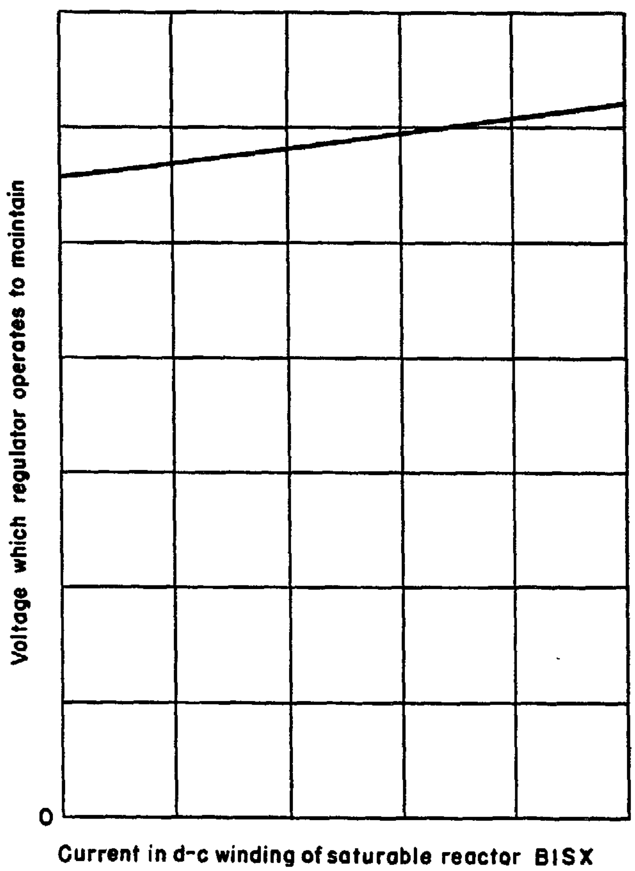
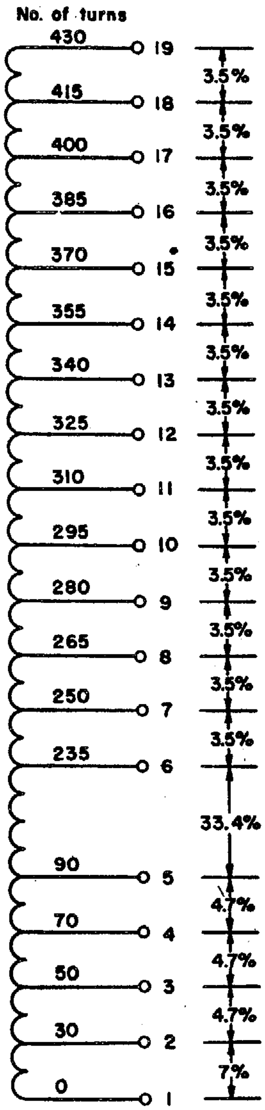



*Fig. 11. Over-all characteristic of voltage-resetting circuit and a typical voltage-regulator equipment*




Numbers indicate corresponding winding taps and terminal numbers. Percentage figures refer to percentage of total winding between respective taps.

*Fig. 12. Saturable-reactor winding connections*

active-ampere limit circuit combined are given in a later paragraph.

In general, regulators are adjusted at the factory for a signal voltage of 115 volts a-c and the rated frequency of the equipment with which they are to be installed. Where potential-transformer ratings and a-c machine voltages are known, adjustments are made for the expected signal voltage, but regulators are almost always nominally rated for 115 volts a-c. Saturable-reactor taps may be used for adjustment of the regulator for other signal voltages at the time of installation. The maximum normal voltage level should not exceed 135 volts for normal operation or with the minimum excitation limit operating to raise the voltage.

Saturable reactors are provided with fourteen voltage-level adjusting taps and with five taps for the voltage-adjusting unit, Fig. 12. The voltage-adjusting unit permits manual control of voltage level over a total range of about 10, 14, 20 and 25 percent of the rated voltage of the regulator. Voltage-level taps on the reactor permit adjustment over a range of roughly 4 percent of the rated voltage, with about a 4 percent change between individual taps. In general, the minimum voltage level may not be less than 100 volts.

## MINIMUM EXCITATION LIMIT

### Underexcited Reactive Ampere Limit

The underexcited reactive ampere limit circuit imposes a burden of about 250 volt-amperes on the current transformer with 5 amperes flowing in the secondary. The voltage regulator and the reactive-ampere limit circuit together imposes an unbalanced burden on the generator potential transformer and will require, from the secondaries of the potential transformer, a maximum of approximately the following currents:

| LIMIT RESETTING | AMPERES IN PHASE 1 | PHASE 2 | PHASE 3 |
|---|---|---|---|
| From 115 volts to 125 volts | 4.0 | 2.0 | 3.0 |
| From 125 volts to 135 volts | 4.5 | 2.3 | 3.5 |

# AUXILIARY EQUIPMENT

## EQUALIZING REACTOR OR REACTIVE CURRENT COMPENSATOR

The equalizing reactor is used to equalize division of reactive kva and to prevent circulating reactive current between a-c machines when two or more machines with individual regulators are operating in parallel. As shown in Fig. 13, the adjustable reactor winding is connected to the secondary of a current transformer located in one of the a-c machine lines, while the insulating winding is connected on one phase of the three-phase regulation signal voltage. IT IS ESSENTIAL THAT TWO WINDINGS OF THE EQUALIZING REACTOR BE CONNECTED IN THE SAME PHASE.

The equalizing reactor will vary the regulator signal voltage in this phase mainly as a function of the machine reactive current. As the machine over-excited reactive current increases, the voltage will be increased. As a result, the average three-phase signal voltage supplied to the regulator will rise. Due to this higher voltage signal, the regulator will act to reduce excitation, thereby reducing the over-excited reactive current if the machine is operating in parallel with another machine.

**If two a-c machines are connected through transformers, the equalizing reactor is not normally used as described above, instead one winding is reversed to obtain the opposite effect to that described above. This makes it possible to adjust the transformer impedance to an optimum value of 6 or 7 percent on a reactive basis, improving system voltage regulation.**

If the a-c machine is operating in the under-excited region, the equalizing reactor will decrease the average three-phase voltage signal presented to the regulator, so that the regulator will act to increase the excitation and decrease the underexcited reactive current. The effect of the equalizing reactor can be increased by increasing the active reactance of the unit appearing in the current-transformer secondary circuit. This may be done readily with the tap switches located on the reactor.

The reactor is adjustable in one-volt steps, on the basis of five amperes in the current-transformer secondary, by means of two manually operated tap switches. One of the separately adjustable tap switches gives coarse adjustments and the other fine. The voltage across this winding in the regulator signal voltage circuit is proportional to the current flowing through the current-transformer secondary winding. With five amperes flowing through the reactor and with the reactance all cut in, the total drop is 24 volts. This is equivalent to about 36 percent line-to-neutral voltage drop in one signal lead to the regulator, or an average effect of approximately 12

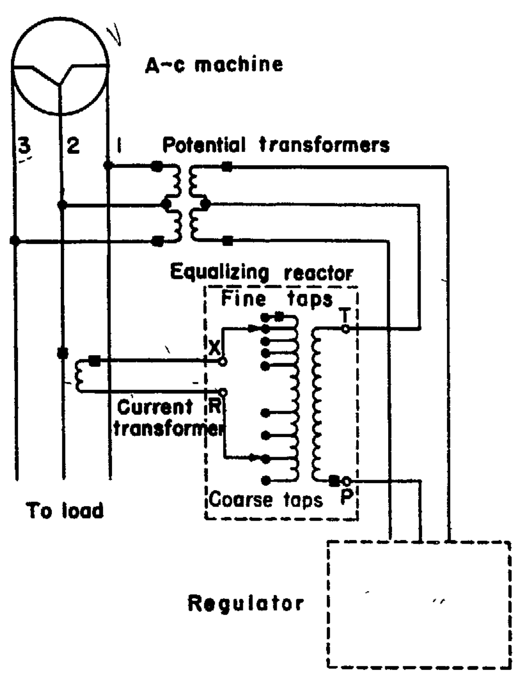



*Fig. 13. Equalizing-reactor connections*

percent line-to-line voltage drop on a three-phase basis at zero power factor.

The equalizing reactor imposes a burden of 120 volt-amperes on the current transformer at five amperes secondary current, and with all the reactance cut in. Approximately 25 volt-amperes is the burden encountered in actual practice since it is usually necessary to turn in only a few steps of the equalizing reactor for successful parallel operation.

The equalizing reactors are built with two independent windings, as shown in Fig. 13, so that the current and potential transformer secondaries are electrically separate and both may be grounded. The unit is enclosed in a perforated steel case with a dead-front control panel. It is arranged for surface or bracket mounting.

## LINE-DROP COMPENSATOR OR ACTIVE AND REACTIVE CURRENT COMPENSATOR

In certain special applications, the line-drop compensator is used to reproduce in miniature, at the regulator, the resistance and reactance between the a-c machine and some predetermined point in the system. The function of the compensator is to lower the signal voltage to the regulator as the machine load increases, thereby causing the regulator to maintain normal voltage at some predetermined point on the system regardless of changes in the voltage drop over the system impedance, between the machine and this point.

In case line-drop compensation is required on regulators equipped with equalizing reactors and which control machines that operate in parallel, provision may be made to prevent interference between the reactor and line-drop compensator. This is accomplished by special connections of current transformer supplying the equalizing reactors, or by special line-drop compensator connections.

As far as physical appearance is concerned, this device is very similar to the equalizing reactor. In addition to a variable reactance and insulating winding, it has a variable resistor with insulating current transformer.

The resistance and reactance of the compensator are each divided into a number of equal sections. Taps are brought out from these sections and connected to independently adjustable tap switches, one having coarse adjustments and the other fine. Both the reactance and resistance elements are variable in one-volt steps based on five amperes in the current transformer. Each has a total of 24 steps, and will introduce a maximum of 24 volts total drop each in the regulator signal voltage circuit with five amperes in the current-transformer secondary. This voltage drop is proportional to the current flowing in the compensator.

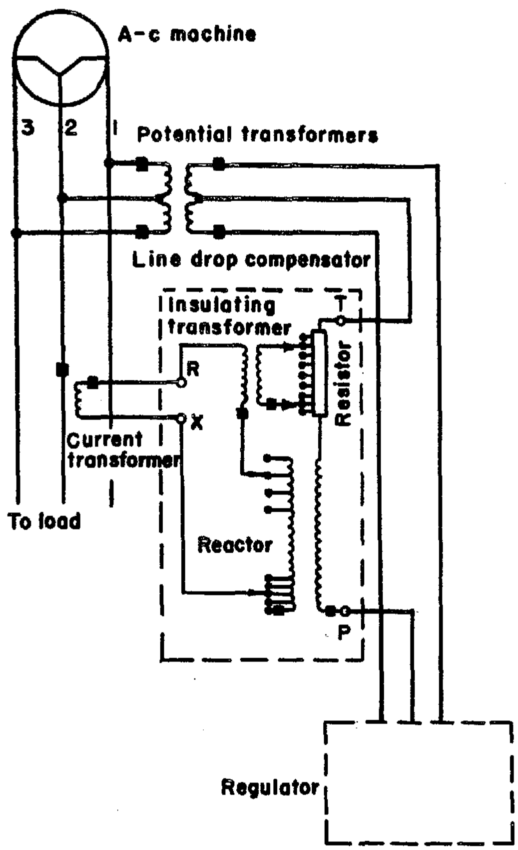



*Fig. 14. Line-drop compensator connections*

Figure 14 shows the connections for this device when used with a single machine. Insulating windings are provided for both the reactor and resistor to permit grounding the current and potential-transformer secondaries separately. It is essential that the current transformer be in the same phase as the signal-voltage line in which the line-drop compensator is connected.

