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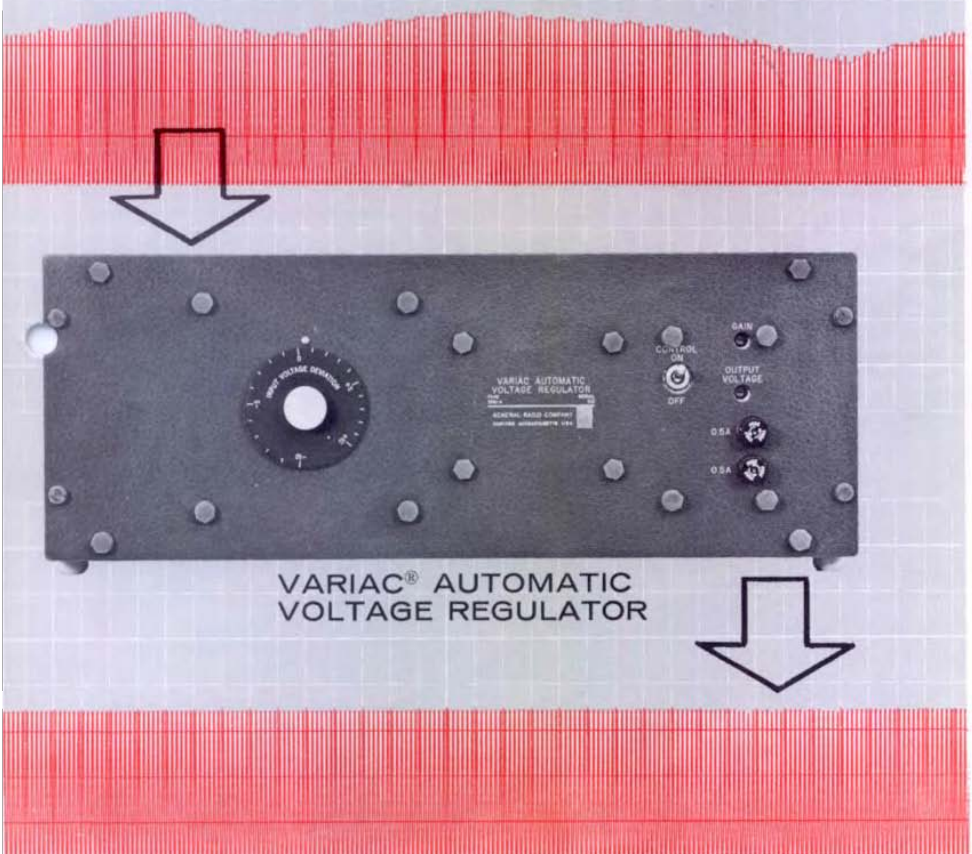
Experimenter

High Performance Line-Voltage Regulators



VARIAC® AUTOMATIC VOLTAGE REGULATOR

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Figure 1. General Radio's three new Variac® Automatic Voltage Regulators: *(above)* Type 1581-A, a 6-kVA unit, shown for bench mounting; *(right, top)* its militarized counterpart, Type 1571-A; and *(right, bottom)* a 10-kVA commercial unit, Type 1582-A, shown without cabinet, for rack mounting.

IN THIS ISSUE

A NEW SERIES OF HIGH-PERFORMANCE LINE-VOLTAGE REGULATORS

GR's Type 1570 series of automatic line-voltage regulators has won wide acceptance since its introduction 11 years ago. Now a new series, including 26 different models, makes its debut. Major improvements in the new regulators: all-solid-state design, faster response, wider line-voltage ranges, increased power-handling capacity, and availability of all models in 400-cycle versions.

Regulated voltage is a necessity wherever voltage-sensitive elements are present — for instance, in many laboratory calibrations and measurements, industrial processes, and test programs. For such applications, as well as for more routine work in places where line-voltage regulation is poor, the automatic line-voltage regulator is indispensable. By regulation of the ac line, a number of critical load voltages — ac or dc — can be controlled with a single instrument.

