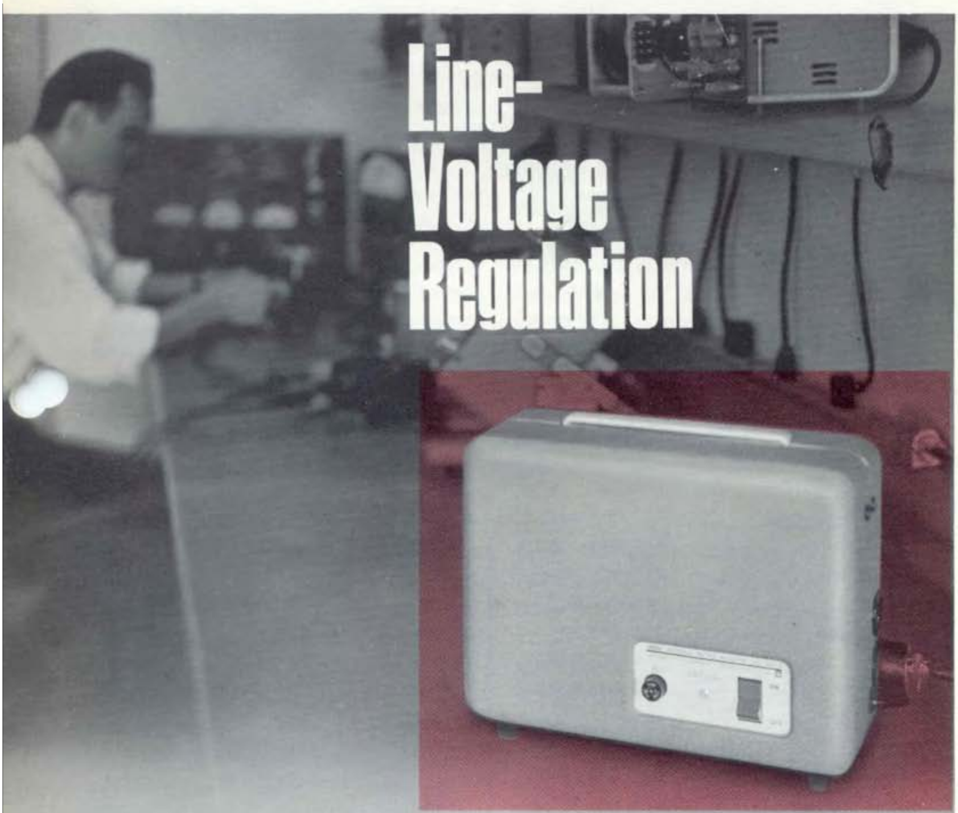
THE GENERAL RADIO

Experimenter



- CONSIDERATIONS IN CHOOSING A VOLTAGE REGULATOR
- AN INEXPENSIVE 1-kVA REGULATOR
- A NEW THREE-PHASE REGULATOR

VOLUME 41 · NUMBER 10 / OCTOBER 1967

Volume 41 • No. 10
October 1967

the GR Experimenter

Published monthly by the General Radio Company

THIS ISSUE

CONSIDERATIONS IN THE CHOICE OF A LINE-VOLTAGE REGULATOR

A line-voltage regulator seems a simple enough device, designed to perform a simple task. The temptation is to compare different models merely by looking at one or two of the more obvious specifications. The "simple task," however, is complicated by a number of factors, especially including the characteristics of the load connected to the regulator output. The following article discusses some of the more subtle aspects of this widely used and widely needed family of instruments.

It is widely appreciated that line voltage, as delivered by the public utility, varies in amplitude by at least a few percent (the most widely followed standard is 120 volts ±5%) and that much wider swings are likely when the line is subject to wide load variations. It is also fairly well understood that line voltage that is too high or too low — even by as little as a few volts — can decrease the efficiency or shorten the life of many electric devices and can introduce significant errors in measurements made with electrical instruments. For these reasons, many laboratories and manufacturers use automatic line-voltage regulators to hold the line voltage to within a few tenths of a volt or better of a nominal value.

At first glance, the criteria for a voltage regulator seem to be simple, chiefly including the speed with which the regulator can act to restore voltage to a nominal value and the accuracy with which it re-establishes this nominal value. Actually, there is a great deal more involved, and the engineer looking for a line-voltage regulator must be willing to read all the specifications and to assess their impact on one another and on his problem.

Distortion

Take, for instance, the matter of distortion. To appreciate the significance of distortion in a voltage regulator, one must keep in mind that a line-voltage regulator must be designed to detect and regulate a specific characteristic of ac voltage. (The root-mean-square characteristic is usually chosen as the best compromise.) That value may or may not correspond to the needs of the devices operated from the regulator. A lightly loaded capacitive-input dc power supply responds to peak voltage; thermal devices respond to rms; heavily loaded capacitive-input as well as inductive-input power supplies and mechanical systems generally respond to the average value of voltage. A relay rack full of instruments or even a single instrument may well include devices or power supplies with all three response characteristics. The less distortion introduced by the regulator, the better the regulator's ability to track all three characteristics of the voltage while regulating only one.

