US 20060130504A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2006/0130504 A1**

Agrawal et al. (43) **Pub. Date: Jun. 22, 2006**

(54) **METHOD AND APPARATUS FOR CONTROL OF A VARIABLE SPEED COMPRESSOR**

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(21) Appl. No.: **11/016,431**

(22) Filed: **Dec. 17, 2004**

Publication Classification

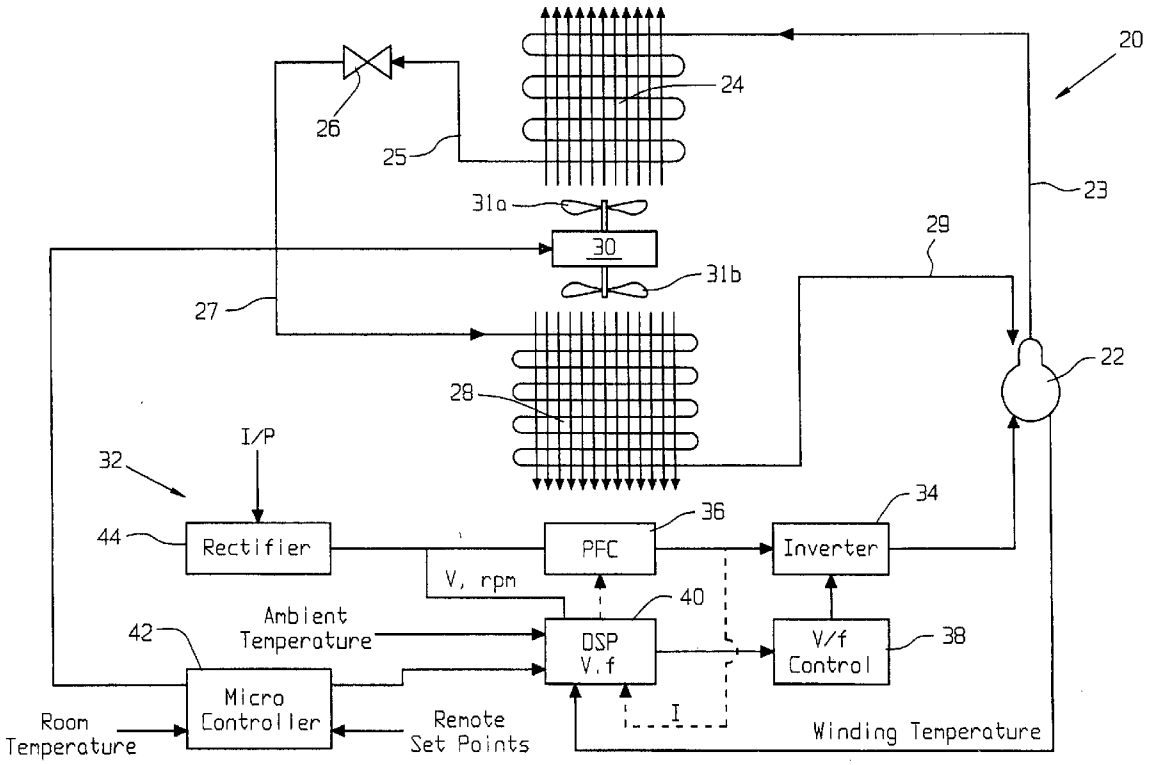
(51) **Int. Cl.**

F04B 49/00	(2006.01)
F25D 17/00	(2006.01)
F25B 39/04	(2006.01)
F25B 1/00	(2006.01)
F25B 49/00	(2006.01)

(52) **U.S. Cl.** **62/228.4**; 62/179; 62/181; 62/183

(57) **ABSTRACT**

A vapor compression system includes a fluid circuit circulating a refrigerant in a closed loop. The fluid circuit has operably disposed therein, in serial order, a variable speed compressor, a first heat exchanger, an expansion device and a second heat exchanger. A first blower device is associated with the first heat exchanger. A speed of the first blower device is dependent upon a speed of the compressor. A second blower device is associated with the second heat exchanger. A speed of the second blower device is dependent upon the speed of the compressor.



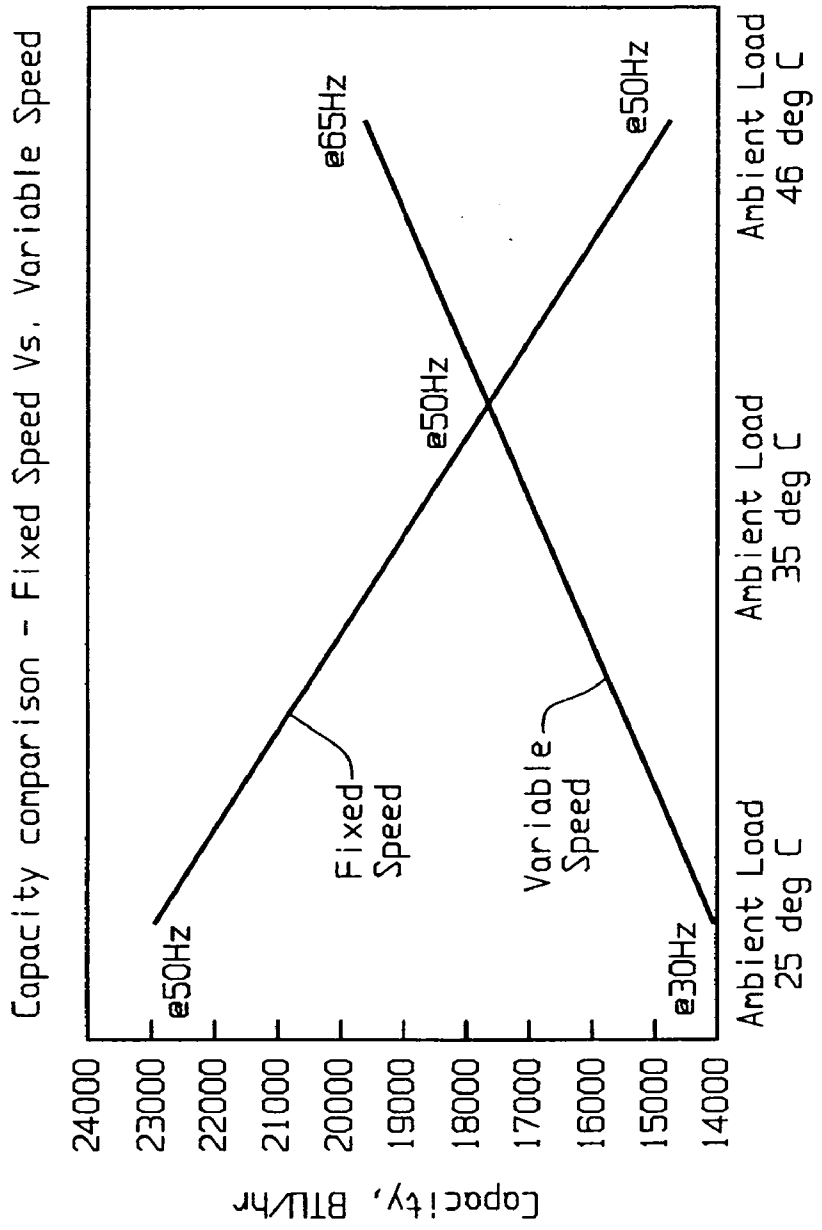

Capacity comparison - Fixed Speed Vs. Variable Speed
Capacity, BTU/hr
24000
23000
22000
21000
20000
19000
18000
17000
16000
15000
14000
@50Hz
@65Hz
@50Hz
@50Hz
@30Hz
Fixed Speed
Variable Speed
Ambient Load 25 deg C
Ambient Load 35 deg C
Ambient Load 46 deg C
Different Ambient Load Conditions

Fig. 1

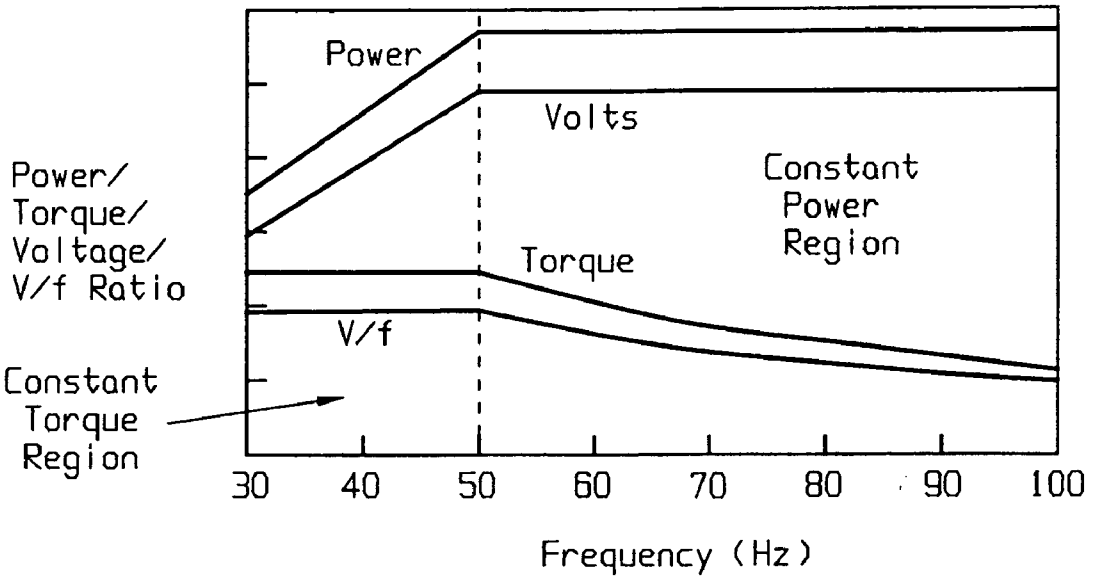

Power
Volts
Power/
Torque/
Voltage/
V/f Ratio
Constant
Power
Region
Torque
V/f
Constant
Torque
Region
30
40
50
60
70
80
90
100
Frequency (Hz)