CONSIDERATIONS IN VOLTAGE REGULATION

Three fundamental characteristics of ac line voltage are its frequency, magnitude, and waveform. Most commercial power systems hold line frequency within very close tolerance, and frequency instability is seldom a serious problem. Magnitude is the most critical parameter of line voltage, the one most generally subject to deviation, and the *raison d'être* for the line-voltage regulator. Although the primary function of the regulator is to stabilize the magnitude of the voltage, it is desirable that it do this without distorting the waveform.

An obvious measure of the performance of a line-voltage regulator is the accuracy with which it holds the magnitude of the output voltage to the nominal value. Accuracy can be specified as a long-term figure, if we disregard brief voltage fluctuations that exceed the regulator's response capability and thus pass from input to output undiminished. The ability of a regulator to react to very brief fluctuations is related to its response speed, another important measure of a regulator's performance.

Magnitude of an ac voltage requires further definition as peak, average, or root-mean-square, and the line-voltage regulator must choose one of these values to hold constant. Most regulators stabilize the rms or average magnitude, because these are the values most loads respond to.

What the regulator does to the waveform of the voltage it regulates is significant wherever the regulator and the load respond to different values of voltage magnitude (as, for instance, where an rms regulator is regulating voltage into a peak-responding device).

Another possible source of trouble is the power factor of the load. Specifications for many regulators assume a resistive load (power factor = 1.0), and departures from this condition can cause these regulators to shift output voltage by an amount well in excess of the stated accuracy.

Accuracy, response speed, introduced distortion, vulnerability to load power-factor — these, plus the practical factors of cost, reliability, and size, are the chief factors in the selection of a regulator.

TYPES OF LINE-VOLTAGE REGULATORS

There are three principal types of line-voltage regulators: electronic, magnetic, and electromechanical (servo). All operate by sensing the output voltage and adding voltage to, or subtracting it from, the input to restore the output to its nominal value.

The Electronic Regulator

The electronic (amplifier-type) regulator approaches the ultimate in ac-voltage-regulation devices. The regulated output voltage is continuously compared with a pure-sine-wave reference, and any errors are electronically removed. Such a regulator can actually remove distortion on the incoming line and can reduce, if not completely eliminate, transients on the regulated output voltage. Disadvantages are a sensitivity to line frequency and load power factor, modest power-handling capacities, and high cost per kVA.

The Magnetic Regulator

The several types of magnetic regulators are characterized by moderate correction speed, good to excellent reliability, a tendency to introduce distortion in the voltage waveform, and sensitivity to load current, power factor, and line frequency. Magnetic regulators also are usually quite heavy.

One type of magnetic regulator — the ferroresonant — is completely passive and boasts the highest reliability and the lowest cost. It is inherently short-circuit-proof, which adds to its reliability but which also severely limits its ability to handle large starting currents. Its output voltage level is factory set and cannot be changed.

Another type, the saturable-reactor regulator, uses an electronic feedback loop to achieve higher performance than the ferroresonant type. Harmonic filters are often included to reduce the considerable distortion introduced by the regulator.

A third type of magnetic regulator uses silicon-controlled rectifiers in an electronic switching scheme. Unlike other magnetic types, the SCR regulator operates satisfactorily with load power factors from 1.0 to 0 lagging, although its performance is not specified for leading power factors. The distortion introduced by this type of regulator characteristically exhibits itself as a large change in the peak value of the output voltage, which may persist independently of the regulator's normal rms- or average-correcting action.

Electromechanical Regulators

The electromechanical line-voltage regulator combines the power-handling capabilities of a motor-driven variable autotransformer with the fast response and accuracy of an electronic feedback loop. This type of regulator introduces no distortion, is totally unaffected by changes in load power factor from 0 leading to 0 lagging, and is insensitive to load current. With proper design, it can hold output voltage constant in the face of wide swings of line frequency, a factor important in the regulation of voltage from unstable sources, such as emergency generators. On a kVA-per-pound basis, it is the lightest of all automatic voltage regulators. It is well suited for applications involving heavy starting currents and can safely withstand transient overloads of up to 10 times the rated output current. Electromechanical regulators are practical over a wide range of power ratings, from one to hundreds of kVA.

