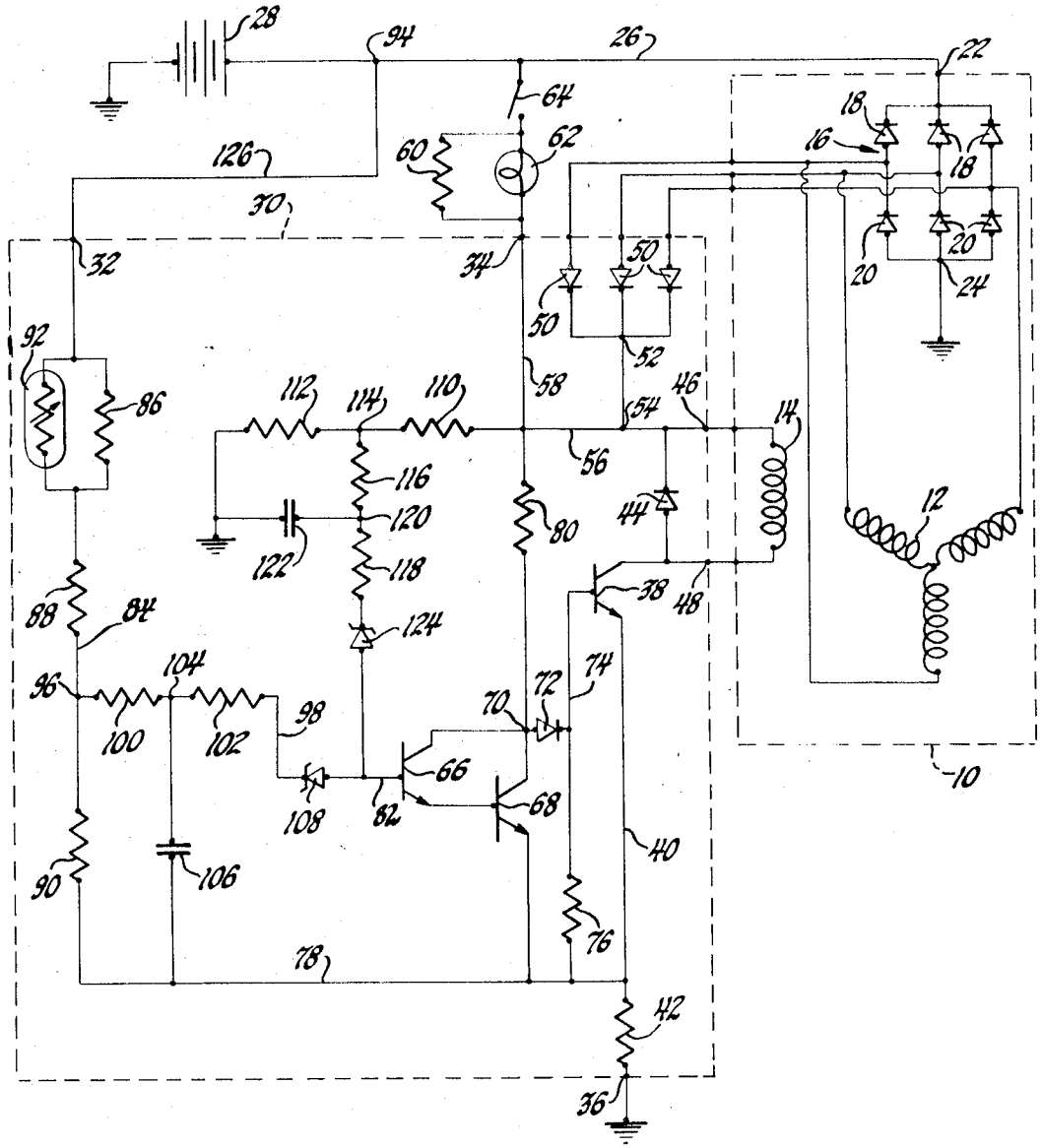
Sept. 16, 1969 G. E. HARLAND, JR., ET AL 3,467,854