Fig. 2

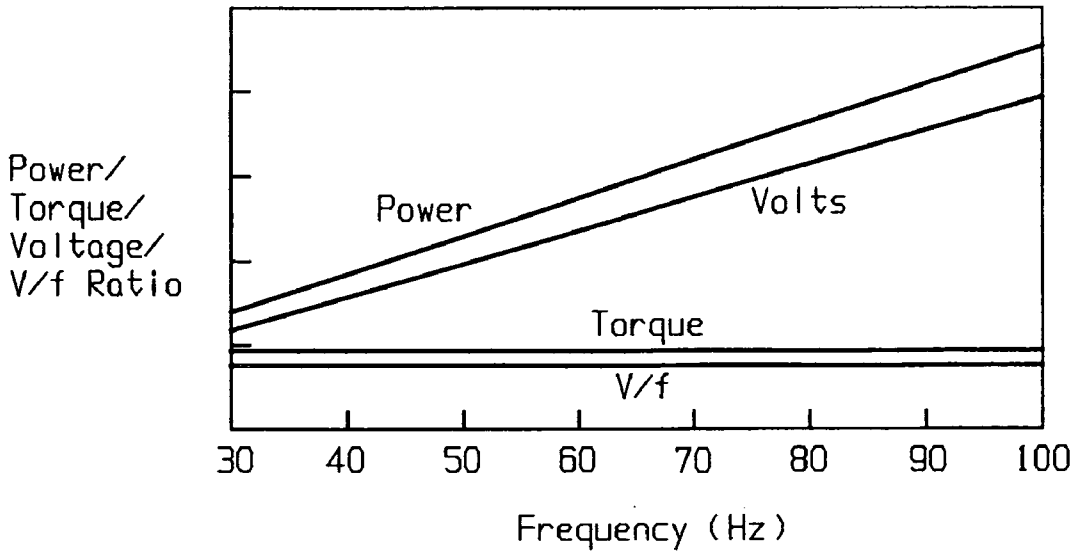

Power/
Torque/
Voltage/
V/f Ratio
Power
Volts
Torque
V/f
30
40
50
60
70
80
90
100
Frequency (Hz)

Fig. 3

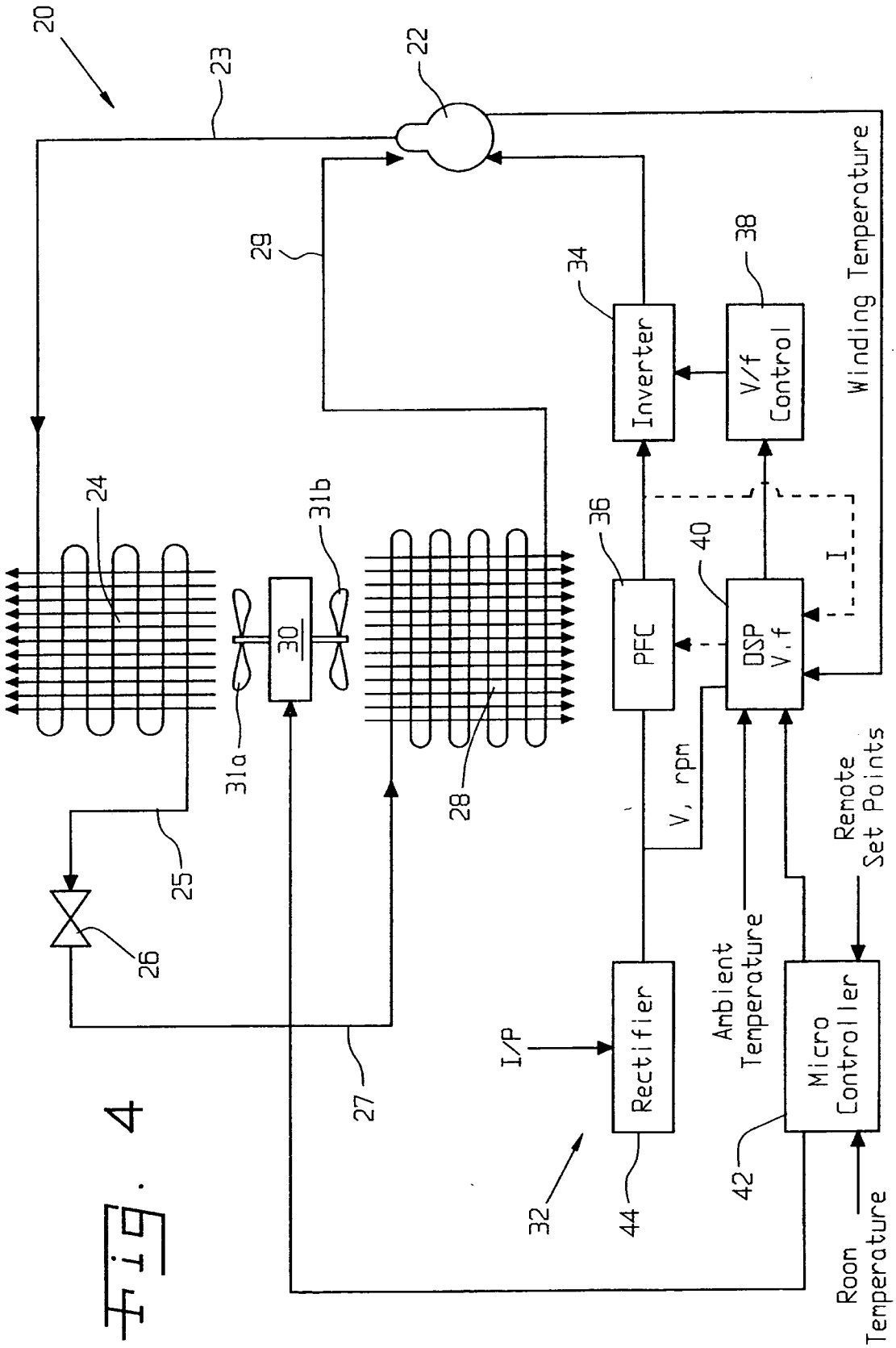

20
23
22
29
34
Inverter
38
V/f Control
Winding Temperature
24
31b
30
31a
28
36
PFC
40
DSP V,f
I
V, rpm
Remote Set Points
25
26
27
I/P
Rectifier
Ambient Temperature
Micro Controller
42
44
32
Room Temperature

