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[72] Inventor Thomas L. Vandervort
Erie, Pa.

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[73] Assignee General Electric Company

[54] GENERATOR LOAD CONTROL SYSTEM
14 Claims, 2 Drawing Figs.

[52] U.S. Cl. ..... 322/23, 290/40 A, 322/24, 322/27, 322/36, 322/37
[51] Int. Cl. H02p 9/00
[50] Field of Search 322/23, 24, 25, 27, 36, 37; 290/40

[56] References Cited

UNITED STATES PATENTS

2,886,763	5/1959	Zelina	322/36 X
3,105,186	9/1963	Zelina	290/40 X
3,263,142	7/1966	Adoutte et al.	318/99

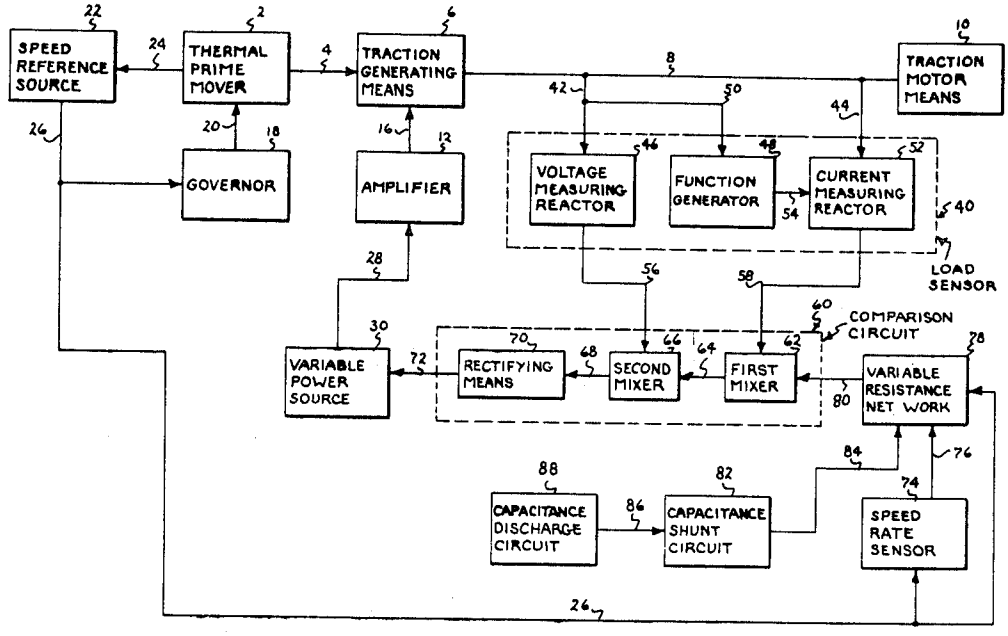
OTHER REFERENCES

General Electric Publication- GEJ- 3851- Model U30 Diesel Electric Locomotive Circuit Operation " Applicant' s Non-Patent Citation" Aug. 1968

Primary Examiner—Oris L. Rader
Assistant Examiner—H. Huberfeld
Attorney—Walter C. Bernkopf

ABSTRACT: A control system for regulating the power output of a traction generator in response to the power capability of the diesel engine prime mover wherein feedback signals responsive to the generator output current and voltage are applied to the inputs of bridge rectifiers whose outputs are serially connected in a reference current circuit. A unidirectionally conducting circuit coupled across the bridge rectifiers provides a control signal to limit the generator load when feedback signals exceed the reference current. The reference current circuit includes in series connection a source of reference voltage whose magnitude corresponds to the power output level of the diesel engine, a resistance network and the bridge rectifier. Provision is made for retarding the rate at which the generator load is increased upon increases of diesel engine output power by a stepped increase of the resistance of the resistance circuit during an increase of diesel engine power. During such time a circuit, responsive to an increase of a reference voltage, opens a shunt connected in parallel with a portion of the resistance circuit. A capacitance connected serially across the load voltage source and a portion of the resistance network additionally shunt a portion of the reference current to prevent a stepped increase of reference current. A capacitance discharge circuit is operative during reductions of diesel engine power to prevent the capacitance circuit from affecting the rate of load control during such power reduction.

This invention relates to a generator excitation control system and more particularly to a system regulating the power demand of a traction generator in response to the available power of a thermal prime mover, such as a diesel engine. Provision is made for controlling the rate at which the generator output is increased responsive to increasing diesel engine power output in order to reduce the generation of smoke by the diesel engine during increases of diesel engine power.



