Solid State Automotive Voltage Regulators

A discussion of solid-state voltage regulators for automotive electrical systems. The author looks at a previous design, suggests improvements and extends the concept to accommodate both polarities. Finally, he describes similar control systems suitable for use with alternators.

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In the "Reader Built It" series for May, 1967 (reprinted June 1970) a circuit and description for a solid-state voltage regulator for a negative chassis DC generator system was published (figure 1).

Using this as the starting point, the following developments are discussed in this article.

(1) Improvement of regulation characteristics.

(2) A circuit for positive chassis systems.

(3) Optional facilities which eliminate the need for internal generator modifications.

(4) A simple attempt at temperature compensation.

(5) Regulation of automotive alternators. Developments from figure 1 for solid-state alternator control are given.

The purpose of the current regulating function is solely to prevent more than the maximum rated current being drawn from the generator. Ideally, no regulation should begin until the output rises to the rated maximum for the generator, after which generator output would remain constant (see figure 2). (Relay regulators approximate closely to this performance). The performance of the type of regulator represented by figure 1 is shown in figure 3.

This curve shows that the regulator is imposing a further degradation of performance on the already marginal low speed generator characteristic. This effect will be greatest when the threshold current is low (corresponding with low regulator sensitivity) and least when the threshold current is high (corresponding with high regulator sensitivity). The highest regulator sensitivity requires the highest practicable regulator amplifier gain.

It was considered after testing a regulator of similar sensitivity to that of figure 1, that provision of higher sensitivity would provide a worthwhile improvement in performance. An extra transistor was added in composite connection with the output transistor, leading to the circuit of figure 4 for negative chassis systems. The circuit was rearranged to use type AY8108 in the output stage, as this type has advantages which will be discussed later. The final gain had to be reduced by adding R10, which together with the capacitor across R8, was required to prevent "hunting".

A corresponding high gain circuit for positive chassis systems is shown in figure 5.

In the original circuit (figure 1) the cutout relay was eliminated by using a power diode. For reasons explained in the May 1967 article, this led to a need for internal generator modifications to bring out the chassis ends of armature and field to a new terminal isolated from the frame.

The question arises — is the removal of the cutout relay so very necessary, considering the generator modification required? Most of the objections to mechanical relays are aimed at the regulator relays, and cutout relays do not give much trouble. Options have therefore been included which permit the cutout to be eliminated or not as desired. Retaining the cutout makes generator alteration unnecessary. The circuit will regulate with either option, although adjustment settings are different for each.

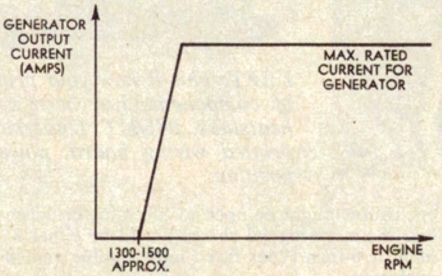

Figure 2

An ideal current regulator curve. Relay regulators approximate this very closely.

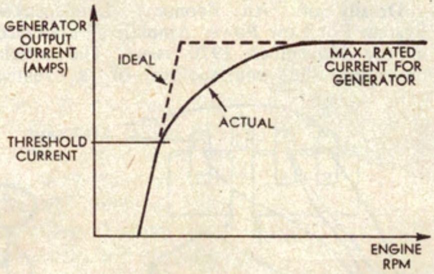

Figure 3

The actual current regulator performance provided by the circuit in figure 1.

The cutout relay is housed in the original regulator box, which will have to be retained if the cutout is to be retained. A separate box is then required for the electronic regulator. In this series, small diecast aluminium boxes were used.

Internal modifications to the original relay regulator are not required. The generator field connection is transferred from the old to the new regulator, leaving the regulator section of the old regulator still connected internally, but no longer controlling the field.

An extra damper diode is included in the electronic regulator from output to chassis to suppress transients from the cutout relay coil.

