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(54) **ELECTRONIC CONTROL TRANSFORMER USING DC LINK VOLTAGE**

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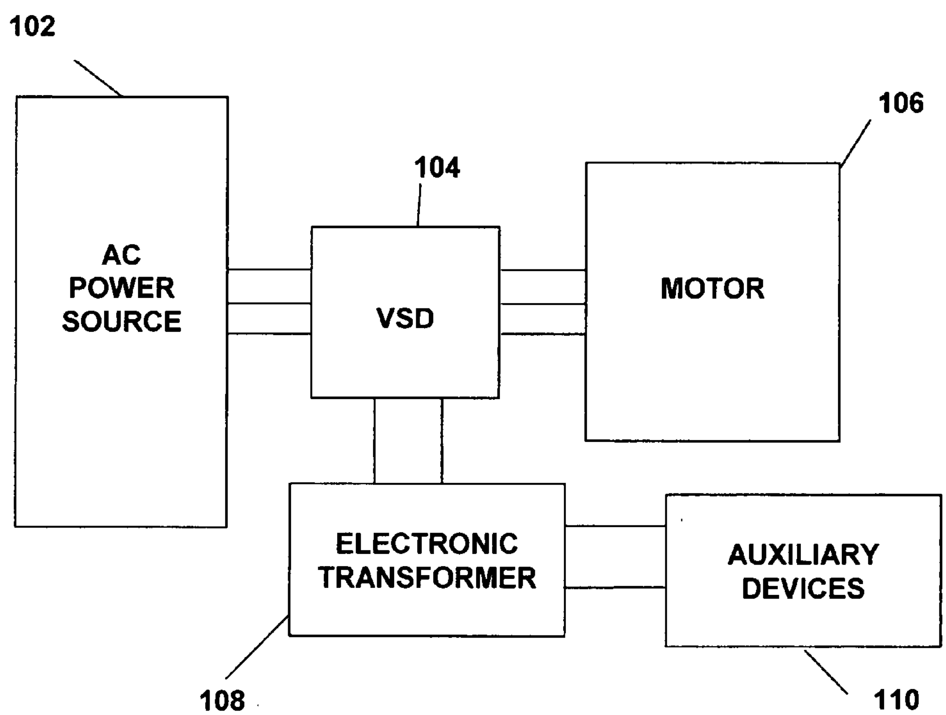
(57) **ABSTRACT**

In a chiller system, an electronic control transformer is powered by the DC link of a variable speed drive that drives a compressor motor. The electronic control transformer converts the DC voltage to a constant 120 VAC at 60 Hz, for providing power to auxiliary electrical devices associated with the chiller system. The electronic transformer includes four semiconductor switches to convert the DC voltage to AC. The energy stored in the compressor motor is transferred to the DC link of the VSD during an input voltage sag. The electronic control transformer maintains the control voltage and prevents the system auxiliary loads from dropping out during a voltage sag. The chiller system is able to ride through the input voltage sag or interruption. A boost converter may be provided at the input of the VSD to increase ride through capability.