THE NEW VARIAC® AUTOMATIC VOLTAGE REGULATORS

General Radio has developed an entirely new line of electromechanical regulators, consisting of 26 electrically different models, with militarized versions and several mounting options running the total to 114. Of the 26 electrically different models, 13 are for 60-cycle operation and the other 13 are designed to regulate 400-cycle voltage (with no 60-cycle power required). Each group of 13 regulators includes four 115-volt units, six 230-volt units, and three 460-volt units, covering an over-all range of power-handling capacity from 2 to 20 kVA.

These regulators can also be used in combination on three-phase systems.

Principles of Operation

The diagram of Figure 2 shows how these line-voltage regulators work. A voltage deviation at the output activates a servo feedback loop, consisting of a control unit, a two-phase motor, a VARIAC® autotransformer, and a step-down buck-boost transformer. The deviation is thus translated into a correction voltage that is added to or subtracted from the input to restore the regulated voltage to its correct value.

Control Unit

The solid-state control unit converts any small deviation in output voltage into a proportional electrical signal to drive the motor. The deviation is first sensed by an rms detector, whose dc output, after filtering, is compared with a constant 9-volt reference derived from a Zener diode. The resultant difference voltage is chopped into an ac error signal whose magnitude is propor-

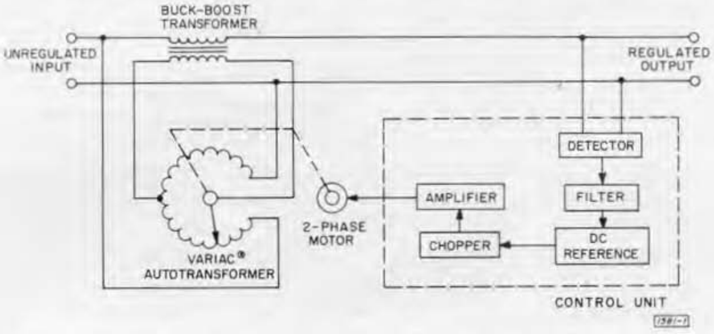

Figure 2. An elementary diagram of General Radio's electromechanical regulator.

Figure 3. Rear view of a regulator with dust cover removed and etched board swung out for access to components and wiring.

tional to the output voltage deviation and whose phase is determined by the direction of this deviation. A solid-state amplifier converts the small ac error signal into the large ac voltage required by the motor.

An important feature of the General Radio regulator — and one that distinguishes it from most other electromechanical units — is the completely proportional control system. That is, the control unit continuously feeds a proportional correcting voltage to the motor. This technique helps give these regulators greater accuracy and higher response speed than are possible with a simple on-off motor control.

Motor and Transformer Circuits

The ac error signal from the control unit drives a two-phase servo motor, with the phase and magnitude determining the direction of rotation and the speed of the motor, respectively. The motor used in all models is built to the rigid specifications demanded for the militarized units (for instance, the stator is epoxy encapsulated). The low-inertia rotor contributes importantly to the excellent response and accuracy of the regulator.

The motor drives a VARIAC® autotransformer through a heavy-duty, instrument-type gear train. The autotransformer is positioned either side of a center tap (depending on the sense of the correction) by an amount proportional to the output-voltage deviation. All autotransformers are ball-bearing models with take-off brushes that are designed for the unusual demands imposed by regulator service.

The autotransformer output voltage is stepped down by a buck-boost transformer. Thus the full adjustment range of the autotransformer can be used to produce the relatively narrow range of correction voltage, and the current rating of the autotransformer is effectively multiplied. The phase of the voltage applied to the buck-boost transformer depends on the position of the autotransformer brush with respect to the center tap and determines whether this correcting voltage is added to or subtracted from the line voltage.

Remote Operation

All regulators can be easily connected for remote sensing, detection, or programming. Remote sensing at the load corrects for the voltage drop on the line between the regulator and the load. Remote detection permits use of an external detector to regulate dc voltage or a characteristic of ac voltage other than rms. For remote programming, the regulated output voltage

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level can be adjusted by an external variable resistance.

