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(54) **TURBOGENERATOR/MOTOR CONTROLLER**

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(58) **Field of Classification Search** 322/58, 322/10; 290/52, 7; 318/140, 145, 147, 375
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,864,244	A		12/1958	Prachar
3,124,924	A		3/1964	Smith
3,124,942	A	*	3/1964	Rothfuss et al. 464/99

(Continued)

FOREIGN PATENT DOCUMENTS

DE	3634328	4/1987
DE	19704662	8/1998
EP	0 472 294	2/1992
EP	0 679 800	4/1995
EP	0 837 231	4/1998
EP	0 901 218	3/1999
JP	6-108879	4/1994
WO	WO 94/27359	11/1994
WO	WO 98/25014	6/1998
WO	WO 99/32762	7/1999
WO	WO 99/52193	10/1999
WO	WO 00/28191	5/2000

OTHER PUBLICATIONS

Japanese Patent Application Abstract entitled "Turbogenerator/Motor Control System"; filed May 13, 1999, Japanese Serial No. 133003/1999.

Japanese Patent Application Abstract entitled "Command and Control System and Method for Multiple Turbogenerators", filed Oct. 27, 1999, Japanese Serial No. 305375/1999.

Japanese Patent Application Abstract entitled "Turbogenerator/Motor Controller", filed Aug. 4, 1998, Japanese Serial No. 220231/1998.

(Continued)

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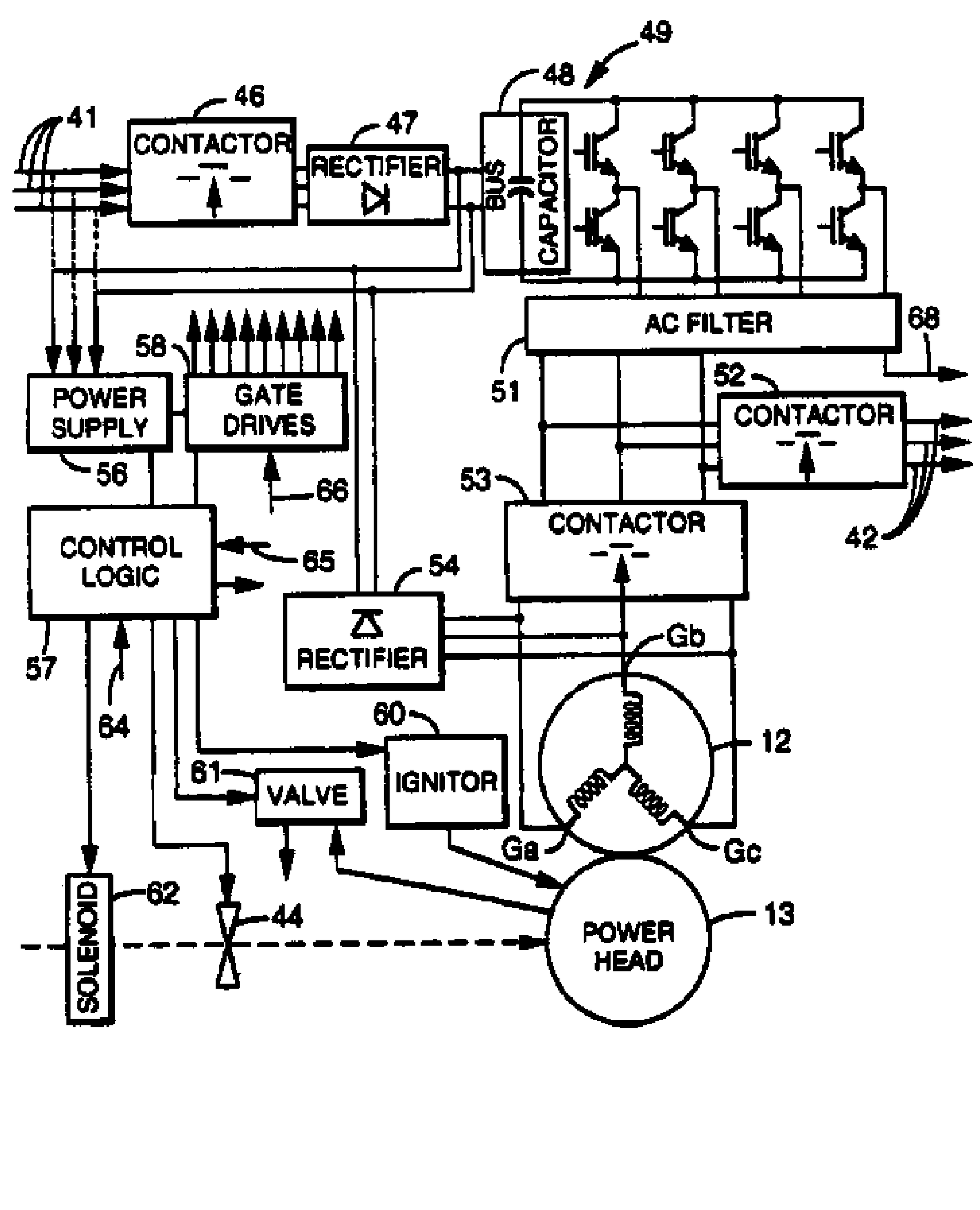
(57) **ABSTRACT**

A turbogenerator/motor controller with a microprocessor based inverter having multiple modes of operation. To start the turbine, the inverter [connects to and] supplies fixed current, variable voltage, variable frequency, AC power to the permanent magnet turbogenerator/motor, driving the permanent magnet turbogenerator/motor as a motor to accelerate the gas turbine. During this acceleration, spark and fuel are introduced in the correct sequence, and self-sustaining gas turbine operating conditions are reached. The inverter is then [disconnected from the permanent magnet generator/motor,] reconfigured to a controlled 60 hertz mode, and then either supplies regulated 60 hertz three phase voltage to a stand alone load or phase locks to the utility, or to other like controllers, to operate as a supplement to the utility. In this mode of operation, the power for the inverter is derived from the permanent magnet generator/motor via high frequency rectifier bridges. The microprocessor monitors turbine conditions and controls fuel flow to the gas turbine combustor.

