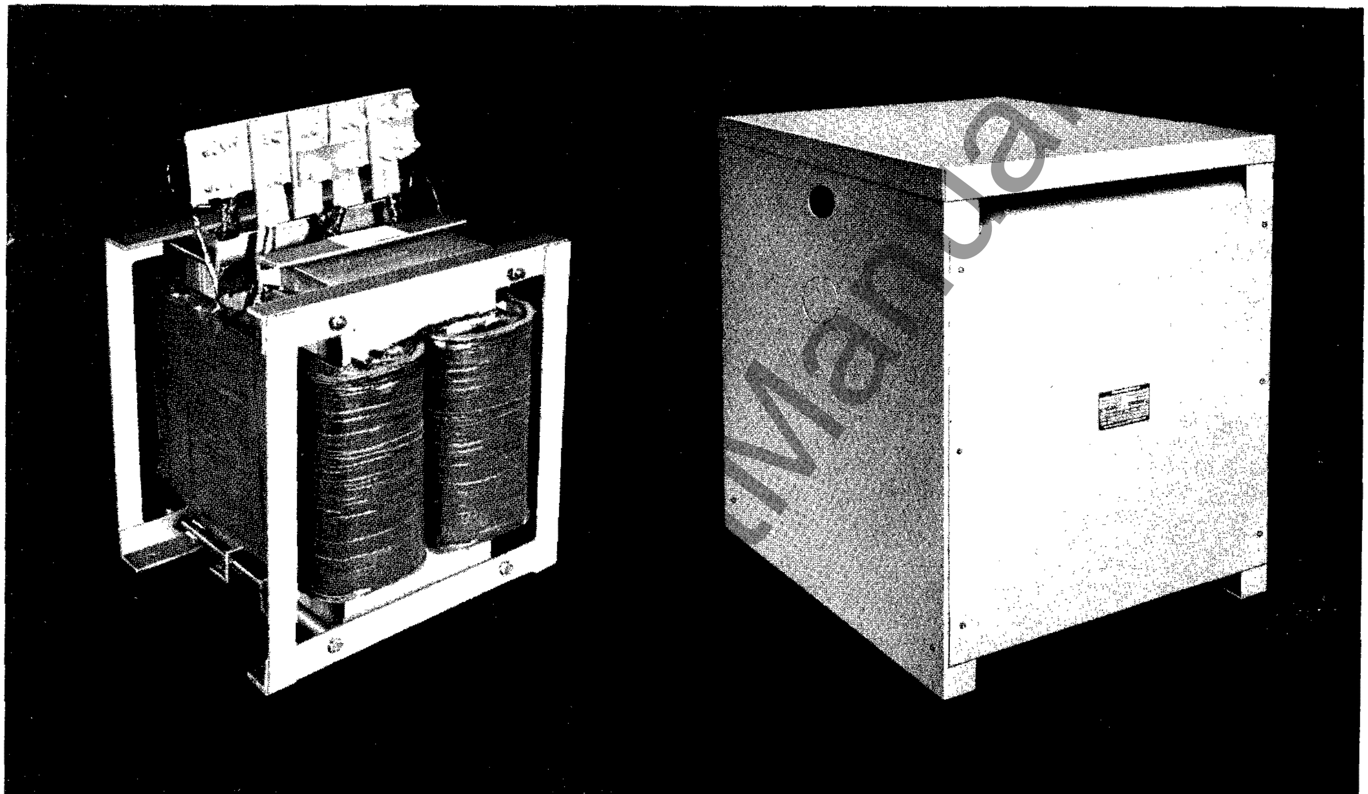
Westinghouse

Saturable Core Reactors Type SCR

Single Phase, 60 Hertz
5000 Volts and Below
150°C Rise System



Ratings

Single Phase

Kva	Volts Ac
37½ to 200	5000 and below

Application

A saturable core reactor is a variable impedance device. Its performance may be likened to a variable resistance in a dc circuit, except that its impedance is changed by controlling the magnetic saturation in an iron core by circulating a direct current. With no dc excitation, it behaves as a simple iron core reactor. With 100% dc control current applied, the core becomes saturated with dc flux, thereby reducing the reactor's impedance as far as ac is concerned. Thus a complete range of control from 1% to 100% power can be obtained in a smooth stepless manner. Large amounts of ac power can be controlled by a small amount of dc power, usually 1% or less of the ac power to be controlled. Some of the applications are listed below:

1. To control the current in a load of approximately constant resistance.

2. To maintain a constant current in a load of variable impedance.

3. As a variable loading reactor to provide the lagging component in testing of alternating current generators.

4. To control motor starting voltage when allowable increments of motor starting current are small, and when starting current must be closely controlled.