Thus, the stated accuracy of a regulator must be interpreted in the light of the distortion specification. A ±0.1% accuracy statement usually means that the regulator will hold the rms voltage within ±0.1% of nominal. But if this specification is accompanied by a 3% distortion figure, peak-responding devices operating from the regulator may be faced with as much as a 3% change in input voltage, and an average-responding device may encounter as much as a 1% variation, or 30 or 10 times the maximum error implied by the specification.

The electromechanical regulator, utilizing the continuously adjustable autotransformer, introduces no distortion; in contrast, all magnetic regulators available at present introduce distortion in the process of regulating. Furthermore, the distortion components generated are often at high frequencies, i.e. some portion of the output waveform has a fast rise time, which may raise havoc with some digital equipment.

Overshoot

The response characteristics of voltage regulators frequently display some overshoot, the amount being a function of the degree of damping in the regulator. Although one's instincts might suggest that the optimum amount of overshoot is no overshoot at all, some overshoot usually exists as a byproduct of a fast response characteristic. Moreover, the effect of overshoot can be positive — as, for instance, when the overshoot compensates in part for the effects of a voltage transient on the devices powered from the regulator. There is a delicate balance here; too much overshoot can initiate oscillation and mean an intolerable delay in returning voltage to its nominal value.

Overshoot introduces a problem in the specifying of response time. When can a voltage transient be said to be corrected — when the voltage first comes within specified accuracy limits (even though overshoot subsequently takes it outside those limits) or when the voltage is within the accuracy limits to stay? Common practice ignores the overshoot, but the canny buyer will do otherwise.

kVA Ratings and Overloads

Load rating is another innocent-looking specification that can be misleading. Not that a 1-kVA regulator won't handle 1 kVA; it almost certainly will, but starting surges can momentarily overload a regulator that is otherwise adequately rated. Electromechanical regulators using autotransformers can readily withstand 1000-percent short-term overloads. But magnetic units typically use fast-blow fuses or disabling circuits to protect components from damage, and such fast-acting protective devices can prevent measurements of start-up times of servo or induction motors, high-powered, keyed, or pulsed equipment, etc. In tests at GR, a 1-kVA, 120-volt magnetic regulator, which one would normally expect to control a kilowatt comfortably, blew fuses repeatedly when a 1000-watt incandescent bulb was connected to its output.

High starting surges must be expected in the turn-on of incandescent lamps, induction motors, and transformer-equipped devices.

Response Speed

The time required for a regulator to restore proper output voltage after a line or load disturbance is another important characteristic. Since the correction proceeds essentially exponentially in a magnetic regulator and linearly in an electromechanical regulator, each type expresses response speed or correction time differently. For electromechanical regulators, response speed or correction time has traditionally been stated in volts per second or seconds per volt, respectively, with the given values based on the full slew speed of the servo system. Of course, The system requires some small amount of time to attain this speed, and a more accurate expression for correction time would therefore be in terms of a fixed time plus a time proportional to the magnitude of the correction. We have adopted this method of expression in the specifications for the line-voltage regulators introduced later in this issue.

For a magnetic regulator, the time constant is specified — i.e., the time taken to correct 63 percent of the error. Usually from two to four time constants are required to correct an input disturbance to within the specified accuracy.

How can these two different expressions be compared? Obviously, one must know the magnitude of the input disturbance before any direct comparison can be made. In general, for the usually encountered small but sudden voltage steps superposed on larger but slower voltage excursions, the response speeds of the electromechanical and magnetic regulators are approximately the same. For the less usual case of 10- to 20-percent instantaneous line-voltage steps, neither regulator is very fast, but the magnetic type is definitely the faster of the two.

Load Effects

Common conception has the line-voltage regulator accepting varying voltage at its input and presenting a constant voltage at its output. Changes in load or power factor, as well as the surge effects discussed earlier, can easily create voltage changes as great as those on the unregulated power line. All the magnetic regulators tested at GR were significantly affected by moderate load changes, resulting in a recovery time comparable to that required to correct a large input transient even though the input voltage remained constant. Furthermore, the waveform was modified, changing the peak and average values of output voltage even though the rms level was maintained.

The electromechanical regulator, on the other hand, is little affected by load changes, because of the low output impedance and close coupling between input and output of the autotransformer.

Line-Frequency Effects

The power company generally holds its line frequency very close to the nominal value, and what slight deviations there are do not normally affect regulator performance. In the field, however, a portable generator may well be *off* 50 or 60 Hz more often than it is on, and therein lies a major source of distortion and poor voltage regulation. Line-frequency shifts pose a particular problem for the magnetic regulator, and manufacturers of these caution that the stated performance specifications apply only *at* 50 or 60 Hz. A deviation of 5 percent in frequency increases the distortion to typically 5 percent, a 10-percent deviation to the 8- to 10-percent level. The electromechanical regulator, on the other hand, is essentially unaffected by line-frequency variations, even of the degree encountered with portable generators.