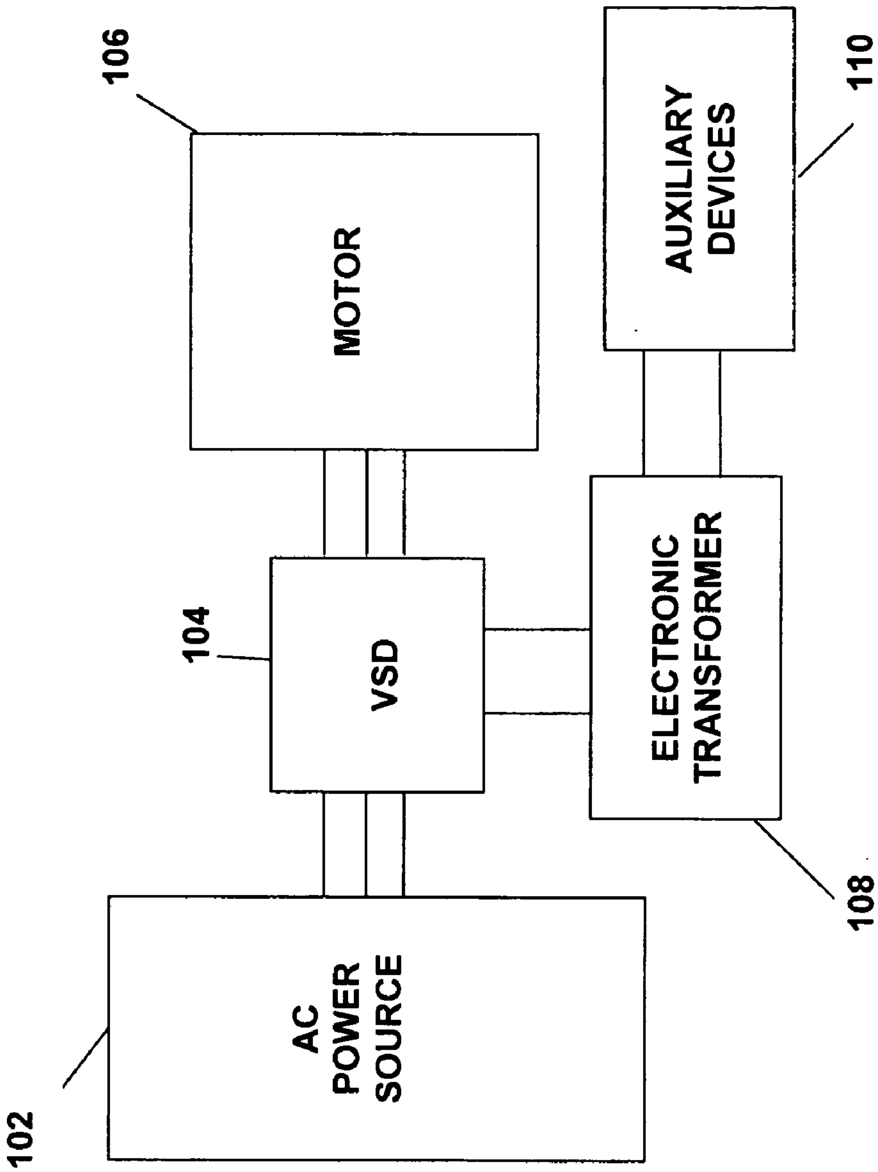

106
MOTOR
AUXILIARY DEVICES
110
104
VSD
ELECTRONIC TRANSFORMER
108
AC POWER SOURCE
102

Figure 1

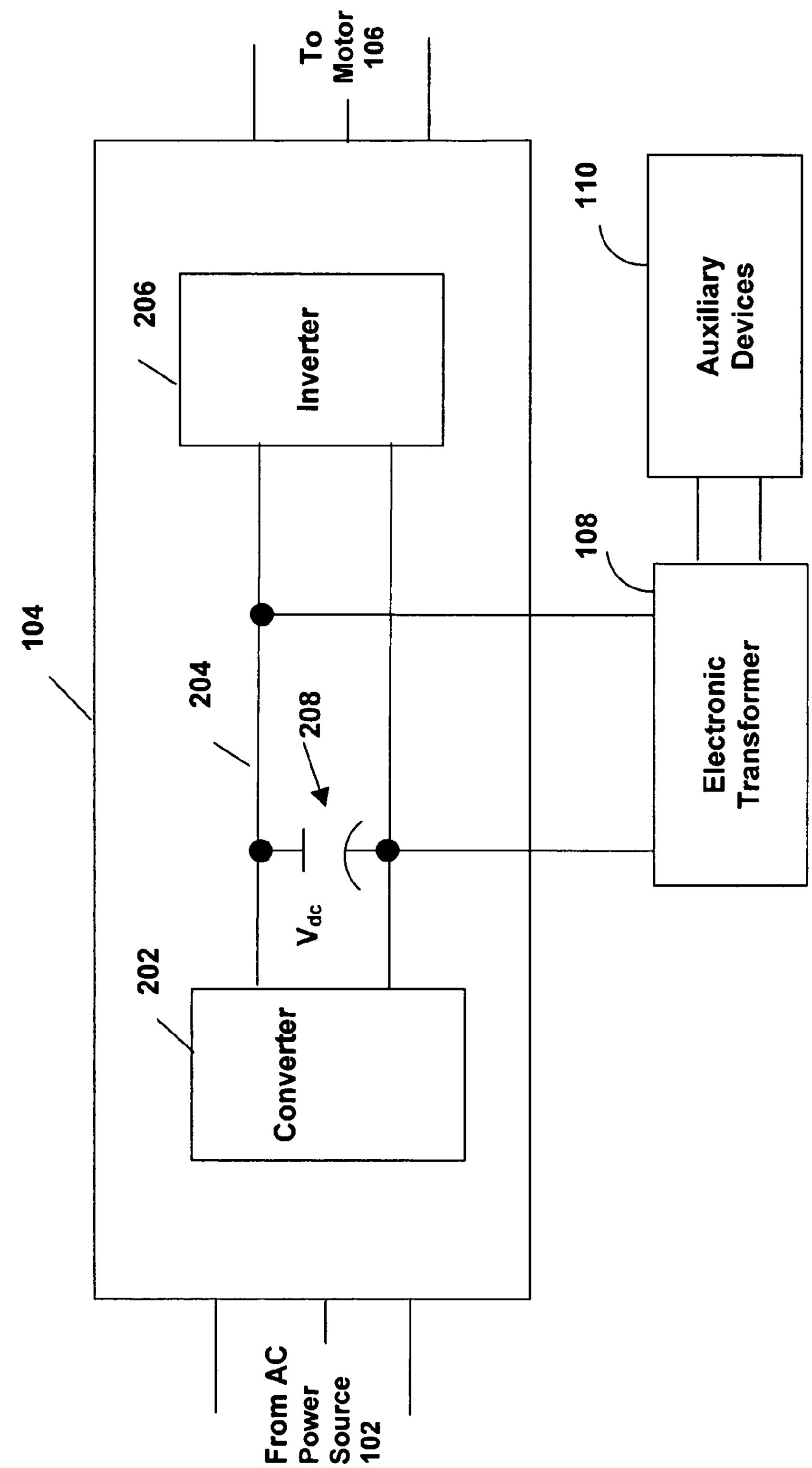

To
Motor
106
104
206
Inverter
110
Auxiliary
Devices
108
204
208
Electronic
Transformer
V_{dc}
202
Converter
From AC
Power
Source
102

Figure 2

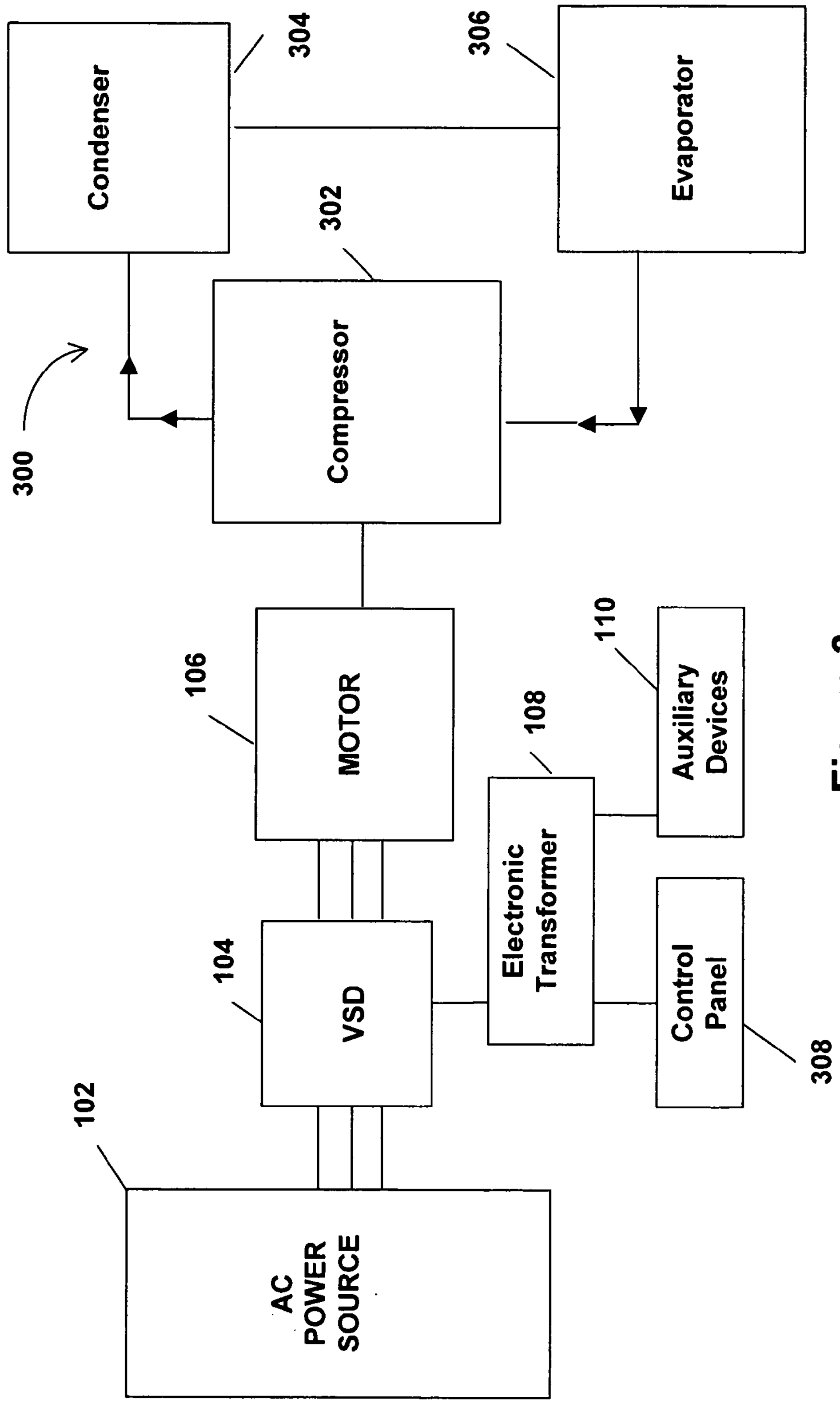

Condenser
304
306
Evaporator
302
Compressor
300
106
MOTOR
110
108
Auxiliary Devices
104
VSD
Electronic Transformer
Control Panel
308
102
AC POWER SOURCE