Fig. 4

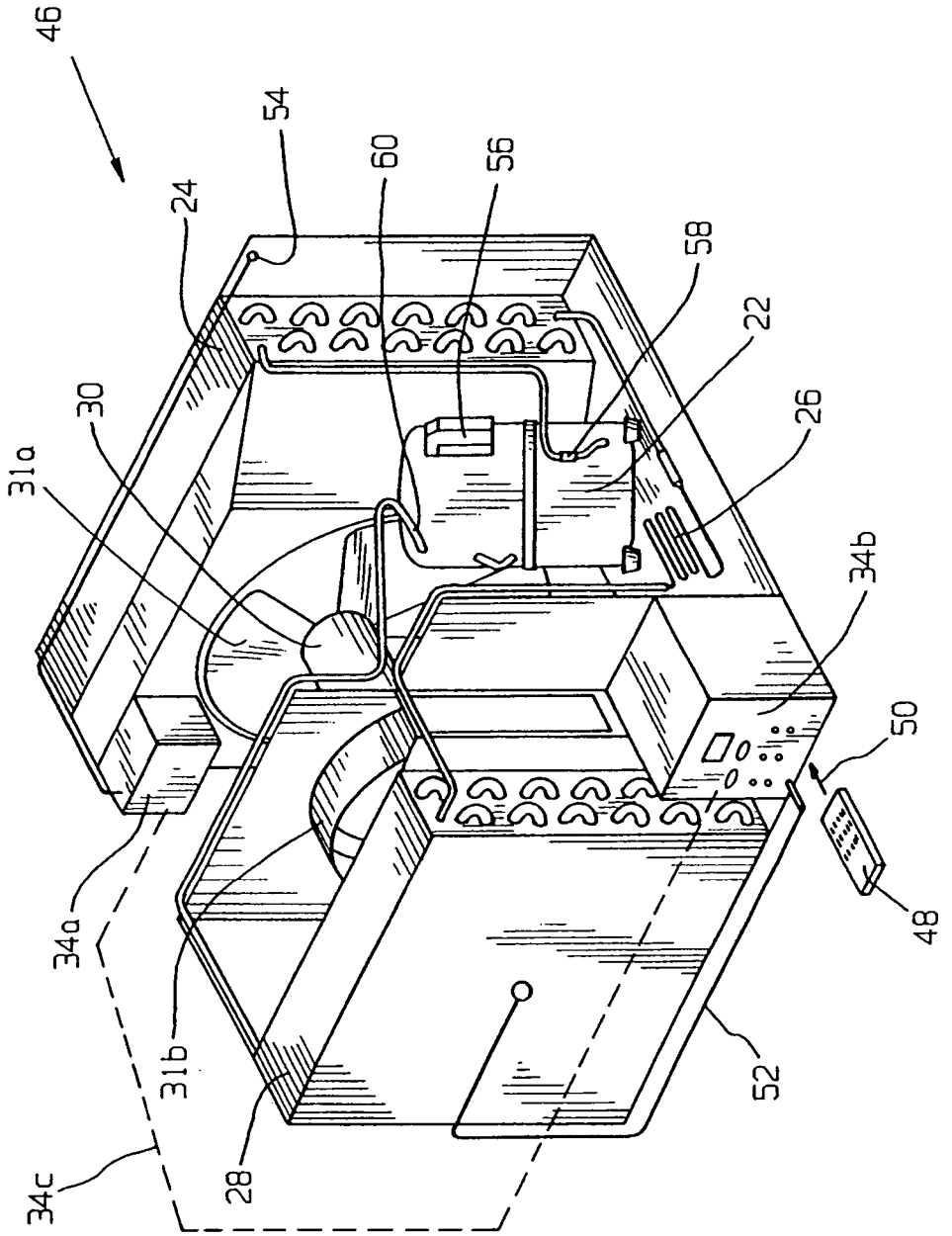


Fig. 5

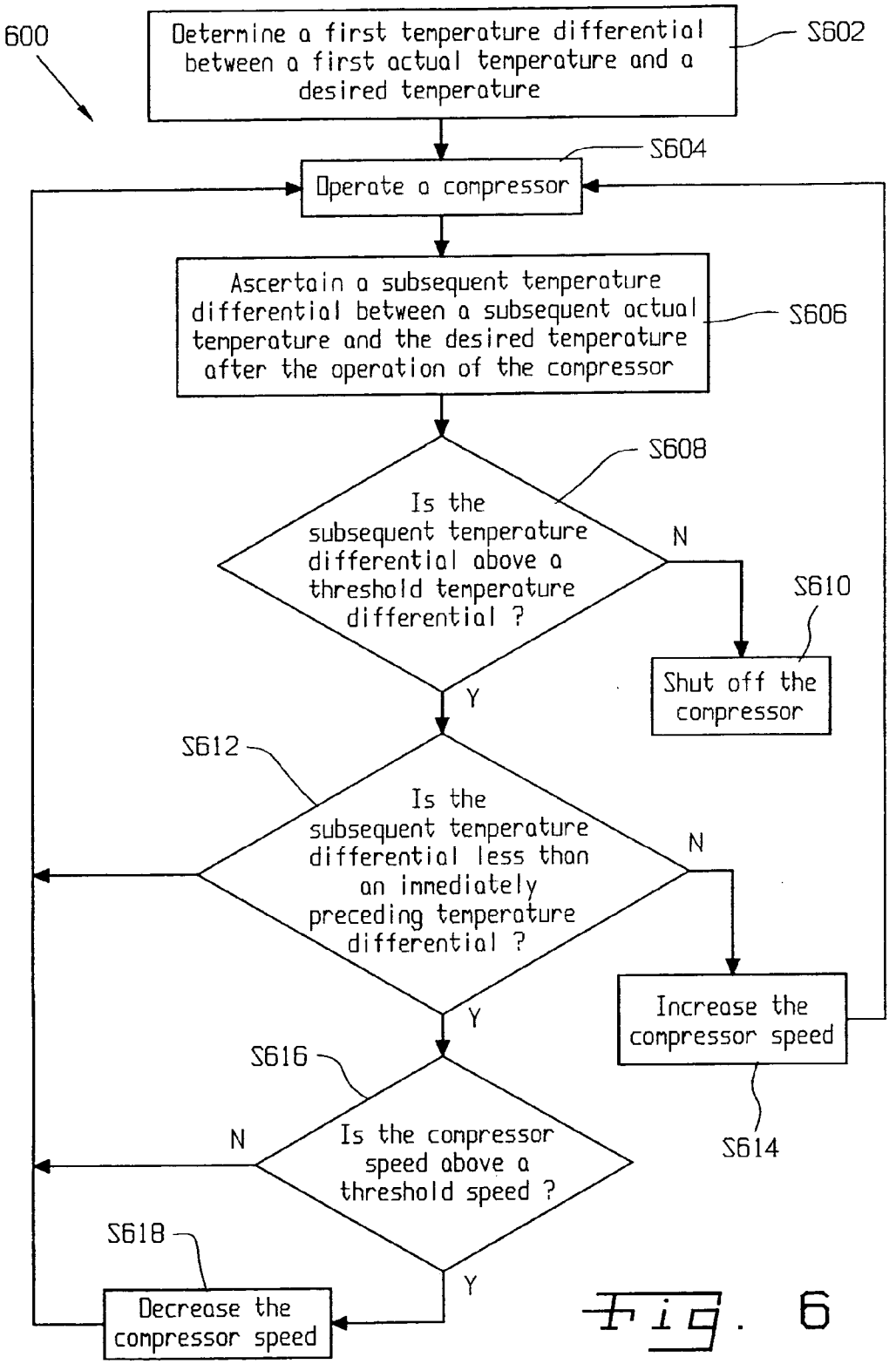

600
Determine a first temperature differential between a first actual temperature and a desired temperature
S602
S604
Operate a compressor
Ascertain a subsequent temperature differential between a subsequent actual temperature and the desired temperature after the operation of the compressor
S606
S608
Is the subsequent temperature differential above a threshold temperature differential ?
N
S610
Shut off the compressor
Y
S612
Is the subsequent temperature differential less than an immediately preceding temperature differential ?
N
Increase the compressor speed
S614
Y
S616
Is the compressor speed above a threshold speed ?
N
S618
Decrease the compressor speed
Y

Fig. 6

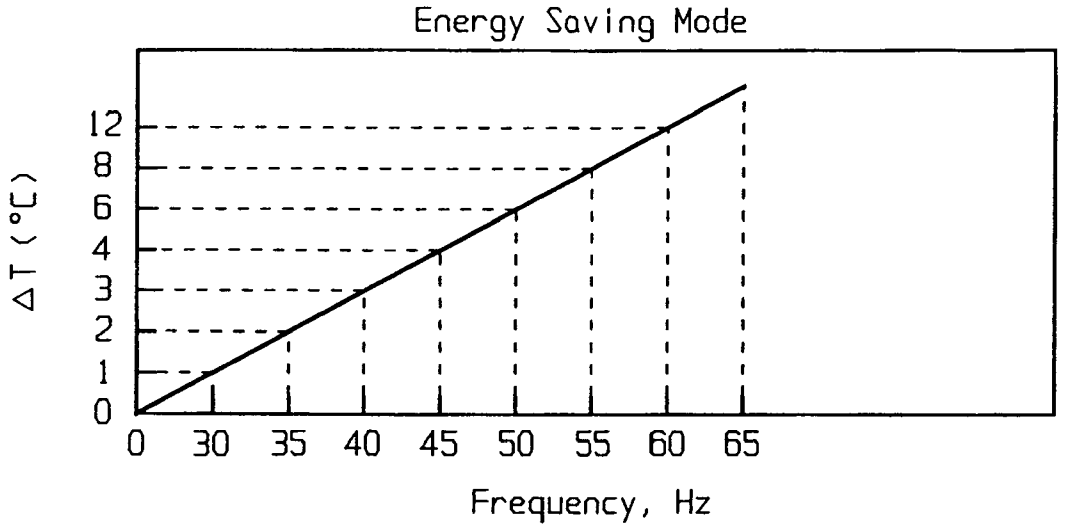

Energy Saving Mode
ΔT (°C)
12
8
6
4
3
2
1
0
0 30 35 40 45 50 55 60 65
Frequency, Hz

Fig. 7

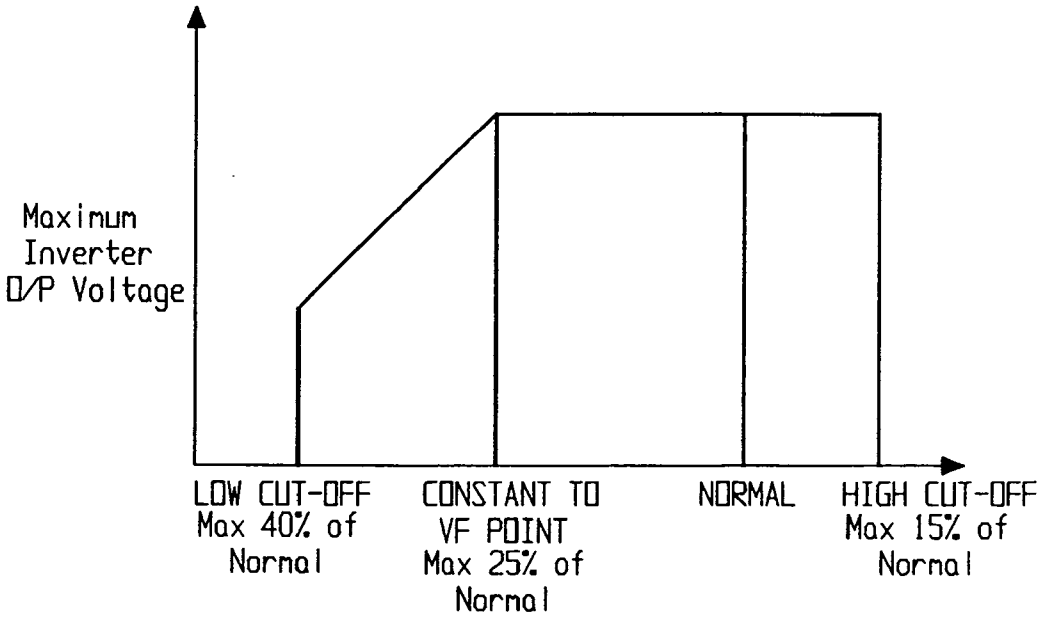

Maximum
Inverter
O/P Voltage
LOW CUT-OFF
Max 40% of
Normal
CONSTANT TO
VF POINT
Max 25% of
Normal
NORMAL
HIGH CUT-OFF
Max 15% of
Normal
AC Input Voltage

Fig. 9

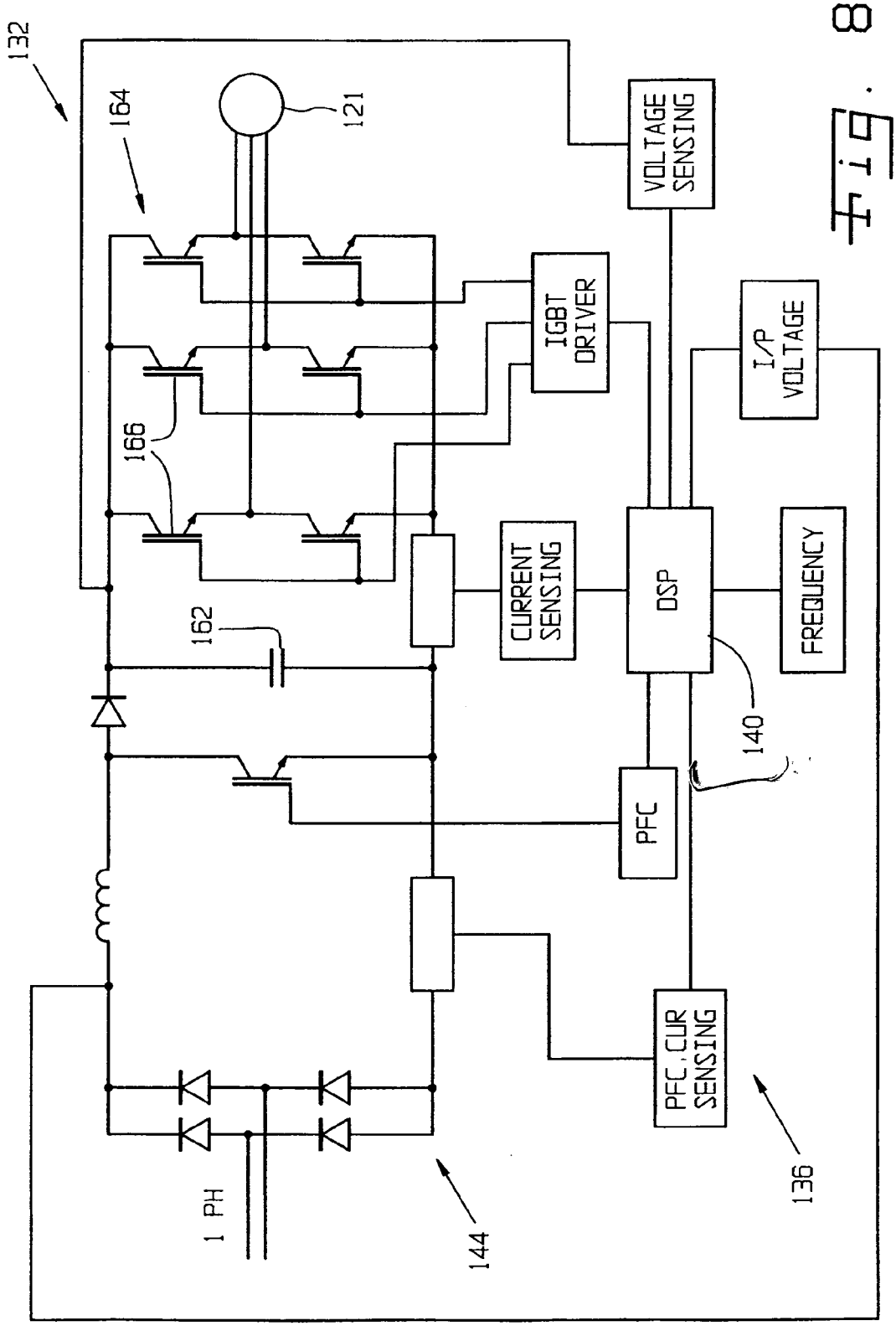

132
164
121
VOLTAGE SENSING
IGBT DRIVER
I/P VOLTAGE
166
CURRENT SENSING
DSP
FREQUENCY
162
140
PFC
PFC.CUR SENSING
1 PH
144
136