Efficiency

Since a voltage regulator is often a continuous-duty device, efficiency is an important factor, both from the point of view of thermal problems associated with relay racks full of equipment and from that of the increased physical size and weight necessary to dissipate large amounts of power. Small size and weight are, of course, also important for their own sake, especially where the regulator is expected to see portable or field service. For a given power level, the electromechanical regulator is now available at less than one third the weight and at significantly lower cost than comparable magnetic regulators.

Summary

The following table summarizes the important characteristics of the two important classes of line-voltage regulator. A third type, the fully electronic regulator (oscillator-power amplifier) potentially has the highest performance of all but at present is not commercially competitive with the other types.

The table indicates the relative merits of the electromechanical and magnetic regulators.

TABLE 1.

Characteristics of Voltage Regulators

	Magnetic	*Electro-mechanical*
ACCURACY	excellent	excellent
RESPONSE SPEED	excellent	excellent
kVA	wide range available	wide range available
DISTORTION	moderate	none added
EFFICIENCY	moderate to high	highest
SENSITIVITY TO LINE FREQUENCY	high	none
SENSITIVITY TO POWER FACTOR	low to high	none
WEIGHT	high	low
COST/kVA	moderate	low

C. Chitouras

A NEW 1-kVA LINE-VOLTAGE REGULATOR

Type 1591-A Automatic Line-Voltage Regulator, available in portable (top) and relay-rack (bottom) versions.

A new, greatly simplified control circuit has allowed us to extend the advantages of the electromechanical line-voltage regulator to the low-power range. The 1-kVA regulator described below (and shown on this month's cover) is a small, lightweight, inexpensive unit scaled to serve the average bench or relay rack.

In the preceding article, the electromechanical line-voltage regulator is seen to have significant advantages over the magnetic regulator, particularly with respect to distortion (hence, ability to maintain the peak and average, along with the rms, levels of voltage) efficiency, insensitivity to line-frequency and power-factor variations, size and weight. For over a decade GR has offered 6-kVA and larger regulators with the above advantages. However, all attempts to offer lower-powered units at commensurate prices have been frustrated by the fact that the manufacturing cost of the control circuitry was essentially independent of the power-handling rating of the regulator; there was thus no incentive for the customer to buy or therefore for GR to offer a low-power unit. Nevertheless, the need for small regulators has increased with time, spurred by the relatively low power requirements of solid-state designs and the increased use of groups of instruments in relay racks. On the performance side, we have seen increased demands for higher levels of accuracy in measurement and control and for the highest reliability consistent with reasonable cost. It is surprising that, in spite of the elementary calculation involved, few realize that a line-voltage change from — 10% to + 10% of nominal represents nearly a 50% increase in power dissipation — a first-order effect on reliability.

THE GR TYPE 1591 SERIES OF REGULATORS

As a result of the development of a new, greatly simplified control circuit, it is possible for the first time to produce an inexpensive 1-kVA electromechanical regulator. This new regulator, the portable version of which weighs only 17 pounds and is priced under $300*, is GR's Type 1591.

Four models are available to cover 115- and 230-volt service in both portable and relay-rack packages. The only difference in ratings is that the 230-volt models are rated at 0.8 kVA, resulting from the 20% derating of autotransformers in going from 115- to 230-volt operation. All models have identical control circuits.

* Price applies in U.S.A. only.

Costa Chitouras received his BSEE and MSEE degrees from Massachusetts Institute of Technology in 1955. After service with the U.S. Army Signal Corps Engineering Laboratories, he joined General Radio in 1956. A development engineer in GR's Industrial Group, he has worked on stroboscopes, recorders, frequency meters, and voltage regulators.

Operating Characteristics

The 1591 will maintain the output voltage at 115 volts (adjustable from 105 to 125 volts) with an accuracy of ±0.2 percent for simultaneous input-line variations from 100 to 130 volts, load variations from no load to full load, power-factor variations from 1.0 to 0 leading or lagging, and line-frequency variations of ±10 percent. Correction takes place within 6 cycles +1.5 cycles per volt.

Output voltage of the 230-volt units is adjustable from 210 to 250 volts and input-line variations from 200 to 260 volts are corrected when the output voltage is set to 230 volts. Correction takes place within 6 cycles +0.7 cycle per volt.

Figure 1 shows recordings of the output voltage of four different 1591's under various combinations of input voltage and load.

Behind the recordings of Figure 1 lies an interesting story. Over a year ago 100 models of the 1591 were constructed. Of the many tests conducted, perhaps the most important was a one-year round-the-clock life test of 40 of these units. There were no failures. From this group of 40, four units were randomly selected and put through an accelerated life test, in which the 115-volt line was modulated at a 3.5-hertz rate, subjecting motor-gear train, Variac® autotransformer, and control circuitry to well over a quarter of a million oscillations per day, while operating at nearly full load rating. As of this writing, the 10-million-cycle mark is at hand. There has been no lubrication or adjustment (the only adjustment possible — internal or external — is the front-panel voltage control). Two of these four instruments, again randomly selected, were used as two of the instruments for the tests in Figure 1. The other two instruments were new. Can you tell the difference?