One compensator, connected in one phase of a three-phase circuit, gives an average of approximately 12-percent resistance compensation and 12-percent reactance compensation on a three-phase basis. Two or three compensators may be used if more compensation is required.

This device imposes a maximum burden of 225 volt-amperes with five amperes in the current-transformer secondary and with the total reactance and resistance in the circuit.

## MAXIMUM EXCITATION LIMIT

### General

A maximum excitation limit is sometimes provided for applications where it may be desirable to limit the a-c machine excitation or armature current to some maximum value. It may be controlled by a signal from a current transformer in one of the a-c machine leads or by a voltage-sensitive relay connected across the a-c machine field circuit. When it is energized, the limit will operate to reduce excitation on the a-c machine by decreasing the number of active turns in the regulator nonlinear-circuit saturable reactor. This will effectively recalibrate the regulator for a lower normal voltage and will, therefore, reduce the amplidyne boost voltage and lower the a-c machine exciter voltage and field current.

### Maximum Excitation Limit Circuit

The maximum excitation limit circuit as applied to armature current limit control is shown in Fig. 15. When the a-c machine armature current exceeds the maximum desired value which is set with resistor C4R and current sensitive control relay CR, this relay will operate to open its "raise" contact and close its "lower" contact. Time relay 2TR is thereby energized. After a time delay determined by the setting of time relay 2TR, the contact TC closes. Lower relay LR will be energized and timing motor 1TR will operate to intermittently close and open timer contact 1TR. When contact 1TR is closed, driving motor M will move the slider of variable transformer VT, called the recalibrating unit, in the "lower" direction, and reduce the number of active saturable reactor A1SX turns. Timer 1TR may be adjusted to operate motor M intermittently to vary the total recalibrating time. Thus the recalibrating rate may be selected to suit the requirements of individual installations.

After recalibrating unit VT has completed its total traverse in the lower direction, lower limit switch LLS will be opened to de-energize driving motor M and timer motor TR circuits.

When the a-c machine armature current is reduced to normal by action of this maximum excitation limit or due to any other factor, during or following the recalibrating cycle, current-sensitive control relay CR will operate to de-energize time relay 2TR which de-energizes "lower" relay LR and energizes "raise" relay RR. This will cause driving motor M to return recalibrating unit VT to its normal position at the "raise" position end of the active part of the saturable-reactor A1SX winding. When this position is reached, raise limit switch RLS will be opened to de-energize driving motor M and the timer motor 1TR circuits.

Recalibrating unit VT is usually connected to the saturable-reactor taps located at the opposite end of the winding used for the voltage-adjusting unit. The operation of recalibrating unit VT is in every way identical to that of the voltage-adjusting unit, except that the former is subject to automatic control while the latter is usually controlled manually.

When exciter voltage is to be limited, the control relay is sensitive to exciter voltage instead of armature current.

### Component Arrangement

The limit components are mounted on a steel base and connected to a terminal board. This assembly includes the control relay, raise and lower relays, motor-operated variable-transformer recalibrating unit, and the timing relays.

Separate instructions for the components are usually supplied with the equipment.

### Ratings

The current-sensitive type of control relay is equipped with a coil rated at a normal current of 0.5 amperes, 50/60 cycles a-c. The adjustable resistor C4R in parallel with the coil provides for adjustment of the limit current from approximately 2.5 to 5.0 amperes. At 5.0 amperes it will impose a burden of approximately seven volt-amperes on the signal-current transformer. The voltage-sensitive control relay is usually equipped with a coil rated at 0.5 ampere d-c. An adjustable series resistor is provided to permit selection of the limit voltage for values up to approximately the rating of the exciter.

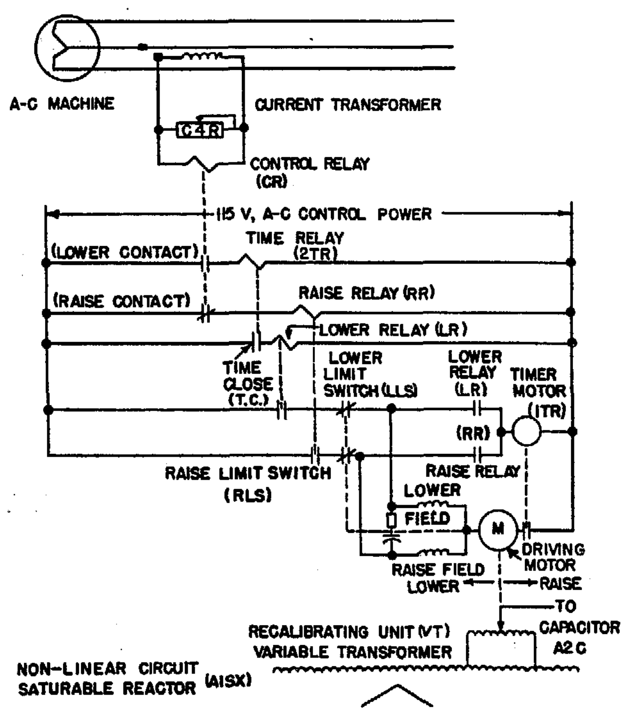



*Fig. 15. Maximum excitation limit circuit*

The raise and lower relays are usually each provided with a 115-volt, a-c coil rated at approximately 0.12 ampere.

The recalibrating-unit driving motor is normally rated at 115 volts, a-c, 0.5 ampere. The total travel time for the recalibrating unit, with the driving motor operating continuously, is 45 seconds for most applications. The limit operates to reduce the regulator voltage level by approximately 10 percent of the normal rated voltage of the regulator.

The timer relay 1TR has a 15-second time-cycle. The timer motor is rated at 115 volts, a-c, and requires less than 0.1 ampere. The relay may be adjusted to vary the total recalibrating time from a minimum of 90 seconds to a maximum of over 45 minutes. Time relay 2TR provides a time delay that can be adjustable from 3 seconds to 100 seconds. The relay motor and coil is rated at 110 volts and requires less than 0.25 ampere.

## MISCELLANEOUS EQUIPMENT

### Amplidyne Generator

**The amplidyne generator is normally supplied with the regulator equipment and assembled in a four-bearing motor-generator set. Amplidynes are commonly rated at 2, 3, 5 or 7 1/2 kw, and 125 or 250 volts d-c, with driving motors rated at 5, 7 1/2, 15 or 20 hp and 220/440 or 550 volts, three-phase, 50/60 cycles a-c. Separate instructions for the amplidyne are usually supplied with the equipment, and additional copies may be secured upon request.**

The amplidyne usually has two control-field windings. The field and armature leads are marked with metal identification tags which should not be removed even after installation is completed. The field leads are connected to a small terminal board mounted on the machine frame and the terminals are marked with the field-lead identification numbers.

The F1-F2 field, which is excited by the voltage regulator, normally has a resistance of approximately 10 ohms at 25 C (77 F). The winding usually consists of 250 turns per pole, and has a continuous duty rating of two amperes.

The F3-F4 field is normally excited by the stabilizing transformer circuit. The F3-F4 winding has a normal resistance of approximately 30 ohms, usually consists of 320 turns per pole, and has a continuous duty rating of one ampere.

The armature leads are marked A1 and C2. The polarity of the leads will depend upon the magnitude and direction of current flow through the amplidyne fields. If the F1-F2 field is energized with the F1 terminal positive, armature terminal C2 will become positive. Likewise if the F3-F4 field is energized with F3 positive, terminal C2 will become positive. If both fields are simultaneously energized in opposite directions, the amplidyne polarity will depend upon the resultant ampere turns of the two control fields.

The amplidyne motor-generator set is usually equipped with an overspeed switch having a normally closed contact which will open when the speed is too high. This is desirable since overspeeding might occur if the driving motor were disconnected from the line so that the amplidyne operates as an unloaded d-c motor in the exciter-field circuits. The switch contact is rated at 115 volts, 10 amperes a-c; 125 volts, 0.3 ampere d-c; and 250 volts, 0.15 ampere d-c.

### Control Equipment

The regulator equipment usually includes the components required for the control of the regulator and the amplidyne generator. Multicontact, dead-front, switchboard-type, cam-operated control switches are used for control of the regulator circuits. These switches are used for transfer and control functions, and may be supplied with fixed handles, or with removable handles where protective interlocking is required.

A motor starter is provided when the amplidyne is supplied directly coupled to a driving motor. This starter may be equipped with a fusible disconnect switch or a circuit breaker. The starter magnetic switch is a 3-pole d-c operated device with overload relays. The operating coil may be rated for 125 or 250 volts d-c.

A transfer contactor is provided for switching the amplidyne into and out of the exciter field circuit. This contactor may be a two-pole double-throw device with two normally open and two normally closed main contacts; or it may be a single-pole double-throw device with one normally open and one normally closed main contact. In the latter instance, two contactors are used with interconnected operating coils. The single-pole device is a latched-in type switch which will remain closed after the closing coil has been de-energized, and which can only be opened by energizing a separate opening coil. This latched-in feature is obtained by means of a permanent magnet inserted in the operating-coil core.

To protect against the possibility of establishing a serious amplidyne short circuit through the normally open and normally closed contacts of the transfer contactor, a current-limiting resistor is supplied for connection in this short-circuit path. This resistor is usually composed of several resistance units assembled with mounting brackets. The total resistance may be as much as approximately seven or as little as approximately four ohms, depending upon the installation.

For reference purposes, a zero-center d-c voltmeter is usually supplied for connection across amplidyne terminals.

The various control devices are covered by individual instructions which are usually included with the equipment. Additional copies may be obtained upon request. Instruction references are generally given on the device nameplates.

### Variable Transformers

Variable transformers are generally used as adjusting units at various points in the regulator equipment. The voltage-adjusting unit is normally a manually operated, semiflush-mounted, 115-volt, 50/60-cycle, 0.69-kva, single-phase variable transformer. In some cases, however, a surface-mounted, motor-operated variable transformer is used. This latter device is usually rated at 230 volts, 50/60 cycles, 2.07 kva, single phase, and is driven by a 115-volt, 50/60-cycle, 0.5-ampere motor or a 115-volt d-c, 0.23-ampere motor. Total travel time for the motor-operated units is 45 seconds. Motor-operated units are usually controlled with standard, cam-operated, dead-front switchboard-type control switches for remote semiflush mounting to permit locating the motor-operated unit with the principal components of the regulator equipment.

The manually operated voltage-adjusting unit is provided with a knob and dial. Since the dial is numerically graduated in the clockwise direction, it may be suitable for use only when clockwise rotation for increased voltage is desired. The variable transformer on the reactive ampere limit panel is rated 115 volts, 50/60 cycles, 0.345 kva, single phase. The maximum excitation limit unit variable transformer, which is identical to that used for the motor-


Manually operated voltage adjusting unit


Motor operated voltage adjusting unit and maximum excitation recalibrating unit.

NOTE: Voltage adjusting and recalibrating unit connections should be made to terminals marked● Limit adjusting unit terminals normally used are marked ⊙

*Fig. 16. Variable transformer internal connections*

operated voltage-adjusting unit, is driven by a 115-volt, 50/60-cycle, 0.5-ampere motor, and has a total travel time of 45 seconds.

Variable transformers should operate easily and care should be exercised to prevent the rotor from being slammed against the stop since this tends to damage and weaken the entire variable-transformer assembly.

Internal connections for the variable transformers are shown in Fig. 16. Connections for driving motors, when used, are shown in the applicable connection diagram for the complete regulator equipment. Variable transformers used as voltage-adjusting and recalibrating units are always connected with the full winding across the proper saturable-reactor taps.