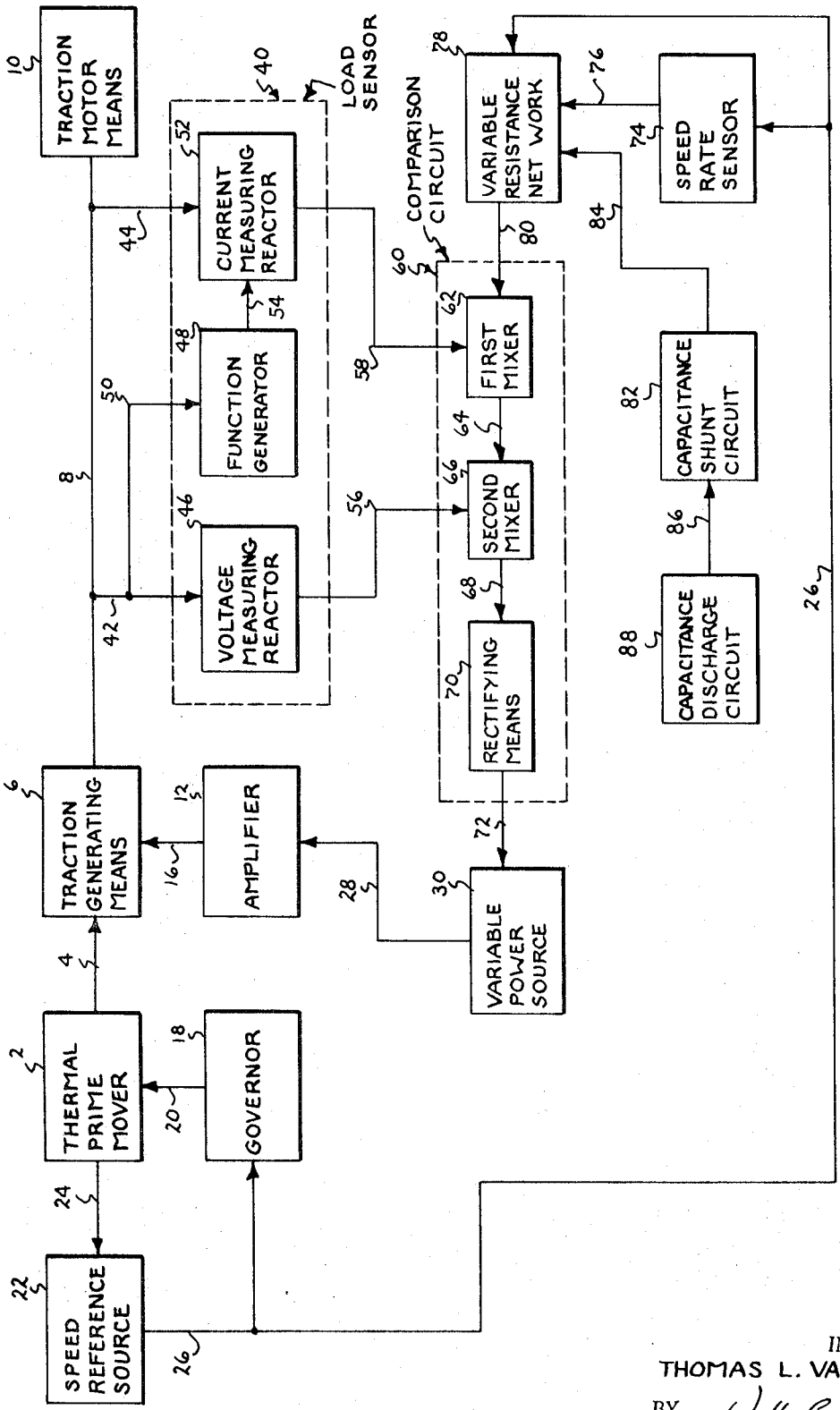


FIG. 1

INVENTOR.
THOMAS L. VANDERVORT
BY Walter C. Bernkopf

HIS ATTORNEY

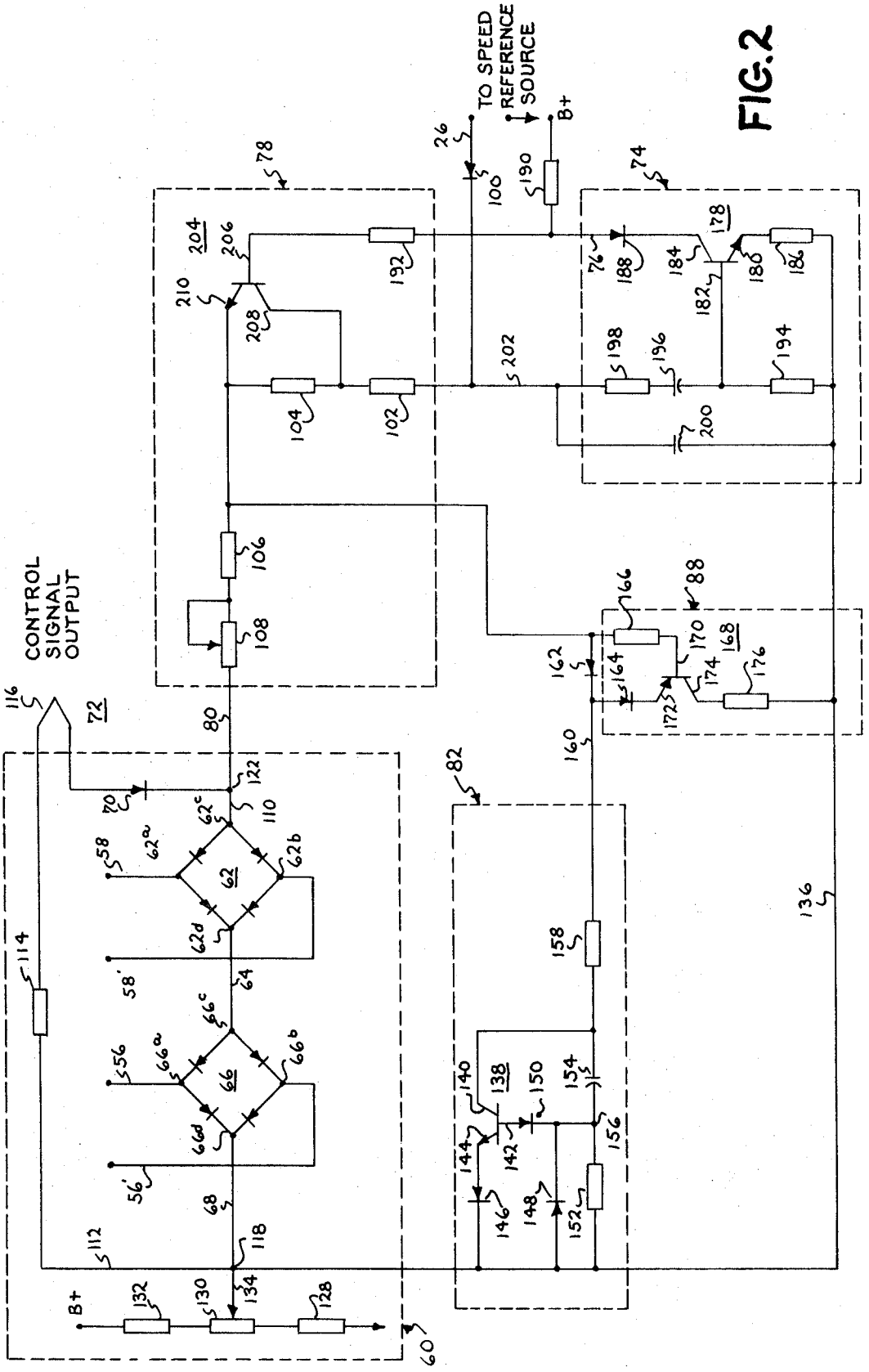

TO SPEED REFERENCE SOURCE
B+
CONTROL SIGNAL OUTPUT
78
74
88
82
72
60
26
100
190
192
204
206
210
208
104
102
202
198
196
194
178
76
188
184
182
180
186
200
106
108
166
170
168
174
176
164
172
162
160
80
122
110
70
62a
62b
62c
62d
62
58
58'
64
66a
66b
66c
66d
66
56
56'
68
114
116
112
118
132
130
134
128
158
140
138
150
154
156
144
142
146
148
152
136

FIG. 2

GENERATOR LOAD CONTROL SYSTEM

BACKGROUND OF THE INVENTION

Traction vehicle propulsion systems commonly use a thermal prime mover, such as a diesel engine, to drive electrical-generating means for providing power to the traction motors. Diesel engines employed for traction applications generally develop practically constant available horsepower for a given diesel engine speed or throttle setting. This available horsepower may be varied by a proportionate change of diesel engine speed. Stepped increases of available diesel engine horsepower are usually attainable by increasing engine throttle settings to accordingly increase engine speed.

Modern traction propulsion systems, such as the type utilized in diesel-electric locomotives, limit the actual load imposed on the diesel engine by the traction generators to the available diesel engine horsepower. An increase in available horsepower accordingly results in a corresponding increase of generator load. However, an increase of available diesel engine power accompanied by a simultaneous increase of power demand or generator load frequently results in generation of smoke. This results from a sudden application of fuel which upsets the proper air to fuel relationship required for efficient burning and minimum smoke until the diesel engine turbocharger has attained an adequate speed to provide sufficient air. It has accordingly been recognized that some smoke reduction under these conditions could be obtained by delaying the application of a load to the diesel engine for a short time period subsequent to an increase of throttle setting or diesel engine output power.