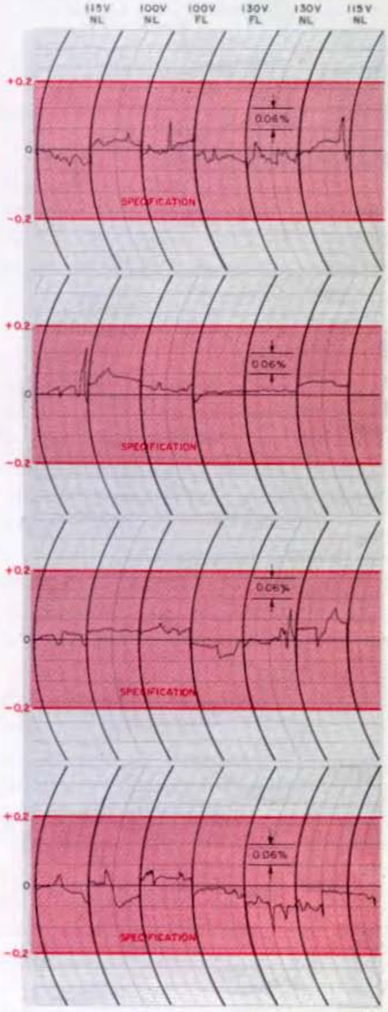


Figure 1. Recordings showing the performance of four different 1591 regulators under changing line and full-load and no-load conditions. Two of the regulators (top and bottom) were new; the other two had been put through a one-year round-the-clock life test.

The two relay-rack versions of the 1591, in addition to meeting the usual GR instruments standards for humidity, storage and operating temperature, etc, passed a test in which they were vibrated from 10 to 55 Hz in one-minute sweeps for 15 minutes in all three planes and at a 30-mil peak-to-peak amplitude. They also passed the Air-Force bench-drop test and the standard 30-g, 11-ms shock test, having been subjected to this three times in six different directions. These tests were conducted while the 1591's were both operating and nonoperating.

The ability of the electromechanical regulator in general and the 1591 specifically to track the average and peak values while actually detecting the rms value is illustrated in Figure 2a. (The resolution of all three voltmeters was 0.1 percent; the band therefore indicates the minimum detectable limits or resolution.) As a comparison, similar plots of two of the best currently available magnetic regulators are shown in Figure 2b and 2c. Figure 2d, 2e, and 2f show the corresponding output waveshapes of these regulators.

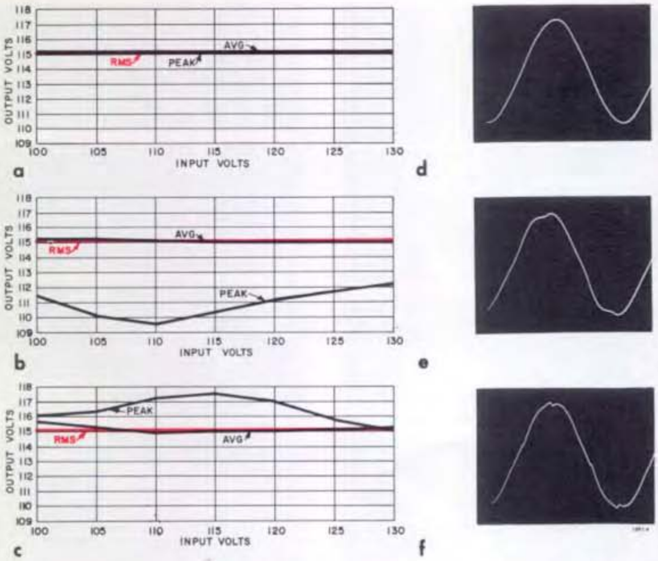


Figure 2. Curves showing the ability (a) of the 1591 and (b, c) of two new magnetic regulators to track peak and average voltage as well as rms. Distortion introduced by the three regulators is seen in the corresponding waveforms at the right (d, e, f).

Figures 3a, 3b, and 3c compare the peak, rms, and average output levels for these three regulators with constant input voltage but varying load current. Varying load current introduces distortion in the magnetic regulators but not in the 1591's. As suggested in the preceding article, there are few instances in which a 1-kVA load, whether it consists of one or many instruments, requires regulation of rms voltage level to within ±0.1 percent and yet can tolerate up to 1- or 3-percent level changes in average and peak voltage.

Speed of Response

The speed with which the 1591 corrects large voltage transients is shown in Figure 4a, an oscilloscope recording of the positive peaks of the output voltage (rms readings at these correction

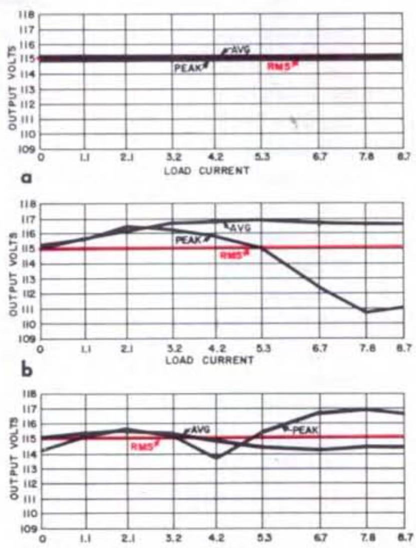


Figure 3. Curves showing the effects of load-current changes on output voltage for (a) the 1591 and (b, c) two magnetic regulators.