5. For speed control of motors, either direct on ac motors or through rectifiers to control armature current in dc motors.

Since saturable core reactors are a static device, and contain no moving parts, they present no maintenance or spare parts difficulties, as would appear in an induction regulator or powerstat. They do not necessitate shutting down the circuit to make voltage adjustments as in a tap changing transformer. Since without dc control current, impedance is high, they are inherently a "fail safe" device. Manual or automatic control can be located at any convenient control point, some distance from the reactor itself.

Special performance, other than that covered herein, may require a change in the kva rating of the parts used or a special core-coil configuration. The term "kva rating of load" means the kva of load which the saturable reactor is capable of controlling.

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E, D, C/2078/DB

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Design Characteristics

To fully describe possible misapplications, it is necessary to examine each characteristic and its effect upon the reactor performance:

Ac Line Voltage

The maximum no-load flux density is determined by the line voltage. Commercial practice provides a minimum of 10 percent voltage and a maximum of 90 to 95 percent voltage into a unity power factor load. If the ac line voltage is greater than that for which the reactor was designed, the core will tend to saturate with ac flux, and the reactance will thereby decrease. Under these circumstances, the dc control tends to become ineffective and the minimum voltage to the load will be larger than the normal 10 percent minimum. If the ac line voltage is greatly above the design value, the core will become saturated completely with ac flux, and the device will act as an air-core reactor. Under such a condition, the dc control will have no effect whatever. It is possible that the ac current may rise to such a magnitude as to burn out the ac coil.

If the line voltage value is lower than the design value, more than the original design value of dc control current will be required to achieve the 90 to 95 percent maximum output. In application, this means that either the thermal rating of the dc coil will be exceeded with a resultant failure, or the operating range of ac control will be limited to substantially less than the guaranteed value. In practice, reasonable performance can be anticipated if the actual line voltage is within plus or minus five percent of the design voltage.

Frequency

As with a transformer, flux density is determined by the frequency of the supply. A frequency lower than normal will cause saturation of the core at no load by the ac flux, thus rendering the control ineffective. A frequency higher than normal will decrease the no-load flux density and thereby require more than the design dc current to produce the guaranteed 90 to 95 percent maximum of line voltage at the load.

Phase

On three-phase systems, general practice is to connect the reactor in series with the line. The reactor ac design voltage must be equal to line to neutral voltage, whether the load is delta or wye connected. In such a connection, two of the three reactors share line-to-line voltage at all times. Since these voltages add vectorially, each reactor effectively sees line voltage divided by 1.732. Misapplications of saturable reactors often result from failure to observe this factor on three-phase systems. The result is that the operating voltage of the reactor will be lower than the value for which it is designed, and full output cannot be achieved.

Ac Load

Commercial practices guarantee load current control from a minimum 10 percent to maximum 100 percent for a given design. Along with the voltage guarantees of 10 percent minimum to 95 percent maximum, this provides control power from 1 to 100 percent. In this case, power is defined as the product of current and load voltage.

Saturable core reactors are intended to work into a constant impedance load of the magnitude for which they are designed. If a given reactor is used on a load lower or smaller than that for which it is designed, the control characteristics will change. For example:

A 100 kva reactor is applied to control a 75 kva load. The minimum load current will be determined by the exciting current of the reactor. The minimum current, in this case, would be equal to the exciting current of the 100 kva reactor and would be greater than the exciting current of a 75 kva reactor.

To obtain the maximum voltage and current, the required control power would be considerably less than that normally required for the 100 kva reactor controlling a 100 kva load.

A small degree of overload is permissible. The extent, however, is limited by the thermal rating of the ac and dc windings, and the availability of the dc control power. To obtain an over-rated ac current, it is necessary to drive the control winding harder than the design level. The increase in dc control current is greater in proportion than the increase in ac current.