44 Claims, 3 Drawing Sheets



U.S. PATENT DOCUMENTS

3,569,809	A		3/1971	Comer	
3,703,076	A		11/1972	Hagemeister	
3,764,815	A		10/1973	Habock et al.	
3,829,758	A		8/1974	Studtmann	
3,991,357	A		11/1976	Kaminski	
4,015,187	A		3/1977	Sasaki et al.	
4,119,861	A		10/1978	Gocho	290/13
4,258,424	A		3/1981	Giras et al.	
4,265,099	A		5/1981	Johnson et al.	
4,292,534	A		9/1981	Diegel et al.	
4,340,820	A		7/1982	Meyer-Pittroff et al.	
4,401,938	A		8/1983	Cronin	
4,442,385	A		4/1984	Van Sickle	
4,498,551	A		2/1985	Arbisi	
4,551,980	A		11/1985	Bronicki	
4,560,364	A		12/1985	Cohen	
4,565,957	A		1/1986	Gary et al.	
4,684,814	A		8/1987	Radomski	
4,709,318	A		11/1987	Gephart et al.	
4,719,550	A		1/1988	Powell et al.	
4,730,397	A		3/1988	Weiford et al.	
4,754,607	A		7/1988	Mackay	
4,757,686	A		7/1988	Kawamura et al.	
4,772,802	A		9/1988	Glennon et al.	
4,802,882	A		2/1989	Heidrich	
4,833,887	A		5/1989	Kawamura et al.	
4,841,216	A	*	6/1989	Okada et al.	322/10
4,862,009	A	*	8/1989	King	290/22
4,883,973	A		11/1989	Lakey et al.	
4,908,565	A		3/1990	Cook et al.	
4,955,199	A		9/1990	Kawamura	
4,967,096	A		10/1990	Diemer et al.	
4,968,926	A		11/1990	Dhyanchand	
4,982,569	A		1/1991	Bronicki	
5,013,929	A		5/1991	Dhyanchand	
5,015,941	A		5/1991	Dhyanchand	
5,029,062	A		7/1991	Capel	
5,038,566	A		8/1991	Hara	
5,055,764	A		10/1991	Rozman et al.	
5,057,763	A		10/1991	Torii et al.	
5,088,286	A		2/1992	Muraji	
5,115,183	A		5/1992	Kyoukane et al.	
5,158,504	A		10/1992	Stocco	
5,191,520	A		3/1993	Eckersley	
5,250,890	A		10/1993	Tanamachi et al.	
5,252,860	A		10/1993	McCarty et al.	
5,260,637	A		11/1993	Pizzi	
5,291,106	A		3/1994	Murty et al.	
5,309,081	A		5/1994	Shah et al.	
5,325,043	A		6/1994	Parro	
5,345,154	A		9/1994	King	
5,363,032	A		11/1994	Hanson et al.	
5,364,309	A		11/1994	Heidrich et al.	
5,373,195	A		12/1994	De Doncker et al.	
5,381,081	A		1/1995	Radun	
5,404,092	A		4/1995	Gegner	
5,406,797	A		4/1995	Kawamura	
5,477,091	A		12/1995	Fiorina et al.	
5,488,286	A		1/1996	Rozman et al.	
5,495,162	A		2/1996	Rozman et al.	
5,495,163	A		2/1996	Rozman et al.	
5,510,696	A		4/1996	Naidu et al.	
5,512,811	A		4/1996	Latos et al.	
5,545,090	A		8/1996	Kirschey	
5,546,742	A		8/1996	Shekhawat et al.	
5,550,410	A		8/1996	Titus	
5,550,455	A		8/1996	Baker	
5,559,421	A		9/1996	Miyakawa	322/58
5,563,802	A		10/1996	Plahn et al.	
5,568,023	A		10/1996	Grayer et al.	
5,572,108	A		11/1996	Windes	
5,581,168	A		12/1996	Rozman et al.	
5,594,322	A		1/1997	Rozman et al.	
5,637,987	A		6/1997	Fattic et al.	
5,646,458	A		7/1997	Bowyer et al.	
5,656,915	A		8/1997	Eaves	
5,767,637	A		6/1998	Lansberry	
5,903,116	A		5/1999	Geis et al.	
5,905,346	A		5/1999	Yamada et al.	
5,929,537	A		7/1999	Glennon	
5,936,312	A		8/1999	Koide et al.	
5,939,794	A		8/1999	Sakai et al.	
5,946,086	A		8/1999	Bruce	
5,982,645	A		11/1999	Levran et al.	
5,998,976	A		12/1999	Steffan	
6,005,297	A		12/1999	Sasaki et al.	
6,020,713	A		2/2000	Geis et al.	
6,023,135	A		2/2000	Gilbreth et al.	
6,031,294	A	*	2/2000	Geis et al.	290/52
6,051,951	A		4/2000	Arai et al.	
6,064,122	A		5/2000	McConnell	
6,093,975	A	*	7/2000	Peticolas	290/52
6,147,414	A		11/2000	McConnell et al.	
6,153,942	A		11/2000	Roseman et al.	
6,169,332	B1		1/2001	Taylor et al.	
6,169,334	B1		1/2001	Edelman	
6,175,210	B1		1/2001	Schwartz et al.	
6,194,794	B1		2/2001	Lampe et al.	
6,265,786	B1	*	7/2001	Bosley et al.	290/52
6,281,596	B1	*	8/2001	Gilbreth et al.	290/52
6,281,601	B1	*	8/2001	Edelman et al.	307/29
6,294,842	B1	*	9/2001	Skowronski	290/7
6,323,625	B1		11/2001	Bhargava	
6,487,096	B1		11/2002	Gilbreth et al.	

OTHER PUBLICATIONS

English Language Abstract for Japanese Patent 6–108879 (Apr. 1994).

German Patent Application Abstract entitled Control Circuit for Turbine AC Motor–Generator—Monitors Power Supply to Regulate Secondary Excitation Windings for Constant Operation of Synchronous Machine, filed Oct. 8, 1986, German Serial No. DE 3634328 (Apr. 1987).

German Patent Application Abstract entitled "Load Symmetrising e.g. for Several Power Supply Modules Including Rectifier Modules—Involves Checking Each Module to Assess Whether Bus Functions in Recessive or Dominant Condition," filed Feb. 7, 1997, German Serial No. DE 19704662 (Aug., 1998).