#### Exciter Voltage Relay Panel

When a voltage regulator and an underexciter reactive ampere limit are used with a synchronous condenser, an exciter voltage relay panel is provided. The relay panel will detect and respond to incorrect polarity and magnitude of the exciter voltage. When a synchronous condenser is operated near the steady-state stability limit it will always operate with negative excitation. If the synchronous condenser slips a pole when initially operating with negative excitation, the operation of the amplidyne voltage regulator will be incorrect and the exciter voltage will be driven to ceiling in the negative direction. The exciter voltage relay senses this condition and closes a contact. The exciter voltage relay panel consists of an adjustable resistor 1R, a rectifier 1REC and a relay CR1. When the relay panel operates, the synchronous condenser should automatically be removed from the line, the regulator removed from service and the amplidyne driving motor should be de-energized.

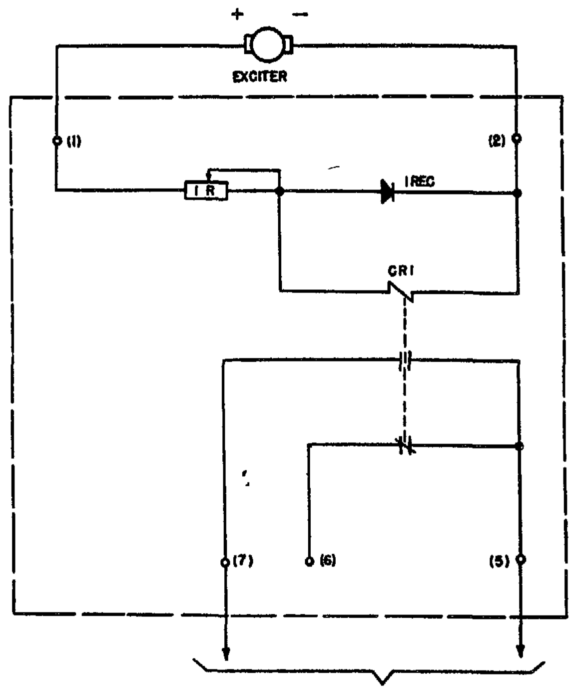



*Fig. 17. Exciter voltage relay panel*

Figure 17 shows the exciter voltage relay circuit, with the exciter operating with exciter voltage as shown. For this case, current passes from the exciter through resistor 1R and through rectifier 1REC. Since the rectifier has a low forward resistance, the voltage drop across the relay CR1 is insufficient to cause CR1 to pick up. For reverse polarity, due to the blocking action of rectifier 1REC, current will pass through relay CR1 and resistor 1R. Resistor 1R is adjusted so that relay CR1 will operate with negative exciter voltage at approximately 70 percent of the exciter rated voltage.

# INSTALLATION

## LOCATION AND MOUNTING

The various components of the regulator equipment may be supplied unmounted or panel mounted with or without an enclosing case. It is important that all components be placed in a well-ventilated, clean, dry location, and securely mounted on surfaces which are relatively free from vibration. The normal ambient temperature should not be greater than 40 C (104 F).

The amplidyne current-limiting resistors must not be mounted in a position which will permit dissipated heat to pass over any of the other components.

The static equipment should be readily accessible for adjustment and testing. The amplidyne should be located to permit easy inspection and maintenance. The variable transformer used as a voltage-adjusting unit should be placed in a reasonably dust-free location which will permit ready inspection of the contact-brush assembly.

## CONNECTIONS

Connections must be made in accordance with the diagram supplied with the equipment for each particular installation. Care must be exercised to determine that connections are correct to avoid damaging the equipment. Interconnecting wires will conduct a maximum current of approximately five amperes in all regulator circuits. Maximum currents in the amplidyne driving motor lines and amplidyne armature connections will be appreciably greater and will vary depending upon the ratings of these units.

It is suggested that disconnect switches be provided in the a-c supply lines and the control power-supply lines and that fuses be provided in the latter case. Amplidyne driving motors, may, in most cases, be connected for either of two voltages and the proper connections for the appropriate voltage must be made to avoid damaging the motor. Rotation of the motor should be investigated to determine that it is in the proper direction.

### POLARITY AND PHASE ROTATION

When making connections from the exciter-armature leads to the voltage regulator, polarity should be carefully checked to ascertain that the connections are as shown in the applicable diagram.

The amplidyne-armature lead marked A1 must be connected to the positive side of the exciter-armature circuit. Amplidyne-field polarity should be checked at the regulator control terminals before the amplidyne-field leads are connected to the regulator. For this purpose it is possible to use a small dry cell, or a low-voltage d-c supply from a potentiometer or other source which will not deliver a voltage in excess of 10 volts. Amplidyne-armature polarity should be determined with a portable voltmeter directly at the machine terminals, rather than with a remote switchboard instrument, to prevent errors due to incorrect meter connections.

The amplidyne must be operated disconnected from the exciter field circuit to make this test, and care should be taken to avoid exceeding the amplidyne field-current and armature-voltage ratings. Polarities should be as described on Page 15 under heading "Amplidyne Generator." If discrepancies exist, the amplidyne-field leads must be interchanged to obtain the correct polarity at the armature terminals.

Equalizing-reactor and line-drop compensator polarities must be carefully observed when connections are made. THE CURRENT TRANSFORMERS USED WITH THESE UNITS MUST BE LOCATED IN THE SAME PHASE AS THE SIGNAL VOLTAGE PHASE IN WHICH THEY ARE CONNECTED.

The phase rotation of the a-c signal-voltage supply from the a-c machine potential transformers to the regulator equipment must be determined at the T-connected transformer (1T) terminal board. Phase rotation should be measured at terminals 1, 2 and 3 at the terminal board, and should be in the order 1, 2, 3 referred to the terminal numbers.

## INITIAL OPERATION, TESTING AND ADJUSTMENT

### CONTROL CIRCUITS

If the a-c machine is equipped with a single, independent regulator equipment including an integral motor-amplidyne set, the following tests should be made. With the a-c machine and exciter out of service and with the amplidyne driving motor power supply not energized, the regulator control switch should be turned to OFF or MANUAL, and the control power supply energized. Under this condition, the amplidyne driving motor starter magnetic switch, the undervoltage relay, and the transfer contactor should remain de-energized. The control switch may then be turned to TEST. The motor-starter magnetic switch should be energized and the switch should close, the undervoltage relay should be energized but the transfer contactor should remain in the de-energized condition. The switch may then be turned to ON or AUTO, the transfer contactor should be energized and should operate to place the amplidyne in the exciter-field circuit. The switch may again be turned to TEST to determine that the transfer contactor will be properly de-energized and the motor-starter magnetic switch will remain closed. Turning the switch to OFF or MANUAL should de-energize the coil of the magnetic switch and the coil of the undervoltage relay. The undervoltage relay should drop out in about 1 to 1 1/2 seconds after its coil is de-energized.

The overspeed-switch circuit should be checked after placing the control switch at ON to energize the motor-starter magnetic switch and transfer contactor. Disconnect one overspeed-switch lead at the overspeed-switch terminals on the motor-amplidyne set. This should de-energize all three devices. The control switch should be left at ON and the lead reconnected; the devices should not be re-energized.

Some installations involve two or more regulator equipments consisting of normal equipments and spare equipments for a single or for several a-c machines. In such cases, transfer switches are frequently provided for selection of the proper regulator. If these switches are equipped with removable handles for protective interlocking, all handles but one must be immediately removed and stored in a remote location to prevent incorrect and dangerous operation of the regulator equipment. The previously described tests must then be conducted on each equipment by turning the transfer switches to the proper positions to place the regulators successively under control of the respective control switches.

Occasionally regulator control circuits are interlocked with exciter circuit breaker opening and closing control circuits, either with or without the use of relays. These circuits must be carefully tested by operation of the circuit-breaker control switches and the circuit breakers themselves to ascertain that all details of operation are correct.

In general, this type of interlocking is provided to prevent placing two regulators in service with one a-c machine and exciter, to prevent placing a single regulator in service with an exciter operating in parallel with a second exciter on the same a-c machine field, and to permit closing exciter breakers only when the regulator control switches are at the OFF or MANUAL positions. The regulator diagrams must be carefully studied to determine what control functions are provided, and no further tests should be made until the control circuits have been completely tested.

## VOLTAGE REGULATOR

### Preliminary

The regulator should be tested with the a-c machine operating at normal speed and normal voltage, and in the case of a generator, at no load and disconnected from the system.

The underexcited reactive ampere limit should be removed from service by disconnecting the wire from terminal 4 on the terminal board for saturable reactor B1SX on the CR7932-KA reactive-ampere limit panel.

If a maximum-excitation limit is provided, it should also be disconnected at the CR7930-NA voltage-regulator terminal board. This may be done by removing external connections from terminal numbers 8, 9 and 10; terminals 9 and 10 should then be connected together with an external jumper.

If an equalizing reactor and/or line-drop compensator are used, they should be connected in the single-voltage circuit and the adjusting knobs for these units turned to the zero position.

### Voltage Adjusting Unit

The regulator control switch should be kept at OFF or MANUAL until the a-c machine has been started and brought up to normal speed and voltage. The exciter polarity should be checked to be certain that it is correct. After the control power supply has been energized, the switch may be turned to TEST to energize the regulator circuits. When this is done, the amplidyne armature voltage may suddenly increase in either direction. Do not allow the amplidyne to operate continuously at more than rated voltage. It should be possible to reduce the amplidyne voltage to zero by turning the voltage-adjusting unit. Turning the voltage-adjusting unit knob or voltage-adjusting control switch clockwise should cause the amplidyne voltage to increase in the boost direction so that the amplidyne-voltmeter needle will move up scale from zero and amplidyne terminal C2 will become positive with respect to A1. Turning the voltage-adjusting unit knob or voltage-adjusting control switch counterclockwise should cause the amplidyne voltage to increase in the buck direction, so that the voltmeter will read downscale from zero and amplidyne terminal A1 will become positive with respect to C2. If the operation of the voltage-adjusting unit must be reversed, it may be changed as follows after the regulator control switch has been returned to OFF.

The external connections to the two terminals of the voltage-regulator panel which connect to the winding of the voltage-adjusting unit may be interchanged. (The connection from the voltage-regulator panel to the slider on the voltage-adjusting unit should not be changed.) The control switch should then be turned to TEST and the operation of the voltage-adjusting unit rechecked to determine that it is satisfactory.

It is possible that operation of the voltage-adjusting unit will have no noticeable effect on the amplidyne voltage when the regulator is first tested. If the amplidyne voltage is in the boost direction and cannot be reduced to zero by operating the voltage-adjusting unit, it may be caused by either incorrect phase sequence or the signal voltage being out of range. The phase sequence of the regulator signal-voltage connections from the potential transformers to the primary of T-connected transformer 1T may be incorrect. This should be checked at the T-connected transformer terminals 1, 2, and 3 with a phase-rotation meter and should be in the order 1, 2, 3 referred to the terminal board. Connections from T-connected transformer 1T to the voltage-regulator panel should also be checked. If the amplidyne voltage is in the buck direction and cannot be reduced to zero by operation of the voltage-adjusting unit, it may be caused by the signal voltage being out of range.

### T-connected Transformer

The T-connected transformer (1T) is usually provided with taps on one secondary winding. Normally these taps are factory adjusted, but since there may be instances in which this adjustment is to be made during installation, the following procedure is given:

Turn the voltage control switch to OFF. Turn the regulator sensitivity dial toward 100 until the stop is reached. Adjust resistor A4R to 25 ohms. Set the voltage-regulator control switch at TEST, set the voltage-adjusting unit for zero amplidyne volts, and turn the knobs on the equalizing reactor and the line-drop compensator to their zero positions. Measure the a-c voltage at the primary of the transformer 1T between terminals 1 and 2, 2 and 3, 3 and 1, and average the three voltages.