Physical Characteristics

All regulators are single, self-contained units seven inches high and 19 inches wide. The commercial models are available for bench, rack, or wall mounting. (A fourth option allows the customer to buy a rack model without cabinet, at a saving in cost.)

Militarized models are designed to meet or exceed the general requirements of specifications MIL-E-4158B and MIL-E-16400C. They are constructed on seven-inch U-shaped extruded aluminum channel to meet military shock and vibration requirements and are supplied for relay-rack installation.

The mechanical design, based on a modular approach, provides easy access to all components. Removal of six screws permits the dust cover to be removed and the etched board to be swung out (see Figure 3), exposing every wiring connection and component.

The two screwdriver adjustments (gain and output voltage), the manual-automatic control switch, and the control-unit fuses are all accessible at the front panel. Also on the front panel is a dial that indicates the percent difference between input and output voltages. This dial also permits manual voltage adjustment when the front-panel switch is thrown to MANUAL. There are no internal operating controls or adjustments.

Performance

The introduction of General Radio's new automatic line-voltage regulators establishes the electromechanical regulator as comparable in performance to magnetic types, but lower in cost.

Accuracy and response speed are the best available in electromechanical regulators. Accuracy is 0.25 or 0.5 percent, depending on model, and is independent of load current, power factor, and frequency and voltage changes in the line. Response speed is 20 to 160 volts per second, depending on model, and is comparable to the speed of magnetic regulators of equivalent ratings. Figure 4 shows the actual performance of regulators responding to step changes in line voltage.

No waveform distortion is introduced by these regulators, and transient over-

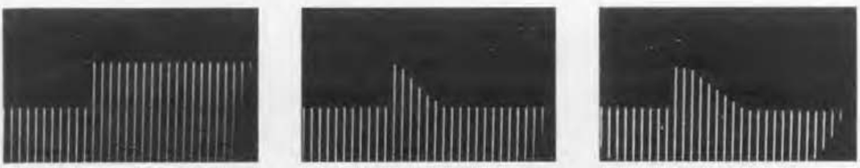

Figure 4. Oscillograms showing response of two of the new regulators to a 2% step change in line voltage. *Left,* the unregulated input; *center,* the response of a 6-kVA model; *right,* the response of a 10-kVA model.

loads up to 10 times the nominal ratings can be handled safely.

The 114 variations of GR's new family of regulators span wide ranges of voltage, correction range, frequency, and power rating, with several mounting options. The use of modular construction and interchangeable parts, moreover, suggests a further proliferation to meet special customer requirements.

— C. E. MILLER

Acknowledgment

The author wishes to acknowledge the work of M. J. Fitzmorris, who was associated with the development of these regulators in the early stages of the project.

COMMERCIAL MODELS

Regulators are available in the following ranges for either 400-cycle or 60-cycle service. By means of a change in connections, 60-cycle models can cover the range of 50 to 60 c/s, with only a slight reduction in correction range. Both Type 1581-A and Type 1582-A can be supplied for bench, wall, or rack mounting, or without cabinet.

TYPE 1581-A

*Output Volts**	*Correction Range %*	*kVA*	*Accuracy (% of output voltage)*
115	90 to 110	5.8	0.25
115	82 to 124	2.9	0.5
230	95 to 105	9.2	0.25
230	90 to 110	4.6	0.25
230	82 to 124	2.3	0.5

*Adjustable, ± 10%.

PRICES: from $495 to $575.

TYPE 1582-A is available in the same ranges of operation but has approximately twice the kVA rating. Additional models, connected for 460-volt service, have kVA ratings approximately ¾ those for 230-volt service.

PRICES: from $555 to $635.

MILITARIZED MODELS

TYPE 1571-A is a militarized version of the Type 1581-A. It is designed to meet the requirements of MIL-E-4158B and MIL-E-16400C.

PRICES: $650 for 60-cycle service
$695 for 400-cycle service

For Complete Listings with Specifications, Consult General Radio Catalog S, pages 223 to 226, or Call or Write Your Nearest GR Sales Office.

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