* cited by examiner

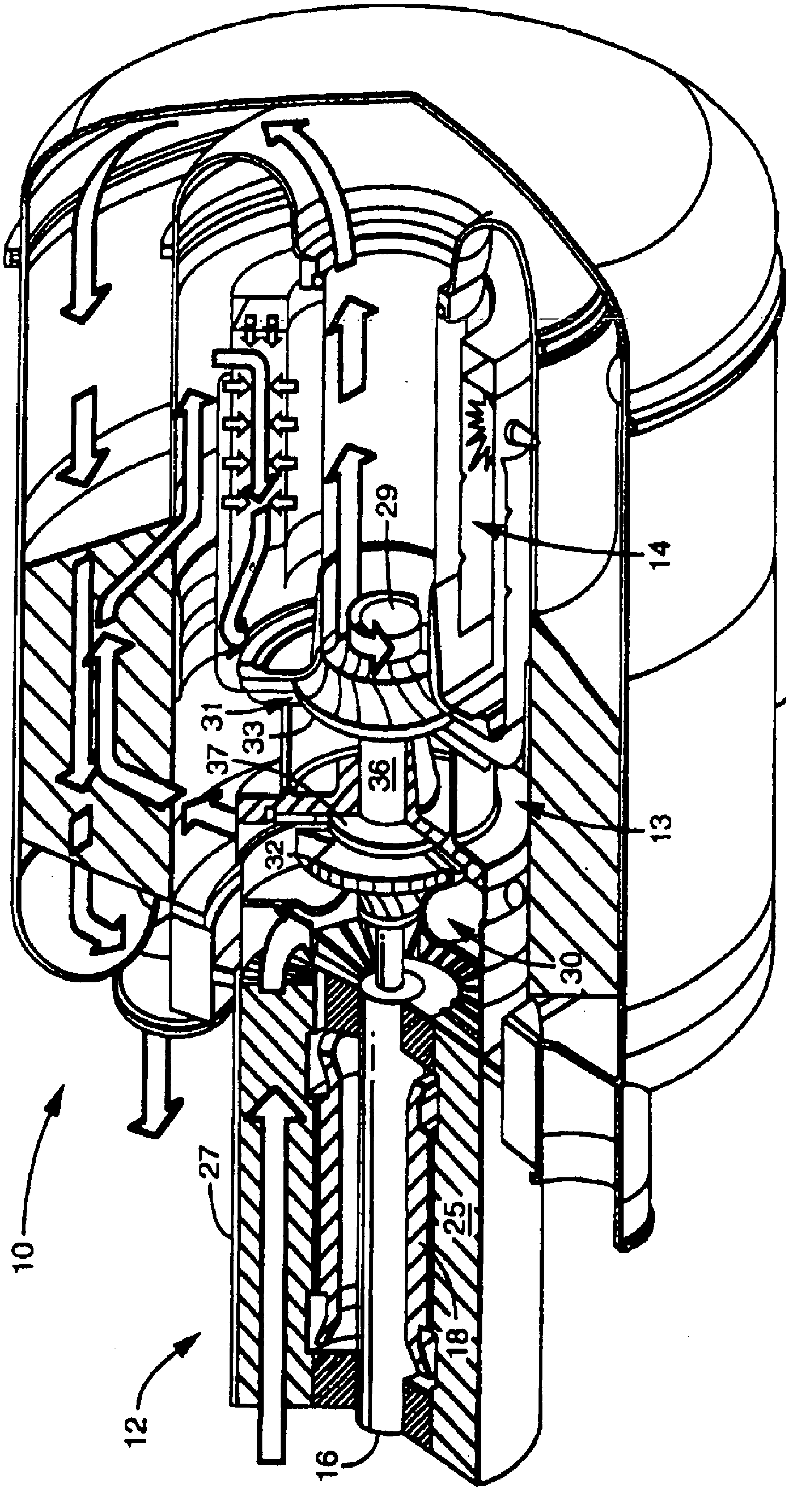


FIG. 1

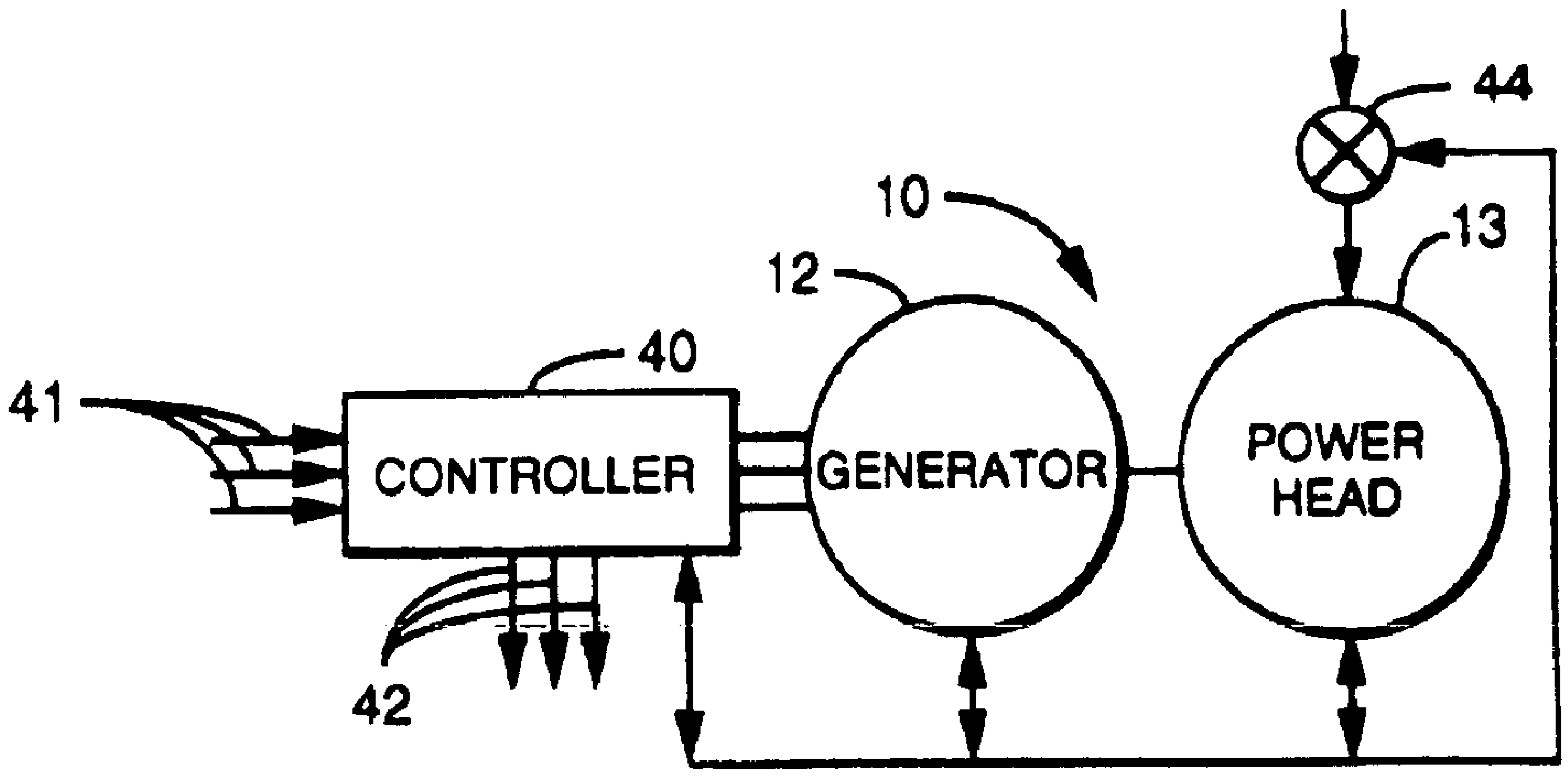

44
10
12
13
40
41
CONTROLLER
GENERATOR
POWER
HEAD
42

FIG. 2

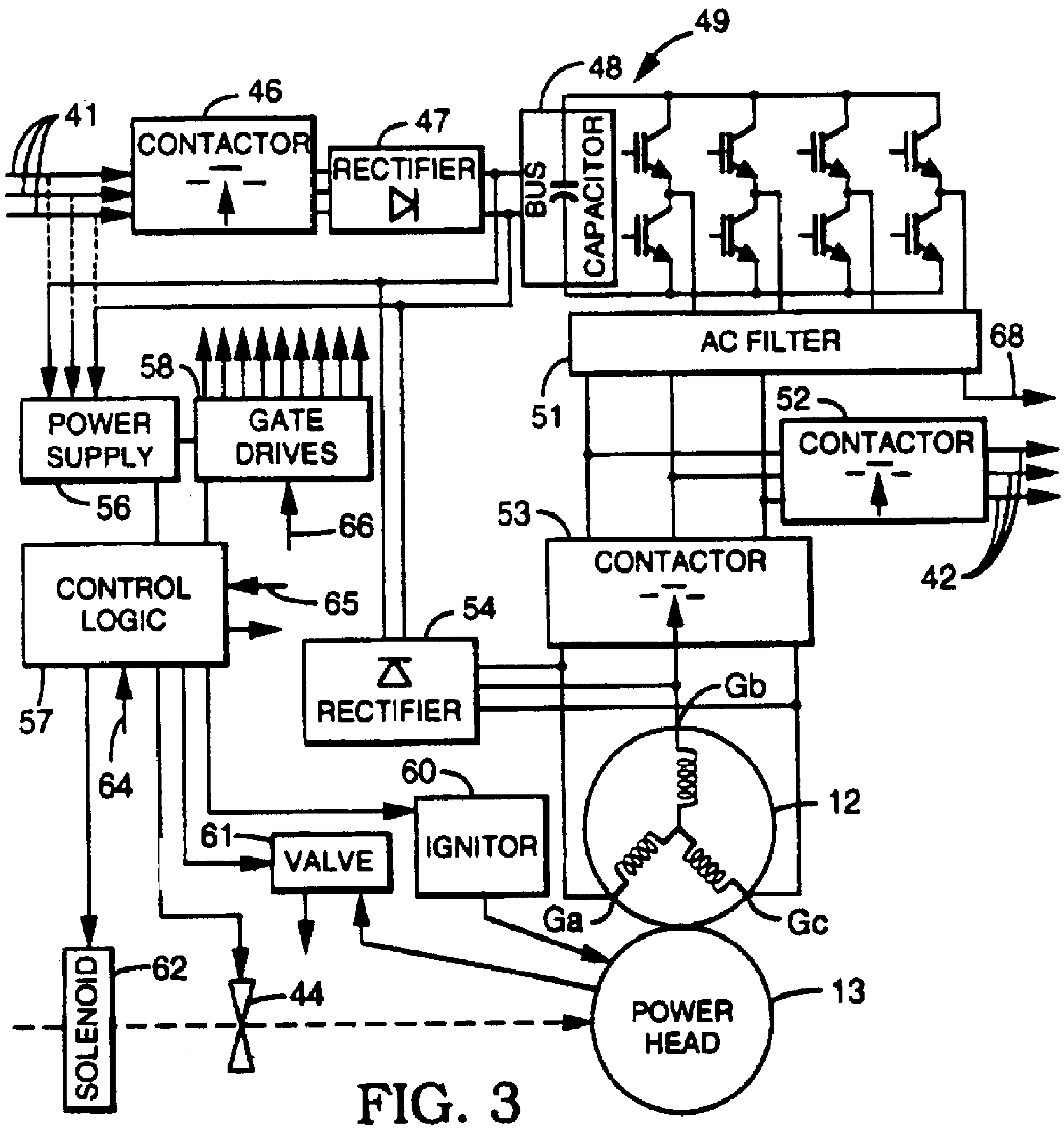

49
48
46
47
41
CONTACTOR
RECTIFIER
BUS
CAPACITOR
AC FILTER
68
58
51
52
POWER
SUPPLY
GATE
DRIVES
CONTACTOR
56
66
53
42
CONTROL
LOGIC
65
CONTACTOR
54
RECTIFIER
Gb
57
64
60
12
IGNITOR
61
VALVE
Ga
Gc
62
44
13
SOLENOID
POWER
HEAD

