

July 8, 1969

W. B. BURKETT ET AL

3,454,860

VOLTAGE CUT OFF CIRCUITS

Filed Feb. 25, 1966

Sheet 1 of 4

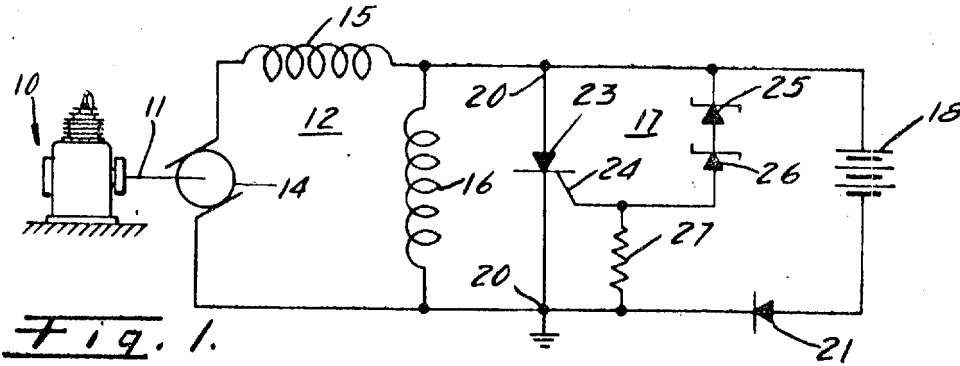


Fig. 1.

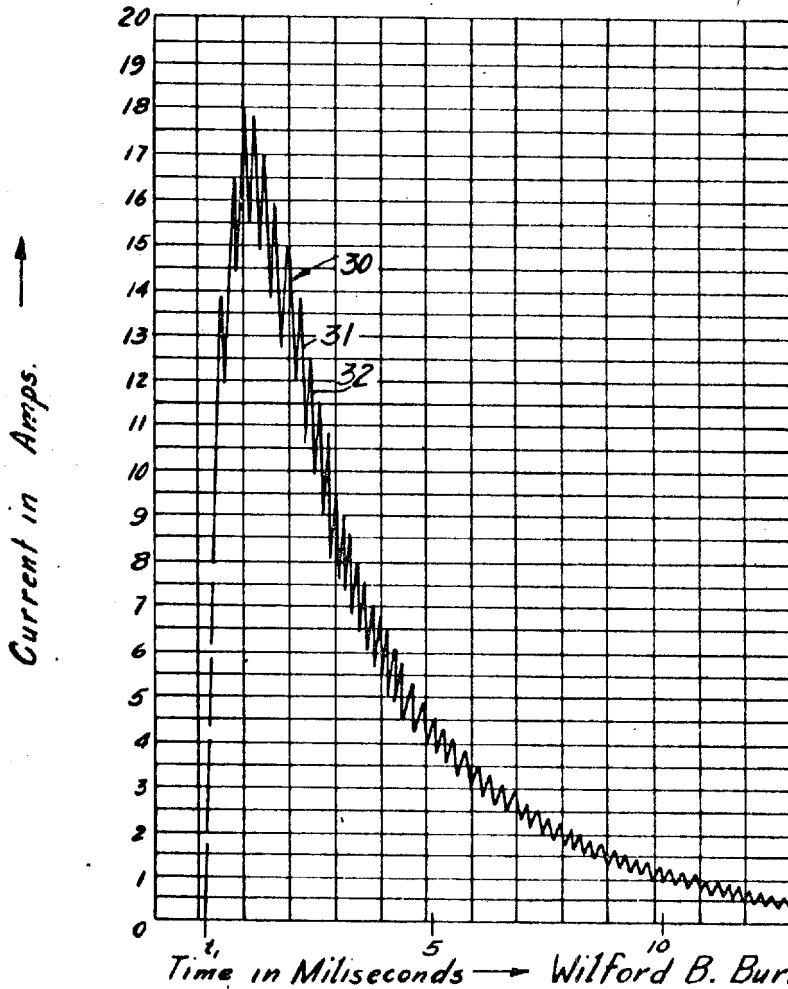


Fig. 2.