Figure 3

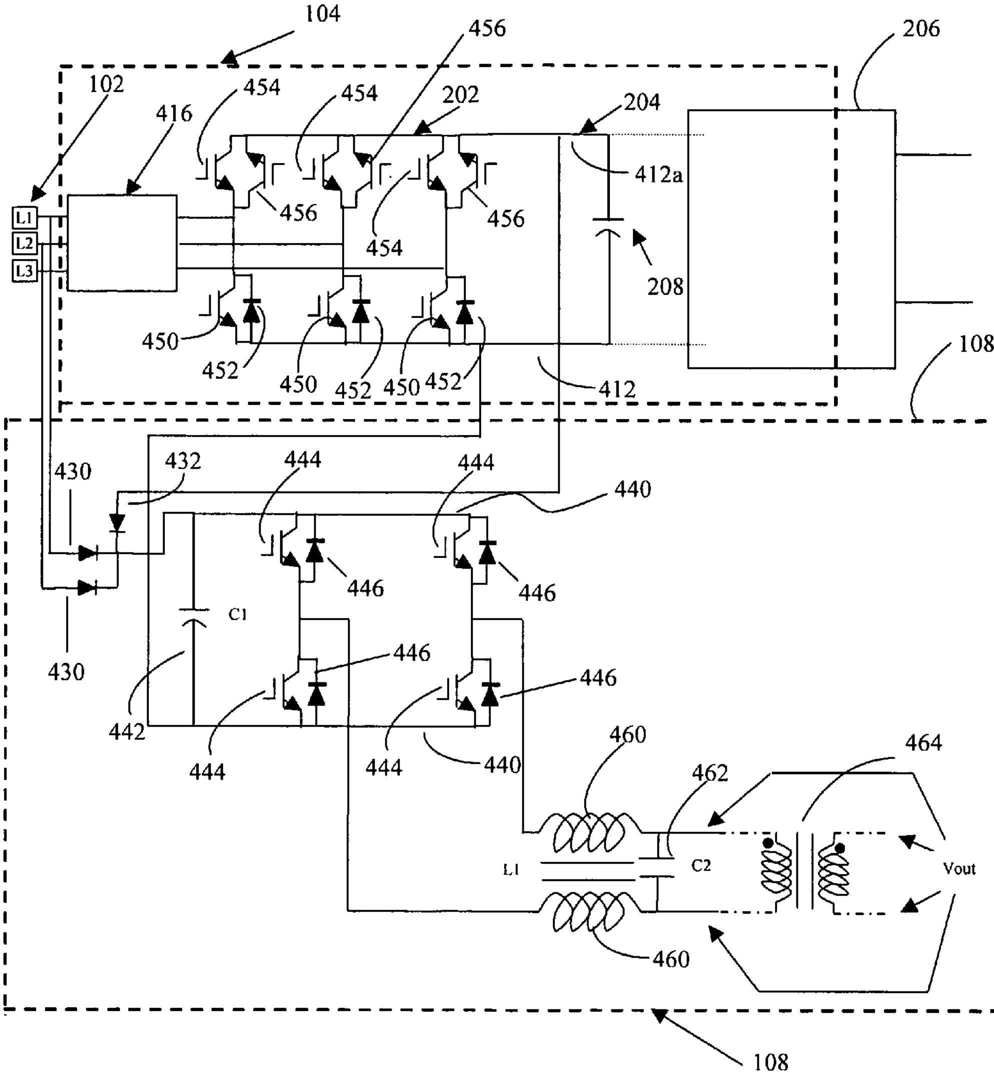

104
456
206
102
454
454
202
204
416
412a
L1
L2
L3
456
454
456
208
450
452
450
452
450
452
412
108
430
432
444
444
440
446
446
C1
446
446
430
442
444
444
440
460
464
462
L1
C2
Vout
460
108

Fig. 4

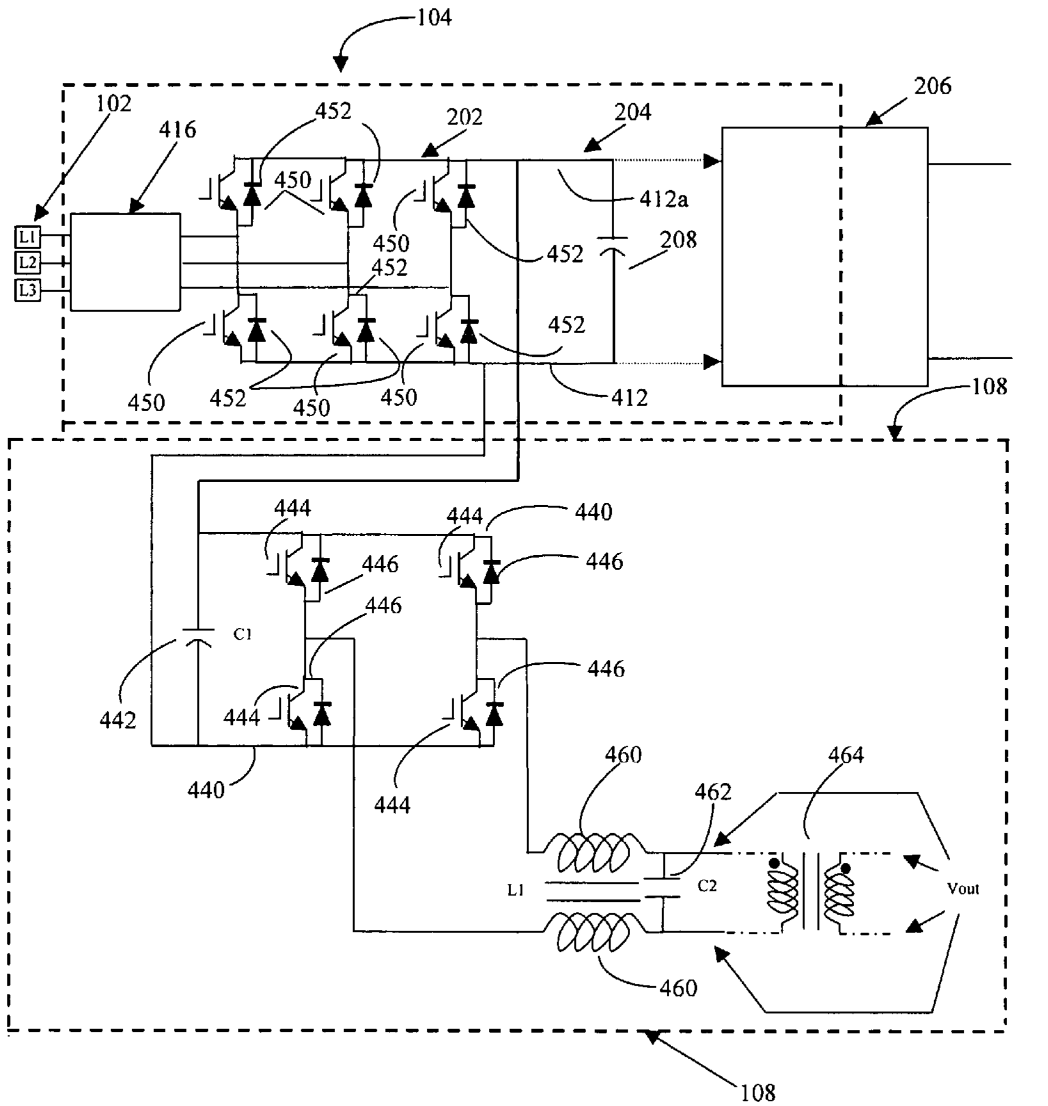

104
102
416
452
202
204
206
450
412a
L1
L2
L3
450
452
208
452
452
450
452
450
450
412
108
444
444
440
446
446
446
C1
446
442
444
440
444
460
464
462
L1
C2
Vout
460
108