Fig. 8

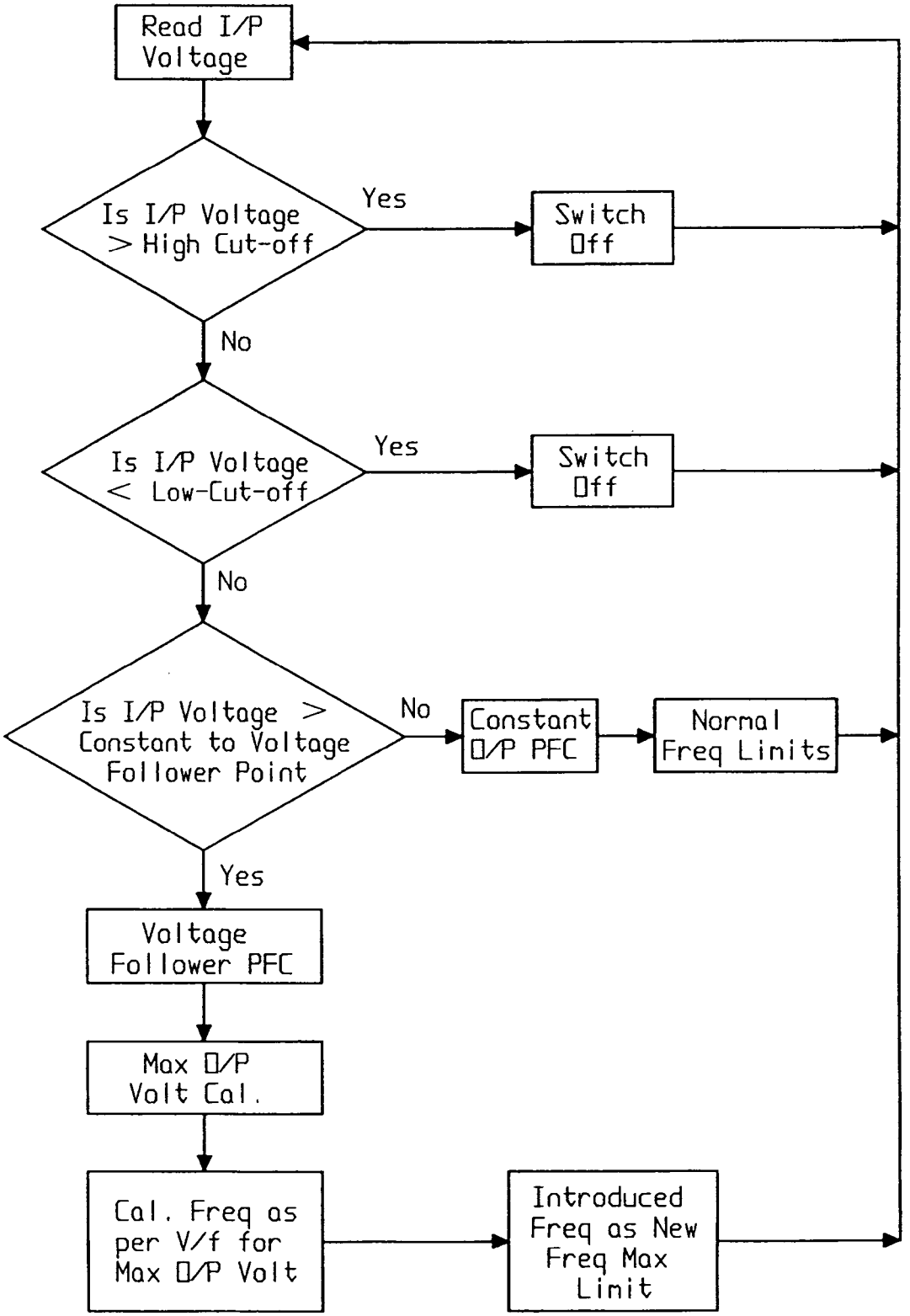

Read I/P Voltage
Is I/P Voltage > High Cut-off
Yes
Switch Off
No
Is I/P Voltage < Low-Cut-off
Yes
Switch Off
No
Is I/P Voltage > Constant to Voltage Follower Point
No
Constant O/P PFC
Normal Freq Linits
Yes
Voltage Follower PFC
Max O/P Volt Cal.
Cal. Freq as per V/f for Max O/P Volt
Introduced Freq as New Freq Max Linit

Fig. 10

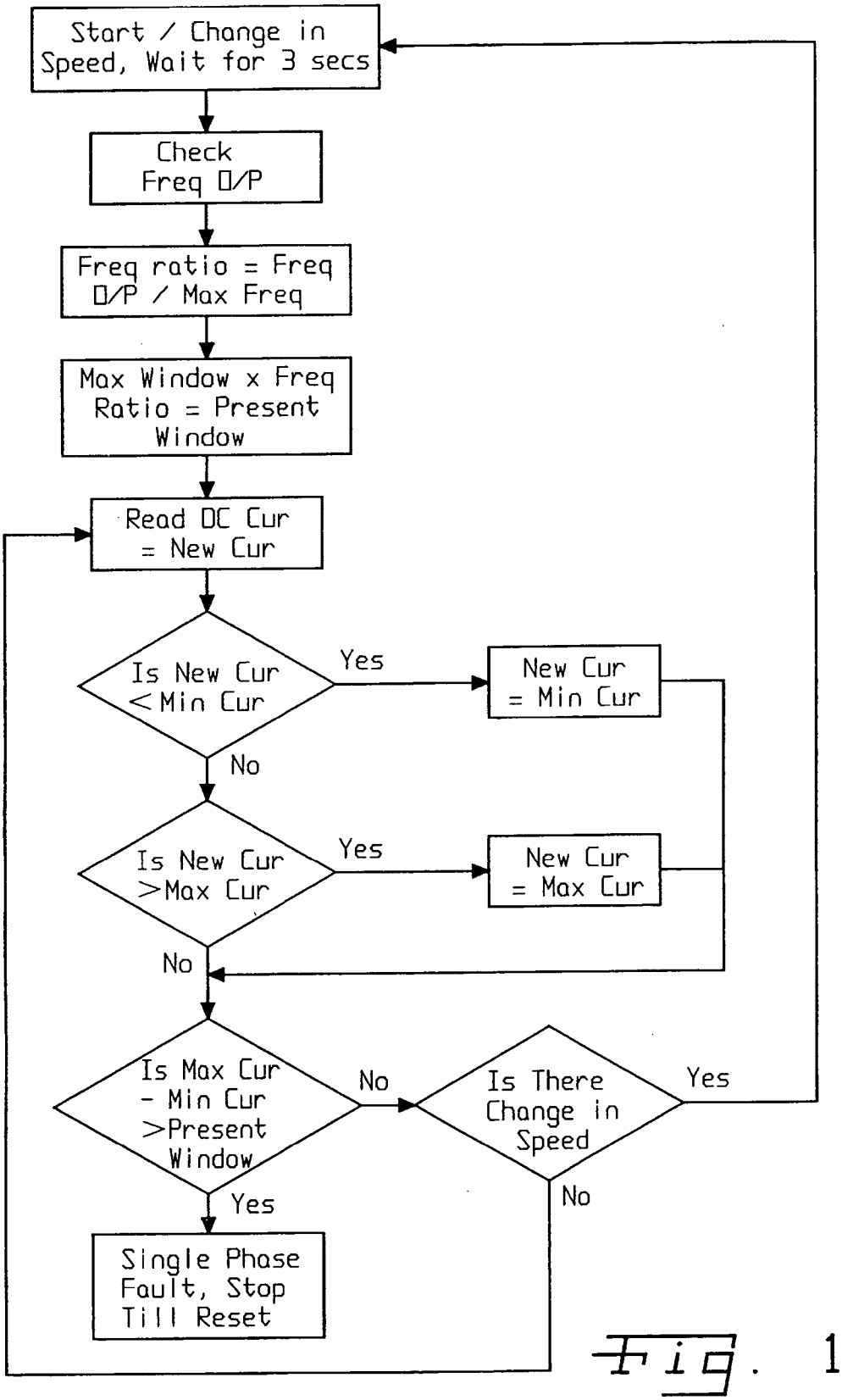

Start / Change in Speed, Wait for 3 secs
Check Freq O/P
Freq ratio = Freq O/P / Max Freq
Max Window x Freq Ratio = Present Window
Read DC Cur = New Cur
Is New Cur < Min Cur
Yes
New Cur = Min Cur
No
Is New Cur > Max Cur
Yes
New Cur = Max Cur
No
Is Max Cur - Min Cur > Present Window
No
Is There Change in Speed
Yes
No
Yes
Single Phase Fault, Stop Till Reset