FIG. 3

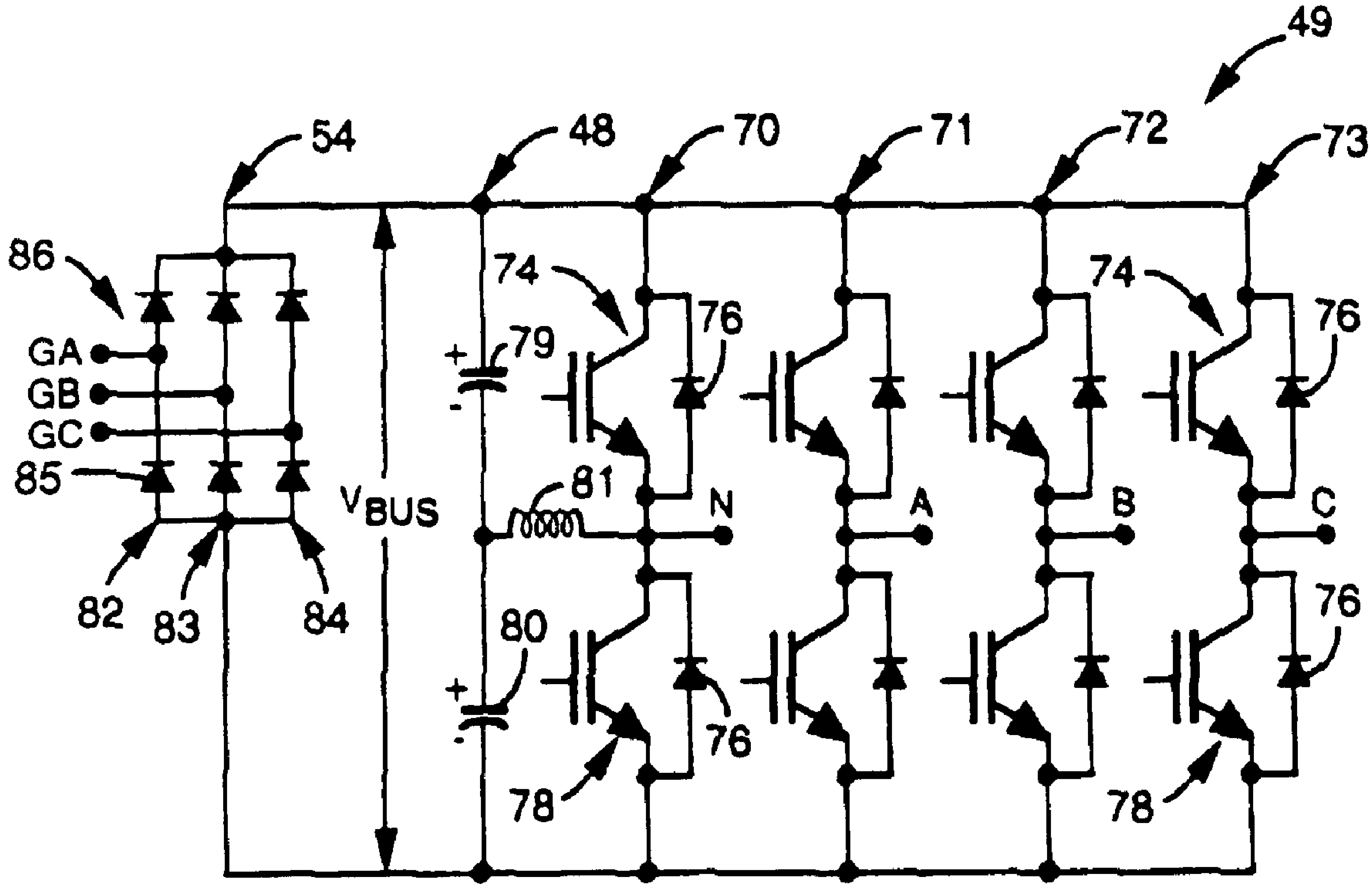

49
54
48
70
71
72
73
86
GA
GB
GC
85
82
83
84
V_{BUS}
74
76
79
81
80
78
N
A
B
C

FIG. 4

TURBOGENERATOR/MOTOR CONTROLLER

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

TECHNICAL FIELD

This invention relates to the general field of power converting systems and more particularly to an improved controller for a turbogenerator/motor.

BACKGROUND OF THE INVENTION

Electric utilities are now grappling with the challenge of deregulation and competition at a time of relatively slow growth in electricity demands. While plans for huge power plants are being shelved because of high costs and environmental concerns, new customers must still be supplied with electrical power. Existing plants and transmission lines are simply becoming overwhelmed in some areas. Nuclear power plants are fast becoming economic dinosaurs.

One alternative to generating electrical power is called a "turbogenerator", a small gas turbine engine combined on a common shaft with an electric generator. When a permanent magnet generator/motor is utilized, the combination is referred to as a permanent magnet turbogenerator/motor.

Intake air is drawn through the permanent magnet turbogenerator/motor by the gas turbine compressor which increases the pressure of the air and forces it into a recuperator which receives exhaust gases from the gas turbine. The recuperator preheats the air before it enters the gas turbine combustor where the preheated air is mixed with fuel and burned. The combustion gases are then expanded in the turbine which drives the compressor and the permanent magnet rotor of the permanent magnet turbogenerator/motor is mounted on the same shaft as the gas turbine and compressor. The expanded turbine exhaust gases are then passed through the recuperator before being discharged from the turbogenerator/motor.

A permanent magnet turbogenerator/motor generally includes a rotor assembly having a plurality of equally spaced magnet poles of alternating polarity around the outer periphery of the rotor or, in more recent times, a solid structure of samarium cobalt or neodymium-iron-boron. The rotor is rotatable within a stator which generally includes a plurality of windings and magnetic poles of alternating polarity. In a generator mode, rotation of the rotor causes the permanent magnets to pass by the stator poles and coils and thereby induces an electric current to flow in each of the coils. Alternately, if an electric current is passed through the stator coils, the energized coils will cause the rotor to rotate and thus the generator will perform as a motor.

A permanent magnet turbogenerator/motor can be utilized to provide electrical power for a wide range of utility, commercial and industrial applications. While an individual permanent magnet turbogenerator may only generate 24 to 50 kilowatts, powerplants of up to 500 kilowatts or greater are possible by linking numerous permanent magnet turbogenerator/motors together. Standby power, peak load shaving power and remote location power are just several of the potential utility applications which these lightweight, low noise, low cost, environmentally friendly, and thermally efficient units can be useful for.

In order to meet the stringent utility requirements, particularly when the permanent magnet turbogenerator/motor is to

operate as a supplement to utility power, precise control of the permanent magnet turbogenerator/motor is required.

SUMMARY OF THE INVENTION

[The turbogenerator/motor controller of the present invention is a microprocessor based inverter having multiple modes of operation. To start the turbine, the inverter connects to and supplies fixed current, variable voltage, variable frequency, AC power to the permanent magnet turbogenerator/motor, driving the permanent magnet turbogenerator/motor as a motor to accelerate the gas turbine. During this acceleration, spark and fuel are introduced in the correct sequence, and self-sustaining gas turbine operating conditions are reached.

At this point, the inverter is disconnected from the permanent magnet generator/motor, reconfigured to a controlled 60 hertz mode, and then either supplies regulated 60 hertz three phase voltage to a stand along load or phase locks to the utility, or to other like controllers, to operate as a supplement to the utility. In this mode of operation, the power for the inverter is derived from the permanent magnet generator/motor via high frequency rectifier bridges. The microprocessor monitors turbine conditions and controls fuel flow to the gas turbine combustor.

Since the voltage derived from the permanent magnet generator/motor is a function of rotational speed and the load, inverter input voltage requirements limit the operational speed of the gas turbine from approximately 72,000 rpm to a top speed of 96,000 rpm. The inverter is direct coupled to the utility, therefor the inverter voltage rating is established by the utility for grid connect operation, and has a narrow range for stand along operation.]

In one aspect of the present invention, a turbine generator system is provided including a turbine engine, a motor/generator rotationally coupled to the turbine engine for generating AC power for a load, and a controller connected to the turbine engine for controlling fuel flow to the turbine engine. The controller includes microprocessor-controlled switched elements for inverting internal DC power to output AC power for the load, and is connected to the motor/generator for applying the output AC power to the motor/generator at varying voltage and varying frequency to adjust the motor/generator speed.

In another aspect of the present invention, the controller is connected to the load for transferring AC power to the load and includes microprocessor-controlled switched elements for applying AC power to the motor/generator at varying voltage and varying frequency to adjust the motor/generator speed.

In yet another aspect of the present invention, the controller is connected to the turbine engine and includes microprocessor-controlled switched elements for applying AC power to the motor/generator to start the turbine engine, and is also connected to the load for supplying output AC power to the load after the turbine engine has started.

The controller may include a pulse width modulated inverter that comprises the microprocessor-controlled switched elements, which may comprise integrated crate bipolar transistors. The inverter may further comprise at least one microprocessor-controlled switched element connected to the motor/generator for providing an artificial neutral pole.

The controller may further include control logic connected to the turbine engine and responsive to a turbine exhaust temperature for controlling fuel flow to the turbine engine. The controller may also include control logic con-

nected to the switched elements to phase lock the output AC power to AC power supplied by at least one other controller.

The controller may further include a DC bus connected to the microprocessor-controlled switched elements for transferring the internal DC power from the motor/generator to the microprocessor-controlled switched elements. The DC bus may also be connected to the motor/generator for receiving internal DC power from the motor/generator, and the microprocessor-controlled switched elements connected to the DC bus for inverting the internal DC power to output AC power for the load.