TRANSISTOR VOLTAGE REGULATOR INPUT CIRCUIT

Filed Sept. 19, 1967



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United States Patent Office 3,467,854
Patented Sept. 16, 1969

3,467,854

TRANSISTOR VOLTAGE REGULATOR INPUT CIRCUIT

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Filed Sept. 19, 1967, Ser. No. 668,800
Int. Cl. H02h 7/06
U.S. Cl. 322—28 4 Claims

ABSTRACT OF THE DISCLOSURE

This invention relates to a high gain transistor voltage regulator for generators. The transistor regulator has an input filter and an input circuit which is designed to provide stable operation for the high gain transistor regulator. The input network of the regulator includes two resistors connected in series between a Zener diode and a junction of a voltage divider that senses the output voltage of the generator. A capacitor is connected between a junction of the two resistors and one end of the voltage divider.

This invention relates to high gain transistor voltage regulators which are utilized to control the output voltage of a generator such as a diode-rectified alternating current generator that is useful in supplying the electrical loads in a motor vehicle. The transistor regulator of this invention includes a high gain amplifier circuit and is designed so that it can be manufactured as an integrated circuit in a very small size. The small size regulator has the advantage that it takes up less space in a motor vehicle electrical system and can, if desired, be built in to the end frame of the generator.

Although it is desirable to have a high gain and therefore high performance transistor voltage regulator for regulating the output voltage if the generator this type of regulator is susceptible to unstable operation. Where the regulator utilizes one or more Zener diodes for voltage regulation the Zener diodes themselves become a source of electrical noise which, when used with a high gain amplifier of the type contemplated by this invention, can cause unstable operation of the regulator. This unstable operation is due to the production of oscillations and due to the fact that there is feedback from the output of the regulator to the input which enhances the unstable operation.

It accordingly is one of the objects of this invention to provide a high gain transistor voltage regulator for generators which is capable of high performance but yet is substantially immune to oscillation and therefore provides stable operation at all loads of the generator which it regulates.

Another object of the invention is to provide a high gain transistor regulator that includes a Zener diode for controlling the operation of the regulator and which includes an electrical circuit for reducing the effect of random electrical noise produced by the Zener diode.

A further object of this invention is to provide a high gain transistor voltage regulator where an input circuit is provided to prevent oscillation due to feedback conditions.

Still another object of this invention is to provide an input circuit for high gain transistor regulators which includes a Zener diode, first and second resistors connected in series with the Zener diode and a capacitor which with the first resistor forms a filter network. The second resistor insures stable operation of the high gain system.

In the drawings:

The single figure drawing is a schematic circuit diagram of a complete motor vehicle electrical system made in accordance with this invention which utilizes input circuits for the transistor voltage regulator that provide stable operation.

Referring now to the drawing, the reference numeral **10** generally designates a source of direct current for supplying the electrical loads on a motor vehicle. This source of direct current includes an alternating current generator having a three phase Y-connected output winding **12** and a field winding **14**. The field winding **14** controls the output voltage of the generator over the varying electrical load and over the varying speed range of the engine of the vehicle which is used to drive the generator. The three phase Y-connected winding **12** is connected with the AC input terminals of a three phase full-wave bridge rectifier generally designated by reference numeral **16** and comprised of positive silicon diodes **18** and negative silicon diodes **20**. The bridge rectifier **16** has a positive direct current output terminal **22** and a grounded negative direct current output terminal **24**. The positive output terminal **22** is connected with a power supply conductor **26** which supplies charging current to a battery **28** and which also supplies the other electrical loads on the motor vehicle which are not illustrated.

The field current for the field winding **14** is regulated by a high gain transistor voltage regulator generally designated by reference numeral **30**. This transistor regulator has a voltage sensing terminal **32**, an indicator light terminal **34** and a ground terminal **36** which is connected to ground.

The transistor regulator has a field energizing circuit which includes the field winding **14**, the collector-emitter circuit of an NPN transistor **38**, conductor **40** and resistor **42**. A field discharge diode **44** is connected across the field winding **14** and this field winding can be connected to junctions **46** and **48** by means of slip rings and brushes where the field winding **14** rotates with a rotatable part of the alternating current generator. The transistor **38** is the output transistor or power switch for the system since it switches on and off to regulate the output voltage of the system.