For example, a 10 percent overload in ac current can require approximately 20 to 30 percent more than rated dc control current. If the control power source does not have this capability, the overload cannot be achieved. Due to this nonlinear relationship between ac and dc current requirements there is a very definite limit to the amount of overload that can be obtained. Consequently, the physical size of a reactor built for a short-time duty cycle does not diminish in the same ratio as would a transformer.

For a variable impedance load, the design must be based upon ac line volts and maximum load current. A constant power load, for instance, whose resistance might double during operation, will require a saturable core reactor twice the kva size indicated by the power rating of the load.

Power Factor

As previously stated, saturable core reactors are rated on the basis of the unity power factor load that they control. For a lagging power factor load, such as an induction motor, the reactor voltage adds arithmetically to the reactive voltage component of the load. For a given condition, the same degree of control cannot be obtained with a lagging power factor load as with the unity power factor load. To obtain 95 percent of the line voltage across the lagging power factor load, the voltage across the reactor must be substantially less than 31 percent of line voltage drop shown in Figure 2. This requires more dc control power. In terms of physical size, the reactor will be considerably larger.

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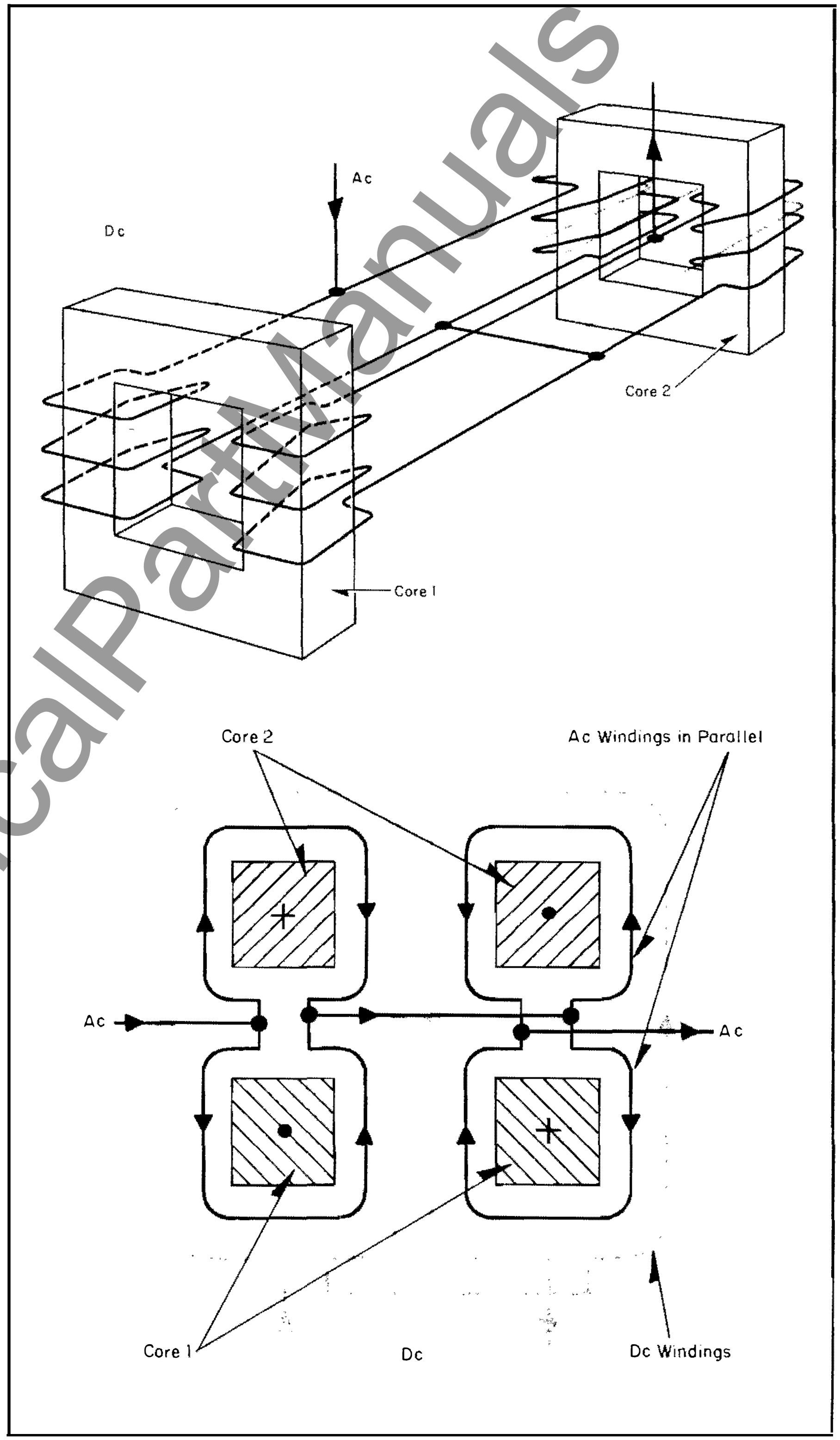
Construction