In another aspect of the present invention, a controller is provided for controlling a motor/generator driven by a turbine engine, the controller comprising a plurality of microprocessor-controlled switched elements connected to the motor/generator for applying power to the motor/generator at varying voltage and varying frequency to adjust the motor/generator speed, and a DC bus for transferring rectified DC power from the motor/generator to an inverter circuit to supply AC power to a load, the DC bus being connected to the microprocessor-controlled switched elements for providing DC power to the microprocessor-controlled switched elements.

In still another aspect of the present invention, a controller is provided for controlling a motor/generator driven by a turbine engine, the controller comprising a DC bus connected to the motor/generator for receiving rectified DC power from the motor/generator, and a plurality of microprocessor-controlled switched elements connected to the DC bus for inverting DC power received from the DC bus to supply AC power to a load.

In yet another aspect of the present invention, a controller is provided for controlling a motor/generator driven by a turbine engine, the controller comprising a rectifier circuit connected to the motor/generator for rectifying AC power from the motor/generator, and a plurality of microprocessor-controlled switched elements connected to the rectifier circuit for inverting DC power from the rectifier circuit to supply AC power to a load.

In another aspect of the present invention, a controller is provided for controlling a motor/generator driven by a turbine engine, the controller comprising a rectifier circuit connected to the motor/generator for rectifying AC power from the motor/generator, the rectifier circuit being reconfigurable to rectify AC power from a power grid, and an inverter including a plurality of microprocessor-controlled switched elements connected to the rectifier circuit for inverting DC power from the rectifier circuit to supply AC power to the power grid, the inverter being reconfigurable to supply AC power to the motor/generator.

In another aspect of the present invention, a method is provided for controlling a system including a motor/generator rotationally coupled to a turbine engine, the method comprising connecting a controller to the motor/generator for applying power to the motor/generator at varying voltage and varying frequency to adjust the speed of the motor/generator, connecting the controller to the turbine engine to control fuel flow to the turbine engine, operating the controller to apply power to the motor/generator to accelerate the turbine engine to a predetermined speed, initiating combustion in the turbine engine at the predetermined speed, and operating the controller to apply power to the motor/generator to adjust the speed of the motor/generator after initiating combustion in the turbine engine.

BRIEF DESCRIPTION OF THE DRAWINGS

Having thus described the present invention in general terms, reference will now be made to the accompanying drawings in which:

FIG. **1** is a perspective view, partially cut away, of a permanent magnet turbogenerator/motor utilizing **[**the**]** *a* controller **[**of**]** *in accordance with* the present invention;

FIG. **2** is a functional block diagram of the interface between the permanent magnet turbogenerator/motor of FIG. **1** and **[**the**]** *a* controller **[**of**]** *in accordance with* the present invention;

FIG. **3** is a functional block diagram of **[**the**]** *a* permanent magnet turbogenerator/motor controller **[**of**]** *in accordance with* the present invention; and

FIG. **4** is a circuit diagram of **[**the**]** *a* PWM inverter **[**of the**]** *that may be used with a* permanent magnet turbogenerator/motor controller **[**of**]** *in accordance with* the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The turbogenerator/motor controller of the present invention is a microprocessor based inverter having multiple modes of operation. To start the turbine, the inverter connects to and supplies fixed current, variable voltage, variable frequency, AC power to the permanent magnet turbogenerator/motor, driving the permanent magnet turbogenerator/motor as a motor to accelerate the gas turbine. During this acceleration, spark and fuel are introduced in the correct sequence, and self-sustaining gas turbine operating conditions are reached.

At this point, the inverter is disconnected from the permanent magnet generator/motor, reconfigured to a control 60 hertz mode, and then either supplies regulated 60 hertz three phase voltage to a stand alone load or phase locks to the utility, or to other like controllers, to operate as a supplement to the utility. In this mode of operation, the power for the inverter is derived from the permanent magnet generator/motor via high frequency rectifier bridges. The microprocessor monitors turbine conditions and controls fuel flow to the gas turbine combustor.

A permanent magnet turbogenerator/motor **10** is illustrated in FIG. **1** as an example of a turbogenerator/motor **[**utilizing the**]** *that may be utilized with a* controller **[**of**]** *in accordance with* the present invention. **[**The**]** *A* permanent magnet turbogenerator/motor **10** generally **[**comprises**]** *includes* a permanent magnet generator **12**, a power head **13**, a combustor **14** and a recuperator (or heat exchanger) **15**.

[The**]** *A* permanent magnet generator **12** *generally* includes a permanent magnet rotor or sleeve **16**, having a permanent magnet disposed therein, rotatably supported within a stator **18** by a pair of spaced journal bearings. Radial stator cooling fins **25** are enclosed in an outer cylindrical sleeve **27** to form an annular air flow passage which cools the stator **18** and thereby preheats the air passing through on its way to the power head **13**.

The power head **13** of the permanent magnet turbogenerator/motor **10** **[**includes**]** *will typically include* compressor **30**, turbine **31**, and bearing rotor **36** through which the tie rod **29** passes. The compressor **30**, having compressor impeller or wheel **32** which receives preheated air from the annular air flow passage in cylindrical sleeve **27** around the stator **18**, is driven by the turbine **31** having turbine wheel **33** which receives heated exhaust gases from the combustor **14** supplied with air from recuperator **15**. The compressor wheel **32** and turbine wheel **33** **[**are**]** *may be* rotatably supported by bearing shaft or rotor **36** **[**having**]** *which may have* radially extending bearing rotor thrust disk **37**. The bearing rotor **36** **[**is**]** *may be* rotatably supported by a single journal bearing within the center bearing housing while the bearing rotor thrust disk **37** at the compressor end of the bearing rotor **36** [is] *may be* rotatably supported by a bilateral thrust bearing. [The] *A* bearing rotor thrust disk **37** is *usually* adjacent to the thrust face at the compressor end of the center bearing housing while a bearing thrust plate is *typically* disposed on the opposite side of the bearing rotor thrust disk **37** relative to the center housing thrust face.

Intake air is drawn through the permanent magnet generator **12** by the compressor **30** which increases the pressure of the air and forces it into the recuperator **15**. In the recuperator **15**, exhaust heat from the turbine **31** is used to preheat the air before it enters the combustor **14** where the preheated air is mixed with fuel and burned. The combustion gases are then expanded in the turbine **31** which drives the compressor **30** and the permanent magnet rotor **16** of the permanent magnet generator **12** which is mounted on the same shaft as the turbine **31**. The expanded turbine exhaust gases are then passed through the recuperator **15** before being discharged from the turbogenerator/motor **10**.

A functional block diagram of the interface between the generator controller **40** and the permanent magnet turbogenerator/motor **10** for stand alone operation is illustrated in FIG. **2**. The generator controller **40** receives power **41** from a source such as a utility to operate the permanent magnet generator **12** as a motor to start the turbine **31** of the power head **13**. During the start sequence, the utility power **41** is rectified and a controlled frequency ramp is supplied to the permanent magnet generator **12** which accelerates the permanent magnet rotor **16** and the compressor wheel **32**, bearing rotor **36** and turbine wheel **33**. This acceleration provides an air cushion for the air bearings and airflow for the combustion process. At about 12,000 rpm, spark and fuel are provided and the generator controller **40** assists acceleration of the turbogenerator **10** up to about 40,000 rpm to complete the start sequence. The fuel control valve **44** is also regulated by the generator controller **40**.

Once self sustained operation is achieved, the generator controller **40** is reconfigured to produce 60 hertz, three phase AC (208 volts) **42** from the rectified high frequency AC output (280–380 volts) of the high speed permanent magnet turbogenerator **10**. The permanent magnet turbogenerator **10** is commanded to a power set-point with speed varying as a function of the desired output power. For grid connect applications, output **42** is connected to input **41**, and these terminals are then the single grid connection.

The functional blocks internal to the generator controller **40** are illustrated in FIG. **3**. The generator controller **40** includes in series the start power contactor **46**, rectifier **47**, DC bus capacitors **48**, pulse width modulated (PWM) inverter **49**, AC output filter **51**, output contactor **52**, generator contactor **53**, and permanent magnet generator **12**. The generator rectifier **54** is connected from between the rectifier **47** and bus capacitors **48** to between the generator contactor **53** and permanent magnet generator **12**. The AC power output **42** is taken from the output contactor **52** while the neutral is taken from the AC filter **51**.

The control logic section consists of control power supply **56**, control logic **57**, and solid state switched gate drives illustrated as integrated gate bipolar transistor (IGBT) gate drives **58**, but may be any high speed solid state switching device. The control logic **57** receives a temperature signal **64** and a current signal **65** while the IGBT gate drives **58** receive a voltage signal **66**. The control logic **57** sends control signals to the fuel cutoff solenoid **62**, the fuel control valve **44**, the ignitor **60** and release valve **61**. AC power **41** is provided to both the start power contactor **46** and in some instances directly to the control power supply **56** in the control logic section of the generator controller **40** as shown in dashed lines.