Traction propulsion systems of the type utilizing a diesel engine and traction generator conventionally utilize a power regulation control system which regulates the power output from the traction system in response to the available power output of the diesel engine. In such systems feedback signals responsive to the generator electrical output are compared to a reference current responsive to the available power of the diesel engine to generate a control signal for controlling generator excitation, such as by modulating the generator field current, and thus control the generator output power.

An increase of generator loading in response to an increase of diesel engine power may be delayed by an arrangement for initially retarding the magnitude of the reference current. Attempts have been made to achieve such retardation utilizing control circuitry operative in conjunction with the engine governor. However, a governor depended retardation system is subject to problems, such as variations with ambient temperature. It is therefore preferable and simpler to utilize a purely electronic circuit for achieving retardation. However, electronic arrangements for accomplishing this are subject to provide inadequate smoke control by failing to reduce or divert adequate reference current. Accordingly, the magnitude of reference current reduction or the time duration during which reference current is reduced is not sufficient to permit the turbocharger to come up to speed to provide sufficient combustion at full load conditions. This results in excessive loading per unit of time on the engine and unacceptable smoke generation.

Therefore, an object of the invention is to provide an electronic arrangement which provides an adequate retardation of reference current upon increases of available diesel engine output power to reduce transient smoke below the levels required for operation of transit vehicles in metropolitan areas.

Another object is a control system which, while providing transient smoke control during increases of diesel engine power, will not adversely affect control system operation during steady state diesel engine power operation or during reductions of diesel engine output power.