Construction of the reactor can be best described by referring to it as two transformers with the low voltage windings connected in parallel as the ac winding of the reactor and the high voltage windings connected in series as the dc control winding of the reactor. By connecting the ac power windings in a bucking configuration, the ac voltage induced in the two dc windings will cancel out. By using the tandem core type construction the entire core is active, carrying both ac and dc flux and mutual inductance of the coils is kept high. This system provides the maximum control range obtainable in a saturable core reactor.

The same basic principle of close magnetic coupling is used throughout the range of applications in saturable core reactor designs by Westinghouse, whether dry type or oil-filled, or whether small or large in physical size and power handling capability.



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Operation

The most unusual characteristic of the saturable core reactor is that the iron core carries both ac and dc fluxes at the same time. As the direct current is increased, the dc flux begins to saturate the core causing the reactance of the ac circuit to decrease. Conversely, decreasing the direct current increases the ac reactance until the point is reached where the direct current is zero and the device behaves simply as an ac reactor. The characteristics of this type of reactor are shown in Figure 3.

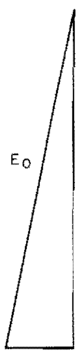

Figure 1

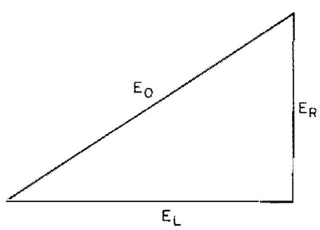

Figure 2

The vector diagram shown indicates the voltage relationship of the reactor and the load in a typical constant impedance circuit.

Figure 1 shows the reactor with no control current applied. Here, nearly 99 percent of the applied voltage E_o is developed across the reactor, leaving 10 percent voltage at the load E_L.

In Figure 2, only 31 percent of applied voltage E_o is developed across the reactor due to the saturation of the core with dc flux. This leaves approximately 95 percent of the applied voltage at the load E_L. In larger size units above 250 kva, as little as 15 percent of the applied voltage is developed across the reactor, thereby leaving 99 percent of the applied voltage at the load (see Figure 4).

The above mentioned values are based on performance with a sinusoidal wave form applied. Results in actual application may vary, since it is nearly impossible to determine the performance with a distorted wave form applied.

In a usual application, the reactor is in series with a constant load impedance which is of the same general order of magnitude as the reactor impedance when fully saturated. By decreasing the dc control current, the reactor impedance can be varied by a ratio of approximately 20:1.

By examining the vector diagrams, it can be seen that saturable core reactors introduce a lagging power factor condition into the circuit. At full load condition, this will be of a minor nature (approximately .95 pf). At decreasing values of dc control current, the angle of lag becomes greater, but, since the load current becomes smaller, the effect of the poorer power factor is less important in the system.

Due to the inherent characteristics of an inductive circuit to oppose any change in circuit conditions, there is a definite time lag between the change in dc control current and the change in ac impedance of the reactor. This is primarily due to the delay in build-up and decay of the dc magnetic field. This time lag can be decreased by the following methods:

1. Connecting the ac line coils as well as the dc control coils in series.

2. "Forcing" of the dc circuit by applying overvoltage during the time of change.

3. By keeping the ratio of dc turns to dc resistance at a low value and by inserting additional external dc resistances in the control circuit.