The operation of the circuit is as follows: Resistors R1, R2, R3 (with the parallel thermistor) constitute an adjustable voltage divider across the battery. When voltage is low, the zener diode does not conduct, therefore TR1 base and collector currents are zero. R8 supplies full base current to the composite pair TR2, TR3 which supply full field current. When the battery voltage rises, the zener diode begins to conduct, supplying base current to TR1, which in turn diverts current away from TR2 base. Field current and therefore generator output drop. Adjustment of the voltage limit is by varying R2.

Current limitation to protect the generator is provided by R6 (0.01 ohm). When generator output current flows through R6, the voltage developed across it forward-biases TR1. This

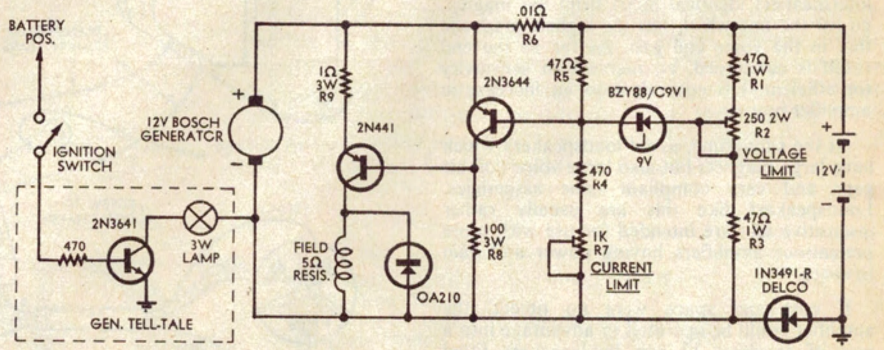

Figure 1

The solid state voltage regulator as originally presented in the May 1967 issue. It required that the generator be modified to insulate the chassis ends of both the armautre and field windings. The author of this article uses it as a starting point.

reduces the field current as before. R7 provides means of adjusting the current limit.

The power transistor chosen was Fairchild AY8108 for both positive and negative chassis systems. It requires no heatsink. A feature of this type is that it contains integrated emitter resistors which help to prevent thermal runaway. Resistor R9 can be omitted if desired, further improving generator output at low speeds, though it provides some protection against accidental short circuiting of the field winding. For this reason it was left in the prototype circuits.

Temperature compensation is provided by replacing R3 (originally 47 ohms) with 68 ohms paralleled by a thermistor. This certainly produces temperature-sensitive behaviour, though it was not rigorously temperature-tested.

When the temperature is low, the thermistor resistance is high, making R3 high, in effect. This shifts the voltage tap on the divider network so as to make the voltage applied to the zener diode low, reducing or stopping zener diode current.

This increases generator output. When the temperature rises, the thermistor resistance falls, producing the reverse effect. This provides an initial "booster" charge when it is most needed; after first starting up for the day when a cold engine has required maximum cranking effort.

The regulator unit containing the thermistor should be mounted in the engine compartment, so that heat from the engine and radiator will warm it. Final voltage adjustment is always carried out when the engine is well warmed up.

Individual constructors may prefer to omit the thermistor. In this case R3 reverts to the original value; 47 ohm 1 watt.

The specification for the heavy duty 0.01 ohm resistor R6 has been changed. It was thought that fencing wire may give trouble with rusting connections. A 2'6" length of 3/0.029 standard plastic-covered copper wire (used by electricians to wire houses) was wound on a cotton reel. A 1'11" length of the more common 1/0.044 wire also provides the same resistance but would be more liable to fatigue failure due to its single conductor.

To adjust the system, connect an ammeter into the battery lead. Inactivate the voltage regulator part of the system by turning the voltage limit control to its highest voltage setting (R2 zero). Start engine. With lights and accessories off, adjust R7 so that the maximum charging current is at the desired figure. This

Suggested changes to the original circuit to take advantage of the improvements in the later design.