Fig. 11

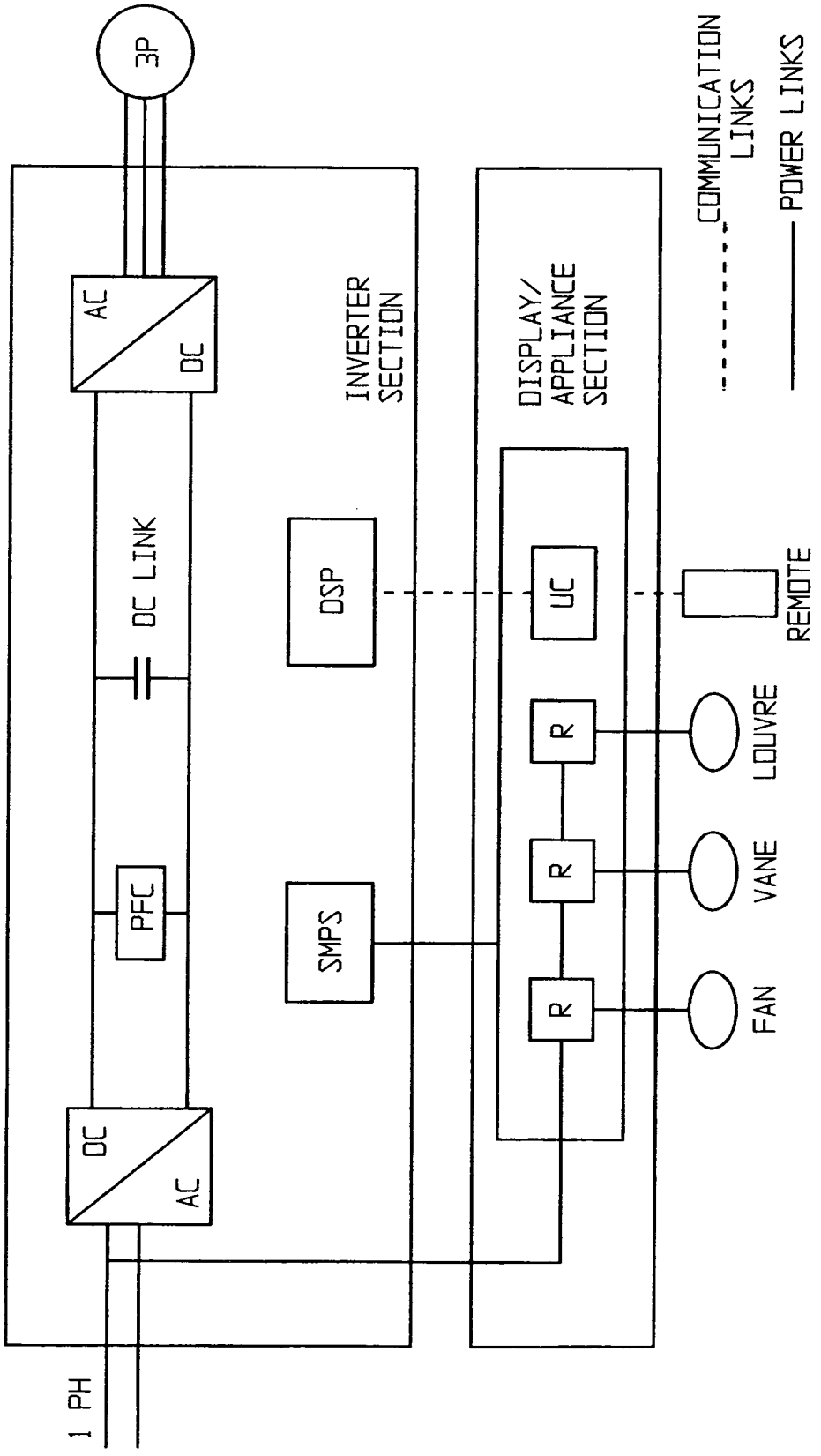

3P
AC
DC
INVERTER SECTION
DISPLAY/ APPLIANCE SECTION
COMMUNICATION LINKS
POWER LINKS
DC LINK
DSP
UC
REMOTE
R
LOUVRE
R
VANE
R
FAN
PFC
SMPS
DC
AC
1 PH

Fig. 12

METHOD AND APPARATUS FOR CONTROL OF A VARIABLE SPEED COMPRESSOR

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a vapor compression system and, more particularly, to a method and apparatus for controlling a variable speed compression system.

[0003] 2. Description of the Related Art

[0004] Vapor compression systems are used in a variety of applications including heat pump, air conditioning, and refrigeration systems. Conventional air conditioners include fixed speed compressors. A thermostat or another type of temperature sensor may be used in controlling the operation of the compressor. The temperature sensor may be located at the inlet side of the evaporator and may be used to sense the room temperature. When the sensed temperature becomes lower than a set temperature selected by the user, either manually or by remote control, the compressor is switched off. When the measured temperature of the room rises again to a level above the set temperature, the compressor is switched on and the cycle continues. This type of intermittent operation not only results in more power consumption but also results in variation of room temperature leading to conditions uncomfortable to the user. Fixed speed air conditioners are found to have low capacity when most needed, say for instance, when ambient temperatures are high, and have higher capacity when ambient conditions are low.

[0005] A variable speed compressor can be used in order to avoid some of the drawbacks of a fixed speed compressor. A variable speed compressor may have a variable capacity that is based on the demands of the room being cooled. **FIG. 1** plot the capacities of fixed and variable speed compressors as a function of ambient load conditions. The capacity of a variable speed compressor may increase with increasing ambient load, while the capacity of a fixed speed compressor may decrease with increasing ambient load. Variable speed of the compressor may be enabled by an inverter and other related electronic controls.

[0006] A variable speed compressor has the advantage of being able to operate for extended periods at near 100% duty cycle at a reduced frequency that is just enough to maintain a required level of cooling. The reduced frequency of the variable speed compressor provides a level of power consumption that is much lower than that of a fixed speed compressor.

[0007] The majority of the industrial loads driven by motors comes under two major broad categories, i.e., constant power and constant torque application. **FIG. 2** illustrates the characteristics of a constant torque/constant power application in which constant torque is achieved up to a base frequency, i.e., compressor speed, of approximately 50 Hz. Above the base frequency, the torque decreases due to the fact that the output voltage of an inverter that drives the compressor cannot be increased due to limitations of the input voltage. In this case, the voltage increases up to a base frequency above which the voltage is constant. Thus, the voltage to frequency ratio V/f is constant up to the base frequency and decreases above the base frequency.

[0008] In the case of a given load, such as a compressor, the torque value remains constant throughout the operating frequency. **FIG. 3** illustrates the characteristics of such a constant torque application. The motor is designed for a maximum voltage and maximum frequency zone considering the available input voltage so that V/f is constant throughout the operating range. The power increases linearly with frequency.

[0009] In both types of systems associated with **FIGS. 2 and 3**, there is a considerable torque drop at lower frequencies due to a significant stator resistive drop. This results in the voltage applied across the stator being less than the voltage applied across the terminal. The stator thus creates lesser flux, thereby creating lesser torque at lower frequencies. To overcome this problem, additional voltage, generally known as "boost voltage", may be applied to the stator terminal. The user may select a predetermined boost voltage and a frequency up to which the boost voltage is to be applied.

[0010] One drawback of a constant torque application is that the user must select the boost voltage, which may not result in optimum efficiency from the motor. Another drawback of a constant torque application is that the performance characteristics of the motor, specifically the efficiency, eventually degrade even though V/f may remain constant. The degradation of motor performance characteristics may be due to the fact that different losses of the motor, e.g., stator copper loss, rotor conductor loss, hysteresis loss, eddy current loss, and stray loss, behave differently with respect to the change in frequency. For example, the hysteresis loss and eddy current loss may be a greater part of the total loss at higher frequency than at lower frequency.

[0011] Inverter driven compressor motors are typically protected for locked rotor, over-current and over and under voltage. However, single phasing protection is not included because it involves addition of current sensing circuits at the output of the inverter and means for sensing protection of the same. Normally, inverters used to drive compressor motors are only suited to carry out that particular function. The other accessories are not controlled, or are controlled by another control system in window air conditioners.

[0012] Normally, inverters used to drive compressor motors are only suited to carry out that particular function. The other accessories are not controlled, or are controlled by another control system in window air conditioners.

[0013] What is needed in the art is a method of operating a compressor such that a wide range of cooling demands may be met in an efficient manner.

SUMMARY OF THE INVENTION

[0014] The present invention provides a vapor compression system including a variable speed compressor that is capable of providing different capacities on the basis of the demands of a room or rooms being cooled. A method of efficiently operating a compressor in a plurality of modes is provided, with each mode corresponding to a different level of cooling demand.

[0015] The compressor may be an inverter driven compressor with an electronic controller. The controller may operate the compressor in one of three different modes (quick chill, standard or energy saver mode) when it functions as an air conditioner and also may operate the compressor in a heating cycle mode when the system is employed as a heat pump.

[0016] The controller may seek to operate the compressor motor at a constant torque as the rotational speed or frequency (f) of the compressor is varied. The three different modes of operation may be defined by three different algorithms for controlling the speed of the compressor motor and the speed of the condenser and evaporator fans. The condenser and evaporator fans may each have high/medium/low speeds and the speed at which the fans are operated may be determined by the speed of the compressor motor, with higher compressor motor speeds corresponding to higher fan speeds. Fan motor speeds may be determined for specified compressor speeds without regard to whether the system is operating as a heat pump or air conditioner.

[0017] It may be desirable for the system to quickly cool the room to the desired temperature but do so in a manner that gradually reduces the speed of the compressor and then places it in energy saving mode. The system may operate in accordance with the operating mode that has been selected out of the three different operating modes.

[0018] If the quick chill mode is selected, the compressor may initially operate at its highest operating frequency with the fan speeds at high. When the difference between the desired temperature and the actual room temperature is at 1° C., the speed of the compressor may be reduced and the fans speeds may be reduced to medium. If this does not result in an increase in the room temperature, the speed of the compressor may be further reduced. This process may be repeated with the compressor and fan speeds being repeatedly reduced if the temperature of the room does not increase, until eventually, the desired temperature is achieved and the system is switched off.

[0019] If the standard operating mode is selected, the system may operate generally similar to the quick chill mode but the temperature differential at which the compressor and fan speeds are stepped downward may differ. In the standard operating mode, the compressor may be stepped down from its highest operating frequency when the temperature of the room is 10° C. warmer than the desired temperature instead of 1° C.

[0020] If the energy saving mode is selected, the frequency of the compressor motor may be varied as the temperature differential between the actual room temperature and the desired room temperature varies. The compressor motor speed may be chosen to maximize the efficiency of the compressor.