Wilford B. Burkett,
Robert V. Jackson, INVENTORS.
WHANN & McMANIGAL
BY Attorneys for Applicants
by *[Signature]*

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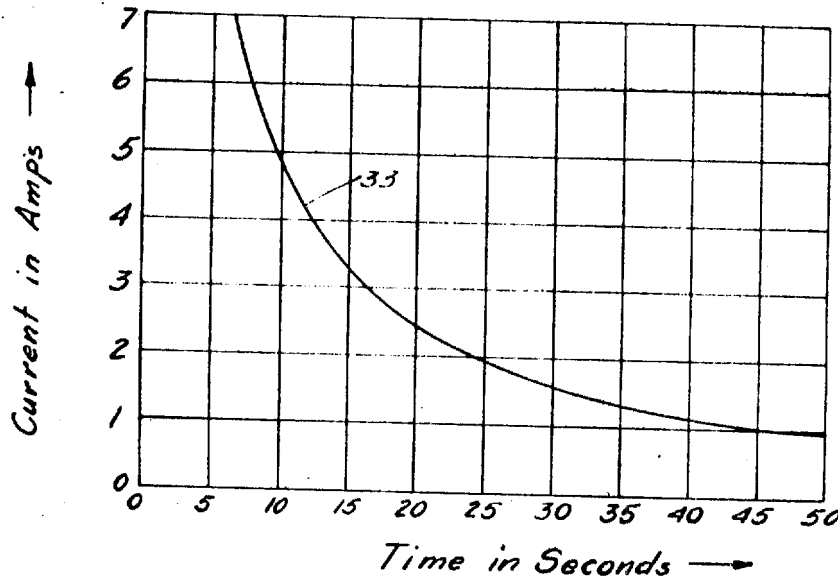


Fig. 3.

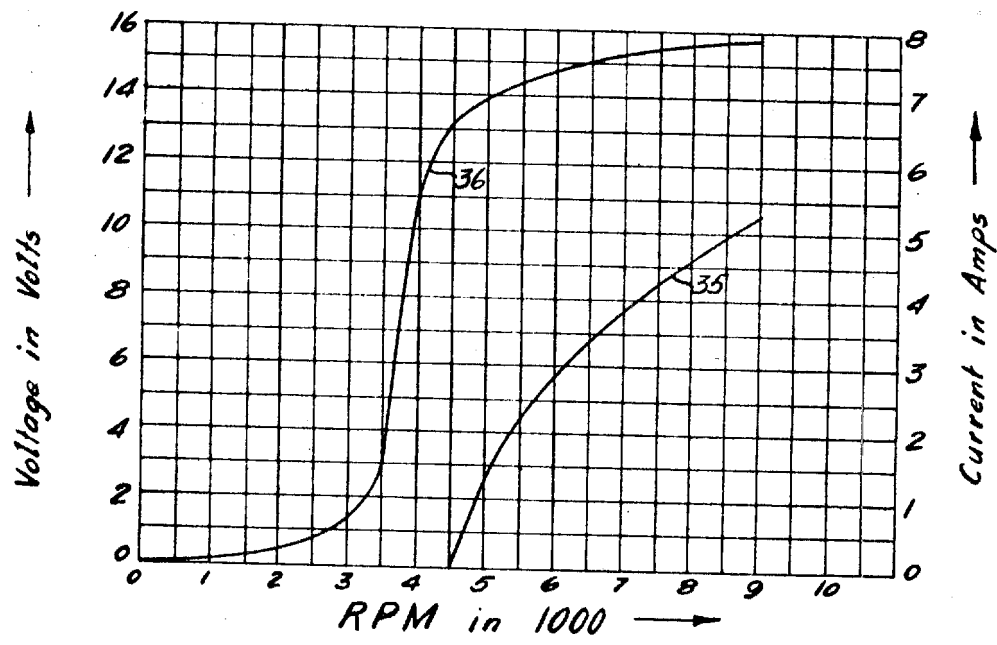


Fig. 4.

Wilford B. Burkett,
Robert V. Jackson,
INVENTORS.

WHANN & McMANIGAL
Attorneys for Applicants

by *[Signature]*

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Fig. 10.