Fig. 5

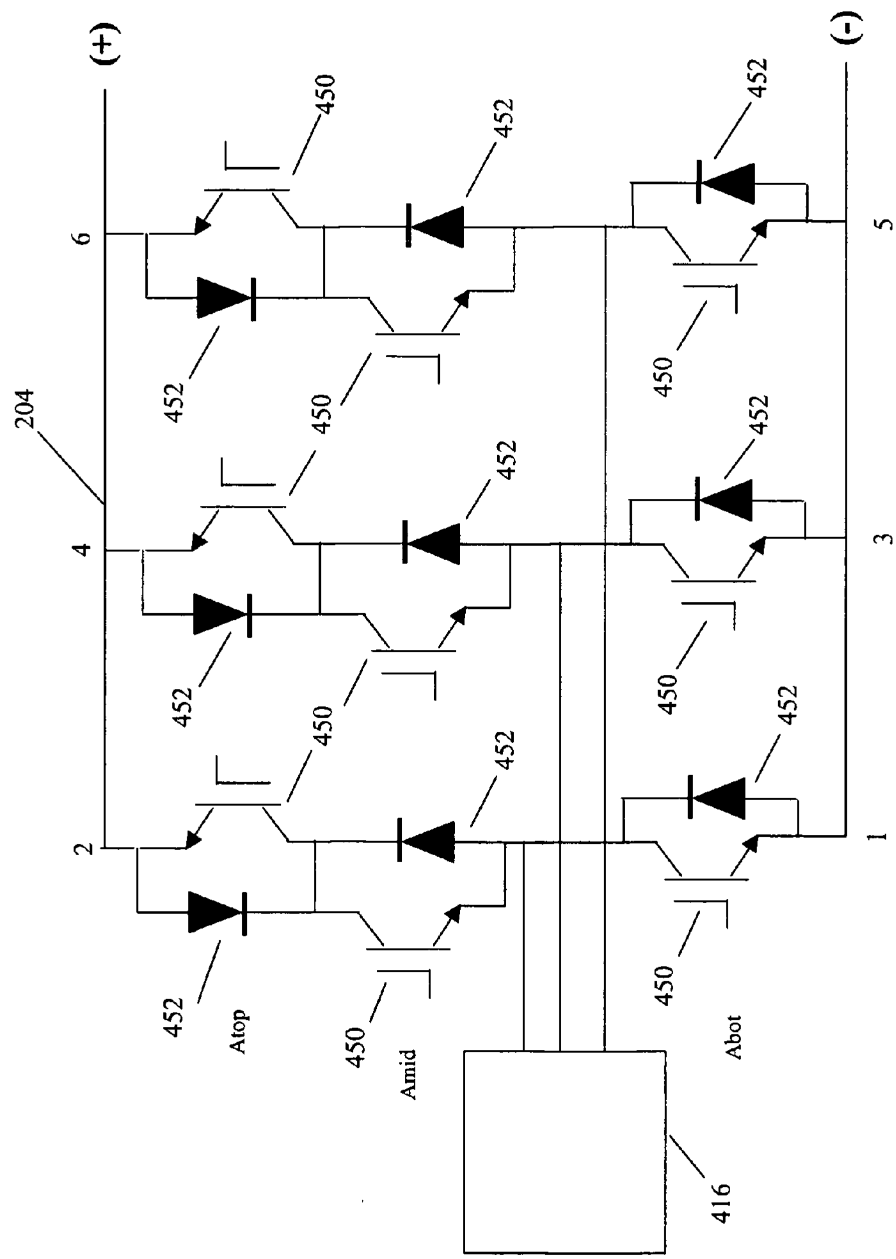


Fig. 6

ELECTRONIC CONTROL TRANSFORMER USING DC LINK VOLTAGE

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to an electronic transformer for supplying control voltage. More specifically, the present invention relates to an electronic control transformer powered by the DC link of a variable speed drive for a chiller system.

[0002] In the past, the motors for driving compressors in chiller systems were designed to operate from standard line (main) voltages and frequencies that were available from the power distribution system of the facility where the motor was being operated. The use of line voltages and frequencies typically limited the options for modulating the capacity of the compressors to less efficient mechanical devices such as inlet guide vanes and slide valves, as a result of the motor being limited to one operating speed that was based on the input frequency to the motor. In addition, if the operating speed of the motor was not equal to the desired operating speed of the compressor, a "step up," or "step down," gearbox was inserted between the motor and the compressor to obtain the desired operating speed of the compressor.

[0003] Next, variable speed drives (VSDs) were developed that could vary the frequency and voltage that was provided to the motors of a chiller system. This capability to vary the input frequency and voltage to the motor resulted in a motor that was capable of providing a variable output speed to the corresponding compressor of the chiller system. The variable speed operation of the motors (and compressors) enabled the chiller system to take advantage of efficiencies that occur during partial loading of the compressors, when operation at a speed lower than full design load speed is desirable. The use of the variable speed drive also permitted the use of other types of motors that required their own electronic drive in chiller systems in addition to the previous motors that were capable of operating directly from a three-phase power line, e.g., induction motors, or synchronous motors.

[0004] Generally, chiller systems include a number of auxiliary devices in cooperation with the compressor. These auxiliary devices normally include a control panel, contactors, relays, pumps and fans, that are rated for a fixed voltage different than that of the compressor motor, and that operate at a fixed frequency, e.g., 60 Hz or 50 Hz. Since the auxiliary devices cannot operate on the variable voltage and frequency output of the VSD, the power for the control voltage is usually provided by a conventional wound magnetic control transformer that is connected at the input AC power to the VSD, or from another input power source. The output voltage of the control transformer secondary winding is proportional to the primary winding input voltage, such that a voltage sag or interruption on the primary winding is reflected nearly instantly on the output voltage of the control transformer. The sag or interruption, if sufficient in magnitude and/or duration, may cause the chiller system's contactors or relays to drop out, or cause the control panel or pumps to shut down, resulting in interruption of chiller system operation.

[0005] The VSD supplying the compressor is also subject to input voltage sags and interruptions for the same reason. VSDs typically include a converter that converts AC input power to DC voltage for a DC link. An inverter is connected to the DC link and converts the DC link voltage to a variable voltage, variable frequency AC power output. The DC link is normally supported by a capacitor which provides limited stored energy, and in some instances an active rectifier or converter may be employed to boost the input voltage above the peak of the RMS value, i.e., greater than 1.414 times the nominal value of the input voltage source. These components of the VSD provide a measure of ride-through capability. Very often, however, the ride-through capability is insufficient to maintain the chiller operation for input voltage sags or interruptions greater than a few cycles on a 60 Hz utility line. In the case where the VSD is configured with ride-through capability, the control transformer can leave the chiller system vulnerable to a voltage sag, even though the VSD and compressor motor may survive the voltage sag.