Generally, the standard configuration with ac coils connected in parallel provides a time constant suitable for most applications. Special applications such as in motor control or precipitation control require faster response. Inherently faster response requires special reactor and control circuit design to include larger amounts of control power and protection of the control circuit against high induced second harmonic ac voltages in the control circuit.

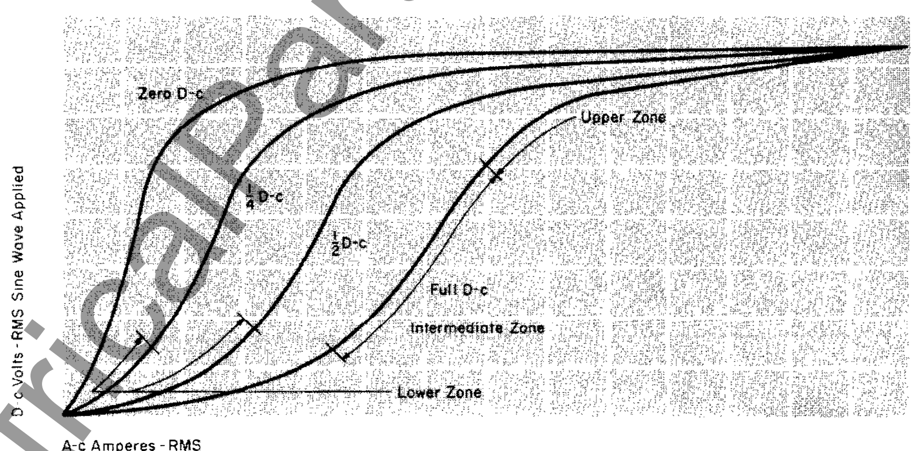

Figure 3: Ac Saturation Curves

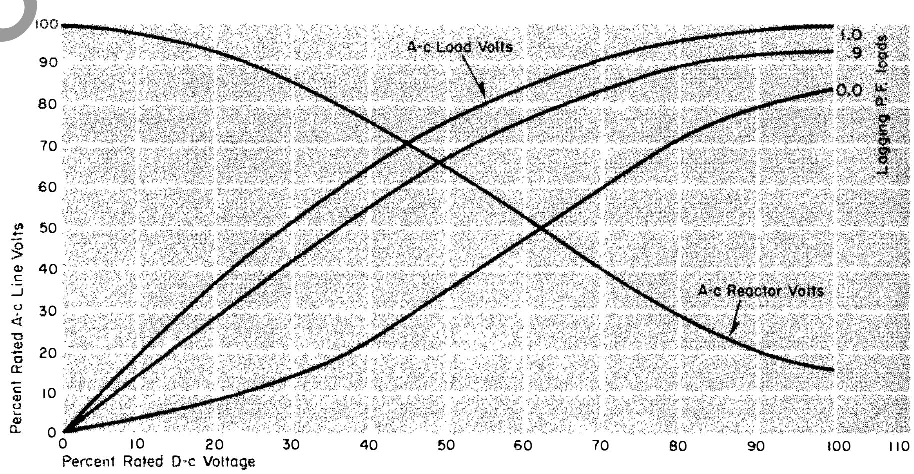

Figure 4: Load Curve Using Saturable Core Reactor Control

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Class H Insulation 150°C Rise

Selection Factors

The saturable core reactor can generally be used in any ac circuit in which a variable impedance is desired. Factors limiting its use are principally economic. First of all, a variable dc excitation source must be provided for control. This requires expense additional to the cost of the reactor itself. Second, the cost of saturable core reactors is usually unfavorable as compared to other means of control when power in excess of 2500 kva is to be controlled.

Selecting and applying SCR reactors requires a thorough knowledge of the circuit to be controlled, since the reactor becomes an integral part of the system it is controlling.

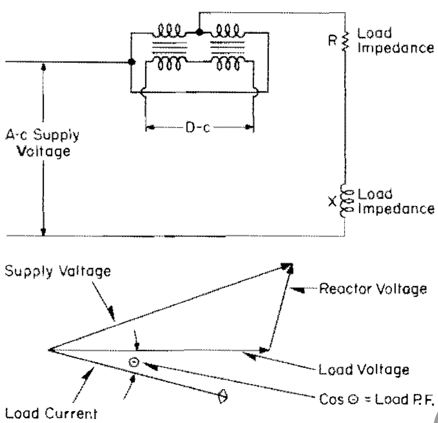

Figure 5: Vector diagram of reactor in series for varing current.