Briefly, in accordance with one aspect of the invention, feedback current signals, responsive to the electrical output of the traction generator, are compared with a reference current signal, responsive to available diesel engine power, in a comparison circuit to provide a control signal to control the power demand of the traction generator in respect to the available power of the prime mover. The reference current signal is applied to the comparison circuit by a series circuit including a source of reference voltage, whose magnitude is a function of the available power of the prime mover, and a resistance network. The increase in traction generator loading, which would otherwise result from an increase of prime mover power, is delayed by automatically increasing the resistance network by a discrete increment during the time period that the prime mover power is increased. In a preferred embodiment the above-described resistance increase is obtained by removing a low impedance shunt which is normally coupled across at least a portion of the resistance network. Additionally, a capacitance circuit is connected across the comparison circuit and a portion of the resistance network to prevent a stepped increase of reference current when the resistance of the resistance network is subsequently reduced to its normal magnitude. A capacitance multiplier is utilized for this purpose in a preferred embodiment. Additionally, arrangements are preferably provided for rapidly discharging the capacitance in the shunt circuit during reductions of prime mover power to prevent any delay in traction generator load reduction during such time.

The novel and distinctive features of the invention are set forth in the appended claims. The invention itself, together with further objects and advantages thereof, may be understood by reference to the following description and accompanying drawings:

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a simplified block diagram illustration of a traction propulsion system incorporating the control system of this invention; and

FIG. 2 is a schematic circuit diagram of the control system in accordance with one embodiment of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference is now made to FIG. 1. A thermal prime mover 2, such as a diesel engine, has its output shaft 4 to drive traction generating means 6 whose output is connected, as diagrammatically illustrated by line 8, to energize traction motor means 10. Field current for the traction generating means is supplied by line 16 from amplifier 12, which may be a rotary exciter. The amplifier input power is supplied by line 28 from variable power source 30. Adjustment of the output of the power supply by a control circuit thus controls the field current of the traction generating means and thus the load imposed on the prime mover.

A prime mover of the diesel engine type characteristically tends to deliver constant power output for a given diesel engine operating speed. Variations in the diesel engine speed result in variations of diesel output power. Governor 18 regulates the speed of the diesel engine, such as by controlling fuel supplied to the engine as diagrammatically indicated by line 20. A speed reference source 22, such as a tachometer, is coupled, as indicated by line 24, to the diesel engine so as to produce at its output 26 a voltage whose amplitude is responsive to the diesel engine speed, and thus also to the available output power of the diesel engine. This voltage signal may be applied to the governor to normally maintain a constant diesel engine speed. Provisions are also made for varying the diesel engine speed to vary available traction power, as may be required, for example, in starting, accelerating, or decelerating a vehicle. Generally, available diesel engine power is varied in discrete steps by changing a throttle control between a plurality of notch positions. Such changes, generally effected by control of the governor, result in appropriate variations of the voltage magnitude of the speed reference source signal appearing on line 26.

The power output of the traction generating means is controlled to prevent excessive voltages and currents and additionally to prevent the power requirements of the traction generating means from exceeding the available power output of the diesel engine. Thus limiting the electrical horsepower requirements of the traction generating means to the available horsepower output of the diesel engine, substantially decreases diesel engine wear and avoids diesel engine speed variations and stalling. This limiting action is achieved by a control system wherein feedback current signals, whose average amplitude is a function of the electrical output of the generating means, are compared with reference current signal, whose amplitude is responsive to the available horsepower of the diesel engine, to provide a control signal for regulating the excitation and thus the power output of the traction generating means.

A load sensing arrangement **40** senses the output voltage and output current of the generating means. Lines **42** and **44** represent control windings or other means for coupling, respectively, voltage and current signals to the load sensors. Appropriately, converted voltage and current feedback signals are provided, respectively, by lines **56** and **58** to comparison circuit **60** for comparison with a reference current signal whose magnitude is responsive to the available horsepower of the diesel engine. Generator overload conditions are manifested when either the voltage feedback signal in line **56** or the current feedback signal in line **58** exceeds the magnitude of the reference current. Under these conditions a control signal is produced whose magnitude is a function of the difference between the greater one of the feedback signals **56** or **58** and the reference current signal. This control signal is coupled from the comparison circuit over line **72** to variable power source **30**. This control signal reduces the output of the variable power source so as to reduce the excitation, and the power output, of the generating means.

While various load sensing arrangements may be utilized, a preferred embodiment is of the type disclosed in U.S. Pat. No. 3,105,186—Zelina, which is assigned to the assignee of the subject application. As disclosed in that patent, the load sensor comprises voltage measuring reactor **46** having a control winding **42** connected to sense traction generator output voltage and a current measuring reactor **52** having a control winding **44** connected to sense the output current of the generating means. These reactors may be of the two-core type wherein the primary windings on each of the cores are serially connected with an AC signal source and a bridge rectifier. The AC signal is modulated by the change in primary winding impedance induced by the control winding signal and is rectified by the bridge rectifier, which also acts as a mixer. The reactor components and AC signal source are not shown in FIG. 1. The current feedback signal output of the current measuring reactor **52** is thus applied by line **58** to the input of first mixer **62** and the voltage feedback signal output of the voltage measuring reactor **46** is applied by line **56** to the input of second mixer **66**.