[0006] One limitation of chiller systems having separate AC input power sources for the compressor and the auxiliary devices is that if either the VSD output voltage or the control voltage sags or experiences a brief interruption, then the chiller system fails. Another limitation of chiller systems having separate AC input control power sources for the compressor and the auxiliary devices is that different control transformers must be used for power systems having different distribution voltages, the design of the control transformer being dependent upon the input AC voltage and frequency supplied to the chiller system.

[0007] Therefore, what is needed is a control transformer that is powered by the VSD driving the compressor of a chiller system, and that has improved ride-through capability.

SUMMARY OF THE INVENTION

[0008] The present invention includes an electronic transformer configured to provide single phase AC control power from the DC link of a VSD for powering at least one auxiliary device associated with a chiller system. The electronic control transformer includes an inverter module to convert a DC voltage to an AC voltage to power a load. The inverter module includes: a plurality of pairs of power switches, wherein each pair of power switches includes an insulated gate bipolar transistor connected in anti-parallel to a diode; an input DC connection for connecting the electronic control transformer to a DC link of a variable speed drive; an input AC connection for connecting the electronic control transformer to the AC input to the variable speed drive and an output AC connection for connecting the at least one auxiliary device. The inverter module is controllable to provide a fixed output AC voltage and fixed frequency for powering the at least one auxiliary device.

[0009] In a preferred embodiment, the invention is directed to a drive system to power a plurality of components of a chiller system having different voltage requirements than the drive system itself. The drive system includes an active rectifier or converter stage connected to an AC power source to receive an input AC power at a fixed input AC voltage and a fixed input frequency. The active converter or rectifier may also be configured with a pre-charge circuit for controlling the inrush current to the DC link upon start up. The active converter stage is configured to convert the fixed input AC voltage to a boosted DC voltage, the boosted DC voltage being greater than the peak value of the fixed input AC voltage. A DC link is connected to the converter stage. The DC link is configured to filter the boosted DC voltage and store energy from the converter stage. Also, a first inverter stage is connected to the DC link. The first inverter stage is configured to convert the boosted DC voltage from the DC link to provide an output power at a variable voltage and variable frequency to a motor of a chiller system. The variable voltage has a maximum voltage capability greater in magnitude than the fixed input AC voltage. The variable frequency has a maximum frequency capability greater than the fixed input frequency. The active converter provides additional ride-through capability to the extent that the AC input voltage may decrease without a corresponding decrease in the DC link. When the active converter reaches saturation, the inverter is controlled to reverse the flow of energy from the motor and compressor to the DC link stage to transfer electrical power from energy stored in a rotating mass of a motor connected to the first inverter stage to maintain a voltage level of the DC link in response to a decreasing fixed input AC voltage; and an electronic control transformer connected to the DC link, the electronic control transformer being configured to convert the boosted DC voltage from the DC link into an auxiliary output power source having a fixed output AC voltage and a fixed output frequency for at least one component of a chiller system. The fixed output AC voltage is less than the fixed input AC voltage to the converter of the drive. In addition, the fixed output AC voltage and fixed output frequency of the electronic control transformer is maintained in the event of a temporary decrease in the fixed input AC voltage.

[0010] In another embodiment, the VSD contains a conventional rectifier or converter at the input end. There is a DC link connected to the converter stage, the DC link being configured to filter the DC voltage and store energy from the converter stage. A first inverter stage is connected to the DC link. The first inverter stage is configured to convert the DC voltage from the DC link into the output power for the motor. The first inverter stage is configured to reverse power flow through the first inverter stage to the DC link stage to transfer electrical power from energy stored in a rotating mass of the motor to maintain the voltage level of the DC link stage in response to a decreasing input AC voltage; and an electronic control transformer connected to the DC link, the electronic control transformer being configured to convert the DC voltage from the DC link into an auxiliary output power source having a fixed output AC voltage and a fixed output frequency for at least one component of a chiller system. The fixed output AC voltage is less than the fixed input AC voltage to the converter of the drive. In addition, the fixed output AC voltage and fixed output frequency of the electronic control transformer is maintained in the event of a temporary decrease in the fixed input AC voltage.

[0011] In another embodiment of the present invention there is a chiller system which includes an electronic control transformer. The chiller system includes a refrigerant circuit comprising compressor, a condenser, and an evaporator connected in a closed refrigerant loop. A motor is connected to the compressor to power the compressor. A variable speed drive is connected to the motor. The variable speed drive is configured to receive an input AC power at a fixed input AC voltage and a fixed input frequency and provide an output power at a variable voltage and variable frequency to the motor. The variable voltage has a maximum voltage capability greater in magnitude than the fixed input AC voltage and the variable frequency having a maximum frequency capability greater than the fixed input frequency.

[0012] The variable speed drive includes an active converter or rectifier stage connected to an AC power source providing the input AC power. The converter stage is configured to convert the input AC voltage to a boosted DC voltage. The boosted DC voltage is greater than the fixed input AC voltage. There is a DC link connected to the converter stage, the DC link being configured to filter the boosted DC voltage and store energy from the converter stage. A first inverter stage is connected to the DC link. The first inverter stage is configured to convert the boosted DC voltage from the DC link into the output power for the motor. The first inverter stage is configured to reverse power flow through the first inverter stage to the DC link stage to transfer electrical power from energy stored in a rotating mass of the motor to maintain the voltage level of the DC link stage in response to a decreasing input AC voltage.

[0013] An electronic control transformer is connected to the DC link. The electronic control transformer is configured to convert the boosted DC voltage from the DC link into an auxiliary output power source having a fixed output AC voltage and a fixed output frequency, the fixed output voltage being less than the fixed input AC voltage to the active converter or rectifier. The fixed output AC voltage and fixed output frequency of the electronic control transformer is maintained in the event of a temporary decrease in the input AC voltage.

[0014] In another embodiment, the present invention is directed to an electronic control transformer for powering at least one auxiliary device associated with a chiller system. The electronic control transfer includes an inverter module to convert a DC voltage to provide a fixed output AC voltage and fixed frequency to power the at least one auxiliary device. The inverter module has a plurality of pairs of power switches, wherein each pair of power switches includes an insulated gate bipolar transistor connected in anti-parallel to a diode. An input DC connection is provided for connecting the electronic control transformer to a DC link of a variable speed drive. An input AC connection is also provided for connecting the electronic control transformer to the AC input of the drive system. An output AC connection is provided for connecting the at least one auxiliary device to the inverter module.

[0015] One advantage of the present invention is that the electronic transformer is connected to a variable speed drive with improved ride-through capabilities thereby providing ride-through capability to auxiliary components of the chiller system and providing improved reliability of the chiller system.

[0016] Another advantage of the present invention is the use of a single electronic control transformer for powering the chiller controls, that is independent of the input AC voltage magnitude and input frequency to the VSD equipped chiller system.