From the vector diagram (Figure 5) it can be seen that the power factor of the load should be as near unity (100%) as possible to provide proper performance. If the load has a power factor less than 100%, it is apparent that the load voltage with a given reactor will decrease as the power factor angle increases. This can be compensated by overdesign of the reactor, but is generally not practical or economic. In any case, competent design engineers should be consulted on applications where the power factor of the system is something less than 100%. As an example, a reactor designed to control an 85% power factor load over the same range of control as a similar unit for 100% power factor load, can be as much as twice the physical size and cost of the 100% power factor unit. Extreme caution should be exercised in trying to compensate low power factor conditions with capacitors, as resonant circuits could be set up so as to cause difficulty.

Saturable core reactors used on a 3 phase system should be rated at line voltage divided by 1.732. This is due to the fact that reactors are normally placed in series with the line, and share the voltage as though the load were wye connected. This is true even though the load may be connected in delta. Reactors can be inserted in the legs of a delta system, but this is usually less convenient than a series line connection. If a 240 volt rated reactor were placed in a 3 phase system of 240 volts, the ac voltage impressed across the reactor would be only 139 volts and full control could never be obtained.

Another application which may be illustrated by the same circuit diagram is a situation in which a saturable core reactor is connected in series with the load for the purpose of maintaining a constant current through a load of variable impedance. This application generally requires a relatively large reactor because the reactor has to be of sufficient size to absorb nearly full-line voltage and at the same time, carry full-load current. Another useful application of the saturable core reactor is loading a circuit by means of shunt connection. One such application is to supply the quadrature component of a load for testing alternators. In this service, the reactor is called upon to carry full-load current at full-load voltage. The circuit arrangement is shown below:

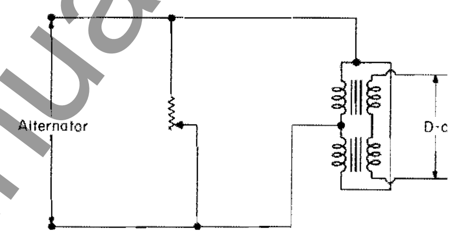

Figure 6: Current arrangement for testing alternators.

Normal Dc Excitation Requirements

Standard dc control range is 80 to 95 volts.

The values shown below are for normal duty requirements and will produce a minimum of 95% of applied voltage at the load.

In 3 phase applications dc coils may be arranged for either series or parallel operation from a common source.

Kva	Dc Watts
37½	400
50	450
75	650
100	700
167	800
200	1250

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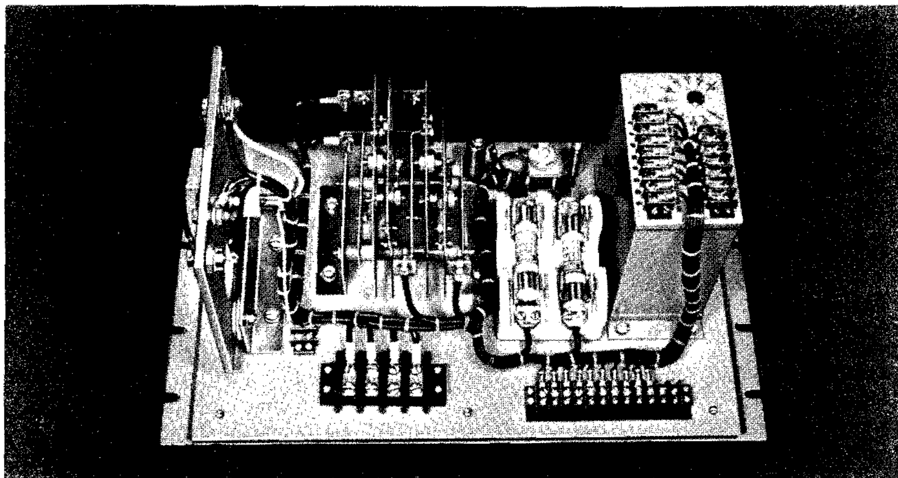
Saturable Reactor Driver