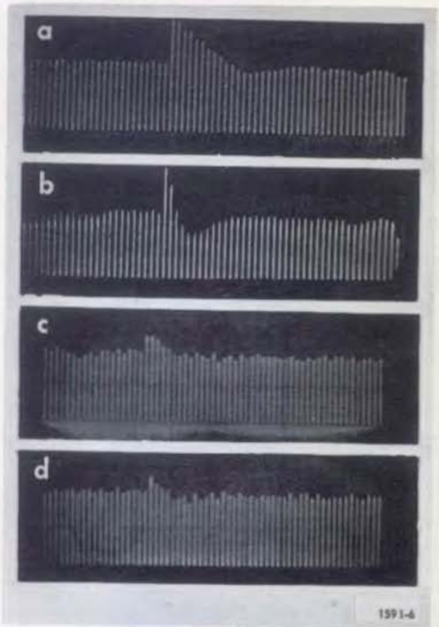


Figure 4. In a and b, we see the response of the 1591 and of a magnetic regulator, respectively, to a 10-V transient. The magnetic regulator corrects faster, but overshoot appears excessive. The response characteristics of the same regulators to a 2-V transient (c and d) show little difference.

rates are virtually impossible to obtain). Note that it takes approximately 10 cycles for the voltage to reach nominal level, followed by a small overcorrection. This is equivalent to a correction speed of 60 volts per second. The correction rate specified for the 1591's takes into account worst-case conditions, such as output voltage set to lower limit, etc.

Figure 4b shows the same test made on a magnetic regulator. Here we see the forte of the magnetic regulator — a high correction rate for large input-line transients.

For the smaller input-line transients more commonly encountered, the results are often different, as shown in Figures 4c and 4d. In this case, the input voltage changed by 2 volts; the response characteristics of the two regulators are now seen to be comparable.

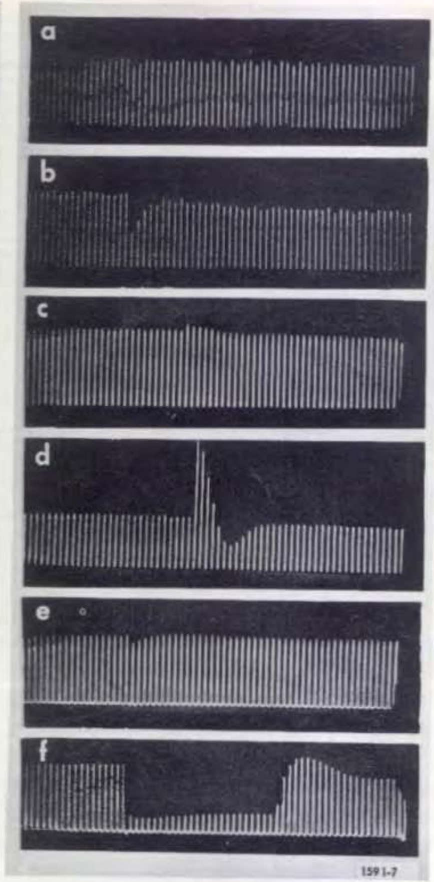


Figure 5. Oscillograms showing the performance of a 1591 (a, c, e) and of a magnetic regulator (b, d, f) in the face of changing load conditions. In a and b, load current was changed from 5 to 6 amperes. In c and d, half the load current was removed. In e and f, a 600-watt incandescent light was connected. Note that the magnetic regulator's protective circuit was triggered by the starting surge of the 600-watt load, even though the regulator was rated at 1 kVA.

Load Effects

The extremely stable characteristics of the 1591 under varying load conditions are illustrated in Figure 5.

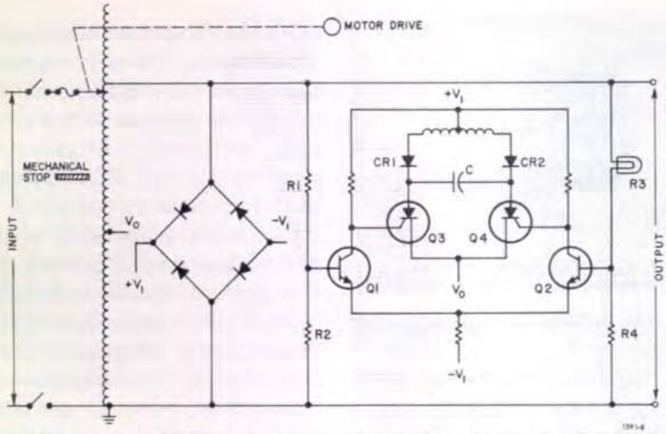


Figure 6. Elementary schematic diagram of the Type 1591 Automatic Line-Voltage Regulator.