[0017] Another advantage of the present invention is that the electronic transformer eliminates the need for a conventional control transformer and provides a common source of electrical power for the entire chiller system.

[0018] Other features and advantages of the present invention will be apparent from the following more detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. **1** illustrates schematically a general system configuration of the present invention.

[0020] FIG. **2** illustrates schematically an embodiment of variable speed drive and electronic control transformer of the present invention.

[0021] FIG. **3** illustrates schematically a refrigeration system that can be used with the present invention.

[0022] FIG. **4** illustrates a circuit diagram of one embodiment of the electronic control transformer.

[0023] FIG. **5** illustrates an alternate embodiment of the electronic control transformer.

[0024] FIG. **6** illustrates an alternate embodiment of an active converter arrangement.

[0025] Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

DETAILED DESCRIPTION OF THE INVENTION

[0026] FIGS. **1** and **2** illustrate generally the system configuration of the present invention. An electronic transformer **108** is configured to provide AC power from the DC link **204** of a variable speed drive (VSD) **104**. The electronic transformer **108** has at least four semiconductor switches and converts the DC link voltage to a fixed voltage, fixed frequency AC output. An AC power source **102** supplies AC power to the VSD **104**, which in turn, supplies AC power to a motor **106**. In another embodiment of the present invention, the VSD **104** can power more than one motor **106**. The motor **106** is preferably used to drive a corresponding compressor of a refrigeration or chiller system. The VSD **104** also supplies power to an electronic transformer **108** from the DC link **204**. The electronic transformer **108** converts the DC power from the DC link **204** to a fixed voltage and frequency AC control power source for various auxiliary devices **110**, e.g. a control panel, contactors, relays, pumps and fans, that are components of a chiller system (see generally, FIG. **3**). The AC power source **102** provides three-phase, fixed voltage, and fixed frequency AC power to the VSD **104** from an AC power grid or distribution system that is present at a site. The AC power grid can be supplied directly from an electric utility or can be supplied from one or more transforming substations between the electric utility and the AC power grid. The AC power source **102** can preferably supply a three phase AC voltage or line voltage of 200 V, 230 V, 380 V, 460 V, or 600 V, at a line frequency of 50 Hz or 60 Hz to the VSD **104** depending on the corresponding AC power grid. It is to be understood that the AC power source **102** can provide any suitable fixed line voltage or fixed line frequency to the VSD **104** depending on the configuration of the AC power grid. In addition, a particular site can have multiple AC power grids that can satisfy different line voltage and line frequency requirements. For example, a site may have 230 VAC power grid to handle certain applications and a 460 VAC power grid to handle other applications.

[0027] Referring next to FIG. **2**, the VSD **104** receives AC power having a particular fixed line voltage and fixed line frequency from the AC power source **102** and provides AC power to the motor **106** at a desired voltage and desired frequency, both of which can be varied to satisfy particular requirements. Preferably, the VSD **104** can provide AC power to the motor **106** having higher voltages and frequencies or lower voltages and frequencies than the fixed voltage and fixed frequency received from the AC power source **102**. FIG. **2** illustrates schematically some of the components in one embodiment of the VSD **104**. The VSD **104** can have three stages: a converter stage **202**, a DC link stage **204** and an inverter stage **206**. The converter **202** converts the fixed line frequency, fixed line voltage AC power from the AC power source **102** into DC power. The DC link **204** filters the DC power from the converter **202** and provides energy storage components such as capacitors **208** and/or inductors (not shown). The inverter **206** converts the DC power from the DC link **204** into variable frequency, variable voltage AC power for the motor **106**.

[0028] The electronic transformer **108** is also connected to the DC link **204** of the VSD **104**. The electronic transformer **108** converts the DC power from the DC link **204** into a fixed AC voltage, preferably 120 VAC, at a fixed frequency, preferably 60 Hz, although the fixed voltage and/or frequency may be changed to suit various localities or operating requirements. Auxiliary devices **110** for the chiller system are connected to the output of the electronic transformer **108**, and can include a control panel, contactors, relays, pumps and fans. If required, the electronic transformer **108** may be configured to supply three-phase power to the auxiliary devices. The electronic transformer **108** has the ability to provide control power at the rated voltage of the auxiliary devices **110**, as long as the DC voltage of the DC link is maintained at a sufficient level. The benefit of a ride-through capability of VSD **104** is transferred to the auxiliary devices **110** of the chiller system, as discussed below in further detail. The electronic transformer **108** may be built within the same enclosure that houses the VSD **104**. Alternately, the electronic transformer **108** may be built into the control panel, or may be housed in an enclosure having distribution circuit breakers and switches to feed the control panel **308** (see FIG. **3**) and/or the auxiliary devices **110**.

[0029] The motor **106** is preferably an induction motor that is capable of being driven at variable speeds. The induction motor can have any suitable pole arrangement including two poles, four poles or six poles. The induction motor is used to drive a load, preferably a compressor of a refrigeration or chiller system as shown in FIG. **3**. FIG. **3** illustrates generally the system of the present invention connected to a refrigeration system.

[0030] As shown in FIG. **3**, the HVAC, refrigeration or liquid chiller system **300** includes a compressor **302**, a condenser **304**, an evaporator **306**, and a control panel **308**. The control panel **308** can include a variety of different components such as an analog to digital (A/D) converter, a microprocessor, a non-volatile memory, and an interface board, to control operation of the refrigeration system **300**. The control panel **308** can also be used to control the operation of the VSD **104** and the motor **106**. Electronic transformer **108** provides control power to the control panel **308** as well as to other single-phase auxiliary devices **110** for the chiller system **300**.

[**0031**] Compressor **302** compresses a refrigerant vapor and delivers the vapor to the condenser **304** through a discharge line. The compressor **302** is preferably a centrifugal compressor, but can be any suitable type of compressor, e.g., screw compressor, reciprocating compressor, etc. The refrigerant vapor delivered by the compressor **302** to the condenser **304** enters into a heat exchange relationship with a fluid, e.g., air or water, and undergoes a phase change to a refrigerant liquid as a result of the heat exchange relationship with the fluid. The condensed liquid refrigerant from condenser **304** flows through an expansion device (not shown) to an evaporator **306**.

[**0032**] The evaporator **306** can include connections for a supply line and a return line of a cooling load. A secondary liquid, e.g., water, ethylene, calcium chloride brine or sodium chloride brine, travels into the evaporator **306** via return line and exits the evaporator **306** via supply line. The liquid refrigerant in the evaporator **306** enters into a heat exchange relationship with the secondary liquid to lower the temperature of the secondary liquid. The refrigerant liquid in the evaporator **306** undergoes a phase change to a refrigerant vapor as a result of the heat exchange relationship with the secondary liquid. The vapor refrigerant in the evaporator **306** exits the evaporator **306** and returns to the compressor **302** by a suction line to complete the cycle. It is to be understood that any suitable configuration of condenser **304** and evaporator **306** can be used in the system **300**, provided that the appropriate phase change of the refrigerant in the condenser **304** and evaporator **306** is obtained.