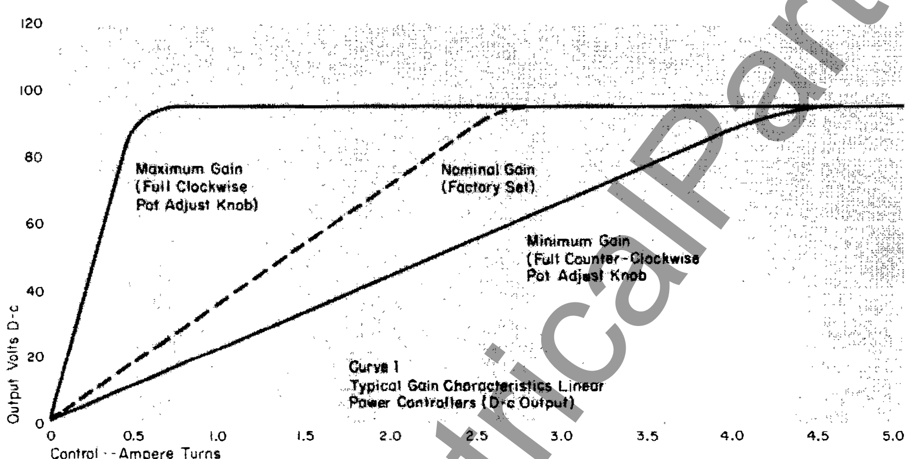


Figure 7

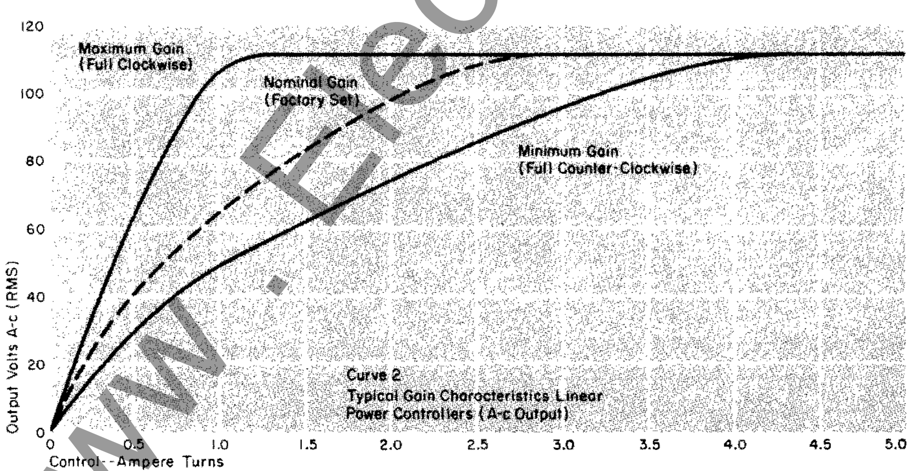


Figure 8

Driver units to control saturable core reactors are available with the reactor units. These drives employ controlled rectifier elements. Operating from a 120 volt, 60 hertz supply, the standard units deliver output voltages of 0-95 volts dc. Output power ratings are conservatively based on continuous operation in a 50°C (122°F) ambient temperature. All units may be operated at temperature up to 85°C (185°F) with suitable derating. Units may be operated at full current ratings into resistive or inductive loads. There is no need to match reactor ratings with driver ratings, as is the case with power magnetic amplifiers.

Efficiencies range from greater than 99 percent for the higher power units to a minimum of 97 percent for the 400 watt controllers.

Control sensitivity of all units is approximately 5 milliwatts for a response time constant of 16 milliseconds. Input dc control currents from as low as 0-0.80 milliamperes to as large as 0-80 milliamperes can be used to give full proportional control of output voltage. Integral surge suppressors limit normal line transients to the working voltage ratings of other installed semiconductor components.

Flexible Settings

Control Ampere-Turns

The value of ampere-turns of dc controls current required to vary the output voltage from 0 to rated output is approximately:

Maximum gain setting . . . . 1.0 A-T
Minimum gain setting. . . . . .4.0 A-T
Nominal gain setting . . . . .2.5 A-T
(Factory adjusted)

Gain Adjustment

The gain adjustment (screwdriver control on the driver can) provides approximately a 4:1 variation of gain.