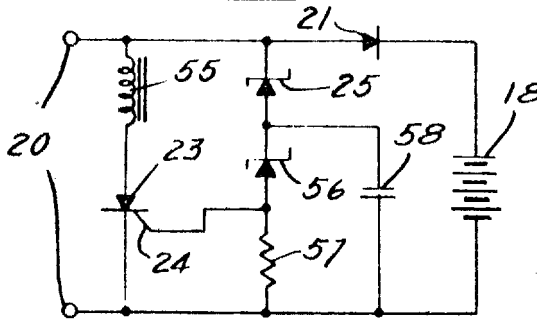


Fig. 13.

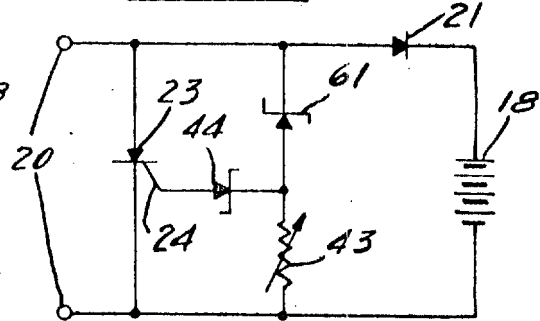


Fig. 11.

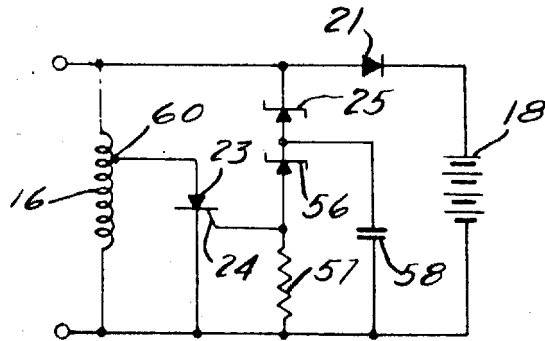


Fig. 14.

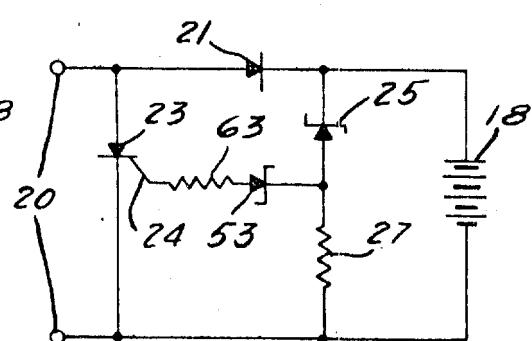
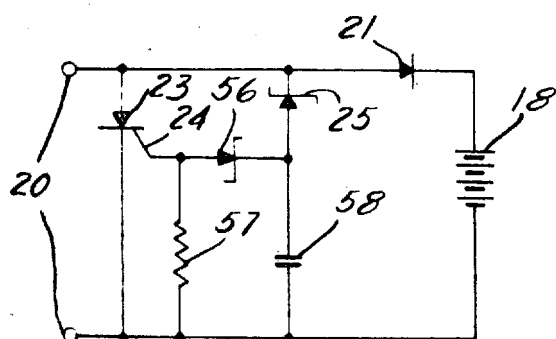


Fig. 12.



Wilford B. Burkett,
Robert V. Jackson,
INVENTORS.