The field power for the electrical system of this invention is provided by auxiliary diodes **50** that have their anodes connected with the phase windings **12** and the cathodes connected with junction **52**. The junction **52** is connected with junction **54** and conductor **56**. The field power is supplied between junction **52** and ground and it will be appreciated that diodes **50** and diodes **20** form a three phase full-wave bridge rectifier having DC output terminals **52** and ground for supplying field power. The field current is regulated by transistor **38** which continuously switches on and off in a manner to be more fully described hereinafter.

The terminal **34** of the regulator is connected with a conductor **58** and with a parallel connected resistor and signal lamp **60** and **62**. An ignition switch **64** is connected between power supply conductor **26** and the parallel connected resistor and signal lamp.

The voltage for biasing the transistor **38** conductive or nonconductive is provided by NPN transistors **66** and **68** which form a switching driver stage amplifier. The collectors of these two transistors are connected together at junction **70** and this junction is connected with the base of transistor **38** by a PN junction diode **72** and conductor **74**. A resistor **76** is connected across the base-emitter circuit of transistor **38**. The emitter of transistor **66** is connected with the base of transistor **68** and the emitter of transistor **68** is connected with a conductor **78**. A resistor **80** connects conductor **56** and the junction **70**. The conductor **78** can be termed a reference potential conductor.

The base of transistor **66** is connected with a conductor **82** and this conductor is connected with two voltage sens-

ing circuits which are capable of controlling the switching of the circuit including transistors **66, 68** and **38**. The first voltage sensing circuit includes a voltage divider generally designated by reference numeral **84** and comprised of resistors **86, 88** and **90** and a thermistor **92** connected in parallel with resistor **86**. This voltage divider is connected between junction **94** on power supply conductor **26** and the reference potential conductor **78**. This voltage divider has a junction **96** and the voltage between it and conductor **78** will be a function of the voltage appearing between conductor **26** and ground. The voltage appearing across resistor **90** is utilized to control the switching of the voltage regulator and this voltage is applied between conductors **98** and **78** through an input circuit which provides stable operation for the regulator. This input circuit includes resistors **100** and **102** having a junction **104** and a capacitor **106** which connects junction **104** and conductor **78**. A Zener diode **108** connects conductor **98** with conductor **82**.

The second voltage sensing circuit for the regulator is provided by a voltage divider connected between conductor **56** and ground and comprised of resistors **110** and **112** having a junction **114**. This circuit includes the same type of input circuit as previously described for providing stable operation of the generator and includes resistors **116** and **118** having a junction **120**. A capacitor **122** is connected between junction **120** and ground and another Zener diode **124** connects one end of resistor **118** and the conductor **82**.

Since the resistors **100** and **102** and the capacitor **106** perform the same function in the system as resistors **116, 118** and capacitor **122** only the operation of one of these input circuits will be described in detail.

Before proceeding to the specific operation of the input circuits used in this regulator, a brief description will be given of the overall operation of the system. When the system is initially started, as when the engine on the vehicle is started, the switch **64** is closed to initially energize the field winding **14** from the battery **28**. The transistor **38**, at this time, is biased conductive since the voltage between junction **96** and conductor **78** which is a portion of battery voltage is not sufficient to turn off transistor **38**.

As the generator begins to develop an output voltage the potential between junction **96** and conductor **78** increases and when this potential is sufficient to break down the NP junction of Zener diode **108** and the two PN junctions of the base-emitter circuits of transistors **66** and **68** these two transistors conduct which lowers the potential of junction **70**. When this potential is lowered to a point where it cannot forward bias the two PN junctions formed by diode **72** and the base-emitter circuit of transistor **38** this transistor turns off. When transistor **38** turns off, the output voltage of the generator decreases causing transistors **66** and **68** to turn off and then biasing transistor **38** on. The transistor **38** switches on and off to maintain the output voltage of the generator substantially constant and the two switching circuits, namely transistors **66** and **68** forming the driver switch and output transistor **38**, provide a high gain circuit and good regulator performance.