Reference current is applied to the mixers in the comparison circuit by a circuit including a source of reference voltage, such as speed reference source **22**, and a resistance network **78**. The outputs of the first and second mixers are connected serially, by lines **80**, **64** and **68**, in the reference current circuit. Accordingly, a comparison is effected between the reference current and the voltage or current feedback signal having the larger magnitude. If the voltage and/or current feedback signals exceed the reference current signal in magnitude, a current signal, of magnitude proportional to the difference between the greater one of the feedback signals and the reference current, is applied through rectifying means **70** to the control signal line **72**. This arrangement limits the maximum voltage and current outputs of the traction generating means in reference to the available power output of the diesel engine. As disclosed in the referenced Zelina patent, the maximum power output of the generating means intermediate the maximum voltage and current limits may be limited by a function generator **48**. A signal responsive to the output voltage of the generating means is supplied by line **50** to the input of the function generator whose output is applied to an additional control winding **54** of the current measuring reactor. The function generator output varies nonlinearly with variations of generator output voltage in accordance with the desired horsepower output characteristic of the generating means. This arrangement causes the feedback current signal output on line **58** to increase with increasing generator output voltage as a function of the constant power curve of the generating means. Accordingly, the feedback current signal on line **58** exceeds the feedback voltage signal on line **56** and determines the magnitude of any control signal output unless the traction generator output voltage exceeds the maximum permissible level, at which point the voltage feedback current signal on line **56** exceeds that of line **58** and takes over control.

In the above-described arrangement, the magnitude of the reference current signal continuously corresponds to the magnitude of the available diesel engine horsepower and the magnitude of the feedback current signals continuously corresponds to the power output of the generating means. The resulting control signal thus instantaneously controls the power demand of the traction generating means in response to the available horsepower of the diesel engine. Accordingly, when the throttle setting is increased and the available diesel engine power output is increased, the power demand of the generating means increases prior to the time that adequate air is provided by the turbocharger for efficient combustion. This results in an unbalanced fuel to air supply and the generation of smoke. Accordingly, an arrangement is provided for retarding an increase of reference current when the diesel power output is increased so that the reference current increases in a manner permitting the turbocharger to come up to full speed and provide a proper fuel to air mixture prior to the application of full generator load. The speed reference source **22** provides a reference voltage whose magnitude is a function of available diesel engine horsepower. A tachometer arrangement providing an output responsive to diesel engine speed and thus available horsepower is used in the preferred embodiment. However, other voltages, sources such as voltage dividers having an output responsive to available horsepower, can be used. The reference voltage is applied by line **26** to variable resistance network **78**. The reference current circuit comprises a source of reference voltage connected in series circuit with variable resistance network **78** and mixers **62** and **66**. Reference current passes through resistance network **78**, line **80**, first mixer **62**, line **64**, second mixer **66**, and line **68**. Under quiescent diesel engine output the magnitude of resistance network **78** is selected to provide a reference current of appropriate magnitude through the first and second mixers. The resistance of network **78** is additionally automatically variable in response to a signal provided over lines **76** by a speed rate sensor **74**, so that the network resistance is increased during the presence of an output signal on line **76**. Preferably, the resistance is increased by a predetermined magnitude during the presence of this signal. The speed reference voltage **26** is applied to the input of the speed rate sensor **74** and the sensor provides an output signal only during periods when the speed reference voltage increases in magnitude. Accordingly, the resistance of network **78** is reduced to its normal level when the diesel engine available horsepower has been increased to a higher level. This arrangement results in a discrete reduction of reference current from that which would otherwise appear during the time period that the diesel engine power is increased. Additionally, a capacitance shunt circuit **82** is serially connected across a portion of the resistance network **78** and the speed reference voltage source, as indicated by line **84**. This shunt circuit is responsive to increases in reference current and in view of the charging action of a capacitance shunts a portion of the reference current so that the magnitude of the shunted current decreases exponentially over a period of time which can be re-

lated to the maximum time required for the diesel engine to increase its horsepower level. The capacitance shunt circuit thus prevents a sudden increase of reference current, and thus power demand, when the resistance of network is reduced to its normal magnitude. A capacitance discharge circuit **88**, connected to the shunt circuit by line **86**, rapidly discharges the capacitance in the shunt circuit whenever the diesel engine power is reduced to prevent any corresponding delay in reference current reduction which might otherwise result from discharge of the capacitance through the first and second mixer circuits. The above-described arrangement produces a combined stepped and exponential reduction of the reference current which would otherwise appear during increases of diesel engine horsepower so that an adequate fuel to air relationship is maintained to adequately minimize the generation of transient smoke.

Reference is now made to Fig. **2** which illustrates in schematic form the control system portion including comparison circuit **60**, speed rate sensor **74**, variable impedance **78**, capacitance shunt circuit **82**, and capacitance discharge circuit **88**. The dashed line boxes in FIG. **2** identify the portions of the schematic relating to each of these recited components.

COMPARISON CIRCUIT

The comparison circuit includes two bridge rectifier circuits, or mixers, **62** and **66**, which comprise, respectively, input terminals **62***a* and **62***b* and **66***a* and **66***b* and output terminals **62***c* and **62***d* and **66***c* and **66***d*. The output of the current measuring reactor is applied by lines **58** and **58'** to input terminals **62***a* and **62***b*. Similarly, the output of voltage measuring reactor **46** is applied by means of lines **56** and **56'** to inputs **66***a* and **66***b*. As previously described, each of the line pairs **56—56'** and **58—58'** may be connected to a series circuit comprising an AC source and the primary windings of a saturable reactor whose impedance varies in response to a control signal. The rectifying bridges rectify the modulated AC signal. The outputs of the rectifier bridges are serially connected across a unidirectionally conducting output circuit **72**. This comprises in series circuit, first output circuit terminal **122**, line **110**, rectifier terminals **62***c* and **62***d*, line **64**, rectifier terminals **66***c* and **66***d*, line **68** and second output circuit terminal **118**. The output circuit, connected to terminals **118** and **122**, comprises serially connected line **112**, resistor **114**, output means **116** and rectifier **70**. The output means **116**, for controlling variable power source **30**, is illustrated in the form of a control winding of a controlled saturable reactor. The variable power source may, for example, utilize a controlled saturable reactor whose primary windings are energized from an AC source so as to provide an output whose magnitude is reduced in response to the control winding signal. Of course, other forms of control may be utilized. Rectifier **70** is poled to permit the conduction of the rectified feedback current through the output circuit.