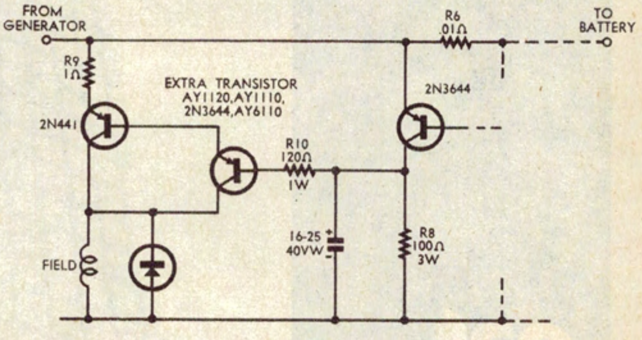

Figure 6

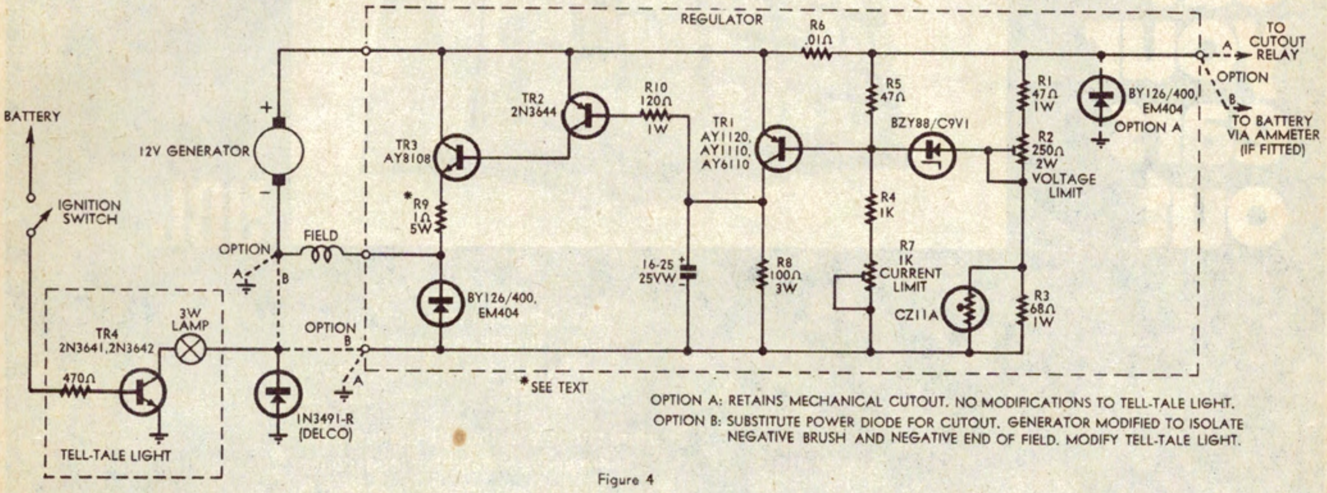

Figure 4

Solid-state regulator for generator type systems having negative chassis. A major feature of the circuit is the additional transistor, higher gain, and improved regulator characteristics which these provide.