Measure the a-c voltage between terminals 1 and 2 at the primary of transformer A1T on the CR7930-NA voltage-regulator panel. (This is the voltage between wires 3 and 15.)

The ratio of the averaged primary voltage of transformer 1T to the primary voltage of transformer A1T should be between 1 to 1.02 and 1 to 1.10.

If the ratio of these voltages is outside the above limits, turn the control switch to OFF, and move the tap on the secondary of transformer 1T to the next lower number if the ratio is too low (less than 1 to 1.10) or to the next higher number if the ratio is too high (greater than 1 to 1.02).

Turn the control switch to TEST and set the voltage-adjusting unit for zero amplidyne volts. Recheck ratio of transformer voltages and if necessary again move taps as described until the ratio is between the specified limits.

### Voltage Level and Range

Inability to control the amplidyne voltage may also be due to the signal voltage falling outside of the regulator range. If the amplidyne voltage is too high in the buck direction, the signal voltage may be too high. If the amplidyne voltage is too high in the boost direction, the signal voltage may be too low. The regulator is normally connected for a signal voltage of approximately 115 volts, but can be adjusted for signal voltages which differ appreciably from this value. After turning the control switch to OFF, this adjustment is made by increasing or decreasing the number of effective nonlinear-circuit saturable-reactor (A1SX) turns to respectively raise or lower the regulator voltage level as follows:

The saturable-reactor (A1SX) taps for changing the number of effective turns are connected to terminals of the same number on those voltage-regulator terminal boards which are located adjacent to and on the same plate as the saturable reactor. Four wires for outgoing connections from the terminal boards are identified by different colored sleeving. The voltage level is determined by the "orange" identified wire. To raise the voltage level, connect the orange wire to a higher numbered terminal and to decrease the voltage level connect it to a lower numbered terminal.

NOTE: If a maximum-excitation limit is used, recalibration unit VT is usually connected to the orange and to the red identified wires. To maintain a predetermined range for recalibration unit VT, it is necessary to move the "red" identified wire an equal number of terminals and in the same direction as the orange wire.

After this adjustment has been completed, the control switch may be turned to TEST to determine if operation is satisfactory. It should be possible to adjust the amplidyne voltage to zero by turning the voltage-adjusting unit. If the brush arm is appreciably away from the midposition, additional adjustment of the regulator voltage level may be required. If the brush arm is too far from the midposition in the direction for increasing the amplidyne voltage toward boost, the number of effective saturable-reactor turns must be increased. This is equivalent to adjusting the regulator for a higher voltage level. If the brush arm is too far from the midposition in the direction for increasing amplidyne voltage toward buck, the number of effective saturable-reactor turns must be decreased, which is equivalent to lowering the regulator voltage level. Adjustments may be made as previously described, and should only be made with the regulator control switch at OFF.

It may be preferable, however, to delay final voltage-level adjustment of centering the voltage-adjusting unit since the equalizing reactor and line-drop compensator may appreciably alter the signal voltage under loaded a-c machine conditions. This might make readjustment of voltage level for a given load desirable. Readjustment may also be required following the addition or removal of equalizing reactors or line-drop compensators.

The range over which the voltage level can be controlled by the voltage-adjusting unit may be increased by connecting the blue identified wire to a higher numbered terminal and decreased by connecting it to a lower numbered terminal. DO NOT CONNECT THE BLUE WIRE TO A TERMINAL HIGHER THAN NO. 5. NOTE: The green wire is normally connected to terminal No. 1.

### Additional Control-switch Circuits

Where additional control, transfer, or exciter-polarity reversing switches are used, the previous tests should be repeated with these switches for all operating conditions, to determine that the amplidyne voltage may be controlled with the voltage-adjusting unit when each of the regulator control switches is at TEST. This will indicate that all switch connections are correct.

### Polarity Tests

Before the regulator is first placed in control of machine excitation, it is recommended that a final polarity test be conducted. With the regulator control switch at OFF, short circuit the normally open contact on the transfer contactor which is connected between amplidyne-armature terminal A1 and the exciter-field rheostat, or occasionally between A1 and the positive exciter-armature lead. This can be done with a small clip lead, since the shorting connection will not be required to carry any current.

Connect a d-c voltmeter across amplidyne-armature terminal C2 and the negative exciter-armature lead, with the positive voltmeter lead on C2. These connections may be made with the a-c machine and exciter in operation, if the necessary precautions are taken.

With the a-c machine operating at normal speed and voltage, turn the regulator control switch to TEST and adjust the amplidyne-armature voltage to zero with the voltage-adjusting unit. The voltage indicated by the previously connected test voltmeter should be roughly equal to that portion of the exciter voltage which appears across the exciter field. Turn the voltage-adjusting unit in the raise direction to increase the amplidyne voltage in the boost direction. The voltage indicated by the test voltmeter should increase by the amount that the amplidyne-armature voltage is increased. Then turn the voltage-adjusting unit in the lower direction to increase the amplidyne voltage in the buck direction. The voltage indicated by the test voltmeter should decrease below the initial value by the amount that the amplidyne-armature voltage is increased. If the above tests are not satisfactory, connections must be carefully checked and proper operation obtained before any further tests are made.

Before proceeding, it is necessary to check the stabilizer connections in the following manner. With the control switch at TEST and the a-c machine and exciter operating at normal speed and voltage, use the voltage-adjusting unit to adjust the amplidyne voltage to zero. Then open the stabilizer primary circuit. As the circuit is disconnected the amplidyne voltage should increase in the boost direction and return to approximately the original value. The actual value to which the amplidyne voltage returns depends upon regulator sensitivity. The actual value is increased as regulator sensitivity is increased. After observing this, close the stabilizer primary circuit. The amplidyne voltage should momentarily increase in the buck direction and then return to zero. If opposite effects are observed, reverse the stabilizer secondary or primary connections and repeat the test.

If an equalizing reactor is provided, its polarity must be checked before putting the regulator in service with a machine which is connected to the system. Turn the reactor tap switches to zero and the control switch to TEST. With the a-c machine operating overexciter, adjust the amplidyne voltage to zero. Then turn the coarse adjustment to a higher number. The amplidyne voltage should increase in the buck direction. If it increases in boost direction, reverse the signal voltage leads to the reactor and repeat the test. Then turn the coarse adjustment to zero and the fine adjustment to 4.

If a line-drop compensator is provided, its polarity must be checked before placing the regulator in service. Turn both adjusting knobs to zero, and operate the a-c machine in the overexcited region. With the regulator control switch at TEST and the amplidyne voltage adjusted to zero, turn the coarse reactance-adjustment knob to the right to insert reactance. The amplidyne voltage should increase in the boost direction. Return the reactance-adjusting knob to zero, and turn the coarse resistance-adjusting knob to the right to increase resistance. This should also increase the amplidyne voltage in the boost direction. If the amplidyne voltage increases in the buck direction during these tests, the compensator potential leads must be interchanged and the tests repeated.

### Initial Operation

It is recommended that where possible the a-c machine be disconnected from the load or system at the time the regulator is first placed in control of a-c machine excitation. If the a-c machine is a generator and must be connected to the system, it is suggested that it be operated at light load to insure a minimum disturbance to the system in the event of improper functioning of the voltage-regulator equipment when first put in service. For complete information on putting the regulator in service and removing it from service, refer to the section on "Operation."

The regulator control switch should be turned to TEST and the amplidyne voltage adjusted to zero with the a-c machine operating at normal speed and voltage. The control switch may then be turned to ON or AUTO. This will place the amplidyne in the exciter-field circuit, and the regulator in control of the a-c machine excitation. The amplidyne voltage may immediately change, but should promptly return to nearly zero. If a very large change in amplidyne voltage appears, and the voltage does not promptly return to zero, remove the regulator from service. Repeat the amplidyne polarity tests and check all connections to determine the cause of the trouble.

Turning the voltage-adjusting unit knob or control switch in the raise direction with the regulator in control of machine excitation should cause the amplidyne voltage to change in the boost direction and the a-c machine terminal voltage to rise. Turning the voltage-adjusting unit knob or switch in the lower direction should cause the amplidyne to change in the buck direction and the a-c machine terminal voltage to fall. If the a-c machine is a generator which is not connected to a load or a system, use of the voltage-adjusting unit should permit a total change of machine voltage of about 10, 14, 20 or 25 percent of rated voltage, depending on whether the blue identified wire on the voltage-regulator panel is connected to terminals 2, 3, 4 or 5, respectively, for saturable reactor A1SX. Usually this change of machine voltage is equally divided about the normal voltage to provide a maximum change of plus or minus half of this total change.

Operation of the voltage regulator may also be tested by changing the resistance of the exciter-field rheostat. As the rheostat resistance is decreased, the amplidyne voltage should change in the buck direction, and as resistance is increased, voltage should change in the boost direction. No appreciable change in exciter voltage should occur.

Where additional control, transfer or exciter-polarity reversing switches are used, the previous tests should be repeated with these switches adjusted for all operating conditions to determine that the a-c machine excitation may be properly controlled with the regulator. This will indicate that all switch connections are correct.

**Regulator Stability**

With the a-c machine operating at rated speed and voltage, and at no load if the machine is a generator, voltage-regulator stability should be satisfactory. If the regulator does not appear to be stable, it may be necessary to increase the stabilizing effect provided by stabilizing transformers 1ST, 2ST or to decrease the regulator sensitivity, or both.

The stabilizer primaries are usually connected in series across the a-c machine exciter armature through resistor 6R so that the maximum voltage impressed across each of the stabilizer primaries will not exceed 90 volts with the a-c machine exciter operating at maximum normal voltage.

If stable operation cannot be obtained by adjustment of stabilizer resistor 6R, special stabilizer connections may be warranted. These arrangements are not normally required and will vary with the equipment and services involved.

It is also possible that the stabilizer connections may be reversed if satisfactory stability cannot be obtained. External connections should be checked and if these are found to be correct, the connections from the secondaries of the stabilizers may be interchanged. Stability should be noticeably improved or definitely poorer after this change is made, and caution should be exercised when placing the regulator in service to prevent excessive voltage oscillations.

It may be necessary under some conditions to desensitize the regulator if stabilizer adjustments do not produce completely satisfactory results. This will aid in producing stable operation.

Resistor A4R, which has a slider adjustable from the back of the panel, is used to decrease regulator sensitivity. Move the slider on resistor A4R so as to increase its resistance about five ohms. This adjustment must be made with the regulator control switch at OFF or MANUAL. It should be remembered that a small increase in resistance will produce a large change in sensitivity. Therefore, it is desirable to increase resistance in small steps. In some cases, in order to obtain stable operation, it may be necessary to add resistor 9R, per Fig. 21. An alternative means of obtaining stable operation is to remove one or two stabilizers by shorting both primary and secondary windings.

In general, it is more likely that stability difficulties will appear at reduced excitation, rather than at normal or high values of a-c machine excitation current. Hence, it is usually possible to obtain satisfactory stability under loaded conditions, if satisfactory stability is obtained at no load.

**Regulator Sensitivity and Voltage Regulation**

Determination of a-c machine voltage regulation with the regulator in service is ordinarily a difficult procedure and one which will produce only qualitative results. Since the regulator is adjusted at the factory to provide adequate sensitivity for close regulation, this measurement is usually unnecessary at the time of installation, and for this reason no special test procedure is described. After the equipment has been placed in service, it is possible to obtain data which will provide an approximate measure of voltage regulation, but even these results must be carefully interpreted to gain a reliable estimate of performance.