Reference current is supplied through a closed loop circuit comprising the source of reference voltage, line **26**, diode **100** resistance network **78**, line **80**, the comparison circuit extending from terminal **122** through serially connected bridges **62** and **66** to terminal **118**, arm **134** of potentiometer **130** and resistor **128**. The polarity of the reference voltage is selected so that the resulting reference current passes through the bridge rectifiers **62** and **66**. However, rectifier **70** in the output circuit **72** is poled so as to block the conduction of reference current in the output circuit. With the described arrangement a control signal current flows through the output circuit only when either or both of the feedback signals have a magnitude in excess of the reference current. The amplitude of the control current will then be a function of the difference between the larger one of the feedback currents and the reference current.

Junction **118** of the comparison circuit is connected to arm **134** of potentiometer **130** which is connected respectively through resistance **132** to a source of positive voltage and by resistance **128** to ground. In the reference current circuit the potential between arm **134** and ground opposes the reference voltage. The steady state reference current approximately equals the quotient of the resulting net voltage and of the resistance of resistance network **78**.

The load control potentiometer **130** is actually an integral part of the engine governor. Potentiometer arm **134** is actuated by the governor in case the generator output demand exceeds the maximum available horsepower so as to result in engine speed reduction. In this unusual situation the resulting decrease in engine speed causes movement of the potentiometer arm so as to introduce a greater voltage at the potentiometer arm and to thus reduce reference current. This above-described potentiometer circuit is a desirable safety device, but is not an essential element of the invention.

VARIABLE RESISTANCE NETWORK

The variable resistance network **78** includes resistors **102**, **104**, **106** and variable resistance **108** connected serially. NPN-transistor **204** has its collector **208** and emitter **210** electrodes connected in parallel with resistor **104**. The base **206** is connected through base current limit resistor **192** and bias resistor **190** to a source of positive potential so as to normally maintain transistor **204** in saturation. The resistance of resistor **190** should be of sufficient magnitude so that the resulting base-emitter current is not excessive in respect to the relatively low reference current which may exist when the steady state available horsepower is low. However, its magnitude should be such that transistor **204** is maintained in saturation during steady state conditions.

As described subsequently, transistor **204** is cut off when the speed reference voltage increases. At such time resistor **104** is effectively added serially into the resistance network **78** so as to reduce the magnitude of reference current which would otherwise prevail. It has been found desirable for resistor **104** to have a resistance magnitude which is substantially in excess of the series resistance of the other resistances included in the variable impedance circuit, so that a reduction of generator load occurs during the time that the diesel engine horsepower is increased. However, the magnitude of resistor **104** can be selected for maximum performance in each individual propulsion system. Since resistor **104** is effective only during transient horsepower increases, its magnitude can be selected independently of any steady state considerations.

SPEED RATE SENSOR

The speed rate sensor cuts off transistor **204** during the period that the diesel engine horsepower is increasing. The speed rate sensor includes NPN-transistor **178** which is normally cut off but is driven into saturation during an increase of diesel engine power. The base **182** is connected through resistor **194** to common line **136** which in turn is connected to comparison output terminal **118**. Emitter **180** is connected through resistor **186** to line **136**. Collector **184** is connected through diode **188** and line **76** to the junction of resistors **190** and **192**. Diode **188** is poled so as to block forward base collector current. The reference voltage line **26** is connected to base **182** by a series circuit comprising diode **100**, line **202**, resistor **198**, and capacitor **196**. An increase in reference voltage produces current flow through this circuit to turn on transistor **178**. The magnitude of resistor **198** and capacitor **196** will determine the minimum rate of speed reference voltage increase at which the transistor will conduct. A traction propulsion system may, for example, produce a 7 volt change of reference voltage for each notch change. Upon condition of transistor **178**, the voltage at collector **184** will be substantially reduced. This correspondingly reduces the voltage at the base **206** of transistor **204** so as to cut off that transistor. Transistor **178** will remain in conduction until the diesel engine power has reached a steady state. At this time the voltage at collector **184** will return to its quiescent positive potential resulting in a similar increase of voltage at the base **206** so as to again cause transistor **204** to be driven into saturation.

Capacitor **200** is connected between line **202** and line **136** so as to filter out any ripple in the speed reference voltage signal which might otherwise hold on transistor **178** for an excessive time period.