The voltage divider **110** and **112** does not effect the operation of the system unless the output voltage of the generator rises to an abnormally high value which is higher than the desired regulator value. This can happen if voltage sensing conductor **126** becomes disconnected from junction **94** or if positive DC output terminal **22** becomes disconnected from conductor **26**. In the first case the voltage divider **84** senses no input voltage which would cause transistor **38** to continuously conduct with a consequent high output voltage and destruction of the regulator. If junction **22** becomes disconnected from conductor **26** the regulator senses only battery voltage which is not sufficient to turn off transistor **38** because the desired regulator voltage is somewhat higher than battery voltage.

In either of these high voltage conditions with Zener diode **124** will regulate the output voltage of the system since it, with transistors **66** and **68**, can control the operation of transistor **38** during the high voltage condition.

As pointed out previously the transistor regulator of this invention is a high gain amplifier (h_{fe} greater than 100,000) and is therefore susceptible to an oscillating condition which would destroy the effectiveness of the regulator. In addition, a Zener diode, for example, Zener diode **108** is a source of random electrical noise particularly when it is operating at its threshold point. Moreover, at a frequency of 100 kc. the reactance of capacitor **106**, which with resistor **100** forms an input filter, for the high frequency spikes produced by the ringing of diodes **16** and **18**, may be as low as 75 ohms which places junction **104** essentially at RF ground and produces in effect a grounded base RF oscillator.

It has been found that circuit stability can be achieved by providing a resistor **102** which is connected between junction **104** and Zener diode **108**. This resistor lowers the effective Q of the noise source circuitry comprised of Zener diode **108** and capacitor **106** to thereby increase the losses of the noise source where Q represents the quality factor or figure of merit of the circuit. Q can be determined by the equation

$$Q=\frac{1}{2\pi fCR}$$

where

Q=Quality factor or figure of merit.
f=Frequency of noise generated by Zener diode **66**.
C=Capacitance of capacitor **106**.
R=Resistance of resistor **102**.

The resistor **102** increases regulator stability and eliminates the current gain dependency of the driver stage formed of transistors **66** and **68**.

The resistor **102**, as previously pointed out, decreases the effective Q of the Zener diode noise generator and by lowering the effective Q losses are introduced to the noise source circuitry to prevent an oscillating mode of operation. This resistor also provides additional phase shift in the system to prevent positive feedback conditions within the system and also provides a system where the noise source admittance becomes less reactive and is maintained relatively constant at frequencies at 50 kHz. or higher.

The resistance of resistor **102** although dictated in part by considerations of the Q of the noise generator is also selected to meet Nyquist's criterion for stability. This criterion dictates that amplifier performance is affected by impedances which are frequency dependent and provide phase shift which contributes to self-oscillations at high frequencies. The resistance of resistor **102** together with the equivalent capacitance of the feedback network of the regulator is selected to provide the additional phase shift to prevent an ideal feedback signal which would tend to maintain oscillations.

The resistance of resistor **102** is also selected with regard to Linvills stability equation for amplifier circuits. In this regard, as pointed out above, the noise source admittance becomes less reactive by use of the resistor **102** and is maintained relatively constant at frequencies of 50 kHz. or higher. The input source admittance is adjusted by selecting a resistance for resistor **102** to avoid potentially unstable conditions as dictated by Linvills stability equation.

By way of example and not by way of limitation the values of the resistors and capacitors utilized in the reg-

ulator of this invention in a 12 volt system can be as follows:

Resistor **90** (Zener dependent)	ohms	1500
Resistor **88**	do	642
Resistor **86**	do	283
Resistor **100**	do	1500
Resistor **102**	do	1500
Resistor **80**	do	85
Resistor **76**	do	105
Resistor **110** (Zener dependent)	do	2400
Resistor **112**	do	2500
Resistor **42**	do	.03
Resistor **118**	do	1700
Resistor **116**	do	1000
Thermistor **92**	ohms @ 25° C. NTC	950
Capacitor **106**	μf	.047
Capacitor **122**	μf	.0047

The resistance of the resistors listed above as Zener dependent are approximate and their resistance depends upon the breakdown voltage of Zener diodes **108** and **124**.