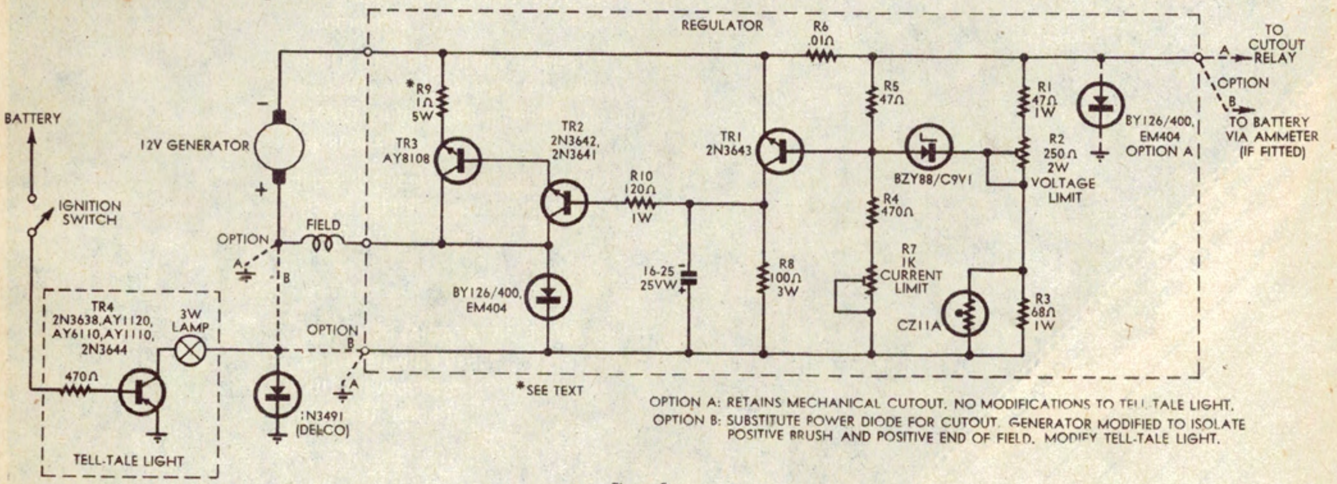

Figure 5

This circuit is similar to that of figure 4, except that it is designed for positive chassis systems. Note that in both circuits the dotted connections provide for mechanical cut-out or diode operation, as the user prefers.

will be between 20 and 30 amps, depending on the generator rating.

Make a temporary adjustment to the voltage control (R2) to provide a moderate charge rate and thus enable the battery to be brought to full charge. The final adjustment is made after a short run, to fully charge the battery and warm the thermistor. Resistor R2 is adjusted for a "trickle" charge of about 3A.

If alternative components are being considered, the following points will serve as a guide.

Zener diodes: Any 9-volt 400 mW or moderately larger unit is suitable.

Damper diodes: Any silicon power rectifier diodes (preferably with a high voltage rating) are suitable.

Transistors: In TR1 and 2 positions, other silicon transistors could be tried if the following conditions are met:

1. Correct Polarity (NPN or PNP).
2. Medium to high gain (hFE 50-200).
3. Satisfactory power ratings, eg. T05 package type.
4. Preferably low VCE (Sat) figure, less than 1 volt.

TR3 should not be changed unless the constructor can be sure that adequate heat-sinking arrangements can be made. For negative chassis systems, germanium type 2N441 using the mounting box as heatsink can be used, as in the original circuit. Types 2N3055 and 2N3054 can also be used.

Thermistor: Type CZ12 is sufficiently close to be substituted.

The voltage control performance is excellent. On starting in the morning, a high rate charge occurs, settling to a low trickle charge on a steady run with a fully charged battery. After this is achieved, even a few seconds battery discharge is compensated for by a brief rise in the charge rate.

Beyond a minimum value, variations in engine speed have no detectable effect on the charge rate. This is in contrast to the original regulator, where this was not achieved.

The temperature compensating system produces a noticeable difference in the charge rate before and after the engine is warmed up. This is in addition to that expected due to the changing battery voltage. Current control performance is improved on the original circuit.

For those who built a unit according to the original design (figure 1), the following simple modification is suggested. (Figure 6).

An extra transistor (eg, AY1120, AY6110, AY1110, 2N3644) is simply added in Darlington Pair configuration with the 2N441, and components R10 and the capacitor across R8 added. The thermistor and 68 ohm resistor may replace R3 (47 ohms). R4 may require changing to 1K to ensure a good range of adjustment of R7.

Modern automotive alternators are three-phase types having built-in groups of diodes to perform three-phase rectification. They can therefore be treated as sources of direct current. Compared with DC generators, they differ considerably in performance and control arrangements. Some of these differences are:

1. As the alternator rotor can withstand higher rotational speeds, the pulley diameters are arranged so that the ratio alternator RPM/engine RPM is higher than in the case of the DC generator. This leads to improved output at low engine speeds. (This is particularly useful, as average speeds have been falling in urban areas, due to increasing traffic congestion.)
2. Because of their design, alternators are self-protecting with respect to current loading. No current regulator is required, as it is impossible to overload these machines.
3. No cutout is required, as the rectifier diodes