Utility start power **41**, (for example, 208 AC voltage, 3 phase, 60 hertz), is connected to the start power contactor **46** through fuses (not shown). The start power contactor **46** may consist of a first normally open relay and a second normally closed relay, both of which are de-energized at start up. Alternately, both relays may be normally open and the control power supply **56** receives input directly from utility power input **41**. Flameproof power resistors can parallel the relays to provide a reduced current (approximately 10 amps maximum) to slowly charge the internal bus capacitors **48** through the rectifier **47** to avoid drawing excessive inrush current from the utility.

Once the bus capacitors **48** are substantially charged, (to approximately 180 VDC, or 80% of nominal), the control power supply **56** starts to provide low voltage logic levels to the control logic **57**. Once the control logic microprocessor has completed self tests, coil power is provided to first normally open relay of the start power contactor **46** to fully charge the bus capacitors **48** to full peak line voltage. The bus capacitors **48** can be supplemented for high frequency filtering by additional film type (dry) capacitors.

The PWM inverter **49** is illustrated in more detail in FIG. **4**. This inverter **49** illustrates four IGBT channels **70**, **71**, **72**, and **73** each across the voltage bus V_{bus}, but as stated previously, these channels may be any number or type of solid state switching devices. Each IGBT channel **70**, **71**, **72**, and **73** includes an upper IGTB **74** and an anti parallel diode **76** and a lower IGBT **78** and an identical anti parallel diode **76**.

The PWM inverter **49** also includes a capacitor channel **48** across the voltage bus V_{bus}The capacitor channel **48** includes upper capacitor **79** and lower capacitor **80** with the midpoint between upper capacitor **79** and lower capacitor **80** connected to the midpoint of IGBT channel **70** through inductor **81**. The neutral connection N or **68** is at the midpoint of IGBT channel **70** while the midpoints of IGBT channels **71**, **72**, and **73** provide output connections A, B, and C, respectively of output **42**. The neutral connection N or **68** may not be required for all applications.

In addition, the PWM inverter **49** includes a rectifier block channel **54** which is also across the voltage bus V_{bus}This rectifier block channel **54** includes a three phase rectifier block **86** having three (3) diode channels **82**, **83**, and **84** each including a pair of diodes **85**. The midpoints of each pair of diodes **85** are connected to generator windings G_A, G_B, and G_C, respectively.

The control logic **57** sequentially drives the IGBT switches of the PWM inverter **49** via the IGBT gate drives **58**. Six of the IGBT switches, those in channels **71**, **72** and **73** are operated at a high frequency and modulated in classic PWM manner to provide sinusoidal output via the AC output filter **51**. The other 2 IGBT switches of the PWM inverter **49**, both in channel **70**, are switched at a 50% duty cycle to create an artificial neutral **68** and balancing the voltage on the pair of capacitors **79** and **80**. The current in the neutral **68** will consist of a relatively small, high frequency, triangle pulse, plus whatever 60 hertz component exists as a result of unbalanced load currents in the 60 hertz generator mode.

The PWM inverter **49** operates in two basic modes: a variable voltage (0–190 V line to line), variable frequency (0–700 hertz) constant volts per hertz, three phase mode to drive the permanent magnet generator/motor **12** for start up or cooldown when the generator contactor **52** is closed; or a constant voltage (120 V line to neutral per phase), constant frequency three phase 60 hertz mode. The control logic **57** and IGBT gate drives **58** receive feedback via current signal **65** and voltage signal **66**, respectively, as the turbine generator is ramped up in speed to complete the start sequence. The PWM inverter **49** is then reconfigured to provide 60 hertz power, either as a current source for grid connect, or as a voltage source.

The AC filter **51** consists of three iron core inductors and three capacitors to remove the high frequency switching component. The nominal current for each AC filter inductor will be fundamental load current at 60 hertz, plus a small high frequency component. The output of the AC filter **51** is connected to the load via the output contactor **52** when the PWM inverter **49** is in 60 hertz output mode. The output contactor **52** is energized from the output of the PWM inverter **49** via a relay.

The generator contactor **53** connects the permanent magnet generator **12** to the inverter **49** during the start sequence. Initial starting current approximates nominal operating current for about 2 seconds then reduces to a lower value for the balance of the acceleration period. After the start sequence is completed, the generator **12** produces enough output voltage at the output terminals of the generator rectifier **54** to provide three phase regulated output from the inverter **49**, so both the start contactor **46** and generator contractor **53** are opened and the system is then self sustaining.

The IGBT gate drives **58** have five sections, four identical gate drive circuits with one for each of the four dual IGBT's and another section consisting of precision resistive (fixed impedance) voltage dividers with integrated circuit amplifiers. Each gate drive section consists of two transformer isolated power supplies driven from a logic level high frequency (–50 kilohertz) driver circuit, two integrated solid state driver circuits and additional optical isolators. One circuit operates referenced to the center point of the two IGBT transistors and the other operates referenced to the negative bus potential. There are two axial lead high voltage diodes which provide "on-state" sensing, and signal control circuits in the event that the associated semiconductor switching device reflects an "on-state" voltage greater than about 10 volts.

The precision resistive divider circuits consist of two metal film type fixed resistors connected in series. A low resistive element provides the low voltage pick-off point, as an example, the inverter output sensor is typically a –40 to 1 divider for the 120 V RMS inverter output voltage, providing a low voltage reference signal at the junction of the precision resistive divider circuits. This signal is buffered by a solid state operational amplifier. In the event one of the high voltage resistors were to fail shorted, the other is capable of standing off the voltage and preventing component damage and/or hazardous conditions from occurring at other locations within the control logic **57**.

The control power supply **56** is really a two stage power converter. The first stage, consisting of semiconductors and related components, is a 400 VDC to 24 VDC isolated converter. The isolation is a function of the transformer and optically isolated components which link the high voltage side components with the 24 VDC regulated side. The second stage, also consisting of semiconductors and related components, is a 24 VDC to ±12 VDC, 12 VDC, and 5 VDC isolated converter. As with the first stage, the isolation is a function of the transformer and optically coupled sensors.

During startup of the permanent magnet turbogenerator/motor **10**, both the start power contactor **46** and the generator contactor **53** are closed and the output contactor **52** is open. Once self sustained operation is achieved, the start power contactor **46** and the generator contactor **53** are opened and the PWM inverter **49** is reconfigured to a controlled 60 hertz mode. After the reconfiguration of the PWM inverter **49**, the output contactor **52** is closed to connect the AC output **42**. The start power contactor **46** and generator contractor **53** will remain open.

The PWM inverter **49** is truly a dual function inverter which is used both to start the permanent magnet turbogenerator/motor **10** and is also used to convert the permanent magnet turbogenerator/motor output to utility power, either sixty hertz, three phase for stand alone applications, or as a current source device. With start power contactor **46** closed, single or three phase utility power is brought through the start power contactor **46** to be able to operate into a bridge rectifier **47** and provide precharged power and then start voltage to the bus capacitors **48** associated with the PWM inverter **49**. This allows the PWM inverter **49** to function as a conventional adjustable speed drive motor starter to ramp the permanent magnet turbogenerator/motor **10** up to a speed sufficient to start the gas turbine **31**.

An additional rectifier **54**, which operates from the output of the permanent magnet turbogenerator/motor **10**, accepts the three phase, up to 380 volt AC from the permanent magnet generator/motor **12** which at full speed is 1600 hertz and is classified as a fast recovery diode rectifier bridge. Six diode elements arranged in a classic bridge configuration comprise this high frequency rectifier **54** which provides output power at DC. The rectified voltage is as high as 550 volts under no load.

The permanent magnet turbogenerator/motor **10** is basically started at zero frequency and rapidly ramps up to approximately 12,000 rpm. This is a two pole permanent magnet generator/motor **12** and as a result 96,000 rpm equals 1,600 hertz. Therefore 12,000 rpm is ⅛th of that or 200 hertz. It is operated on a constant volt per hertz ramp, in other words, the voltage that appears at the output terminals is ⅛th of the voltage that appears at the output terminals under full speed.

Approximate full speed voltage is 380 volts line to line so it would be approximately ⅛th of that. When the PWM inverter **49** has brought the permanent magnet turbogenerator/motor **10** up to speed, the fuel solenoid **62**, fuel control valve **44** and ignitor **60** cooperate to allow the combustion process to begin. Using again the adjustable speed drive portion capability of the PWM inverter **49**, the permanent magnet turbogenerator/motor **10** is then accelerated to approximately 35,000 or 40,000 rpm at which speed the gas turbine **31** is capable of self sustaining operation.