It will be appricated that the resistor **118** for the second voltage sensing circuit provides the same function as resistor **102** and operates to provide transistor regulator stability in a high gain amplifier voltage regulator in the event that this second voltage divider comes into operation. Although discrete components have been illustrated for the voltage regulator, it is preferred that the regulator be fabricated by an integrated circuit technique and this can be done in a manner disclosed in patent application Ser. No. 668,794, filed on Sept. 19, 1967, and assigned to the assignee of this invention.

From the foregoing it can be seen that a high gain high performance transistor voltage regulator has been provided which exhibits stable operation and which can be fabricated into a small integrated unit. The additional stability provided by the system of this invention permits transistors with high current gain characteristics to be utilized without sacrificing regulator performance.

What is claimed is:

1. A transistor voltage regulator comprising, an output transistor having emitter, collector and base electrodes, the collector and emitter electrodes of said output transistor being adapted to be connected in series with the field winding of a generator to be regulated, a high gain driver transistor switching means having an input terminal and an output terminal coupled to the base of said output transistor, said driver switching means supplying base drive for said output transistor, a voltage sensing circuit adapted to be connected with the generator to be regulated developing a voltage which is a function of the output voltage of said generator, and an input circuit connected between said voltage sensing circuit and said input terminal of said driver switching circuit, said input circuit including in a series connection first and second resistors and a Zener diode, said Zener diode connected between said second resistor and said input terminal of said driver switching circuit, and a capacitor connected between a junction of said resistors and one end of said voltage sensing circuit.

2. An electrical system comprising, a source of direct current including a generator having an output winding and a field winding, a voltage regulator including an output transistor having emitter, collector and base electrodes, means connecting said field winding of said generator and the collector and emitter electrodes of said transistor in series across said source of direct current, said regulator including a high gain driver switching section comprised of first and second transistors having their collectors connected together and to the base of said output transistor, the emitter of said first transistor being connected to the base of said second transistor, a Zener diode connected with the base of said first transistor, a voltage divider connected across said source of direct current developing a function of the output voltage of said source, first and second resistors connected between a junction of said voltage divider and the side of said Zener diode opposite from its connection to the base of said first transistor, said first and second resistors having a common junction, and a capacitor connected between said common junction and one end of said voltage divider.

3. An electrical system comprising, an alternating current generator having a polyphase output winding and a field winding, a bridge rectifier comprised of a plurality of diodes having first and second direct current output terminals and AC input terminals connected to said output winding, a voltage regulator including a power output transistor, a field energizing circuit connected with said generator and including in a series connection the collector and emitter of said power output transistor and said field winding, a driver transistor coupled to the base of said output transistor, a voltage divider connected across said output terminals, a first resistor and a capacitor connected in series across a portion of said voltage divider, a second resistor having one end thereof connected to a junction of said first resistor and capacitor, and a Zener diode connected between an opposite end of said second resistor and the base of said driver transistor, said first resistor and said capacitor forming a filter for high frequency voltage spikes developed due to the ringing of the diodes of said bridge rectifier, said second resistor providing stable operation for said regulator.

4. An electrical system comprising, an alternating current generator having an output winding and a field winding, a bridge rectifier comprised of a plurality of diodes having AC input terminals connected with said output winding and direct current output terminals, a voltage regulator including a high gain transistor amplifier circuit comprised of a plurality of coupled transistors, said amplifier having an input coupled to a Zener diode and an output transistor connected with said field winding and generator for controlling field current as a function of the output voltage of said generator, a voltage divider connected across said direct current output terminals, and a circuit connecting said Zener diode and said voltage divider, said circuit including first and second series connected resistors connected between a junction on said voltage divider and said Zener diode, and a capacitor connected between a junction of said resistors and one end of said voltage divider, said resistor connected with said voltage divider and said capacitor forming a filter for high frequency ringing of said diodes of said bridge rectifier, said other resistor provided stable operation for said amplifier.

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U.S. Cl. X.R.

321—9; 322—32, 36, 73; 323—22