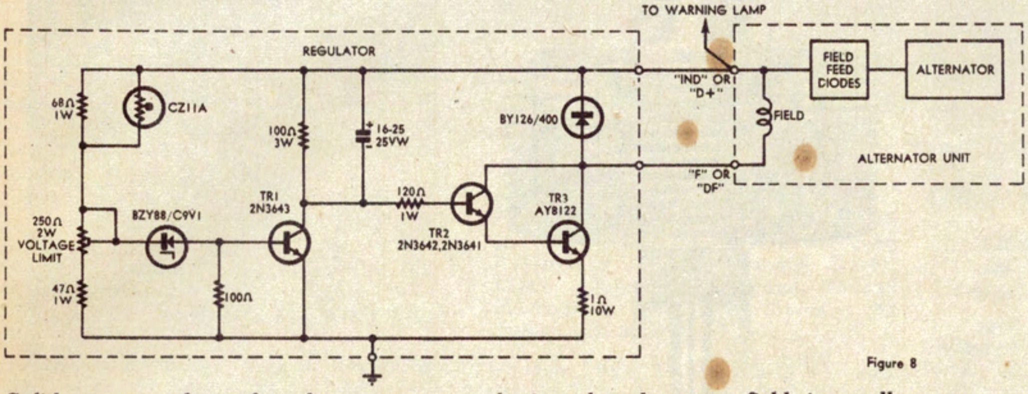

Figure 8

Solid state regulator for alternator system having the alternator field internally connected to the "IND" terminal. Many of the Lucas alternators use this arrangement. No current control components are required with alternators.

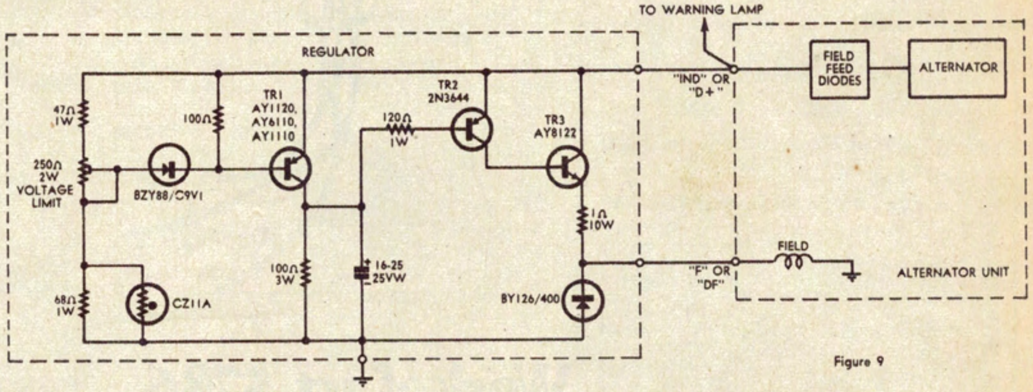

Figure 9

This circuit is similar to that of figure 8, but is designed for use with systems in which the internal field connection is to chassis. Many of the Bosch alternators are examples of this arrangement.

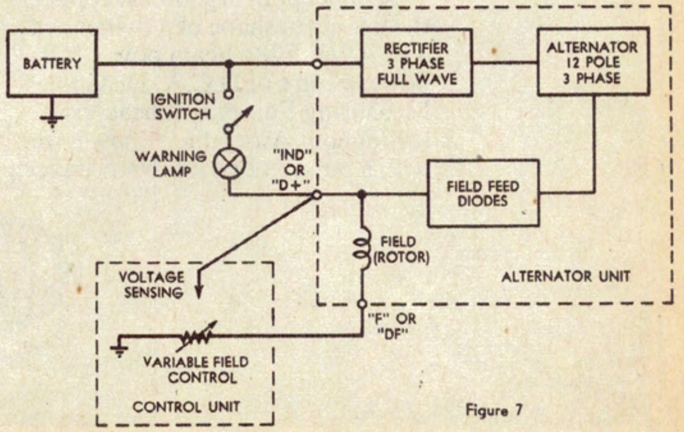

Figure 7

Block diagram showing a typical alternator set-up. Note that two sets of diodes are used, one for the main charging circuit and one for the field.

prevent reverse current flow from the battery through the alternator.

4. There is very low residual magnetism. Initially an external source of field current (derived from the battery) is needed to produce enough field excitation. As the output voltage builds up, the alternator becomes self-exciting. Field excitation in most types is supplied by a separate set of diodes (field feed diodes) providing three phase half wave rectification.
5. The rotor is the field winding. The output comes from the stator. (The reverse compared with DC generators.)