The AC filter **51** is a conventional single pass LC filter which simply removes the high frequency, in this case approximately twenty kilohertz, switching component. Because the voltage in start mode is relatively low, its rectified 208 volt line which is approximately 270 volts, a single bus capacitor **48** is capable of standing that voltage. However, when in generate mode, the DC output of the generator rectifier **54** can supply voltages as high as 550 volts DC, requiring two capacitors to be series connected to sustain that voltage.

The two IGBTs **74** and **78** in IGBT channel **70** function in the generate mode to form a constant duty fifty percent duty cycle divider to maintain exactly half bus voltage at the center tap at all times. That center tap point forms the neutral for the AC output. The neutral is not required for generator starting but is required for utility interface. The IGBT channels **71**, **72**, and **73** form a [classic] six transistor PWM inverter.

The reconfiguration of conversion of the PWM inverter **49** to be able to operate as a current source synchronous with the utility grid [is] *may be* accomplished by first stopping the PWM inverter **49**. The AC output or the grid connect point is monitored with a separate set of logic monitoring to bring the PWM inverter **49** up in a synchronized fashion. The generator contactor **53** functions to close and connect only when the PWM inverter **49** needs to power the permanent magnet turbogenerator/motor **10** which is during the start operation and during the cool down operation. The output contactor **52** is only enabled to connect the PWM inverter **49** to the grid once the PWM inverter **49** has synchronized with grid voltage.

The implementation of the control power supply **56** first drops the control power supply **56** down to a 24 volt regulated section to allow an interface with a battery or other control power device. The control power supply **56** provides the [conventional] logic voltages to both the IGBT gate drives **58** and control logic **57**. The IGBT gate drives **58** have two isolated low voltage sources to provide power to each of the two individual IGBT drives and the interface to the IGBT transistors is via a commercially packaged chip.

This system is also capable of generating 480 volt output directly. By changing the winding in the permanent magnet generator/motor **12**, the voltage ratings of the IGBTs, and the bus capacitors **48**, the system is then capable of operating directly at 480 volts, starting from grid voltage with 480 volts, and powering directly to 480 volts without requiring a transformer.

While specific embodiments of the invention have been illustrated and described, it is to be understood that these are provided by way of example only and that the invention is not to be construed as being limited thereto but only by the proper scope of the following claims.

What we claim is:

1. A method of controlling a permanent magnet turbogenerator/motor comprising the steps of:

providing electrical power to the permanent magnet turbogenerator/motor through a pulse width modulated inverter to start the permanent magnet turbogenerator/motor to achieve self sustaining operation of the permanent magnet turbo generator/motor;

disconnecting the electrical power from the pulse width modulated inverter once self sustaining operation of the permanent magnet turbogenerator/motor is achieved; and

reconfiguring the pulse width modulated inverter to supply voltage from the permanent magnet turbogenerator/motor.

2. The method of controlling a permanent magnet turbogenerator/motor of claim **1** wherein the voltage supplied from the pulse width modulated inverter of the permanent magnet turbogenerator/motor is utility frequency voltage.

3. The method of controlling a permanent magnet turbogenerator/motor of claim **1** wherein the pulse width modulated inverter includes four solid state switching device channels, and three of the four solid state switching device channels are reconfigured to supply utility frequency voltage and the fourth solid state switching device channel is switched at a fifty percent duty cycle to create an artificial neutral.

4. A method of controlling a permanent magnet turbogenerator/motor comprising the steps of:

providing electrical power to the permanent magnet turbogenerator/motor through a pulse width modulated inverter to drive the permanent magnet turbogenerator/motor as a motor to accelerate the gas turbine engine of the permanent magnet turbogenerator/motor;

providing spark and fuel to the gas turbine engine of the permanent magnet turbogenerator/motor during this acceleration to achieve self sustaining operation of the gas turbine engine;

disconnecting the electrical power from the pulse width modulated inverter once self sustaining operation is achieved; and

reconnecting the pulse width modulated inverter to the permanent magnet turbogenerator/motor through a rectifier bridge to reconfigure the pulse width modulated inverter to supply utility frequency voltage.

5. The method of controlling a permanent magnet turbogenerator/motor of claim **4** wherein the pulse width modulated inverter includes four solid state switching device channels, and three of the four solid state switching device channels are reconfigured to supply utility frequency voltage and the fourth solid state switching device channel is switched at a fifty percent duty cycle to create an artificial neutral.

6. A method of controlling a permanent magnet turbogenerator/motor comprising the steps of:

providing electrical power to the permanent magnet turbogenerator/motor through a first contactor and a pulse width modulated inverter to drive the permanent magnet turbogenerator/motor as a motor through a second contactor to accelerate the gas turbine engine of the permanent magnet turbogenerator/motor;

providing spark and fuel to the gas turbine engine of the permanent magnet turbogenerator/motor during this acceleration to achieve self sustaining operation of the gas turbine engine;

opening the first and second contactors to disconnect the electrical power from the pulse width modulated inverter once self sustaining operation is achieved; and

reconnecting the pulse width modulated inverter to the permanent magnet turbogenerator/motor through a rectifier bridge to reconfigure the pulse width modulated inverter to supply utility frequency voltage.

7. The method of controlling a permanent magnet turbogenerator/motor of claim **6** wherein the pulse width modulated inverter includes four solid state switching device channels, and three of the four solid state switching device channels are reconfigured to supply utility frequency voltage and the fourth solid state switching device channel is switched at a fifty percent duty cycle to create an artificial neutral.

8. The method of controlling a permanent magnet turbogenerator/motor of claim **6** and in addition the step of connecting the reconfigured pulse width modulated inverter to a load by closing a third contactor.

9. A method of controlling a permanent magnet turbogenerator/motor comprising the steps of:

providing electrical power to the permanent magnet turbogenerator/motor through a first contactor and a multiple solid state switching device channel pulse width modulated inverter to drive the permanent magnet turbogenerator/motor as a motor through a second contactor to accelerate the gas turbine engine of the permanent magnet turbogenerator/motor;

providing spark and fuel to the gas turbine engine of the permanent magnet turbogenerator/motor during this acceleration to achieve self sustaining operation of the gas turbine engine;

opening the first and second contactors to disconnect the electrical power from the multiple solid state switching device channel pulse width modulated inverter once self sustaining operation is achieved;

reconnecting the multiple solid state switching device channel pulse width modulated inverter to the permanent magnet turbogenerator/motor through a high frequency rectifier bridge to reconfigure the multiple solid state switching device channel pulse width modulated inverter; and

connecting the reconfigured multiple solid state switching device channel pulse width modulated inverter to utility power by closing a third contactor.

10. The method of controlling a permanent magnet turbogenerator/motor of claim **9** wherein the number of multiple solid state switching device channels in said pulse width modulated inverter is four, and three of the four solid state switching device channels are reconfigured to supply utility frequency voltage and the fourth solid state switching device channels is switched at a fifty percent duty cycle to create an artificial neutral.

11. The method of controlling a permanent magnet turbogenerator/motor of claim **10** wherein the four solid state switching device channels are IGBT channels.

12. The method of controlling a permanent magnet turbogenerator/motor of claim **9** wherein the high frequency rectifier bridge is a three phase rectifier having three diode channels.

13. The method of controlling a permanent magnet turbogenerator/motor of claim **12** wherein each of said three diode channels include a pair of diodes.

14. A controller for a permanent magnet turbogenerator/motor, comprising:

a pulse width modulated inverter operably associated with said permanent magnet turbogenerator/motor;

means to provide electrical power to said permanent magnet turbogenerator/motor through said pulse width modulated inverter to start said permanent magnet turbogenerator/motor to achieve self sustaining operation of said permanent magnet turbogenerator/motor;

means to disconnect the electrical power from said pulse width modulated inverter once self sustaining operation of said permanent magnet turbogenerator/motor is achieved; and

means to reconfigure said pulse width modulated inverter to supply voltage from said permanent magnet turbogenerator/motor.

15. The controller for a permanent magnet turbogenerator/motor of claim **14** wherein said pulse width modulated inverter includes a plurality of solid state switching device channels.

16. A controller for a permanent magnet turbogenerator/motor, comprising:

a pulse width modulated inverter operably associated with said permanent magnet turbogenerator/motor, said pulse width modulated inverter having four solid state switching device channels;

means to provide electrical power to said permanent magnet turbogenerator/motor through said pulse width modulated inverter to start said permanent magnet turbogenerator/motor to achieve self sustaining operation;

means to disconnect the electrical power from said pulse width modulated inverter once self sustaining operation of said permanent magnet turbogenerator/motor is achieved; and

means to reconfigure said pulse width modulated inverter to supply voltage from said permanent magnet turbogenerator/motor, and three of the four solid state switching device channels are reconfigured to supply utility frequency voltage and the fourth solid state switching device channel is switched at a fifty percent duty cycle to create an artificial neutral.