[0021] A digital signal processor (DSP) may be used to provide both power factor correction (PFC) and compressor-motor control. The DSP may also receive inputs from a voltage sensor measuring the DC current. When the variation of the DC current extends beyond a defined window of variation, it may be interpreted to be single phasing on the output side of the inverter. The inverter may then be switched off in order to protect the compressor motor from high currents.

[0022] The invention comprises, in one form thereof, a vapor compression system including a fluid circuit circulating a refrigerant in a closed loop. The fluid circuit has operably disposed therein, in serial order, a variable speed compressor, a first heat exchanger, an expansion device and a second heat exchanger. A first blower device is associated with the first heat exchanger. A speed of the first blower device is dependent upon a speed of the compressor. A second blower device is associated with the second heat exchanger. A speed of the second blower device is dependent upon the speed of the compressor.

[0023] The present invention comprises, in another form thereof, a method of controlling a room temperature, including determining a first temperature differential between a first actual temperature and a desired temperature. A subsequent temperature differential between a subsequent actual temperature and the desired temperature is ascertained after a compressor is operated. A speed of the compressor is decreased if the subsequent temperature differential is less than an immediately preceding temperature differential. The operating, ascertaining, and decreasing steps are repeated so long as the speed of the compressor is greater than a threshold speed and the subsequent temperature differential is greater than a threshold temperature differential.

[0024] The present invention comprises, in yet another form thereof, a vapor compression system including a variable speed compressor. A control device repetitively determines a temperature differential between an actual room temperature and a desired room temperature. The compressor is selectively operated in a first mode and a second mode. The first mode includes decreasing a speed of the compressor after each temperature differential determination so long as a most recently determined temperature differential is less than a second most recently determined temperature differential. The second mode includes substantially continuously varying the speed of the compressor based upon the determined temperature differentials.

[0025] An advantage of the present invention is that the compressor may be operated in three different cooling modes having different cooling performance characteristics and different efficiencies. Thus, one of the three modes may be selected for each particular set of cooling conditions such that cooling demands may be met in an efficient manner.

[0026] Another advantage is that simple algorithms are employed which require a low level of electronic computations. Thus, processing time and power are reduced, and implementation is simplified.

[0027] Yet another advantage is that different fan motors speeds such as high, medium and low are defined for compressor speeds within a fixed range to thereby provide better performance in terms of cooling and energy efficiency.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The above mentioned and other features and objects of this invention, and the manner of attaining them, will become more apparent and the invention itself will be better understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

[0029] **FIG. 1** is a representative plot of capacity versus ambient load for a fixed speed compressor and a variable speed compressor;

[0030] **FIG. 2** is a representative plot of various aspects of general purpose motor performance versus speed for constant torque/constant power applications;

[0031] **FIG. 3** is a representative plot of various aspects of compressor motor performance versus speed for constant torque applications;

[0032] **FIG. 4** is a schematic diagram of one embodiment of a vapor compression system of the present invention;

[0033] **FIG. 5** is a perspective view of one embodiment of a room air conditioner of the present invention including the vapor compression system of **FIG. 4**;

[0034] **FIG. 6** is a flow chart illustrating one embodiment of a method of the present invention for controlling a room temperature;

[0035] **FIG. 7** is a representative plot of compressor frequency versus a temperature differential in the energy saving cooling mode;

[0036] **FIG. 8** is a schematic diagram of another embodiment of a control circuit of the present invention for powering and controlling a compressor motor;

[0037] **FIG. 9** is a representative plot of inverter output voltage versus AC input voltage for the control circuit of **FIG. 8**;

[0038] **FIG. 10** is a flow chart of one embodiment of a constant output voltage follower algorithm of the present invention;

[0039] **FIG. 11** is a flow chart of one embodiment of an algorithm of the present invention for making a DC side current measurement and frequency output correlation for deciding on single phase protection; and

[0040] **FIG. 12** is a block diagram illustrating an embodiment of a control circuit of the present invention for powering and controlling a three phase compressor motor.

[0041] Corresponding reference characters indicate corresponding parts throughout the several views. Although the exemplification set out herein illustrates an embodiment of the invention, the embodiment disclosed below is not intended to be exhaustive or to be construed as limiting the scope of the invention to the precise form disclosed.

DESCRIPTION OF THE PRESENT INVENTION

[0042] **FIG. 4** illustrates one embodiment of a vapor compression system **20** of the present invention including a fluid circuit circulating refrigerant in a closed loop. A compressor mechanism **22** compresses the refrigerant from a suction pressure to a discharge pressure. Compressor mechanism **22** may be a variable speed, reciprocating type compressor mechanism, for example. The refrigerant is then cooled in a heat exchanger in the form of a gas cooler or condenser **24**. The pressure of the refrigerant is then reduced by an expansion valve **26**. The refrigerant then enters another heat exchanger in the form of an evaporator **28** where it is boiled and cools a secondary medium, such as air, that may be used, for example, to cool a room or a refrigerated cabinet. The refrigerant discharged from evaporator **28** enters compressor mechanism **22** to repeat the cycle. A fan motor **30** is operatively coupled to and drives blower devices **31***a*, **31***b* to thereby blow air across condenser **24** and evaporator **28**, respectively. The heat-exchanging properties of condenser **24** and evaporator **28** may be enhanced by the moving air. Schematically represented fluid lines or conduits **23**, **25**, **27**, and **29** provide fluid communication between compressor mechanism **22**, gas cooler **24**, expansion valve **26**, evaporator **28** and compressor mechanism **22** in serial order.

[0043] In one embodiment, compressor mechanism **22** is a digital reciprocating compressor controlled and powered by an electronic control circuit **32** which provides a heating cycle mode and three cooling cycle modes, i.e., quick chill, standard, and energy saving modes. Control circuit **32** may select one of the modes based upon the external ambient temperature and a set temperature selected by the user.

[0044] In the embodiment shown in **FIG. 4**, control circuit **32** includes a power inverter **34** for driving compressor **22** in a controlled manner. Inverter **34** receives inputs from a power factor correction module (PFC) **36** and from a voltage/frequency control module (V/f control) **38**. Control circuit **32** also includes a digital signal processor **40**, a microcontroller **42**, and a rectifier **44**.

[0045] **FIG. 5** illustrates one embodiment of a room air conditioner **46** which may include vapor compression system **20**. Room air conditioner **46** may include compressor **22**, condenser **24**, expansion device **26** in the form of a capillary tube, evaporator **28**, fan motor **30**, blowers **31***a*, **31***b*, an outdoor inverter box **34***a*, and indoor inverter box **34***b*, a conduit **34***c* for carrying power and communication between boxes **34***a* and **34***b*, a remote controller **48** for transmitting a set temperature signal **50**, an indoor room temperature sensor **52**, an external ambient temperature sensor **54**, a hermetically covered compressor terminal **56**, a compressor discharge tube **58** and a compressor suction tube **60**.

[0046] According to the present invention, in order to achieve improved energy efficiency, the speed, i.e., the revolutions per minute (rpm) or frequency, of compressor **22** is varied according to the cooling demand of the room or rooms. Both speed and frequency may be referred to interchangeably herein, and it is to be understood that 60 rpm is equivalent to 1 Hz. The cooling demand may be in the form of a temperature differential between the room temperature and the set temperature selected by the user. For different compressor speeds or frequencies, the voltage applied to compressor **22** is varied or selected based on an algorithm to thereby produce a superior level of motor efficiency.

[0047] The control circuit may combine the power factor correction (PFC) and motor control into a single digital signal processor (DSP), thus allowing the PFC to be operated in constant output mode until a certain voltage point, and then switch into a voltage follower mode, thereby increasing the input window for voltage.

[0048] DSP **40** may correlate the measured current in the DC link of the compressor motor with compressor speed to protect against single phasing. Control circuit **32**, apart from controlling and protecting compressor **22**, also may control other window air conditioner accessories using split architecture.

[0049] Initially, based upon the external ambient temperature, the control cycle for either heating or cooling is selected. If the cooling control cycle is selected, three different ambient temperature bands may be defined to represent the possible load conditions. A given ambient temperature represented by a load allows the user to select a set temperature within a predetermined range so as to get energy and cooling benefits. In one embodiment, quick chill, standard and energy saver modes may be selected based upon the measured temperature differential between the set

temperature and the room temperature. Based on the respective algorithms for these modes, the compressor speed may be varied based on the demand of the room as represented by the temperature differential in order to achieve a room temperature that is close to the set temperature. Compressor speed may be reduced or increased depending on the drop or rise of the room temperature for a specified predetermined time period.

[0050] In the energy saving mode, condenser speed may be varied on the basis of the differential between the room and set temperatures in order to improve the energy efficiency. The quick chill mode may provide faster cooling, while the standard mode may provide a performance comparable with regular air conditioners but with better energy efficiency. The selection of a specified mode may decide the compressor speed or frequency, f. Based on this frequency, a desired voltage to be applied to compressor **22** may be calculated or otherwise determined from the V/f algorithm corresponding to the mode. The optimum V/f curve is not constant, but rather may vary with respect to the particular motor and the load system designed for the specific purpose. Compressor **22** may draw much less power than known compressors operating with constant V/f by virtue of compressor **22** being operated at a high efficiency for a given speed. More particularly, a desired level of voltage may be applied to compressor **22** in order to achieve improved performance.

[0051] Three modes of operation namely, quick chill, standard and energy saver modes may each correspond to a respective algorithm to control the speed of the compressor motor and the fan motors of the evaporator and condenser based on the room demand of capacity that is represented by the differential between the room temperature and the set temperature. The present invention may be applicable to both split air conditioners and room air conditioners.

[0052] Microcontroller **42** may process the cooling or heating logic requirements, as well as control fan motor **30** and the user interface which may include displays, buttons and/or remote controls, such as remote controller **48**. Microcontroller **42** may estimate the amount of cooling required and transmit the data to DSP **40**, which via PFC **36** and V/f control **38**, may control inverter **34** and thus the motor of compressor **22**. The data transmission may be performed serially.

[0053] DC Link ripple cancellation and power factor correction (using constant power output) may be used to obtain wide incoming voltage functionality. Power Factor correction may be applied in either constant voltage or voltage follower modes.

[0054] PFC **36** and the incoming rectifier **44** may be designed for a maximum current rating. This current rating may define the maximum power that can be drawn at various voltages (assuming that PFC **36** keeps the incoming power factor constant). Thus, the hardware may be designed by keeping the lowest operating input voltage in mind for the maximum power to be drawn. Once this hardware is in place, the minimum input voltage operation may be fixed. PFC **36** may switch from constant output to voltage follower mode when the minimum input voltage is reached, thereby allowing compressor **22** to still operate beyond this point.