If the machine is connected to a system, the regulation will depend to a great extent upon the characteristics of this system. Regulation will also be considerably affected by the use and adjustment of equalizing reactors and line-drop compensators. Furthermore, the setting of the exciter-field rheostat will have an effect on regulation. And finally, the sensitivity of the regulator itself will be a major factor affecting voltage regulation.

If it is desired to improve regulation by increasing regulator sensitivity, resistor A4R, on the back of the voltage-regulator panel, may be used for this purpose.

**Decrease the resistance of A4R about five ohms by moving the slider. This process may be repeated if necessary. This adjustment should be made cautiously with the regulator out of service.**

Decreasing resistance will not only increase sensitivity but may produce stability difficulties which will only appear at low values of a-c machine excitation current, such as are encountered under no-load or underexcited conditions. Changes should therefore, be made carefully, and the stability should be checked after each change. If necessary, sensitivity may be reduced to increase regulation by increasing the resistance of the sensitivity-adjusting resistor as previously described.

## Underexcited Reactive Ampere Limit

### *Limit Polarity*

After satisfactory operation of the regulator has been obtained, the reactive ampere limit should be tested. Set the REACTIVE AMPERE LIMIT SENSITIVITY dial at zero. Set the REACTIVE AMPERE LIMIT POWER RECALIBRATION switch at zero. Set the REACTIVE AMPERE LIMIT START dial at its highest numbered position.

Set the regulator control switch at OFF. During the preliminary adjustments of the regulator, the wire was disconnected from terminal 4 on the terminal board for saturable reactor B1SX on the CR7932-KA underexcited reactive ampere limit panel. During all limit polarity tests, a test milliammeter (0-10-100 ma DC) should be connected from terminal 4 on saturable reactor B1SX to the wire that normally connects to terminal 4 on B1SX.

**Caution**

When setting the REACTIVE AMPERE LIMIT POWER RECALIBRATION switch at any time the switch knob should be turned to a definite position as evidenced by a snap action.

With the machine carrying power load and some safe value of underexcited reactive current, move the regulator control switch to TEST. Set the voltage-adjusting unit for zero amplidyne volts. Slowly turn the REACTIVE AMPERE LIMIT START dial toward zero. At some setting of the dial, the amplidyne voltage will increase in the boost direction and the test milliammeter will start to indicate. If the amplidyne voltage does not increase appreciably before the dial has been turned to zero, return the dial to the highest numbered position. Decrease the a-c machine excitation to further increase the underexcited current, being careful not to exceed the safe operating limit for the machine.

Again turn the REACTIVE AMPERE LIMIT START dial toward zero. The point at which the amplidyne voltage starts to move from zero is considered the limit-start point. This corresponds to a reading of approximately 5 milliamperes as indicated by the test milliammeter. Continue turning the dial until the amplidyne voltage is 20 volts boost. If the amplidyne voltage cannot be increased from zero by turning the LIMIT START dial to zero, the limit polarity may be reversed. Turn the regulator control switch to OFF and reverse the primary connection of transformer B3T (Fig. 21) by interchanging at terminals 1 and 2 the wires that connect to the CR7932-KA reactive-ampere limit panel. Repeat the test previously described to determine if a boost amplidyne voltage can be obtained by turning the LIMIT START dial toward zero. THIS TEST MUST GIVE PROPER RESULTS BEFORE FURTHER TESTS ARE CONDUCTED. With the REACTIVE AMPERE LIMIT START dial so set that the amplidyne voltage is 20 volts in the boost direction, turn the REACTIVE AMPERE LIMIT POWER RECALIBRATION switch in steps from zero toward 9. If the a-c machine is delivering power, the amplidyne voltage should increase in the boost direction as the switch is turned toward 9. (See preceding CAUTION note.)

Turn the REACTIVE AMPERE LIMIT POWER RECALIBRATION switch to zero. Readjust the amplidyne voltage to 20 volts boost with the REACTIVE AMPERE LIMIT START dial. Before proceeding further with the test on the reactive-ampere limit circuit, it is necessary to check the polarity of the reactive-ampere limit stabilizing transformers.

During this check observe the test milliammeter carefully. Carefully disconnect one of the primary leads of a limit stabilizing transformer. (Refer to the connection diagram supplied with each equipment.)

A careful observation of this test milliammeter is necessary when the primary lead is disconnected. Correct stabilizing polarity results in test milliammeter needle swinging up scale and then returning approximately to its original position. Incorrect stabilizer polarity results in the test milliammeter needle first swinging down scale, then up scale, but beyond its original position, and finally returning to approximately its original position. This should cause the amplidyne voltage to increase in the boost direction. Replacing the primary lead should cause the amplidyne voltage to change in the buck direction. Do not proceed with the reactive-ampere limit test until the polarity of the limit stabilizer is correct.

Turn the regulator control switch to OFF. Disconnect the test milliammeter and reconnect the wire to terminal 4 on the terminal board of saturable reactor B1SX on the underexcited reactive ampere limit panel. This is the wire which was disconnected during preliminary adjustments of the voltage regulator.

*Initial Operation*

Turn the REACTIVE AMPERE LIMIT START dial to its highest reading. Readjust the amplidyne voltage to zero with the voltage-adjusting unit, if necessary. Operate the a-c machine at normal voltage and with underexcited reactive current. Turn the regulator control switch to ON as discussed under "OPERATION." Slowly turn the REACTIVE AMPERE LIMIT START dial toward zero. At some point the amplidyne voltage should increase slightly in the boost direction and the exciter voltage should increase, causing underexcited reactive current to decrease. The dial setting at which the underexcited reactive current starts to decrease is also the limit-start point. If the operation is not as described, immediately remove the regulator from control of the a-c machine by turning the regulator control switch to OFF. Repeat the limit polarity test. Do not proceed further until satisfactory operation is obtained.

With the regulator control switch at ON, and the REACTIVE AMPERE LIMIT START at the limit-start point, observe the amplidyne voltmeter, the exciter voltmeter, and the a-c machine ammeter for signs of oscillation. If oscillation of the reactive current or amplidyne voltage appear, remove the regulator from control of the a-c machine excitation by turning the regulator control switch to OFF. Adjust resistance 7R in series with the primary of the limit stabilizing transformers (3ST and 4ST) in 15-percent steps, first in the direction to decrease resistance and then in the direction to increase resistance. After each of these adjustments, repeat the procedure for putting the limit in service as previously described, being very careful to observe the amplidyne and exciter-voltage oscillation and reactive-current oscillation.

**Note:** Adjustment of resistor 7R and connection of the primaries of stabilizers 3ST and 4ST should be such that the maximum voltage impressed across a stabilizer primary will not exceed 90 volts with the a-c machine exciter operating at maximum normal voltage.

After stable operation of the reactive-ampere limit has been obtained, check the limit operation with the regulator in control of the a-c machine excitation. Move the REACTIVE AMPERE LIMIT START dial to the limit-start point and record the reactive current. Decrease the underexcited reactive-ampere load on the a-c machine by operating the voltage-adjusting unit to raise the a-c machine voltage. The underexcited reactive current should decrease. It should be possible to adjust the underexcited reactive current to any value lower than it was at the limit-start point. Now increase the underexcited reactive current by turning the voltage-adjusting unit to lower the a-c machine voltage. Turning the voltage-adjusting unit to lower the a-c machine voltage causes the amplidyne voltage to increase in the buck direction. As the limit-start point is passed, the amplidyne voltage should continue to increase in the buck direction, but at a reduced rate, and it should be impossible to raise the reactive current appreciably above the previously recorded value, no matter how far the voltage-adjusting unit is turned in the direction to lower voltage.

As a final check of optimum limit stability, move the REACTIVE AMPERE LIMIT START dial until the amplidyne voltage is about 20 volts in the boost direction. Abruptly move the voltage-adjusting unit a few degrees in the lower direction and observe carefully the amplidyne voltmeter and the reactive-current ammeter for signs of oscillation. If oscillations appear, adjust for optimum stability as previously outlined. When the amplidyne voltmeter and the reactive-current ammeter show only a few oscillations after an abrupt change of the voltage-adjusting unit, the limit stability is satisfactory. Move the REACTIVE AMPERE LIMIT SENSITIVITY adjustment slowly toward its highest scale reading. Again check the limit stability.

This completes the initial adjustment of the limit. Final adjustment can be made at any time.

*Final Adjustment*

The final adjustment of the limit may be made by use of Fig. 18 and 19, unless special calibration data are supplied.

The REACTIVE AMPERE LIMIT START adjustment is determined from Fig. 18. This graph shows the value of the machine current-transformer secondary underexcited reactive current which will cause the limit to operate as a function of dial setting, and normal a-c machine potential-transformer secondary voltages. Values of voltages differing from those shown on the graph may be easily interpolated. Figure 19 shows the amount by which the limit-start point will be reduced below the limit-start adjustment as a function of machine current-transformer secondary active current for various values of the REACTIVE AMPERE LIMIT POWER RECALIBRATION switch (B1SW) setting.

The determination of the proper setting of the underexcited reactive ampere limit should be arrived at after a study of the steady-state stability limit for the particular generator and system involved. When the required setting of the limit has been determined by consideration of the desired

RAL - Reel 5
RAL Start 18



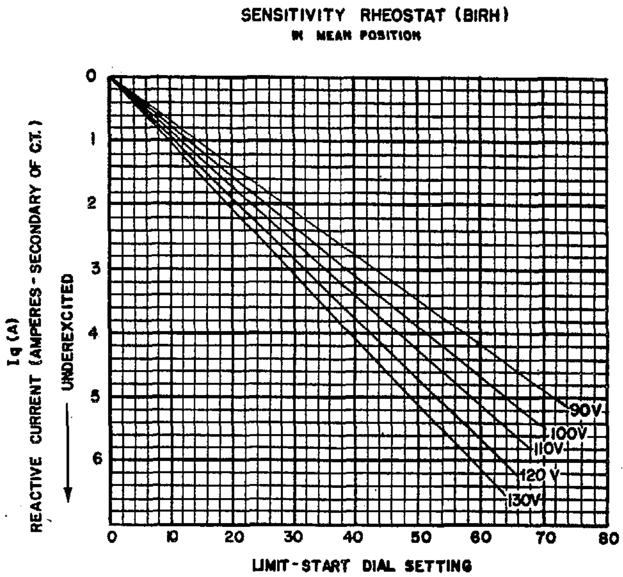



*Fig. 18. Calibration curves for reactive-ampere limit start dial*

operation of the a-c machine involved, the actual setting of the limit can be obtained by adjusting two dials on the underexcited reactive ampere limit panel as follows:

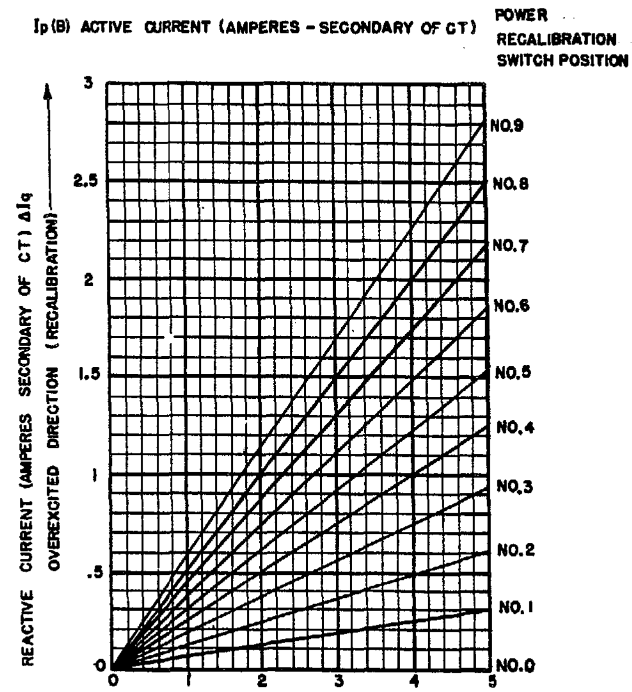
1. For a condition of no load (0 active current, Fig. 20) on the generator, calculate the underexcited reactive amperes (IqA through the secondary of the current transformer) at which the limit is to start. Determine the potential transformer secondary voltage (V1) that is connected to terminals 1 and 2 on the underexcited reactive ampere limit panel. For this voltage (Fig. 18) determine the underexcited reactive ampere limit start dial setting corresponding to the underexcited reactive current Iq(A). Set the UNDEREXCITED REACTIVE AMPERE LIMIT START dial for this setting and lock dial.