17. The controller for a permanent magnet turbogenerator/motor of claim **16** wherein said four solid state switching device channels are IGBT channels.

18. The controller for a permanent magnet turbogenerator/motor of claim **14** wherein the voltage supplied from said pulse width modulated inverter associated with said permanent magnet turbogenerator/motor is utility frequency voltage.

19. A controller for a permanent magnet turbogenerator/motor having a gas turbine engine, comprising:

a pulse width modulated inverter operably associated with said permanent magnet turbogenerator/motor;

means to provide electrical power to said permanent magnet turbogenerator/motor through said pulse width modulated inverter to drive said permanent magnet turbogenerator/motor as a motor to accelerate said gas turbine engine of said permanent magnet turbogenerator/motor;

means to provide spark and fuel to said gas turbine engine of said permanent magnet turbogenerator/motor during this acceleration to achieve self sustaining operation of said gas turbine engine;

means to disconnect the electrical power from said pulse width modulated inverter and said permanent magnet turbogenerator/motor once self sustaining operation of said gas turbine engine is achieved;

a rectifier bridge operably associated with said pulse width modulated inverter and said permanent magnet turbogenerator/motor; and

means to reconnect said pulse width modulated inverter to said permanent magnet turbogenerator/motor through said rectifier bridge to reconfigure said pulse width modulated inverter to supply utility frequency voltage.

20. The controller for a permanent magnet turbogenerator/motor having a gas turbine engine of claim **19** wherein said pulse width modulated inverter includes four solid state switching device channels, and three of the four solid state switching device channels are reconfigured to supply utility frequency voltage and the fourth solid state switching device channel is switched at a fifty percent duty cycle to create an artificial neutral.

21. A controller for a permanent magnet turbogenerator/motor having a gas turbine engine and a permanent magnet generator/motor, comprising:

a pulse width modulated inverter operably associated with said permanent magnet turbogenerator/motor, said pulse width modulated inverter having a plurality of solid state switching device channels;

a first contactor operably associated with said pulse width modulated inverter;

a second contactor **[**operable**]** *operably* associated with said **[**the**]** permanent magnet turbogenerator/motor;

means to provide electrical power to said pulse width modulated inverter through said first contactor when closed to drive said permanent magnet turbogenerator/motor as a motor through said second contactor when closed to accelerate said gas turbine engine of said permanent magnet turbogenerator/motor;

means to provide spark and fuel to said gas turbine engine of said permanent magnet turbogenerator/motor during this acceleration to achieve self sustaining operation of said gas turbine engine;

means to open said first and second contactors to disconnect the electrical power from said pulse width modulated inverter once self sustaining operation is achieved;

a rectifier bridge operable associated with said pulse width modulated inverter and said permanent magnet turbogenerator/motor;

a third contactor operably associated with said pulse width modulated inverter;

means to reconnect said pulse width modulated inverter to said permanent magnet turbogenerator/motor through said rectifier bridge to reconfigure said pulse width modulator inverter; and

means to connect said reconfigured pulse width modulated inverter to supply utility frequency voltage to a load through said third contactor when closed.

22. The controller for a permanent magnet turbogenerator/motor of claim **21** wherein the number of solid state switching device channels in said pulse width modulate inverter is four, and three of the four solid state switching device channels are reconfigured to supply utility frequency voltage and the fourth solid state switching device channel is switched at a fifty percent duty cycle to create an artificial neutral.

23. The controller for a permanent magnet turbogenerator/motor of claim **22** wherein the four solid state switching device channels are IGBT channels.

24. The controller for a permanent magnet turbogenerator/motor of claim **21** wherein said rectifier bridge is a three phase rectifier having three diode channels.

25. The controller for a permanent magnet turbogenerator/motor of claim **24** wherein each of said three diode channels includes a pair of diodes.

26. A method of controlling a turbogenerator/motor, comprising:

providing electrical power to the turbogenerator/motor through an inverter to start the turbogenerator/motor to achieve self sustaining operation of the turbogenerator/motor; and

reconfiguring the inverter to supply voltage from the turbogenerator/motor when self sustaining operation of the turbogenerator/motor is achieved.

27. The method of claim 26, wherein reconfiguring the inverter comprises:

reconfiguring the inverter to supply utility frequency voltage from the turbogenerator/motor.

28. The method of claim 26, wherein reconfiguring the inverter comprises:

reconfiguring an inverter including four solid state switching device channels wherein three of the four solid state switching device channels are reconfigured to supply utility frequency voltage and the fourth solid state switching device channel is switched at a fifty percent duty cycle to create an artificial neutral.

29. The method of claim 26, wherein the turbogenerator/motor comprises:

a permanent magnet turbogenerator/motor.

30. The method of claim 28, wherein the inverter comprises:

a pulse width modulated inverter.

31. The method of claim 26, wherein reconfiguring the inverter comprises:

disconnecting the electrical power from the inverter when self sustaining operation of the turbogenerator/motor is achieved.

32. A method of controlling a turbogenerator/motor comprising the steps of:

providing electrical power to the turbogenerator/motor through an inverter to drive the turbogenerator/motor as a motor to accelerate the turbine engine of the turbogenerator/motor;

providing spark and fuel to the turbine engine of the turbogenerator/motor during acceleration to achieve self sustaining operation of the turbine engine; and

reconnecting the inverter to the turbogenerator/motor through a rectifier to reconfigure the inverter to supply utility frequency voltage when self sustaining operation is achieved.

33. The method of claim 32, wherein providing electrical power through an inverter comprises:

providing electrical power through an inverter including four solid state switching device channels; and

reconnecting the inverter comprises:

reconfiguring three of the four solid state switching device channels to supply utility frequency voltage; and

switching the fourth solid state switching device channel at a fifty percent duty cycle to create an artificial neutral.

34. The method of claim 32, wherein the turbogenerator/motor comprises:

a permanent magnet turbogenerator/motor.

35. The method of claim 34, wherein the inverter comprises:

a pulse width modulated inverter.

36. The method of claim 32, wherein reconnecting the inverter comprises:

disconnecting the electrical power from the inverter when self sustaining operation is achieved.

37. A method of controlling a turbogenerator/motor comprising:

providing electrical power to the turbogenerator/motor through a first contactor and an inverter to drive the turbogenerator/motor as a motor through a second contactor to accelerate the turbine engine of the turbogenerator/motor;

providing spark and fuel to the turbine engine of the turbogenerator/motor during acceleration to achieve self sustaining operation of the turbine engine; and

reconnecting the inverter to the turbogenerator/motor through a rectifier to reconfigure the inverter to supply utility frequency voltage when self sustaining operation is achieved.

38. The method of claim 37, wherein providing electrical power through an inverter comprises:

providing electrical power through an inverter including four solid state switching device channels; and

reconnecting the inverter comprises:

reconfiguring three of the four solid state switching device channels to supply utility frequency voltage; and

switching the fourth solid state switching device channel at a fifty percent duty cycle to create an artificial neutral.

39. The method of claim 37, further comprising:

connecting the reconfigured inverter to a load by closing a third contactor.

40. A method of controlling a turbogenerator/motor comprising the steps of:

providing electrical power to the turbogenerator/motor through a first contactor and a multiple solid state *switching device channel inverter to drive the turbogenerator/motor as a motor through a second contactor to accelerate the turbine engine of the turbogenerator/motor;*

providing spark and fuel to the turbine engine of the turbogenerator/motor during acceleration to achieve self sustaining operation of the gas turbine engine;

reconnecting the inverter to the turbogenerator/motor through a rectifier to reconfigure the inverter when self sustaining operation is achieved; and

connecting the reconfigured inverter to utility power by closing a third contactor.

41. The method of claim 40, wherein providing electrical power through a multiple solid state switching device channel inverter comprises:

providing electrical power through an inverter including four solid state switching device channels; and

reconnecting the inverter comprises:

reconfiguring three of the four solid state switching device channels to supply utility frequency voltage; and

switching the fourth solid state switching device channel at a fifty percent duty cycle to create an artificial neutral.

42. The method of claim 41, wherein the four solid state switching device channels comprise:

IGBT channels.

43. The method of claim 40, wherein the rectifier comprises:

a high frequency three phase rectifier bridge including three diode channels.

44. The method of claim 43, wherein each of said three diode channels comprise:

two diodes.

* * * * *