Bias Adjustment

The bias control (screwdriver adjustment on the driver can) provides an internal negative control signal adjustable from 0 to 2.5 A-T. This control is factory set to give zero output voltage with zero control current input.

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Control Characteristics

Three separate and isolated control windings are provided for signal mixing or for operation from different levels of control currents. The windings are designed to accept directly the standard electronic controller output currents of 0 to 5 ma, 4 to 20 ma, or 10 to 50 ma. All units regardless of power rating use the same magnetic amplifier driver and thus exhibit the same control characteristics. Control winding information is summarized below. Typical control characteristics for dc and ac outputs are shown in curves (Figures 7 and 8).

Terminal numbers	7-8	9-10	11-12
Turns	500	125	50
Current for full control, nominal gain (milliamps)	5	20	50
Winding resistance (ohms)	120	10	1.5
Max. rated currents (milliamps)	50	200	500
Minimum external resistance for 1-cycle response time (ohms)	2500	160	25

Dimensions and Weights

For Ratings 37½ to 200 Kva: Load Voltage Control is 95 to 10 Percent of Supply Voltage②

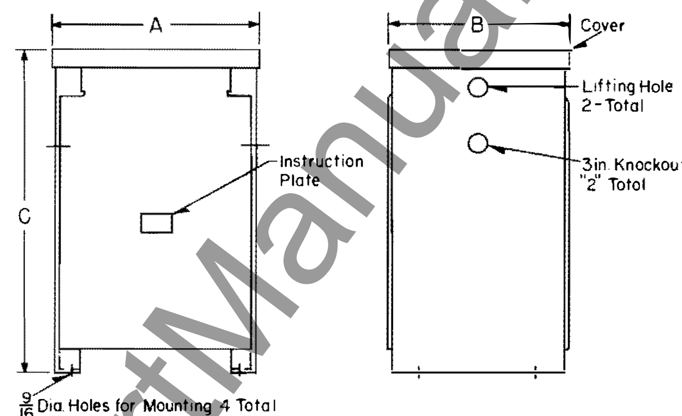

Figure 9

Front View **Top View**

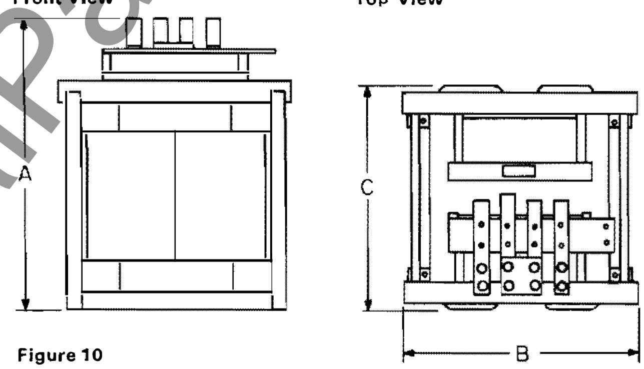

Figure 10

② Load voltage is continuously variable over the range indicated. With fixed resistance load, current will vary proportionately resulting in control down to 10 percent current or 1 percent power.

Kva Rating of Load	Losses at Full Load: Watts		Approx. Overall Dimensions: Inches			Approx. Wt.: Lbs.	Fig. No.
	Ac	Dc	A	B	C		
Reactors in NEMA 1 Drip-Proof Enclosure 600 Volts Ac and Below							
37½	485	400	38	21	19	450	9
50	600	450	38	21	19	500	9
75	950	650	42	21	23	700	9
100	1100	700	42	21	23	900	9
167	1825	800	46	23	28	1200	9
200	2150	1250	46	23	28	1500	9
Open Type Construction 600 Volts Ac and Below							
37½	485	400	21	16	15	350	10
50	600	450	22	16	15	400	10
75	950	650	25	19	16	600	10
100	1100	700	26	19	19	800	10
167	1825	800	28	21	21	1100	10
200	2150	1250	28	21	25	1400	10

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Further Information

Prices: Price List 46-927
Saturable core reactors are also available in sizes above 200 kva through 5000 kva single phase in voltages up through 15000 volts ac. They have maximum ac line currents of 3000 amperes.

Information regarding prices, weights and dimensions may be obtained from Westinghouse, Power Transformer Division.

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