[0055] Single phasing sensing is provided by the present invention by sensing the current on the DC side of the inverter. The compressor motor may be protected for high winding temperature by providing three thermistors, one on each winding, and then measuring the resistance at a 2-pin terminal connected to the thermistors. This winding temperature may be verified. Based on this verification, only the compressor may be turned off to protect the motor from high winding temperature.

[0056] The ambient temperature may be sensed by external ambient temperature sensor **54**, which may be provided on the condenser side of the room air conditioner. Based upon the ambient temperature, control circuit **32** may determine whether to operate in the heating mode or in one of the three cooling modes. In one specific embodiment, the heat pump mode is selected if the ambient temperature T_a is less than a set point of 17° C. The user may select any desired set point. If T_a is greater than or equal to 17° C., then one of the cooling modes is selected.

[0057] Although the selection of the mode may be made by control circuit **32**, a manual override may be provided wherein the user may select the operating mode. For example, remote controller **48** may be used to select heating or cooling, and further may be used to select one of the three cooling modes.

[0058] Based upon the sensed external ambient temperature, limits on the set temperature may be established. In one embodiment, the set temperature limits are defined as shown below:

[0059] 1. 17° C.$<T_a \leqq$37° C. then $T_x \geqq$16° C.

[0060] 2. 37° C.$\leqq T_a \leqq$43° C. then $T_x \geqq$20° C.

[0061] 3. 43° C.$<T_a$ then $T_s \geqq$25° C.

where

[0062] T_a=Ambient temperature or outside temperature

[0063] T_r=actual room side temperature

[0064] T_s=set temperature

[0065] $T_r - T_s = \Delta T$ (for cooling mode)

[0066] $T_s - T_r = \Delta T_1$ (for heating mode)

[0067] ΔT, ΔT_1 are the temperature differential measures of room condition

[0068] P_1, P_2, P_3 are predefined time periods for which the compressor operates at a desired speed

[0069] Remote controller **48** may allow the user to select the desired set temperature within the above limits based upon the band in which the ambient temperature falls.

[0070] Condenser and evaporator fan motor **30** may operate at different speeds, such as high, medium and low speeds. Based on the speed of compressor **22**, the speed of fan motor **30** may be set as given below.

Compressor speed (Hz)	Fan motor speed
Above 50	High
40–50	Medium
Below 40	Low

[0071] Hence, fan motor **30** may be operated at a speed that is dependent upon the speed of compressor **22**. Further, based on the compressor speed or frequency, the speed of fan motor **30** may be predefined. The discrete operating speeds of blower motor **31**, i.e., High, Medium, Low, each may correspond to a respective range of compressor speeds. Further, the speeds of blowers **31***a*, **31***b* may be dependent upon a speed of compressor **22**. Although condenser blower **31***a* and evaporator blower **31***b* are shown in **FIG. 4** as having a common motor **30**, it is possible for the condenser blower and the evaporator blower to have separate motors. Further, these separate motors may be operated at the same speeds or at different speeds.

[0072] When the quick chill mode is selected, compressor **22** starts out at its highest frequency and continues to do so until ΔT (room temperature minus set temperature) becomes equal to 1° C. When ΔT is 1° C., the speed of compressor **22** switches to 50 Hz and continues as per the following algorithm given below. This quick chill mode results in faster cooling. In the quick chill mode, the pull down time required to lower the room temperature to a desired level is about **60**% of that of a conventional air conditioner with a fixed speed compressor.

Logic Table for speed change as a function of Temperature in the Quick Chill Mode

Temperature (° C.)	Compressor speed (rpm)	Fan motor speed	Time Duration	Remarks
$T_r > T_s + 1$	Highest	High	NA	
$T_r = T_s + 1$	3000	Medium	P_1	If there is no rise in temp., then go to next lower compressor speed; otherwise go to next higher speed
$T_r \leqq T_s + 1$	2400	Medium	P_2	If there is no rise in temp., then go to next lower compressor speed; otherwise go to next higher speed
$T_r \leqq T_s + 1$	2100	Low	P_3	If there is no rise in temp., then go to next lower compressor speed; otherwise go to next higher speed
$T_r \leqq T_s + 1$	1800	Low	NA	If there is no rise in temp., then continue at present compressor speed; otherwise go to next higher speed
$T_r = T_s$	Switch off	Low	NA	Switch off regardless of present compressor speed

[0073] After switching off, compressor **22** may be restarted at a lower frequency, e.g., at 30 Hz (1800 rpm) when $T_r=T_s+0.5°$ C.

[0074] As shown in the above logic table and in the flow chart of **FIG. 6**, a method **600** of controlling a room temperature includes determining a temperature differential ΔT between an actual temperature T_r and a desired temperature T_s (S**602**). In a next step S**604**, a compressor is operated in order to reduce the temperature differential. After the compressor is operated, a subsequent temperature differential between a subsequent actual temperature and the desired temperature is ascertained (S**606**). In S**608**, it is determined whether the subsequent temperature differential is above a threshold temperature differential. If not, the compressor may be shut off (S**610**). In the embodiment shown in the above logic table, the threshold temperature differential is zero, i.e., the compressor is switched off if $T_r=T_s$. If the subsequent temperature differential is above the threshold temperature differential, then it is determined whether the subsequent temperature differential is less than an immediately preceding temperature differential (S**612**). If not, the compressor speed may be increased (S**614**), and operation of the compressor may be continued (S**604**). If the subsequent temperature differential is less than the immediately preceding temperature differential, then it is determined whether the compressor speed is above a threshold speed (S**616**). In the embodiment shown in the above logic table, the threshold speed is 1800 rpm, which is the minimum speed in the logic table. If the compressor speed is not above the threshold speed, e.g., is equal to the threshold speed of 1800 rpm, then operation of the compressor may be continued at the present compressor speed of 1800 rpm (S**604**). If the compressor speed is above the threshold speed, then the compressor speed may be decreased (S**618**), and operation of the compressor may be continued (S**604**).

[0075] When the standard mode is selected, compressor **22** may be operated similarly to a conventional cooling cycle of an air conditioner with a fixed speed compressor. The speed change may be as per the following algorithm:

Logic Table for speed change as a function of Temperature in the Standard Mode

Temperature (° C.)	Compressor speed (rpm)	Fan motor speed	Time Duration	Remarks
$T_r > T_s + 10$	Highest	High	NA	
$T_r \leqq T_s + 10$	3000	Medium	NA	
$T_r \leqq T_s + 1$	2400	Medium	P_1	If there is no rise in temp., then go to next lower compressor speed; otherwise go to next higher speed
$T_r \leqq T_s + 1$	2100	Low	P_2	If there is no rise in temp., then go to next lower compressor speed; otherwise go to next higher speed
$T_r \leqq T_s + 1$	1800	Low	P_3	If there is no rise in temp., then continue at present compressor speed; otherwise go to next higher speed
$T_r = T_s$	Switch off	Low	NA	Switch off regardless of present compressor speed

[0076] After switching off, compressor **22** may be restarted at a lower frequency, e.g., at 30 Hz (1800 rpm) when $T_r=T_s+0.5°$ C.

[0077] When the quick chill mode is selected, the compressor may be operated at its highest speed if the T_r-T_s temperature differential exceeds 1° C. In contrast, when the standard mode is selected, the compressor may be operated at its highest speed if the T_r-T_s temperature differential exceeds a higher value of 10° C.

[0078] In both the quick chill mode and the standard mode, the time periods P_1, P_2, P_3 between the individual ascertainments of the T_r-T_s temperature differential are dependent upon the speed of the compressor.

[0079] When the energy saving mode is selected, compressor frequency is varied based on the temperature differential between the room temperature and the set temperature (ΔT) as illustrated in **FIG. 6**. As the temperature difference ΔT increases, the frequency of compressor **22** is also increased. The frequency may increase substantially linearly as shown in **FIG. 7**. This energy saving mode may result in more energy savings as compared to conventional fixed speed compressor energy consumption and also as compared to the quick chill and standard modes of the present invention.

[0080] When room air conditioner **46** is operated in the heating cycle mode, a valving system (not shown) may be activated such that the direction of flow of refrigerant is reversed. Thus, condenser **24** may function as an evaporator, and evaporator **28** may function as a condenser.

[0081] In all three of the cooling modes and in the heating mode, control circuit **32** may repetitively determine the T_r-T_s temperature differential between the actual room temperature and the desired room temperature.

[0082] According to the present invention, the set temperature limits may be defined based on the external ambient temperature measured by temperature sensor **54**. While defining these set temperature limits, due care is taken to consider the comfort level of the occupants and reduce the energy consumption.

[0083] The algorithms of the present invention may be employed with both a reduced level of computation ability and a reduced level of processing time. The quick chill mode results in faster cooling and the standard mode provides a level of air conditioner performance that is comparable to that of known air conditioners. However, in both the quick chill mode and the standard mode the speed changeover is based on a predefined time period, which reduces the delay in the speed changeover as compared to known inverter compressor control algorithms. In these known algorithms, the speed change is based on the capacity required for the room, the calculation of which may require substantial processing power and time.

[0084] The algorithms employed in the energy saving mode may also be computationally simple. The speed change may be based purely on the delta T, i.e., the temperature differential of room temperature sensor **52** and the set temperature. Compressor speed may change only when delta T changes.

[0085] All of the three algorithms for the quick change, standard and energy saving modes, respectively, are aimed at quickly getting room temperature to the set temperature and then gradually reducing the compressor speed. Thus, the algorithms may reduce the power consumption of the air conditioner and achieve a room temperature that is close to the set temperature with minimal temperature fluctuations.

[0086] The present invention may avoid the problems associated with the prior art by making use of a desired V/f curve. No user interface is required to select the boost voltage or to select a different predetermined V/f curve. The desired V/f curve is not constant, but rather varies with respect to the particular motor and the load system designed for the specific purpose. The power drawn is much less as compared to the conventional constant V/f curve because the compressor may be operated at or near the maximum possible efficiency for the given speed by applying a desired voltage for improved performance. The efficiency is better as compared to that of the conventional constant V/f algorithm, thereby offering energy saving.

[0087] An embodiment of a control circuit **132** of the present invention for powering and controlling a compressor motor **121** is shown in **FIG. 8**. A rectifier section **144** may convert an incoming AC voltage into a DC voltage. A power factor correction circuit **136** may operate in continuous conduction mode, thereby functioning as a boost stage. After the power factor correction circuit **136** are one or more DC Link capacitors **162**, which may smoothen the DC voltage. An inverter stage **164** including IGBTs **166** may convert the DC voltage on the DC link **162** to AC voltage for the motor **121**.