CAPACITANCE SHUNT CIRCUIT

A capacitance shunt circuit is connected from common line **136** to the junction of resistors **104** and **106** in the impedance circuit. This capacitance circuit provides for gradually increasing the magnitude of reference current subsequent to transistor **204** having again saturated to shunt resistor **104** at about the time the available horsepower level of the diesel engine has been increased to a steady state. The capacitance shunt circuit shunts the bridge rectifiers and a portion of the resistance network excluding the resistor **104**. Since the voltage across these components may be substantially reduced during the time that the reference voltage increases, the capacitance shunt circuit charges primarily subsequent to the time that the reference voltage has reached a quiescent level. A capacitance of substantial magnitude is required for this purpose and a capacitance multiplier circuit is preferably utilized. This circuit comprises NPN-transistor **138** whose emitter **144** is serially connected through diode **146** to common line **136** and whose collector **140** is connected serially through resistor **158**, line **160**, and diode **162** to the junction of resistors **106** and **104**. Base **142** is connected through zener diode **150** to junction **156**. This junction is connected through capacitor **154** to collector **140** and additionally through parallel connected diode **148** and resistor **152** to common line **136**. The capacitance multiplier provides a capacitance between the collector and emitter which is approximately equivalent to the product of the capacitance **154** and the gain of the transistor. The potential drops in the base-emitter circuit due to the drop across the zener diode **150** and diode **146** establish sharp turnon and turnoff voltages. In one particular arrangement, for example, the drops across these two components were established at 5 volts. The described turnoff feature assures that transistor **138** is cut off during steady state generator load conditions. Were this transistor to remain in conduction, it would continuously shunt reference current and adversely affect the magnitude of the generator load. The primary function of the capacitance shunt circuit is to provide for a gradual increase of reference current subsequent to the shunting of resistor **104** when the speed reference voltage reaches a steady state.

CAPACITANCE DISCHARGE CIRCUIT

During operation of the capacitance shunt circuit, capacitor **154** charges to a voltage level approximating the voltage across the serially connected rectifier bridges and impedances **108** and **106**. The capacitor must be discharged upon any subsequent reduction of diesel engine power and a resulting reduction of speed reference voltage. However, a discharge through the comparison circuit at the time of diesel engine power reduction would result in an unsatisfactory delay of generator load reduction. Accordingly, diode **162** prevents a discharge of capacitor **154** through this circuit and discharge is provided by capacitance discharge circuit **88**. PNP-transistor **168** has its emitter **172** connected through diode **164** to line **160**. Base **170** is connected to the junction of resistors **104** and **106**, and through diode **162** to line **160**. The collector **174** is connected through resistor **176** to common line **136**. The transistor is normally cut off. However, upon a reduction of diesel engine power and a resulting decrease of speed reference voltage, the voltage at the junction of resistors **104** and **106** is reduced. This causes transistor **168** to conduct. The voltage of base **170** is thus reduced below the voltage of emitter **172** causing transistor **170** to conduct. In view of the diode **164**, the base must drop to a discrete potential below the voltage of capacitor **154** in order to initiate conduction of transistor **168**.

Upon conduction of transistor **168**, capacitor **154** discharges through resistor **158**, diode **164**, the collector-emitter path of transistor **168**, resistor **176** and diode **148**. When the potential across the capacitor **154** decreases to the potential across the series combination of the comparison circuit and impedances **108** and **106**, conduction is terminated and the transistor **168** is again cut off. Resistor **166** in the base circuit prevents leakage current from maintaining transistor conduction during quiescent periods.

SYSTEM OPERATION

During diesel engine operation at quiescent horsepower levels the power output of the traction generator is continuously limited to the maximum available diesel engine output power. When the vehicle operator increases the diesel engine output power and notches up to a higher position, the speed reference voltage signal is increased in amplitude. This increase actuates the speed rate sensor so that transistor **204** is cut off so as to substantially increase the resistance in the variable impedance circuit. This retards the increase of reference current which would otherwise occur. Preferably the increased resistance results in a decrease of reference current and a resulting reduction in generator power output. When the engine comes up to the new notch speed and desired power level, the speed rate sensor causes transistor **204** to again saturate and shunt resistor **104**. A sharp increase in power output of the traction generator is avoided by the capacitance shunt circuit. This circuit, in view of its decreasing rate of reference current shunting, causes the reference current to increase gradually so that load is applied to the diesel engine at a rate which permits building up turbocharge pressure so as to maintain the desired fuel to air relationship which produces minimum smoke. When the operator notches back, so as to reduce diesel engine power and to decrease the magnitude of the speed reference voltage, the capacitance discharge circuit is actuated so as to discharge the capacitor in the capacitance shunt circuit to a correspondingly lower voltage level. This assures appropriate operation of the capacitance shunt circuit during any following notch operation.

The invention may be utilized with load sensors or comparison circuits of different design from those specifically set forth herein. In certain equipments transient smoke of unacceptable magnitude may not be generated when notching up is commenced from higher notching levels. Accordingly, an arrangement can be provided to continuously shunt resistance **104** during notching operations which commence from such higher notching levels. This can be achieved by means of a relay which is actuated when the diesel engine has a steady state available power commensurate with a predesignated notching level.