2. Calculate Iq(B) and Ip(B) as defined in Fig. 20. Compute the difference between Iq(A) and Iq(B) from paragraph 1 above. Call this difference ΔIq. From Fig. 19 determine the underexcited reactive ampere limit power calibration switch position corresponding to Ip(B) and ΔIq. Set the UNDEREXCITED REACTIVE AMPERE LIMIT POWER RECALIBRATION switch at this position.

The following example is given to illustrate the method of setting the limit:

Iq(A) Underexcited Reactive Current (Amperes-secondary of current transformer) at which the limit is to start with zero amperes active current to regulator. (No kilowatt load.)

Iq(B) Underexcited Reactive Current at which the limit is to start for a given value of active current, Ip(B) to regulator. (Usually maximum load.)




**Note: For frequencies other than 60-cycle see appropriate curves supplied with the equipment.**

*Fig. 19. Calibration of reactive-ampere power recalibration limit circuit*

Ip(B) Active current (amperes-secondary of current transformer) at a given kilowatt load. (Usually maximum load.)

Example: It is desired to have the reactive-ampere limit start to function when the underexcited reactive current input to the limit reaches four amperes with zero active amperes and when the underexcited reactive current input reaches three amperes with four active amperes. The normal voltage on the secondary of the a-c machine's potential transformers is 110 volts.

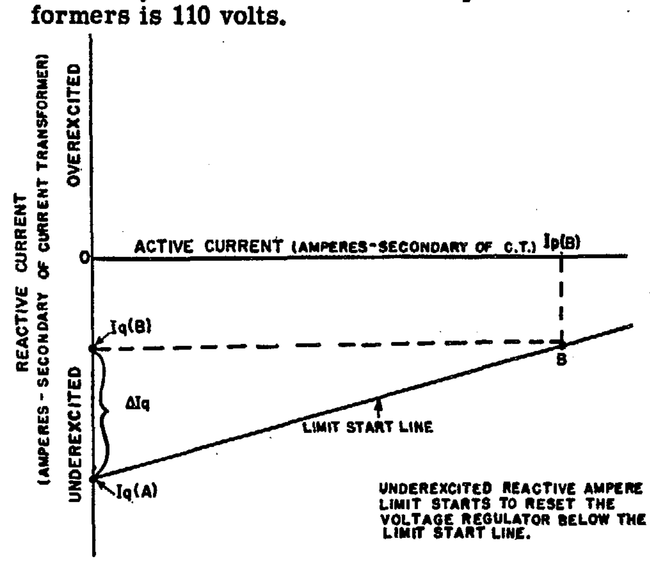



*Fig. 20. Typical limit start characteristics.*

Iq(A) is 4 amperes and from Fig. 18 for 110 volts, the reactive ampere limit start dial should be set at approximately 47. Ip(B) is 4 amperes and Iq(B) is 3 amperes. ΔIq is Iq(A)-Iq(B) or 4 − 3 = 1 ampere. Therefore, from Fig. 19 we observe that for a value of ΔIq = 1 ampere and 4 active amperes to the Limit, the two lines cross on the No. 4 line indicating that the POWER RECALIBRATION switch should be set at tap position No. 4.

If desired, before making the final adjustment of the limit, the calibration curves (Fig. 18 and 19) may be checked in the following manner:

Place REACTIVE AMPERE LIMIT POWER RECALIBRATION dial at position No. 8. Place the REACTIVE AMPERE LIMIT START dial at its highest scale position. Put the regulator in control of the a-c machine excitation. With the a-c machine carrying some convenient power load at about unity power factor, move the REACTIVE AMPERE LIMIT START dial slowly toward zero. At some position of the dial, the limit will start to operate. This position will be that which will just start to decrease the machine underexcited reactive current, or increase the overexcited reactive current.

Determine the active and reactive amperes delivered by the machine current transformer to the limit. Draw a vertical line from the active-ampere scale point in Fig. 19 to the curve for tap 8. Read the corresponding reactive amperes recalibration of the limit, and the setting of the REACTIVE AMPERE LIMIT START dial.

In Fig. 18, use the dial setting and the proper a-c voltage curve to determine the value of underexcited reactive current for which the limit is set. From this value, subtract the reactive-amperes recalibration. The result will be essentially equal to the reactive amperes delivered to the limit if the tests have been carefully conducted.

Set the reactive-ampere limit adjustments to the positions desired for final operation. If it is desired to check the adjustments, the following procedure may be followed. Place the regulator in control of the a-c machine excitation. Operate the machine at the desired power load and at a reactive load which should not cause limit operation. Turn the voltage-adjusting unit in the direction to lower voltage until the limit prevents further reduction in machine overexcited reactive current, or increase in underexcited reactive current. Determine the value of reactive current and active current supplied by the machine current transformer to the limit.

Knowing the a-c machine voltage and the setting of the REACTIVE AMPERE LIMIT START dial, determine the underexcited reactive current setting from Fig. 18. Determine the reactive amperes recalibration from Fig. 19. The result of subtracting the value of reactive amperes read in Fig. 19 from the value of underexcited reactive amperes in Fig. 18 will be essentially equal to the value of underexcited reactive current to the limit at the limit-start point.

## EQUALIZING REACTOR

The polarity of the equalizing reactor is checked as described under "Polarity Tests," page 20. Final adjustment of the equalizing reactor can only be made after considerable experience with the machine operating under control of the regulator. It is desirable to keep the amount of reactance used to the minimum required for optimum voltage regulation. As an initial adjustment, it is frequently desirable to turn the fine-adjustment knob to position No. 4 with the coarse knob at zero. Adjustments may be made with the equalizing-reactor current transformer energized. When making adjustments, the a-c machine overexcited reactive current should automatically decrease as the reactance of the equalizing reactor is increased.

## LINE-DROP COMPENSATOR

The polarity of the line-drop compensator is checked as described under "Polarity Tests," page 20. Final adjustment of the compensator must be made on the basis of operating experience. Preliminary adjustment may be made in accordance with the known values of resistance and reactance for that portion of the system over which compensation is desired. If the voltage at the point which is to be compensated goes down as the power factor becomes more lagging and up as the power factor becomes less lagging, more reactance and possibly less resistance may be required. Adjustments may be made with the compensator and regulator in service.

## MAXIMUM EXCITATION LIMIT

First, remove the external test jumper previously connected to terminals 9 and 10 on the voltage-regulator panel terminal board, page 19 and then reconnect the maximum excitation limit leads to the voltage-regulator panel as shown in the applicable diagram.

Energize the maximum excitation limit control power supply. With the a-c machine operating at rated speed and voltage, turn the regulator control switch to TEST and adjust the amplidyne voltage to zero. Manually close limit control relay CR with a small insulated implement, and maintain the relay in this position. Time Relay 2TR should energize and after a time-delay the contact T.C. will close. Lower relay LR and timer motor 1TR should be energized, and motor-operated recalibrating unit VT should turn either steadily or intermittently until it

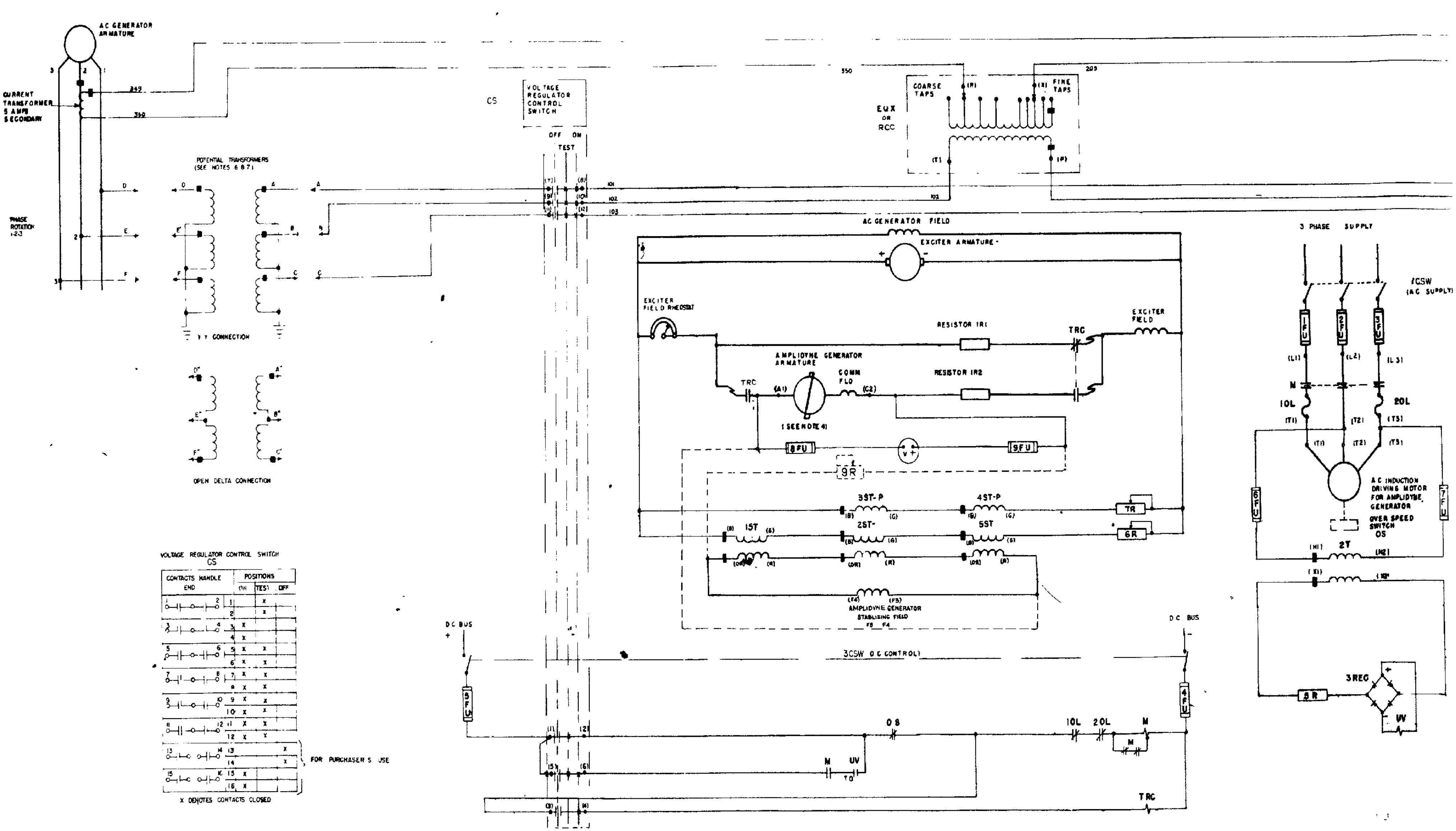



Fig. 21. Elementary diagram of a typical voltage-regulating system

reaches the extreme lower position, at which time it should operate lower limit switch LLS to de-energize timer 1TR and the driving-motor circuits. The amplidyne voltage should increase in the buck direction.