Figure 5a shows the output voltage change when the load current on the 1591 is changed by 1 ampere. Figure 5b illustrates a magnetic regulator's performance under the same test. Note that the input line voltage was held constant. Figures 5c and 5d show the output-voltage variation for the 1591 and for the magnetic regulator respectively, when one half of the maximum load current is removed, simulating the turning off of some of the instruments powered by one regulator. Figures 5e and 5f illustrate the performance when a 600-watt incandescent load was applied to both regulators. The protective circuit of the magnetic regulator reduced the output voltage to some low value for approximately one half a second before turning on again. A 1000-watt incandescent load could not consistently be turned on with this regulator, blowing a fuse approximately every third attempt. A 1591 was tested using a 1300-watt lamp load with an on-off cycle of 5 seconds. The test was concluded many cycles later, with not a single interruption of service.

Warmup Drift and Temperature Coefficient

The warmup drift of the 1591, in spite of the fact that it uses a thermal device as a reference, is negligible — typically less than 0.2 percent from a cold start, with 0.1 percent occurring in the first 5 to 10 minutes.

The temperature coefficient of the instrument is specified at less than 0.01%/°C and is typically 50 ppm/°C.

How It Works

Figure 6 is an elementary diagram of the 1591 voltage regulator. To convert the unregulated line voltage to a regulated output, the high side of the input line is connected to the brush in the Variac autotransformer. By precise control of the brush position on the winding, the volts-per-turn and consequently the output voltage are held constant. Figure 1 has indicated that the resolution of the 1591 is often within a few hundredths of a percent, and yet the Variac has an apparent resolution of three quarters of a volt per turn. The brush of a Variac acts as a fine voltage divider, capable of sub-

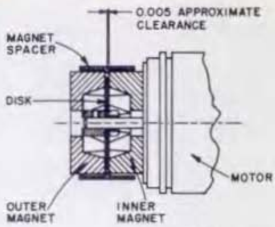


Figure 7. Cross-section view of the eddy-current brake.

dividing the voltage of two adjacent turns of wire by a significant factor.

In this regulator, the Variac brush is driven by a servo motor through a 90:1 gear train. (This motor is the same as that used on the GR 1571 militarized voltage regulator.) To stabilize the servo system, some damping must be introduced. This function is served in the 1591 by an eddy-current brake.

The eddy-current brake (Figure 7) consists of a high-conductance aluminum disk and two magnets. The disk is attached to the motor rotor and revolves between the magnets. At slow motor speeds (minor voltage corrections), no significant hold-back torque is generated by the brake, and full torque is available for brush positioning. When larger corrections (faster motor speed) are required, the brake generates considerable hold-back torque. This torque, which is proportional to velocity, provides the damping necessary to stabilize the system.

The servo motor is driven by a control circuit consisting of a bridge detector (R1 through R4), a differential amplifier (Q1–Q2), and an SCR output stage (Q3–Q4); a total of two transistors and two SCR's form the total active-component complement of this instrument. In spite of the simplicity of this circuit, there is no detectable change in the performance of the 1591 even with a 5-to-1 change in transistor β and a simultaneous 500-to-1 change in sensitivity of the SCR's. In fact, the circuit will tolerate component variations considerably in excess of their specifications for all components but the bridge resistors and lamp.

The relative immunity of regulator performance to component characteristics derives from the unique characteristics of the output signal from a lamp bridge. Lamp bridges have, of course, been used in regulator control circuits before; here, however, use is made for the first time of the two additional zero crossings resulting from the various frequency components generated in a lamp circuit. These components — the 60-Hz bridge voltage, a 90° out-of-phase component, and a third-harmonic component of the line frequency — combine to produce a waveform similar to that shown in Figure 8a. This signal, after amplification, appears as Figure 8b. Note that the positions of the zero crossings are independent of amplifier gain. The amplified signal triggers the two SCR's, whose output waveform is shown in Figure 8c. Note that, while the power applied to the motor remains constant, the direction of rotation and torque are functions only of the phase of the control voltage. The phase is in turn a function of the positions of the zero crossings. At unbalance, the 60-Hz correction signal from the bridge serves to move the zero crossings over a range of about 180° for a 1% change in applied bridge voltage. The result is proportional control of torque, independent of amplifier gain and of characteristics of all components except the lamp and the bridge resistors.

The power-supply voltages are derived from full-wave rectification of the ac voltage at the output of the autotransformer, referenced to its center tap. The Variac is used "backwards" (input line on the brush, output on the tap), eliminating the need for an additional power transformer for the amplifier.

The use of a pulsating, rather than a filtered, dc supply for the SCR's is required to achieve maximum torque in the motor at the rated temperature rise. (Remember that only the line-frequency component in the motor produces torque; the other components resulting from using filtered dc would be dissipated as heat.)

By isolating the control winding from the SCR commutating capacitor by means of rectifiers CR1 and CR2 (see Figure 6), we ensure that there is always available across the capacitor enough voltage (essentially the peak value of supply voltage) to turn off an SCR, independently of the effects of the inductive servo motor. This technique allows us to enjoy both the efficiency of using pulsating dc for the motor and the reliability of using filtered dc for commutation.