Various changes, modificatons, and substitutions may be made in the embodiment described herein without departing from the true scope and spirit of the invention as defined in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States are:

1. In a propulsion system for traction vehicles wherein a thermal prime mover operable over a range of available power output levels drives electrical generating means adapted to energize traction motors and a control system limits the output of said generating means responsive to the output level of said prime mover, said control system having means adapted to control the output of said generating means to reduce smoke produced by said thermal prime mover during increases of available power output comprising:

a. a source of feedback current signals varying as a function of the output of said generating means,

b. a source of reference current signals varying as a function of the available power output level of said prime mover,

c. a comparison circuit having inputs coupled to said aforesaid sources and an output adapted to provide a con-

trol signal for limiting the output of said generating means,

d. said source of reference current comprising in series circuit;

1. a source of reference voltage varying in magnitude as a function of the available power level of said prime mover,

2. resistance means having a resistance of a first predetermined value, said resistance means being adapted for modifying said resistance to a second discretely increased value,

e. reference current control means responsive to variations of said reference voltage being coupled to said resistance means to increase said resistance from said first predetermined value to said second discretely increased value when the available power level of said prime mover is increasing and to subsequently return said resistance to its first predetermined value,

f. capacitance means connected across said source of reference voltage and at least a portion of said resistance means, the capacitance of said capacitance means being adequate to prevent an abrupt increase of reference current upon said resistance being returned to its first predetermined value.

2. The control system of claim 1 wherein said resistance means comprises a plurality of resistors connected in series circuit and shunting means for normally applying a shunt of negligible impedance magnitude across less than all of said plurality of resistors, said shunting means being responsive to said reference current control means to temporarily remove said shunt upon an increase of the available power level of said prime mover.

3. The control system of claim 2 wherein said shunting means comprises a first semiconductor device having two electrodes connected across less than all of said plurality of resistors, and a control electrode, means for biasing said control electrode to normally maintain full current conduction between said two electrodes, and means for coupling said control electrode to said reference current control means to temporarily cut off current conduction between said two electrodes upon an increase of available power level of said prime mover.

4. The control system of claim 3 wherein said reference current control means comprises a second semiconductor device having a control electrode and output electrodes connected in circuit with the control electrode of said first semiconductor device, control means coupled to said control electrode and responsive to a variation of the magnitude of said source of reference voltage, to modify the state of conduction of said second semiconductor device to temporarily cut off current conduction between the two electrodes of said first semiconductor device.

5. The control system of claim 4 wherein said control means comprises resistance and capacitance means coupled intermediate said control electrode and said source of reference voltage whereby the state of conduction of said second semiconductor device is modified solely during voltage variations of said source of reference voltage.

6. The control system of claim 5 wherein rectifying means are connected serially with said resistance and capacitance means to prevent modification of the state of conduction of said second semiconductor device in response to decreases of available power output.

7. The control system of claim 2 wherein the resistance of the resistors normally shunted by said shunting means exceeds the resistance of the remaining serially connected resistors in said shunting means.

8. In a propulsion system for traction vehicles wherein a thermal prime mover operable over a range of available power output levels drives electrical generating means adapted to energize traction motors and a control system limits the output of said generating means responsive to the output level of said prime mover, said control system having means adapted to control the output of said generating means to reduce smoke produced by said thermal prime mover during increases of available power output comprising:

a. bridge-rectifying means,

b. first and second resistance means,

c. a source of reference voltage varying in magnitude as a function of the available power level of said prime mover,

d. means for serially connecting said bridge-rectifying means, first and second resistance means and said source of reference voltage in a unidirectionally conducting loop circuit,

e. said bridge-rectifying means having a first set of input terminals connected in said loop circuit and a second set of input terminals connected to a source of feedback current signals varying as a function of the available power output level of said prime mover,

f. switching means connected across said second resistance means to normally apply a shunt of negligible resistance across said second resistance means,

g. reference current control means responsive to variations of said reference voltage being coupled to said switching means to remove the shunt across said second resistance means temporarily when the available power level of said prime mover is increasing, and to subsequently reapply said shunt,

h. capacitance means connected in parallel circuit with the series combination of said source of reference voltage and said second resistance means, the capacitance of said capacitance being adequate to prevent an abrupt increase of reference current upon the reapplication of said shunt,

i. output means coupled to said first set of input terminals adapted to provide a control signal for limiting the output of said generating means.

9. The control system of claim 8 wherein said switching means comprises a first semiconductor device having two electrodes connected across said second resistance means and a control electrode, means for biasing said control electrode to normally maintain full current conduction between said two electrodes, and means for coupling said control electrode to said reference current control means to temporarily cut off current conduction between said two electrodes upon an increase of available power level of said prime mover.

10. The control system of claim 9 wherein said reference current control means comprises a second semiconductor device having a control electrode and output electrodes connected in circuit with the control electrode of said first semiconductor device, control means coupled to said control electrode and responsive to a variation of the magnitude of said source of reference voltage, to modify the state of conduction of said second semiconductor device to temporarily cut off current conduction between the two electrodes of said first semiconductor device.

11. The control system of claim 10 wherein said control means comprises resistance and capacitance means coupled intermediate said control electrode and said source of reference voltage whereby the state of conduction of said second semiconductor device is modified solely during voltage variations of said source of reference voltage.

12. The control system of claim 11 wherein rectifying means are connected serially with said resistance and capacitance means to prevent modification of the state of conduction of said second semiconductor device in response to decreases of available power output.

13. The control system of claim 8 wherein the resistance of said second resistance means exceeds the resistance of said first resistance means.

14. The control system of claim 8 wherein first unidirectionally conducting means are connected with said capacitance means to prevent discharge of said capacitance means through said bridge-rectifying means, and second unidirectionally conducting means are connected across said capacitance means to permit discharge of said capacitance means to a potential across the series combination of said first resistance means and said bridge-rectifying means.