Release control relay CR and determine that raise relay RR is energized and timer 1TR and driving motor M operate to return recalibrating unit VT to the extreme raise position. Raise limit switch RLS should operate to de-energize driving motor M and timer 1TR. The amplidyne voltage should have been returned to approximately zero during this operation.

If the amplidyne voltage did not increase in the buck direction, but increased in the boost direction when control relay CR was held closed, the recalibrating unit (VT) connections may be reversed. This may be corrected by interchanging the external connections at terminals 5 and 7 of the maximum excitation limit unit terminal board. The above tests should be repeated if this change was required.

The recalibrating time may then be adjusted by use of timing relay TR. The optimum time will depend upon the particular installation involved and no general statement can be made regarding a desirable setting. However, a preliminary setting of approximately two minutes is suggested.

The initial time delay may be adjusted by use of Time Relay 2TR. Control relay CR and resistor C4R must be adjusted to close at the proper point. This adjustment may be made with relay coil CR energized from a separate a-c or d-c voltage source, or with the a-c machine in operation under loaded conditions. The a-c machine should be operated under manual control, with the regulator control switch at TEST and the amplidyne voltage adjusted to zero. The limit-control signal may then be increased to the value at which the limit should operate, and resistor C4R adjusted so that CR closes at this value. Set 1TR and 2TR as required.

#### EXCITER VOLTAGE RELAY

Where necessary, the exciter voltage relay is adjusted as follows:

The regulator is removed from service by turning the regulator control switch to the OFF position. Carefully disconnect the wires from the exciter armature to terminals 1 and 2 of the exciter voltage relay panel. Connect a test voltmeter and an auxiliary adjustable d-c supply to terminals 1 and 2 of the relay panel with the positive side of supply connected to terminal 2. Set resistor 1R so that relay CR1 operates when the d-c voltage is approximately 70 percent of the rated exciter armature voltage. Disconnect the test voltmeter and auxiliary supply and reconnect wires from the exciter armature to terminals 1 and 2 of the relay panel.

For positive exciter polarity, relay CR1 should not pick up because the current by-passes the relay coil and flows through rectifier 1REC. This is shown in Fig. 17. For negative exciter polarity relay CR1 should pick up because the current flows through the relay coil due to blocking action of rectifier 1REC.

# OPERATION

## NORMAL OPERATION

#### GENERAL

The complete voltage-regulator equipment should be placed in normal service with the a-c machine only after the control circuits, regulator, minimum excitation limit, equalizing reactor, line-drop compensator, and maximum excitation limit have been properly tested in general conformance with the previously described instructions. Final adjustment of these units may, of course, be delayed until operating experience has been obtained, but circuits which have not been thoroughly tested must not be employed with the regulator in service if the possibilities of damage to the equipment and disturbance of the system are to be avoided.

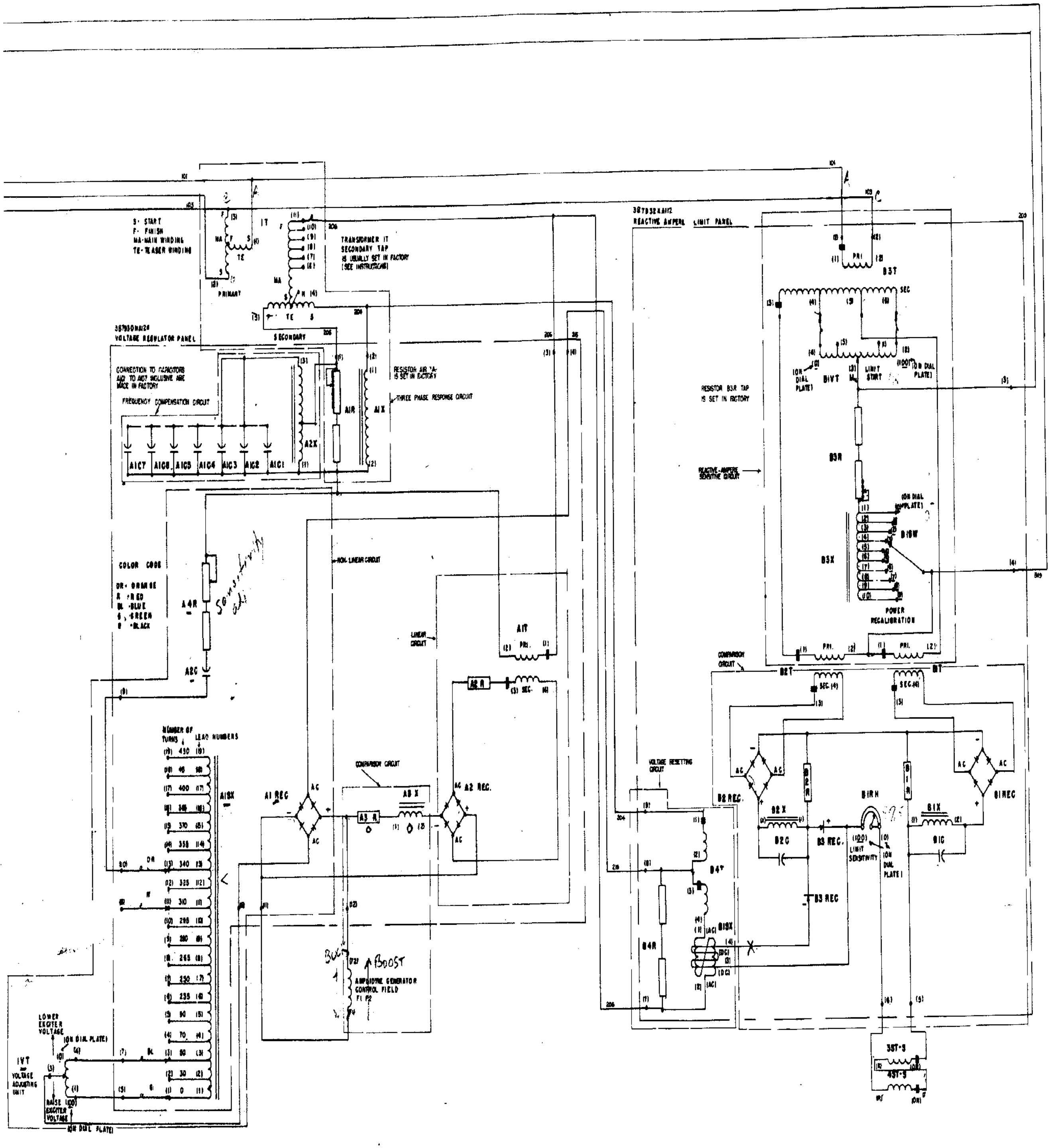
#### OPERATION WITH ATTENDED EQUIPMENT

In attended stations, the a-c machine is generally brought up to normal speed and voltage under manual control before the regulator is placed in service. Generators are frequently connected to the load or system before the regulator is used, but this is not essential since the regulator may be placed in service with the machine under any load condition and with the machine connected to or disconnected from the system.

The following procedure should be used to place the regulator in control of machine excitation:

1. With the regulator control switch at OFF or MANUAL, and with the a-c machine at normal speed, adjust the machine terminal voltage to approximately normal with the exciter-field rheostat. If the machine is operating under loaded conditions or connected to the system, this step should not be necessary.

2. Turn the regulator control switch to TEST.




NOMENCLATURE AND MATERIAL LIST

AC MOTOR - AMPLIDYNE GENERATOR SET

| | |
|---|---|
| OS | OVERSPEED SWITCH (INCLUDED ON ABOVE SET) |
| EQX | EQUALIZING REACTOR |
| 1FU, 2FU, 3FU | FUSES |
| 4FU, 5FU | FUSES |
| 6FU, 7FU | FUSES |
| 8FU, 9FU | FUSES |
| M | MAGNETIC SWITCH |
| 1OL, 2OL | OVERLOAD RELAY HEATERS |
| 3 REC | RECTIFIER |
| 1R1, 1R2 | RESISTOR |
| 9R | RESISTOR, 1800 OHMS, 200 WATT |
| 5R | RESISTOR |
| 6R, 7R | RESISTOR |
| 1ST, 2ST, 5ST | STABILIZERS |
| 3ST, 4ST | STABILIZERS |
| CS | VOLTAGE REGULATOR CONTROL SWITCH, TYPE SBI |
| 1T | TRANSFORMER |
| 2T | TRANSFORMER |
| TRC | TRANSFER CONTACTOR |
| UV | UNDERVOLTAGE RELAY |
| V | AMPLIDYNE GENERATOR VOLTMETER |
| 1VT | VOLTAGE ADJUSTING UNIT - VARIABLE TRANSFORMER |
| T.O. | TIME OPENING CONTACT |

THE FOLLOWING ITEMS PREFIXED BY LETTER "A" IN THE DEVICE DESIGNATIONS ARE LOCATED ON THE CR7930-NA100 VOLTAGE REGULATOR PANEL:

| | |
|---|---|
| A1C1 | CAPACITOR, 6 MFD OR 4 MFD |
| A1C2 | CAPACITOR, 0.25 MFD |
| A1C3 | CAPACITOR, 0.5 MFD |
| A1C4, 5, 6, 7 | CAPACITOR, 1 MFD |
| A2C | CAPACITOR, 20 MFD |
| A1R | RESISTOR (ADJUSTED IN FACTORY) |
| A2R, A3R | RESISTOR, 25 OHMS |
| A4R | RESISTOR, 50 OHMS |
| A1 REC | RECTIFIER |
| A2 REC | RECTIFIER |
| A1SX | SATURABLE REACTOR |
| A1T | TRANSFORMER |
| A1X | REACTOR |
| A2X | REACTOR |
| A3X | REACTOR |

THE FOLLOWING ITEMS PREFIXED BY LETTER "B" IN THE DEVICE DESIGNATIONS ARE LOCATED ON THE CR7932-KA100 REACTIVE-AMPERE LIMIT PANEL:

| | |
|---|---|
| B1C, B2C | CAPACITORS, 0.5 MFD |
| B1R, B2R | RESISTOR, 200 OHMS |
| B3R | RESISTOR, (ADJUSTED AT 8 OHMS) |
| B4R | RESISTOR, 15 OHMS |
| B1 REC, B2 REC | RECTIFIER |
| B3 REC | RECTIFIER |
| B1RH | RHEOSTAT, 500 OHMS |
| B1SW | TAP SWITCH |
| B1SX | SATURABLE REACTOR |
| B1T, B2T | TRANSFORMER |
| B3T | TRANSFORMER |
| B4T | TRANSFORMER |
| B1VT | VARIABLE TRANSFORMER |
| B1X, B2X | REACTOR |
| B3X | REACTOR |

NOTES

1. THE COMPENSATING AND MAIN CONTROL FIELD WINDINGS OF THE AMPLIDYNE HAVE THE SAME MAGNETIC AXIS AS THE LOAD CURRENT IN THE ARMATURE.
2. THE VOLTAGE REGULATOR CONTROL SWITCH (CS) IS PROVIDED WITH 3 POSITIONS:
   A. WITH THE SWITCH AT "OFF," THE REGULATOR IS OUT OF SERVICE.
   B. WITH THE SWITCH AT "TEST," THE REGULATOR IS ENERGIZED FOR ADJUSTMENT ONLY, AND IS NOT ACTUALLY IN SERVICE.
   C. WITH THE SWITCH AT "ON," THE REGULATOR IS IN SERVICE.
3. TRANSFORMER PRIMARIES AND SECONDARIES ARE NOT NECESSARILY SHOWN ADJACENT BUT ARE MARKED P OR S AFTER THE TRANSFORMER DESIGNATION.
4. THE AMPLIDYNE GENERATOR ARMATURE LEADS ARE MARKED A1 AND C2 AND WHEN THE GENERATOR IS RUNNING THE POLARITY OF THE LEADS WILL DEPEND UPON THE MAGNITUDE AND DIRECTION OF CURRENT FLOW THROUGH THE AMPLIDYNE CONTROL FIELDS. IF THE F1, F2 FIELD IS ENERGIZED WITH F1 TERMINAL POSITIVE, THE ARMATURE TERMINAL C2 WILL BECOME POSITIVE.
5. THE INSTANTANEOUS POLARITIES OF THE INDUCED VOLTAGES IN THE WINDINGS OF EACH TRANSFORMER, EXCEPT TRANSFORMER 1T, ARE INDICATED BY POLARITY MARKS SHOWN ON THE WINDINGS ON ELEM. DIAGRAM. THE TRANSFORMER WINDINGS MAY OR MAY NOT BE MARKED WITH POLARITY MARKS. INSTANTANEOUS POLARITIES OF INDUCED VOLTAGES IN THE WINDINGS OF TRANSFORMER 1T CAN BE DETERMINED BY REFERENCE TO START (S) AND FINISH (F) SHOWN ON ELEM. DIAGRAM.
6. THE RATIO OF THE POTENTIAL TRANSFORMERS TO BE SUCH AS TO FURNISH 115 VOLTS NOMINAL TO THE REGULATOR.
7. CONNECTIONS TO POTENTIAL TRANSFORMERS FOR Y-Y CONNECTION CONNECT A TO A', B TO B', C TO C', D TO D', E TO E', F TO F'.
   FOR OPEN DELTA CONNECTION CONNECT A TO A", B TO B", C TO C", D TO D", E TO E", F TO F".