WHANN & McMANIGAL
Attorneys for Applicant

by *Sheldon Whann*

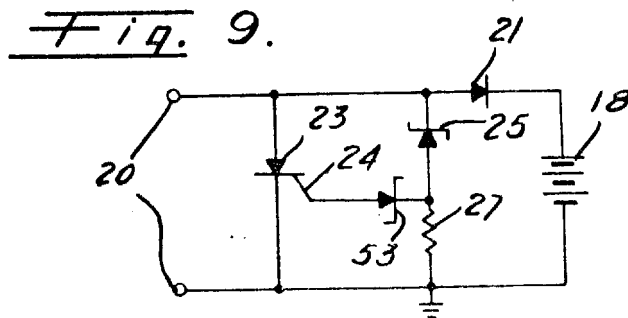
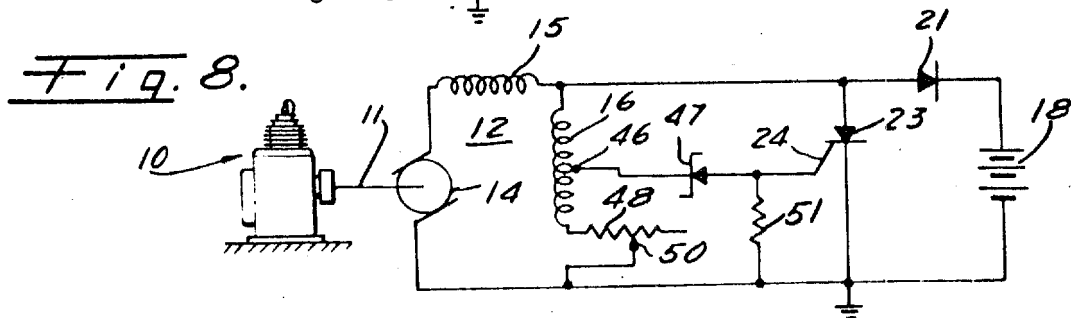
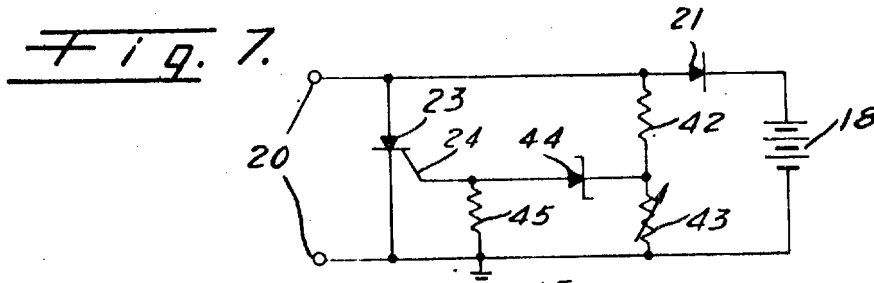
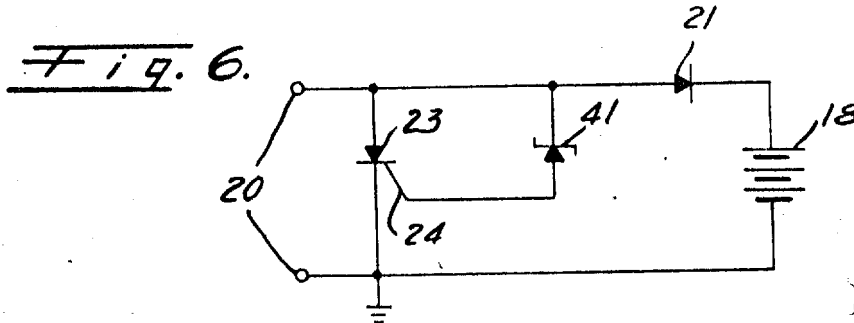
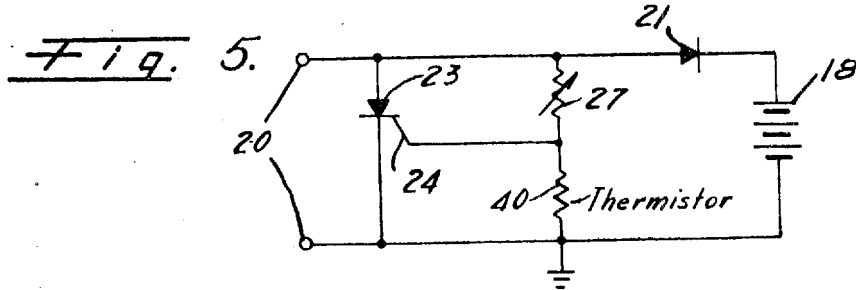
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Wilford B. Burkett,
Robert V. Jackson,
INVENTORS.

WHANN & McMANIGAL
Attorneys for Applicants

by *Sheldon*

United States Patent Office

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Patented July 8, 1969

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VOLTAGE CUT-OFF CIRCUITS

Wilford B. Burkett, Pacific Palisades, and Robert V. Jackson, Los Angeles, Calif., assignors to McCulloch Corporation, Los Angeles, Calif., a corporation of Wisconsin

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U.S. Cl. 320—28

12 Claims

ABSTRACT OF THE DISCLOSURE

Voltage cut-off circuits for cutting off the charging current to a battery from a variable direct-current generator having a shunt winding, the circuits include a voltage-responsive switch connected across the shunt winding of the generator for short-circuiting the shunt winding when the battery voltage reaches a predetermined level and a voltage level sensing circuit for controlling the operation of the switch.