Figure 7 shows a typical alternator charging setup. On switching on, current flows from the battery via the warning lamp (which glows) through the field winding and ultimately to chassis via the regulator. This provides initial field excitation for the alternator. When the engine runs, the output of the alternator, rectified by the field feed diodes, progressively builds up the voltage at "IND" (indicator) to approximately battery voltage, so that the warning light is extinguished, and the machine becomes self-exciting; the field current being supplied from the alternator-field feed rectifier combination.

The regulator, whatever its type, monitors the output voltage of the alternator (usually at the field feed diode output, though sometimes at the main output) and introduces some means of variable control into the field circuit to reduce output when required.

At the time of writing, most commercial alternator regulators do this by switching the field current on and off quickly. The higher the proportion of "on", the higher will be the average output. The Lucas regulator performs this switching electronically, using a solid-state circuit. Most other makers use a vibrating regulator relay system. (In this case the changeover of field excitation from battery to field feed diodes may be achieved by a second relay which operates when the alternator is fully functional.)

The same arguments against vibrating mechanical contacts can be applied here as were used in the original 1967 article relating to DC generator control (wearing, sticking, pitting, etc). All "switching" type regulators, whether mechanical or solid state, may be criticised as being prolific producers of transients, requiring careful radio suppression, and also placing greater stress on the bearings by varying the load quickly.

Figure 7 shows an internal connection between the field and "IND" or "D+" terminal, normally at approximately battery potential during operation. This applies to Lucas alternator types 14AC and 15AC. In most other types, especially those using vibrating relay regulators, the internal connection is between field and chassis instead, with the variable control placed externally between "IND" (or "D+") and "F" (or "DF").

The Bosh alternator model U-LJ/DK1/35A 14VR is an example of this type. The Lucas 15AC alternator may have the internal field connection changed to chassis very easily, if desired, with no other dismantling except removal of the cover.

The position of the internal connection makes a big difference to the details of the control circuit required.

Two circuits for solid-state alternator regulators with continuous field current (not rapidly switched) are shown in figures 8, 9. Figure 8 is for those having the field internally connected to "IND"; figure 9 is for those having the field internally connected to chassis (the majority of types).

Figure 8 is similar to figure 5 upside down. Figure 9 is similar to figure 4. In each case, the current-control components are omitted. Except for this omission, the regulating action and adjustment are identical with the corresponding DC generator circuit.

These circuits are suitable for slip ring alternators having separate field feed diodes, which excludes Email alternators as fitted to Falcon XR and perhaps other models. These will be discussed later.

A detail of design is the specification of a larger power transistor (AY8122) because of the high field current drawn by alternators generally, the field resistance being lower than for DC generators. (The Lucas alternators, for example, have field resistances of only 3.3 ohms.) As alternatives, two AY8108 in parallel would be suitable, and cheaper types such as 2N3055, 2N3054, could be used, with the mounting box as a heatsink.

A 1-ohm external emitter resistor for the power transistor was included in the prototypes as a means of partial protection against accidental short circuits of the field winding. Types AY8122 and AY8108 have integrated emitter resistors which reduce the need for an external emitter resistor for thermal considerations.

There are numerous complexities in providing a fully solid-state regulator for Email alternators, due to the absence of separate field feed diodes. It is doubtful if adapting to any form of solid-state control is worthwhile.

For those interested in a compromise, it is suggested that the field relay be retained in the original regulator, while using figure 9 for the regulator function. The wire joining "F" on the old regulator and "F" on the alternator is removed at both ends. The old regulator "F" connection is used in place of "IND" on figure 9, the alternator "F" is used as terminal "F" on figure 9. The old regulator cover is removed, and one end of the regulator relay coil is disconnected and insulated. This relay has the changeover contact, which should identify it. (The field relay has a make contact.)

ACKNOWLEDGEMENTS: Thanks are due to Mr P. D. Kay, BE for the assistance gained from his helpful original article, "Solid State Voltage Regulator" ("EA" May 1967, p 93) and to "Electronics Australia".