Fig. 21

3. Adjust the amplidyne voltage to zero with the voltage-adjusting unit. If this cannot be done, do not proceed further until the trouble has been determined and eliminated.

4. Turn the regulator control switch to ON or AUTO. This will place the regulator in control of the a-c machine excitation.

5. The terminal voltage or excitation level of the a-c machine may now be adjusted with the voltage-adjusting unit as required for the normal operating schedule.

The regulator will successfully control the a-c machine excitation over the complete load range of the machine with the exciter-field rheostat at a position which will give rated machine voltage at no load without the regulator in service, or at a position which will give rated machine voltage at rated load without the regulator in service, or any intermediate position. However, additional excitation system reliability may be secured by the proper adjustment of the exciter-field rheostat when the regulator is in control of machine excitation.

For this purpose, it is recommended that immediately after the regulator has been placed in service, the field rheostat be adjusted to and maintained at a predetermined position. This position should be such that the machine excitation will be sufficient under all normal a-c machine loads to give stable operation and avoid serious operating disturbances if the excitation system should be suddenly returned to manual control through an emergency, resulting in loss of control by the regulator. It is suggested that this rheostat position be so selected that with the excitation system under manual control, it will produce from three-fourths of rated to rated a-c machine field current, with preference given to the latter value. Where the a-c machine is closely paralleled with other machines equipped with automatic voltage regulators, without minimum excitation limits, a position corresponding to the lower value may be found more desirable. Rheostats are normally supplied with a position switch which may be used in conjunction with remote indicating lights to facilitate obtaining the predetermined setting as a normal operating procedure. Operation with the rheostat at such a predetermined position should result in buck amplidyne voltage at most a-c machine loads, and as a result, under most load conditions, sudden return to manual control will actually cause an increase in excitation.

Regardless of the operating procedure employed when the regulator is in control of the a-c machine excitation, it is essential that under any sustained load condition a field-rheostat position be maintained which will give sufficient excitation in the event of sudden return to manual control, to permit stable operation in the case of a generator and to avoid other serious disturbances for all types of a-c machines.

The regulator may be removed from service and the a-c machine excitation returned to manual control under any load condition. The following procedure should be used for this purpose:

1. Adjust the amplidyne voltage to zero by use of the exciter field rheostat.

2. Turn the regulator control switch to OFF or MANUAL.

With the regulator in control, the exciter-field rheostat may be adjusted as follows to bring the amplidyne voltage to zero:

1. If the amplidyne voltage is in the boost direction, slowly reduce the rheostat resistance until the amplidyne voltage is zero. No apparent change in exciter voltage or a-c machine voltage should occur.

2. If the amplidyne voltage is in the buck direction, slowly increase the rheostat resistance. No apparent exciter or a-c machine voltage change should occur.

### OPERATION WITH UNATTENDED EQUIPMENT

**In cases where a synchronous condensor machine is located in an unattended station, the regulator may control the machine excitation throughout the entire machine starting cycle and under all operating conditions, or may be placed in control of machine excitation when the starting cycle is completed by automatic means. The regulator control switch is normally at ON or AUTO and the exciter-field rheostat should be adjusted in accordance with instructions given under "OPERATION WITH ATTENDED EQUIPMENT".**

## EXCITER POLARITY REVERSAL

### INCORRECT POLARITY

If when the a-c machine is started at any time, it is found that the exciter polarity is reversed, this condition should be corrected to obtain proper operation of the voltage-regulator equipment.

The method by which reversed exciter polarity can be corrected depends upon the circuit provided. Comments on typical circuits follow:

UNDEREXCITED REACTIVE AMPERE LIMIT CIRCUIT WITH SEPARATE POLARIZING CIRCUIT

The polarizing circuit will vary depending on the installation. Refer to the elementary diagram supplied with the equipment.

The voltage-regulator control switch usually has five positions: ON, TEST, OFF, INTER, and POLARIZE. The ON, TEST, and OFF positions are the same as previously described.

The exciter should be operated at reduced voltage with the a-c machine disconnected from the load or system. Turn the regulator control switch from OFF to INTER until the amplidyne is running. Then turn the regulator control switch to POLARIZE. The amplidyne voltage should be in the boost direction until the exciter voltage is reduced to zero and starts to build up with the proper polarity. The regulator control switch may then be turned from POLARIZE to OFF.

UNDEREXCITED REACTIVE AMPERE LIMIT CIRCUIT WITHOUT SEPARATE POLARIZING CIRCUIT

No special arrangement is provided in this case for exciter polarity reversal. However, reversal of exciter polarity can be accomplished by use of the amplidyne as follows:

Disconnect amplidyne field F1-F2 and excite it from a separate d-c source to produce boost amplidyne voltage. Turn the control switch to TEST to check the polarity of the amplidyne voltage and then quickly to ON. The exciter polarity will reverse as previously described, following which the control switch should be immediately turned to OFF. This may be done with the exciter at rest and with the exciter rheostat at a low-resistance position; or it may be done with the exciter in operation, in which case the rheostat should be at a higher-resistance position, and the control switch must be turned to OFF as soon as the exciter polarity reverses to prevent excessive exciter voltage.

After the exciter polarity is correct reconnect the amplidyne field F1-F2. The regulator may then be put in service.

### POLARITY REVERSING SWITCH

In certain applications, a separate reversing switch is provided to permit proper operation of the regulator with normal or reversed polarity of the exciter. The reversing switch interchanges the amplidyne-field connections for this purpose, and in some cases, reverses the amplidyne voltmeter and the exciter voltmeter and ammeter connections. Where instrument connections are not reversed, the instruments will read backward when the exciter is operated with reversed polarity. Caution must be exercised under these conditions, since the amplidyne voltmeter will indicate buck voltage when the amplidyne is boosting, and boost voltage when the amplidyne is bucking.

# MAINTENANCE

## STATIC EQUIPMENT

The equipment should be kept relatively clean and dry. If vibration is present, all screw-type connections should be regularly checked to determine that they are properly tightened. Normally, the static components should require no further attention.

## OTHER EQUIPMENT

Maximum excitation limit relays, motor starter, transfer contactor, control relays, and other magnetically operated contact-making devices should be regularly inspected and maintained in accordance with applicable instructions for these devices. Normally, the amplidyne will be the only unit requiring frequent inspection and this machine should be carefully maintained as described in the amplidyne instructions.

Variable-transformer contact brushes should be inspected periodically. If the brush becomes worn a new one should be installed, and since it is made of special material it should be obtained from the transformer manufacturer.

To install a new brush, loosen the locking nut, unsolder the seal, and remove the brush spring screw. Fit the new brush to the commutator by grinding with fine crocus cloth. After the brush has been fitted, carbon particles must be blown off the commutator. To insure proper operation, brush pressures must be carefully adjusted to 15 ounces for the minimum excitation limit units, and to 16 ounces for the manually operated voltage-adjusting units.

On each variable transformer or rheostat whose contact brush is to remain in a fixed position for an extended period of time (such as on the minimum exciter-voltage limit, reactive-ampere limit, or voltage-regulator panel) the shaft should be turned back and forth several times to remove any oxidation that may have formed between the brush and the winding. This should be done at least once each year. In addition where discoloration is present clean the contact surfaces with crocus cloth and reseat the brush.

Driving motors for motor-operated variable-transformers should be inspected periodically and lubricated as required. The d-c motor commutators should be kept clean, and brushes replaced when worn.

# TROUBLE SHOOTING

## GENERAL

In the event of abnormal operation of any part of the regulator equipment, the complete equipment should be immediately removed from service and carefully tested to determine the cause of the trouble. In addition, reference should be made to the instructions previously given. If any changes in connections are made, the circuits affected should be fully tested, in accordance with the applicable section of these instructions, before returning the equipment to service.

## TROUBLE-SHOOTING CHART

| Trouble | Possible Cause |
|---|---|
| Regulator operation apparently normal, except that regulator will not raise a-c machine excitation or terminal voltage to the desired value. | Maximum excitation limit control relay incorrectly, adjusted, control relay or lower relay stuck in closed position, recalibrating unit stuck in lower position, or failure of raise limit switch. |
| Regulator operation apparently normal, except that regulator will not reduce excitation to the desired value. | Underexcited reactive ampere limit incorrectly adjusted. |
| Sudden change in excitation and reduction of amplidyne voltages to zero (no control of amplidyne voltage possible with voltage-adjusting unit). | Opening of amplidyne driving-motor starter switch due to loss of control power, operation of overload relays, operation of amplidyne overspeed switch or failure of control switch. |
| Sudden increase in excitation and amplidyne boost voltage (no control of amplidyne voltage possible with voltage-adjusting unit). | Open connection in nonlinear circuit due to loose connection, failure of voltage-adjusting unit, failure of maximum-excitation recalibrating unit, or other circuit component. |
| Sudden decrease in excitation and increase in amplidyne buck voltage (no control of amplidyne voltage possible with voltage-adjusting unit). | Open connection in linear circuit due to loose connection or failure of any circuit component. |
| Sudden change in excitation (with control of amplidyne voltage possible by use of voltage-adjusting unit, but no control of excitation possible with control switch at ON). | Transfer contactor open due to coil failure, open control circuit, loss of control power, or control-switch contact failure. |
| Variation of machine power factor (with system or load power factor essentially constant). | Incorrect adjustment or failure of equalizing reactor or line-drop compensator, or operation of minimum-excitation limit. |
| Erratic fluctuations of amplidyne voltage and exciter voltage during operation of voltage-adjusting unit. | Poor contact between variable-transformer winding and brush or broken brush. |
| Failure of minimum excitation limit to function at proper point. | High resistance at brush contact in variable transformer. |
| Regulator stable at some amplidyne voltages but unstable at others. | Improper operation of amplidyne due to incorrect brush position. |

# RENEWAL PARTS

When ordering renewal parts, address the nearest Apparatus Sales Office of the General Electric Company and supply the following information:

a. Catalog number stamped on the part and a complete description of part, including its use and location.

b. Complete nameplate data appearing on the assembly of which the part is a component.

c. If possible, data on original order on which equipment was first supplied, including all numerical references.

SPECIALTY CONTROL DEPARTMENT, GENERAL ELECTRIC COMPANY, WAYNESBORO, VA.

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