This invention relates generally to voltage-responsive circuits, and particularly relates to an electronic circuit for cutting off the charging current between a variable, direct-current voltage source and a battery.

The voltage-responsive circuit of the present invention is particularly designed to cut off the charging current which charges a battery of secondary cells from a DC (direct-current) generator driven by an internal combustion engine with a widely varying speed. For example, the circuit of the present invention is particularly designed for use in connection with a chain saw driven by a single cylinder, two-cycle, internal combustion engine. An electric generator having series and shunt field windings may be mechanically coupled to the engine and may be utilized as the starter for the engine. The battery in turn consists of a plurality of secondary cells such as nickel-cadmium cells that are rechargeable. Thus, by driving the DC motor from the battery, the engine can be started. After the engine has been started, the battery must be recharged. To this end the generator may be directly driven by the engine to supply charging current to the battery.

However, the charging voltage must be closely controlled to avoid damage to the secondary batteries. To this end it may be assumed that the voltage across the battery is an indication of the state of charge of the battery.

It is, accordingly, an object of the present invention to provide an electronic circuit for cutting off the charging current between a variable voltage source and a battery consisting of secondary cells in response to a predetermined voltage across the battery, thereby to prevent damage to the battery.

Another object of the present invention is to provide an electronic circuit for short-circuiting the shunt winding of a DC generator utilized for charging a battery consisting of secondary cells in response to the voltage across the battery having reached a predetermined value, thereby to substantially reduce the output voltage of the generator.

A further object of the present invention is to provide an electronic circuit of the type referred to, which is so designed that it is substantially independent of temperature variations and which nevertheless can be manufactured at a competitive price.

In accordance with the present invention there is provided a voltage-responsive circuit for cutting off the charging current between a variable voltage source such as a DC generator and a battery. The generator is subject to being driven at widely varying speeds and includes

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a shunt field winding. A rectifier is connected in series with the battery, the rectifier being so poled as to permit charging of the battery when the voltage across the generator exceeds the battery voltage. There is further provided an electronic switch such, for example, as a silicon controlled rectifier which is connected across the shunt winding of the generator.

This switch is adapted to short-circuit the shunt winding when triggered. The triggering is effected by circuit means coupled to the switch and responsive to the voltage across the battery. Thus, the electronic circuit means may consist of a voltage divider which may, for example, include a Zener or breakdown diode. Preferably the electronic components, particularly the silicon controlled rectifier and the Zener diode, are so designed and arranged as to minimize variation in the voltage response due to changes of temperature which may be caused either by ambient temperature changes or by the operation of the generator and the internal combustion engine connected thereto.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIG. 1 is a circuit diagram of a preferred electronic circuit embodying the present invention and including a DC generator;

FIG. 2 is a graph plotting the current as a function of time and showing the current through an electronic switch included in the circuit of FIG. 1;

FIG. 3 is a graph showing the current as a function of time to show the allowable charging period of a secondary or rechargeable cell;

FIG. 4 is another graph showing the voltage as well as the current as a function of the number of revolutions of the engine driving the generator and indicating the characteristics of the generator output voltage and charging current; and

FIGS. 5 through 14 are circuit diagrams of other embodiments of the voltage cut-off circuit of the present invention.

Referring now to the drawings, wherein like elements are designated by the same reference characters, and particularly to FIG. 1, there is illustrated an electronic circuit embodying the present invention. The circuit of FIG. 1 shows the presently preferred embodiment of the invention and includes a prime mover generally indicated at 10 such, for example, as an internal combustion engine. As previously pointed out, the electronic circuit of the present invention is particularly designed for use with a chain saw driven by a single cylinder, two-cycle, internal combustion engine. However, in general, it will be understood that the electronic circuit of the invention is particularly applicable for all types of internal combustion engines where the engine speed varies over a wide range. Examples of such engines are outboard boat engines, engines for automotive vehicles as well as other engines used for portable or transportable power tools and even for stationary applications.

The gasoline engine 10 is preferably directly connected such as by a drive shaft 11 to a DC generator generally indicated at 12. The DC generator has an armature 14 including the conventional armature windings, a series field winding 15 and a shunt field winding 16. It should be noted, as shown in FIG. 1, that the series winding 15 and the shunt winding 16 are connected in a closed loop with the armature 14.