[**0033**] The HVAC, refrigeration or liquid chiller system **300** can include many other features that are not shown in FIG. **3**. These features have been purposely omitted to simplify the drawing for ease of illustration. Furthermore, while FIG. **3** illustrates the HVAC, refrigeration or liquid chiller system **300** as having one compressor connected in a single refrigerant circuit, it is to be understood that the system **300** can have multiple compressors, powered by a single VSD or multiple VSDs, connected into each of one or more refrigerant circuits.

[**0034**] Preferably, a control panel **308**, microprocessor or controller can provide control signals to the VSD **104** to control the operation of the VSD **104** (and possibly motor **106**) to provide the optimal operational setting for the VSD **104** and motor **106** depending on the particular sensor readings received by the control panel **308**. For example, in the refrigeration system **300** of FIG. **3**, the control panel **308** can adjust the output voltage and frequency of the VSD **104** to correspond to changing conditions in the refrigeration system, i.e., the control panel **308** can increase or decrease the output voltage and frequency of the VSD **104** in response to increasing or decreasing load conditions on the compressor **302** in order to obtain a desired operating speed of the motor **106** and a desired load output of the compressor **302**.

[**0035**] Referring back to FIG. **2**, the converter **202** can be a conventional diode or thyristor rectifier coupled to the DC link **204**. In another example, the converter **202** can be a pulse width modulated boost converter or rectifier having insulated gate bipolar transistors (IGBTs) to provide a boosted DC voltage to the DC link **204** to obtain a maximum fundamental RMS output voltage from the VSD **104** greater than the nominal RMS fundamental input voltage of the VSD **104**. In a preferred embodiment of the present invention, the VSD **104** can provide a maximum output voltage that is greater than the fixed nominal fundamental RMS input voltage provided to the VSD **104** and a maximum fundamental RMS output frequency that is greater than the fixed nominal fundamental RMS input frequency provided to the VSD **104**. Furthermore, it is to be understood that the VSD **104** can incorporate different components from those shown in FIG. **2** so long as the VSD **104** can provide the motor **106** with appropriate output voltages and frequencies.

[**0036**] Furthermore, the active converter or rectifier **202** can be used to improve the ride-through capabilities of the VSD **104** during a decrease of the AC input voltage, also referred to as a voltage sag. The active converter or rectifier **202** can be controlled to provide a desired or predetermined output voltage to the DC link **204** that is independent of the AC input voltage. By providing a DC voltage that is not dependent on the AC input voltage, the active converter or rectifier **202** (and VSD **104**) is unaffected by voltage sags in the AC input voltage and thereby provides improved ride-through performance for the VSD **104**. The active converter or rectifier **202** can continue to provide the desired DC voltage to the DC link **204**, even though the AC input voltage has sagged. This capability of the active converter or rectifier **202** enables the VSD **104** to continue to operate without interruption, or ride through, during times when the AC input voltage sags.

[**0037**] As a further means of improving the ride through in the chiller system, when the active converter or rectifier **202** reaches its current limit during a voltage sag, a compressor control unit (not shown) actuates a mechanical unloading device of the compressor **302** to minimize the power consumed by the mechanical load from the DC link capacitors **208**. Also, at approximately the same time that the mechanical load is uncoupled by the compressor control unit, an inverter control unit (not shown) assumes control of the DC link voltage and controls the motor speed in order to cause energy to be transferred to the DC link capacitors **208** from the energy stored in the rotating mass of the motor **106**. The motor speed decreases during the ride-through, while the DC link voltage is maintained at or near rated voltage. If the energy stored in the rotating mass is sufficiently depleted before the restoration of the line input voltage to normal range, the system will eventually shut down to prevent damage to the chiller system components. If the line input AC voltage recovers to within a predetermined range of the nominal input AC voltage, then the inverter **206** resumes controlling the speed of the motor **106** as required by the HVAC & R's control system and the converter **202** resumes regulating the DC voltage of the DC link **204**, until the next voltage sag occurs.

[**0038**] As discussed in greater detail below, the electronic transformer **108** is comprised of four power semiconductor switches (not shown), such as insulated gate bipolar transistors (IGBTs) or MOSFETs. Preferably, the electronic transformer **108** is configured to convert the DC voltage from the DC link to provide single phase, 120 volt, 60 Hz. AC control power to the auxiliary devices **110**. If the auxiliary devices **110** include three phase motors for the pumps and fans, the electronic transformer **108** may be configured to provide three-phase power and if desired, a different fixed voltage and fixed frequency. The electronic transformer **108** is set for a fixed output voltage and frequency and does not adjust the voltage or frequency of the output power once it has been set.

[**0039**] In the preferred embodiment of the invention, the VSD **104** includes a precharge configuration for precharging the capacitors connected to the DC link. Referring to FIG. **4**, the precharge of the capacitors **208** of the DC link **204** is controlled using the active converter or rectifier module **202** shown in FIG. **4**. The active converter or rectifier module **202** includes three pairs (one pair for each input phase) of power switches or transistors. The active converter or rectifier module **202** also includes the corresponding control connections (not shown for simplicity) to control the switching of the power switches in a manner similar to that described below for the electronic transformer **108**. In a preferred embodiment of the active converter or rectifier module **202**, the power switches are IGBT power switches, as discussed in detail below, that are controlled by a pulse width modulation technique to generate the desired output voltages for the DC link **204**. Preferably, the active converter or rectifier module **202** can operate as a boost rectifier to provide a boosted DC voltage to the DC link **204** to obtain an output voltage from the VSD **104** greater than the input voltage of the VSD **104**.

[**0040**] In the active converter or rectifier module **202**, one of the power switches in each pair of power switches is an IGBT **450** connected to an inverse or anti-parallel diode **452**. The inverse or anti-parallel diode **452** is used to conduct current after the other power switch, IGBT **454**, is turned off when the VSD **104** is operated in a pulse width modulation mode. As shown in FIG. **4**, the IGBTs **450** and inverse diodes **452** are connected between the output of the circuit protective devices and three-phase line inductor **416** and the negative rail of the DC bus **412**. However, in another embodiment of the present invention, a multiplicity of IGBTs **450** and inverse diodes **452** can be connected between the output of the circuit protective devices and three-phase line inductor **416** and the positive rail of the DC bus **412***a*, as shown in FIG. **6**. Circuit protective devices **416** may include inductors, circuit breakers, fuses and other apparatus for protecting the VSD circuit components connected to the load side of the devices **416**.

[**0041**] The other power switch in the pair of power switches is a reverse blocking IGBT **454**, i.e., the IGBT **454** is capable of blocking voltages in the reverse as well as the forward direction. The reverse blocking IGBT **454** is connected to an inverse or anti-parallel IGBT **456**, which anti-parallel IGBT **456** is also a reverse blocking IGBT. The anti-parallel IGBT **456** is then preferably controlled during the precharge operation to permit only small pulses of inrush current to reach the DC link. After the precharge operation is completed, the anti-parallel IGBT **456** can be controlled to conduct at all times, similar to the anti-parallel diode **452**. The reverse blocking IGBT **454** blocks a positive emitter-to-collector voltage that is approximately equal to the peak line-to-line voltage that appears across the IGBT **454** for as long as the conduction of the anti-parallel IGBT **456** is delayed for the purpose of precharge.