[0088] Power factor stage **136** may assist in the correction of the power factor and thereby may remove the discontinuity in the current flow. This may reduce harmonics and improve compliance with standards IEC61000-3-2 and IEC61000-3-4.

[0089] The present invention may implement the motor control as well as the power factor correction in a single digital signal processor **140**. The digital outputs are controlled from the DSP **140** to trigger the devices for the inverter **164** and the PFC **136**.

[0090] As illustrated in the plot of **FIG. 9**, PFC **136** may operate in a constant output voltage mode as long as the incoming voltage is equal to or above the constant to voltage follower point. In this case the DC Link voltage may be held constant irrespective of the incoming voltage as long as the incoming voltage is above the constant to voltage follower point. This may ensure that the output V/f ratio is maintained constant. Until the incoming voltage is within this band, the output frequency and voltage corresponds to the maximum demand possible. In this mode the compressor can run up to its maximum designed speed to provide for enhanced cooling or run at slower speeds to provide for energy savings.

[0091] The constant to voltage follower point may be determined on the basis of the hardware design of the incoming rectifier current capability and the PFC component current rating selections. According to the present invention, the PFC switches from constant output to a voltage follower mode below the voltage constant to voltage follower point, as illustrated in **FIG. 9**.

[0092] Below the constant to voltage follower point, the output voltage onto the DC Link **162** from the PFC stage **136** operates in a voltage follower mode. That is, the DC Link voltage is not constant, but rather may be maintained at a percentage of the incoming voltage. Thus, the DC Link voltage may vary in proportion to the incoming voltage.

[0093] As the DC Link voltage decreases, the motor control algorithm may start to limit the output voltage to the motor, possibly allowing a maximum voltage out depending on the incoming voltage and the DC bus utilization. The V/f control, such as V/f control **38**, may then limit the frequency due to the voltage limitation to ensure that the V/f is maintained as required. Thus, the speed of the compressor motor may be limited due to reduction in the voltage applied to the compressor motor. With reduction in compressor speed, the power consumed by the motor decreases. As the power consumed decreases, the required input current decreases as the power factor on the input side is maintained consistently high by the PFC. Thus, the input side current may be kept within the current rating selection of the rectifier and the PFC sections.

[0094] The present invention using the algorithm illustrated in **FIG. 10** allows the compressor to run at lower speeds, but still provides cooling when the input voltage goes below the specified value for that particular inverter when it operates in constant output mode for the PFC section. If the controls (power factor correction and motor control) were split into two different processors, then a high volume of data exchange would be needed to carry out both the switchover of PFC (from constant output to the voltage follower) and the limitation of speed in the motor control section on basis of the incoming voltage. This would consume a lot of the peripherals and the processing bandwidth of both the control elements. This problem is avoided in the present invention by combining both types of the control software into a common digital signal processor.

[0095] In the embodiment of the present invention illustrated in **FIG. 8**, the current is sensed only on the DC side of the inverter. This current on DC side may be used to protect motor **121** for single phasing in addition to locked rotor and over-current protection. The DC Link current may be measured and compared with the expected current based on the motor speed as is fed to this logic from the motor speed control algorithm, as illustrated in **FIG. 11**.

[0096] The DC Link current may be steady as long as the inverter load is symmetrical. That is, the current flow may be consistent with little variations. However, in reality, this current may vary slightly irrespective of the consistency of the load. However when single phasing occurs, that is, when one of the phases stops conducting, then the current out from inverter **164** may be dependent only on two phases from the inverter, and the total power may be drawn from only these two phases. Now, the current on the DC Link may vary. When the IGBT **166** of the non-conducting phase comes on, there may be no conduction, but when the IGBT of the conducting phase switches on, there may be high current conduction. Thus, there may be significant variation in the DC side current in case of single phasing. Hence, if the variation in DC side current is high (beyond a certain defined window of variation based on the speed and external ambient), the fault is understood to be single phasing on the output of inverter **164**. Inverter **164** is then switched off and thus compressor motor **121** is protected.

[0097] According to the present invention, a warning may be issued when the compressor is in need of service, or when there is an impending failure of the compressor or the air conditioner. The variable speed compressor may be provided with an additional two pin terminal (not shown) and three thermistors (not shown), i.e., one thermistor on each respective phase of a three-phase motor of the compressor. These thermistors may be connected to a two pin terminal where the temperature of the winding can be measured in the form of resistance of these thermistors. Beyond a certain winding temperature, such as approximately 130° C., resistance increases dramatically. This temperature can be tapped from an electronic controller, such as DSP **40**.

[0098] Based on the measured winding temperatures, it can be estimated to determine whether to issue a warning that maintenance service is needed or that the appliance or the compressor is failing.

[0099] It is possible to estimate the motor current based upon the ambient temperature. The electronic controller also measures the current as a protection measure. Power may be removed from the motor based on ambient temperature measurements or current measurements in order to protect the motor from high current.

[0100] In the present invention, the control functions may be classified as appliance control (indoor control) and inverter control (outdoor control). The two controls work together to form a complete control system. The appliance control may function as the master controller and determine requirements on the basis of the user settings and the various measured parameters. The appliance control may determine the amount of cooling needed to satisfy the user requirement. A signal indicative of this required cooling amount may be transmitted to the inverter controller. On receipt of this data, the inverter controller may control the speed of the compressor to provide the desired cooling. The inverter controller may be capable of handling the outdoor side accessories, such as the fan, temperature measurement, etc. In this manner there may be a hardware/software combination for the indoor section and another hardware/software combination for the outdoor section. As most of the controls needing large amounts of processing are performed in the outdoor section, the indoor section may be a smaller portion of the control system.

[0101] The inverter controls and the appliance controls may be separated into two printed circuit boards (PCBs) each. **FIG. 12** illustrates the split architecture of separate indoor and outdoor processing units. In both the inverter controls and the appliance controls there is a control PCB whose hardware may be the same for each type and rating of air-conditioner. The other PCB in the inverter control may be the power PCB. The power PCB may be connected to the control PCB, and may have different designs corresponding to different ratings. The software on the control PCB may be the same for each application.

[0102] In the appliance section, the user and appliance interface section of the PCB may vary with the application, while the hardware of the control PCB may be the same for each application. The software may be modified to suit the particular appliance. In this manner, the inventory control and hardware-software library maintenance is simplified. The window air-conditioner system can easily be made into a split system without any change in hardware or software, further simplifying the version control issues.

[0103] The present invention has been described herein as being used to cool or heat a room of a building. However, it is to be understood that the present invention may also be

used to cool or heat any space or compartment, such as a refrigerated compartment in a drink dispenser or refrigerator.

[0104] While this invention has been described as having an exemplary design, the present invention may be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles.

What is claimed is:

1. A vapor compression system comprising:

a fluid circuit circulating a refrigerant in a closed loop, said fluid circuit having operably disposed therein, in serial order, a variable speed compressor, a first heat exchanger, an expansion device and a second heat exchanger;

a first blower device associated with said first heat exchanger, a speed of said first blower device being dependent upon a speed of said compressor; and

a second blower device associated with said second heat exchanger, a speed of said second blower device being dependent upon the speed of said compressor.

2. The system of claim 1 wherein said first heat exchanger comprises a condenser, said second heat exchanger comprising an evaporator.

3. The system of claim 1 wherein the speed of said first blower device is approximately equal to the speed of said second blower device.

4. The system of claim 3 further comprising a blower motor operatively coupled to each of said first blower device and said second blower device.

5. The system of claim 4 wherein the blower motor has a plurality of discrete operating speeds each corresponding to a respective range of compressor speeds.

6. A method of controlling a room temperature, said method comprising the steps of:

determining a first temperature differential between a first actual temperature and a desired temperature;

operating a compressor;

ascertaining a subsequent temperature differential between a subsequent actual temperature and the desired temperature after said operating step;

decreasing a speed of said compressor if the subsequent temperature differential is less than an immediately preceding temperature differential; and

repeating said operating, ascertaining, and decreasing steps so long as the speed of said compressor is greater than a threshold speed and the subsequent temperature differential is greater than a threshold temperature differential.

7. The method of claim 6 comprising the further step of selecting one of a first mode and a second mode of operating said compressor, said compressor being operated at a highest speed in the first mode if the first temperature differential exceeds a first value, said compressor being operated at the highest speed in the second mode if the first temperature differential exceeds a second value greater than the first value.

8. The method of claim 7 wherein said selecting step includes selecting one of the first mode, the second mode, and a third mode in which the speed of said compressor is substantially continuously varied based upon determined temperature differentials.

9. The method of claim 6 comprising the further step of increasing the speed of said compressor if the subsequent temperature differential is greater than an immediately preceding temperature differential.

10. The method of claim 6 wherein the threshold speed comprises a minimum speed.

11. The method of claim 6 wherein the threshold temperature differential is approximately zero.

12. The method of claim 6 comprising the further step of operating a fan motor at a speed dependent upon the speed of the compressor.

13. The method of claim 6 wherein a time period between said ascertaining steps is dependent upon the speed of the compressor.

14. A vapor compression system comprising:

a variable speed compressor; and

a control device configured to:

repetitively determine a temperature differential between an actual room temperature and a desired room temperature; and

selectively operate said compressor in a first mode and a second mode, the first mode including decreasing a speed of said compressor after each said temperature differential determination so long as a most recently determined temperature differential is less than a second most recently determined temperature differential, the second mode including substantially continuously varying the speed of said compressor based upon the determined temperature differentials.

15. The system of claim 14 wherein the first mode includes increasing the speed of said compressor if the most recently determined temperature differential is greater than the second most recently determined temperature differential.

16. The system of claim 14 wherein the speed of said compressor is decreased after each said temperature differential determination so long as the speed of said compressor is greater than a threshold speed.

17. The system of claim 16 wherein the threshold speed comprises a minimum speed.

18. The system of claim 16 wherein said control device is configured to operate said compressor so long as the actual room temperature is greater than the desired room temperature.

19. The system of claim 16 further comprising a fan motor configured to blow air across a heat exchanger that is in fluid communication with said compressor, said control device being configured to operate said fan motor at a speed dependent upon the speed of the compressor.

20. The system of claim 16 wherein said control device is configured to repetitively determine the temperature differential at time intervals that are dependent upon the speed of the compressor.

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