It should be pointed out that the electronic circuit of the invention will operate with any DC generator as

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long as it has a shunt winding such as shown at 16. In other words, the generator may have no series field winding 15 but only a shunt field winding 16. On the other hand, the generator may have a shunt field winding 16 directly connected across the armature 14 and a series field winding connected in series with the load. In that case the generator may be compounded so that like magnetic poles of the series field winding 15 and the shunt field winding 16 are produced by the field windings. Hence, the two windings 15, 16 are connected in an aiding direction. On the other hand, the two windings may be connected in bucking relationship, that is, unlike magnetic poles may be produced by the field windings. Such a generator is generally referred to as a differentially compounded generator.

The electronic circuit 17 embodying the present invention is connected between the generator 12 and a battery 18 consisting of secondary cells. In other words, it is important that the battery consists of cells which are rechargeable such as nickel-cadmium secondary cells. Hence, the electronic circuit 17 is connected between the output terminals 20 of the generator, one of which may be grounded as shown, and the battery 18. Connected in series with the output terminals 20 and the battery 18 there is a rectifier or diode 21. As shown in FIG. 1, the diode 21 has its cathode connected to ground as shown. However, the rectifier 21 may also be connected between battery 18 and series field winding 15. The rectifier 21 is preferably a semiconductor diode but not necessarily so. It is so poled as to block current flow from the battery 18. Charging current to the battery occurs when the voltage of the generator 12 developed across the output terminals 20 exceeds a predetermined value. This is determined by the voltage across the battery 18 and the forward voltage drop across the diode 21.

Connected across the battery 18 and the diode 21 there is a multilayer diode 23 commonly known as a silicon controlled rectifier which may, for example, consist of an NPNP four-layer diode and operates as an electronic switch. This type of rectifier is provided with a gate or control electrode 24. The silicon controlled rectifier 23 is normally non-conductive. However, it does become conductive when a voltage of a given polarity and magnitude is applied across the device 23 and provided a voltage signal of predetermined magnitude is applied to its control electrode 24. In order to do this, there is provided a voltage divider circuit across the battery 18 and diode 21. This consists of two Zener diodes 25 and 26 connected in series and a resistor 27, their junction point being connected to the control electrode 24.

A Zener diode is also known as a breakdown diode and has characteristics that it permits a current flow in a reverse direction through the diode only when the voltage across the diode exceeds a predetermined value. At that voltage the diode breaks down and begins to conduct. Obviously one of the Zener diodes such as diode 26 may be omitted.

The operation of the voltage cut-off circuit of the invention will now be explained. It is assumed the battery 18 is discharged from time to time. For example, its function may be to drive the generator 12 which then operates as an electric motor for starting the gasoline engine 10. To this end, of course, there must be a switch bypassing the diode 21. However, as far as the present invention is concerned all that is necessary is that the battery 18 has previously been discharged.

When the gasoline engine 10 driving the generator 12 reaches a certain speed, an output voltage is developed across the generator output terminals 20. Accordingly, when the output voltage developed at the generator output terminals 20 exceeds the forward voltage drop of diode 21 and the battery voltage, a charging current flows through the battery 18. As a general rule and as an approx

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charge for any secondary cell battery. As a result the battery voltage increases as the percentage of the charge increases. Thus, the forward voltage drop of the diode 21 may, for example, be 0.6 volt. It may further be assumed that the battery 18 consists of 10 secondary cells each rated at 1.25 volts so that the nominal voltage across the battery 18 is 12.5 volts and may be as high as 15 volts.

Accordingly, assuming the flow of a charging current, the battery voltage increases and the generator output voltage also rises. This generator output voltage appears across the two Zener diodes 25, 26 and the resistor 27. The two Zener diodes 25, 26 are so selected that they conduct current in response to a predetermined voltage thereacross. Thus, when the voltage across the generator output terminals 20 reaches a certain value, the two Zener diodes 25, 26 will conduct and there will be a voltage drop across the resistor 27. This voltage drop appears at the control electrode 24. Assuming that this voltage is sufficiently high, it will trigger the silicon controlled rectifier 23 which subsequently becomes conductive.

This now short-circuits the shunt winding 16 and bypasses the field current of the generator. As a result, the generator loses excitation and the output voltage of the generator decreases to a small value. This small output voltage is sustained by the residual induction or remanence of the magnetic circuit of the generator.