The Lamp

The lamp used in the 1591 is a GR proprietary design. It exhibits remarkable short- and long-term stability characteristics, brought about by close control of the metallurgical and structural design of the filament and its environment. Its ruggedness is attested by the aforementioned environmental tests that the 1591 has passed. The lamp has a typical temperature coefficient of 20 ppm/°C. It is designed to have a "lifetime" of a few centuries, based on the 10% filament evaporation point — a standard end-of-life rating

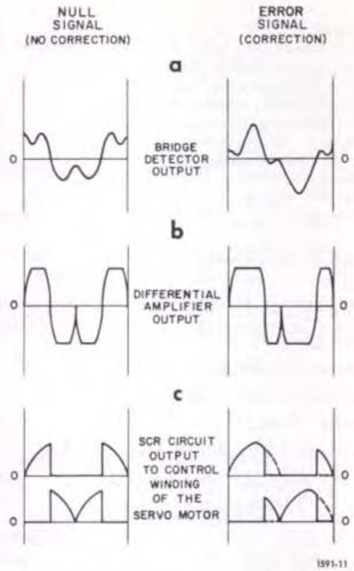


Figure 8. Waveforms present at the bridge detector, differential amplifier, and servo motor for no-error and error conditions. Note that servo action is based on position of zero crossings rather than on amplifier gain.

for incandescent lamps. To test long-term stability, one of these lamps was used as the reference in a dc power supply whose output was compared against a standard cell. The total drift in resistance of the lamp was less than 400 ppm over a three-year period, or an average drift of less than ½ ppm per day.

While it is too costly to measure and guarantee the long-term stability of the 1591's output voltage, our experience indicates that, after a few months of use, the drift of the typical 1591 will be unmeasurable with the usual laboratory ac voltmeters.

C. Chitouras

SPECIFICATIONS

	115-V Models	*230-V Models*
Output kVA	1.0	0.8
Output Current	8.7 A	3.4 A
Input-Voltage Range	100 to 130 V	200 to 260 V
Output-Voltage Range (adjustable)	105 to 125 V	210 to 250 V
Correction Range	± 15 V	± 30 V
Frequency	60 Hz ± 10%	48 to 63 Hz

Correction Time (cycles): 6 c + 1.5 c/V for 115-V models, 6 c + 0.7 c/V for 230-V models.

Output-Voltage Accuracy: ± 0.2% for any combination of line voltage or frequency, load, or power factor.

Temperature Coefficient: <0.01%/°C.

Power Factor: 0 to 1, leading or lagging.

Response: Rms.

Distortion: None added.

Efficiency: 95% at full load.

No-Load Power: Approx 45 W.

ENVIRONMENT

Ambient Temperature (operating): −20 to +52°C, rack model; −20 to +40°C, portable model.

Vibration: Rack model, 30 mils pk-pk at 10 to 55 Hz, three planes, 15 min each plane.

Shock (rack model, operating and nonoperating): AF bench-drop test; 30 g for 11 ms.

GENERAL

Accessories Supplied: Spare fuses.

Dimensions (width x height x depth): Portable, 12¾ × 9½ × 5⅜ in. (325 × 245 × 140 mm); rack, 19 × 5¼ × 6⅜ in. (485 × 135 × 165 mm).

Net Weight: Portable, 17 lb (8 kg); rack, 22 lb (10 kg).

Shipping Weight: Portable, 25 lb (11.5 kg); rack, 31 lb (14.5 kg).

Catalog Number	*Description*	*Price in USA**
	Variac® Automatic Voltage Regulator	
1591-9700	**1591-A,** 115 V, Portable	**$295.00**
1591-9701	**1591-AH,** 230 V, Portable	**320.00**
1591-9712	**1591-AR,** 115 V, Rack	**325.00**
1591-9713	**1591-AHR,** 230 V, Rack	**350.00**

* Quantity discounts available on request.

A NEW THREE-PHASE REGULATOR

With the introduction of the TYPE 1591 Automatic Line-Voltage Regulator (see preceding article), GR can supply regulators rated from 1 kVA (1591) through 20 kVA (1571, 1581, 1582[1]). These instruments are designed primarily to regulate single-phase lines. Obviously, three single-phase regulators can be connected in a wye or closed-delta configuration for use in three-phase systems, and such combinations have been used often, with excellent results. In many installations, however, line voltages and loads are sufficiently well balanced that the use of three separate regulators is more a luxury than a necessity. In such cases, a single control circuit and a single motor could drive

[1] C. E. Miller, "A New Series of High-Performance Line-Voltage Regulators," *General Radio Experimenter*, January 1966.

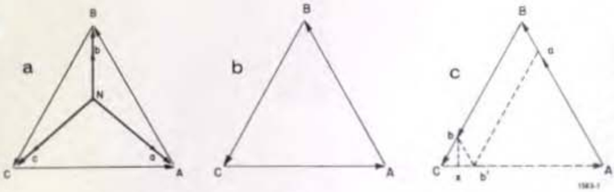


Figure 1. Vector diagrams of (left to right) wye, closed-delta, and open-delta connections. In the open-delta configuration, restoring voltages Aa and Bb to AB and BC automatically restores Ab′ to AC.

an appropriate number of autotransformers. (The autotransformer and a buck-boost transformer are the power-handling elements of a high-powered electromechanical regulator.) The required number of power-handling components is three sets for a wye-connected or closed-delta three-phase system but only two sets from an open-delta system.