Referring now to FIG. 2 there is illustrated a curve showing the current in amperes flowing through silicon-controlled rectifier 23 as a function of time in milliseconds. This curve shows that the current through the silicon-controlled rectifier 23 quickly reaches a peak value, then decays in a generally exponential fashion when the silicon-controlled rectifier becomes conductive.

It will be noted that the curve 30 consists of a multitude of individual falling curve portions such as 31 and rising curve portions such as 32. These are caused by the shape of the commutator of the generator and the speed of the generator. However, in any case, it is apparent that the charging current very rapidly decays within a matter of a few milliseconds.

Referring now to FIG. 3 there is illustrated a curve 33 showing the maximum permissible charging current in amperes as a function of time in seconds. Thus, any charging current for a nickel-cadmium cell below curve 33 is safe while any current above or to the right of curve 33 is unsafe. This curve clearly shows that such nickel-cadmium secondary cells will stand a very high charging current for a short period but can only accept a relatively low charging current for any extended period of time. In accordance with the present invention, use is made of this curve because the battery is charged very rapidly with a large current but for a short period of time. As a result, the battery is again ready to be used, for example, for driving the generator 12 as a motor to start the gasoline engine 10.

FIG. 4 depicts both the generator output voltage across terminals 20 and the battery charging current as a function of the number of revolutions (r.p.m.) of the gasoline engine 10. Thus, the r.p.m. are shown in units of thousands in FIG. 4. The battery charging current is shown by curve 35 while curve 36 indicates the generator output voltage. It will be noted that the output voltage rises rapidly as the engine speed exceeds approximately 3,500 r.p.m. Below that value there is no charging current because the generator output voltage must exceed a certain value as pointed out before, such as about 13 volts before the charging current can flow through the diode 21.

It will thus be apparent that the cut-off circuit of the present invention operates in essence as a voltage limiter. It is triggered when the battery voltage exceeds a certain value and, hence, is sensitive to voltage. But it will not permit the generator output voltage to rise above a certain

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As long as the generator is driven above a certain speed, say about 4000 to 5000 r.p.m., the residual magnetism in the yoke and in the field poles of the generator will be sufficient to maintain the silicon controlled rectifier 23 conductive. However, assuming that the prime mover 10 decreases its speed below some critical value; in that case there will not be enough voltage across the silicon controlled rectifier 23 for it to remain conductive. Accordingly, the controlled rectifier 23 now becomes non-conductive.

As the speed of the prime mover 10 increases again, the generator output voltage rises as shown by curve 36. Then, assuming that the battery had previously been charged sufficiently, the same sequence of events takes place again. In other words, the silicon controlled rectifier 23 is again made conductive, thereby to short-circuit the shunt winding 16 and to reduce the generator output voltage sufficiently to prevent further charging of the battery 18. Thus, the action of the voltage cut-off circuit of the invention is to limit battery voltage to a predetermined level that keeps the battery close to full-charged condition and protects the battery from charging to too high a voltage that can damage the battery.

The voltage cut-off circuit of FIG. 1 is further designed to be substantially insensitive to wide variations of ambient temperature. For example, a chain saw may have to be used at both below freezing temperatures and in hot climates. In addition, of course, the generator 12 and the gasoline engine 10 may cause the circuit to heat up. On the other hand, Zener diodes such as 25, 26, silicon controlled rectifiers and diodes are all temperature sensitive. Therefore, preferably all of the solid state components such as 21, 23, 25 and 26 are disposed close to each other or are arranged in a common housing. This will insure that there is little temperature differential between these components. For example, the diodes 21 and the silicon controlled rectifier 23 operate at a decreasing voltage when the temperature increases. On the other hand, the Zener diodes can be selected to break down at an increasing voltage with increasing temperature or to break down at a decreasing voltage with increasing temperature. Thus, advantage can be taken of this situation to provide for an inherent temperature compensation, or a positive or negative temperature coefficient.

It should also be pointed out that the generator 12 is preferably so designed that it has inherently poor regulation. As a result, the current surge of the generator is low. This, in turn, makes it possible to utilize less costly components. For example, the silicon controlled rectifier 23 may be designed for a normal current of 1.6 amperes. Nevertheless it can handle a surge current for a short period up to 20 amperes.