The Open Delta

Figure 1 explains vectorially the principles of wye and delta connection for a three-phase line. In the wye connection of Figure 1a, vectors NA, NB, and NC represent the line-to-neutral voltages of a three-phase wye system, and vectors AB, BC, and CA indicate the line-to-line voltages. Assume now that the line-to-neutral voltages drop in amplitude to values indicated by Na, Nb, and Nc. It is clear that restoring Na and Nc to NA and NC is sufficient to correct these two line-to-neutral voltages, along with the line-to-line voltage CA; voltages AB and BC will not be restored, however, until Nb is also corrected to the value NB. Thus all three line-to-neutral voltages of a wye system must be adjusted in order for a wye system to be regulated.

Figure 1b represents the line-to-line voltages of a three-phase closed-delta system, in which all three line-to-line voltages (AB, BC, and CA) are separately corrected. If we choose not to regulate one of the phases and to allow that line-to-line voltage to be determined by the amplitudes of the other two phases, we have the open-delta system shown in Figure 1c. If the nominal voltages are represented by AB, BC, and (by vectorial subtraction) CA, and if these voltages drop to Aa, Bb (which equals ab′), and b′A, it is apparent that if we restore Aa to AB and Bb to BC, b′A will increase to the proper value for CA. (Note that each of the two regulated phases contributes equally to the correction.) Thus only two sets of power-handling components are needed to regulate all phases of a three-phase open-delta system.

The 1583 Regulator

The principles of operation of the 1583 three-phase regulator are similar

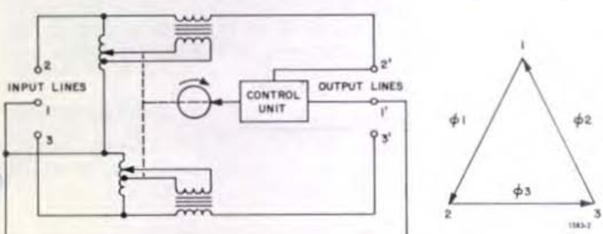


Figure 2. Elementary 1583 Three-Phase Line-Voltage Regulator. φ1 and φ2 voltages are controlled directly by the two sets of power-handling components, and φ3 is automatically corrected as a result.

GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS 01781

to those of the single-phase 1581, except for the two sets of power-handling components in the former. Figure 2 is an elementary diagram. In it, two phases ($\phi1$ and $\phi2$) are controlled directly by the servo system, and $\phi3$ is controlled indirectly. A deviation in the $\phi1$ output voltage activates a servo feedback loop, consisting of a control unit, a two-phase motor, two Variac® autotransformers, and two buck-boost transformers. The deviation in the $\phi1$ voltage is thus translated into equal corrections applied to $\phi2$ and $\phi3$. For a detailed description of the control unit and the motor and transformer circuits, the reader is referred to the January 1966 *Experimenter*.

SPECIFICATIONS

Type	1583-H5	1583-H	1583-H2	1583-LJ	1583-L2J
Input	230 V (line-to-line), 60 Hz			115 V (line-to-line), 400 Hz	
Output	230 V adjustable ± 10%			115 V adjustable ± 10%	
Correction Range* (%)	95 to 105	90 to 110	82 to 124	90 to 110	82 to 124
Line Current (A)	34.0	17.0	8.5	42.5	21.2
Load kVA	13.7	6.8	3.4	8.5	4.2
Correction Time, in cycles (c)	2.5c + 3.0c/V	2.5c + 1.5c/V	2.5c + 0.7c/V	18c + 20c/V	18c + 10c/V
Accuracy (% of output V)	0.25	0.25	0.5	0.25	0.5
Price (depends on mounting)	$620.00 to $655.00			$655.00 to $690.00	

* Ranges listed are for 57- to 63-cycle operation; for 48- to 63-cycle operation, corresponding correction ranges are 95 to 105%, 91 to 109%, and 84 to 119%.

Frequency: 60-Hz models operate from 57 to 63 Hz, and can be modified by a connection change for 48 to 63 Hz; 400-Hz models operate from 350 to 450 Hz.

Response: Rms. **Distortion:** None added.

Efficiency: >98% at full load.

No-Load Power: 45 W.

Ambient Temperature: Operating, −20°C to +52°C; storage, −54°C to +85°C.

Dimensions (width × height × depth): Uncased, 19 × 7 × 14¾ in. (485 × 180 × 375 mm); bench, 19 × 7⅜ × 16 in. (485 × 190 × 410 mm); rack, 19 × 7 × 15 in. (485 × 180 × 385 mm); wall, 19½ × 8⅛ × 16 in. (495 × 210 × 410 mm).

Weight: Uncased, net 54 lb (24.5 kg), shipping 104 lb (47.5 kg); bench, net 64 lb (29 kg), shipping 114 lb (52 kg); rack, net 64 lb (29 kg), shipping 114 lb (52 kg); wall, net 70 lb (32 kg), shipping 120 lb (54.5 kg).

PRINTED IN U.S.A.