The circuit of FIG. 1 shows two Zener diodes 25 and 26 in series. This permits a better temperature compensation. It is economically less expensive to provide a pair of Zener diodes which will break down at a predetermined voltage within 1%. This can be arranged by two complementary Zener diodes. This is less expensive than to provide a single Zener diode designed to break down at a certain voltage with a 1% variation.

Of course, on the other hand, one of the two Zener diodes, such as 26, may be omitted or more than two Zener diodes may be used. The circuit of FIG. 1 with only one Zener diode is characterized by its simplicity and by the few components required. If the Zener diode or diodes are correctly chosen for the proper breakdown voltage, no adjustment is needed, for example, of the resistor 27.

On the other hand, the disadvantage of a circuit with a single Zener diode is that it becomes more difficult to fully compensate for temperature variations. Also, as pointed out before, this requires a single Zener diode which must conduct at a set voltage within 1% and such units are more expensive.

While it will be understood that the circuit specifications of the voltage cut-off circuit of the invention illus-

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trated in FIG. 1 may vary according to the design for any particular application, the following specifications are included, by way of example, only:

Battery 18	-----	13.3 volts.
Silicon controlled rectifier 23	----	Motorola type MCR 2304 or MCR 808.
Zener diodes 25 or 26	-----	IN958.
Rectifier 21	-----	Motorola type MR 322 (silicon rectifier) rated at 18 amps. at 15 volts DC.
Resistor 27	-----	1200 ohms.

The circuit of FIG. 1 is arranged to cut off when the battery voltage has reached 15 volts. The two Zener diodes 25 and 26 are selected for a nominal Zener or breakdown voltage of 7.5 volts.

Further modifications of the voltage cut-off circuit of the present invention are illustrated in FIGS. 5 through 14. Thus, referring to FIG. 5 there is shown a voltage cut-off circuit which does not require any Zener diode. Instead a thermistor 40 is connected in series with the resistor 27, their junction point being connected to the control electrode 24 of the silicon controlled rectifier 23. This circuit otherwise operates in the same manner as does that of FIG. 1. Further description of the operation therefore is not needed. It should be noted that the diode 21 is now provided between the battery 18 and the series winding 15. The generator 12 has not been shown but only the generator output terminals 20.

The advantage of the circuit of FIG. 5 is that it has a temperature compensating resistor, namely, the thermistor 40. This thermistor 40 can be chosen to match the temperature characteristic of the silicon controlled rectifier 23. The resistor 27 may be adjusted at room temperature for the proper trigger voltage.

On the other hand, the circuit of FIG. 5 has the disadvantage that it is difficult to obtain complete temperature compensation over a sufficiently wide temperature range by means of a thermistor to match all silicon controlled rectifiers. Hence, only a partial compensation is possible in practice. It will be realized that in a production run various silicon controlled rectifiers have varying properties and, hence, it is difficult to match the temperature characteristics of a production run of silicon controlled rectifiers with another production run of thermistors.

Thus, in the circuit of FIG. 5 the operating voltage must be present at a particular temperature and this may not be correct at other temperatures.

FIG. 6 illustrates another modification of the invention. In this circuit the resistor 27 has been omitted. Instead there is only a single Zener diode 41 connected between the diode 21 and the control electrode 24 of the silicon controlled rectifier 23. However, there is still a voltage divider consisting of the Zener diode 41 and that portion of rectifier 23 from control electrode 24 to ground.

This circuit can be compensated for changes of the ambient temperature. This ambient temperature may vary between a minimum of -20° F. (Fahrenheit) to a maximum of 150° F. The circuit is quite similar to that of FIG. 1, but it is even simpler because it requires no resistors.

The disadvantage is that the temperature characteristic of the control electrode of the silicon controlled rectifier 23 in turn varies with the temperature. Thus, this requires a precise selection of the Zener diode 41.

The circuit of FIG. 7 includes a voltage divider consisting of a fixed resistor 42 and a variable resistor 43 connected across battery 18 and diode 21. The junction point between resistors 42 and 43 is connected with the control electrode 24 of the silicon controlled rectifier 23 through a Zener diode 44. Furthermore, a resistor 45 connects the control electrode 24 to ground.

In the circuit of FIG. 7 it will be understood that the resistor 45 may be omitted. Discussing first the circuit