[**0042**] In an alternate embodiment of the active converter **202**, as shown in FIG. **6**, the converter includes three power switches per phase. Each of the three power switches per phase is composed of a conventional IGBT **450** that cannot block reverse voltage connected to an inverse or anti-parallel diode **452**. Two of the power switches are connected in an opposing series configuration between the output of the circuit protective devices and three-phase line reactor **416** and the positive rail. In each phase, the uppermost power switch A_{top} is then preferably controlled during the precharge operation to permit only small pulses of inrush current to reach the DC link **204**, through the middle opposing series power switch A_{mid} inverse diode. After the precharge operation is completed, the first power switch A_{top} can be controlled to conduct at all times, similar to the anti-parallel diode **452**. The third power switch of each phase A_{bot} is connected between the output of the circuit protective devices and three-phase line reactor **416** and the negative rail.

[**0043**] Referring to FIG. **4**, in yet another embodiment of the converter **202**, the anti-parallel IGBT **456** is replaced by a silicon carbide controlled rectifier (SiCCR). The reverse blocking IGBT **454** is connected in anti-parallel to the SiCCR. The SiCCR is then preferably controlled during the precharge operation to permit only small pulses of inrush current to reach the DC link **204**. After the precharge operation is completed, the SiCCR can be controlled to conduct at all times, similar to the anti-parallel diode **452**. The reverse blocking IGBT **454** blocks a positive emitter-to-collector voltage that is approximately equal to the peak line-to-line voltage that appears across the IGBT **454** for as long as the conduction of the SiCCR is delayed for the purpose of precharge. In addition, the SiCCR exhibits no reverse recovery phenomena or characteristic when operated as a conventional diode. The absence of the reverse recovery characteristic in the SiCCR prevents a significant reverse recovery loss from occurring in the SiCCR by preventing a significant reverse current from flowing in the SiCCR whenever the IGBT **450** in the same phase turns on.

[**0044**] When precharging the DC link, in the preferred embodiment, the electronic transformer **108** includes a pair of diodes **430** connected to any two of the three phases L1, L2, L3 of the input AC power **102**. This arrangement provides power immediately to the control circuits when the active converter or rectifier is not operating or is precharging the DC link **204**. Diodes **430** are connected to the DC bus **440** of the electronic transformer to convert input AC voltage **102** to the DC voltage of DC bus **440** while the DC link **204** of the converter **202** is precharging. Diode **432** blocks current flow from the DC bus **440** to the DC link **202** during precharging. After the precharge of the DC link **204** is completed, and the Active Converter **202** is enabled, the boosted DC voltage of the DC link **202** is greater than the DC voltage provided by diodes **430**, causing DC current to flow to the DC bus **440** from the DC link **204**. Thus, diodes **430** are reverse biased when the voltage of the DC link **204** exceeds the peak of the input AC voltage, and they stop conducting current to the DC bus **440**. Diodes **430** also isolate the DC link from the input AC line **102**. Preferably, a capacitor **442** is connected across the DC bus **440** to filter the DC power and store energy for the electronic transformer **108**. An additional diode **430** not shown, may be included to allow a three phase AC power source to be provided to the electronic control transformer with voltage when the active converter or rectifier is not operating.

[0045] The electronic transformer **108** is in essence an inverter that converts the DC voltage of the DC bus **440** to the control voltage for the auxiliary devices **110** described above, typically 120 Volt, 60 Hz power. The electronic transformer **108** has four pairs of power switches or transistors. One of the power switches in each pair of power switches is an IGBT **444** connected to an inverse or anti-parallel diode **446**. The inverse or anti-parallel diode **446** is used to conduct current after the other power switch, IGBT **444**, is turned off when the electronic transformer **108** is operated in a pulse width modulation mode.

[0046] As shown in FIG. **4**, the IGBTs **444** and inverse diodes **446** are connected between the DC bus **440** and the inductors **460** at the output of the electronic transformer **108**. The inductors **460** and capacitor C**2** form a low pass filter to filter out the switching frequencies generated by the IGBT's **444** and diodes **446** in the inverter. The electronic transformer **108** converts the DC voltage on the DC bus **440** by selectively switching each of the IGBT power switches in the electronic transformer **108** between an "on" or activated position and an "off" or deactivated position using a modulation scheme to obtain the desired AC voltage and frequency from the electronic transformer **108**. A gating signal or switching signal is provided to the IGBT power switches by a control circuit not shown, based on the modulation scheme, to switch the IGBT power switches between the "on" position and the "off" position. The IGBT power switches are preferably in the "on" position when the switching signal is "High," i.e., a logical one, and in the "off" position when the switching signal is "Low," i.e., a logical zero. However, it is to be understood that the activation and deactivation of the IGBT power switches can be based on the opposite state of the switching signal.

[0047] A capacitor C**2** may be connected across the load terminals of inductors **460** to filter the output voltage of the electronic transformer **108**, and to store electrical energy for loads that require inrush current when energized, such as solenoid valves and relays. Optionally, an isolation transformer **464** may be connected across the capacitor **462** at the output of electronic transformer **108**, to provide electrical isolation, for example, to ground the control circuit. If the isolation transformer **464** is required, the inductor **460** and capacitor C**2** may be connected on the load side of the transformer **464**. This results in a higher frequency being applied at the primary of the transformer **464**, and permits the use of a smaller and less expensive transformer **464**.

[0048] In another aspect of the invention, no precharge configuration is provided in the VSD **104**. Where the inrush current to the DC link is not significant, there may be no need to control the precharge of the capacitors of the DC link. Referring to FIG. **5**, in this configuration, the DC link **204** is directly connected to the DC bus **440** of the electronic transformer **108**. The converter module **202** includes three pairs (one pair for each input phase) of power switches or transistors. The converter module **202** also includes the corresponding control connections as described above, to control the switching of the power switches. The power switches are IGBT power switches are controlled by a pulse width modulation technique to generate the desired output voltages for the DC link **204**. Preferably, the converter module **202** can operate as a boost rectifier to provide a boosted DC voltage to the DC link **204** to obtain an output voltage from the VSD **104** greater than the input voltage of the VSD **104**.

[0049] In the converter module **202** shown in FIG. **5**, each pair of power switches is an IGBT **450** connected to an inverse or anti-parallel diode **452**. The inverse or anti-parallel diode **452** is used to conduct current after the other power switch, IGBT **450**, is turned off when the VSD **104** is operated in a pulse width modulation mode. As shown in FIG. **4**, one set of IGBTs **450** and inverse diodes **452** in each pair of power switches is connected between the output of the circuit protective devices and three-phase line reactor **416** and the negative rail of the DC bus **412**. The other set of IGBTs **450** and inverse diodes **452** in each pair of power switches is connected between the output of the circuit protective devices and three-phase line reactor **416** and the positive rail of the DC bus **412**. Since the anti-parallel diode **452** is conductive in one direction at all times, it is not controllable for precharging the capacitor **208**.

[0050] The configuration of the electronic transformer **108** in FIG. **5** is also modified to eliminate any direct connections to the AC input line **102**. The capacitor **442** of the electronic transformer **108** is connected in parallel with the DC link **204** and the capacitor of the VSD **104**, and with the DC bus **440** of the electronic transformer **440**. There are four pairs of power switches that operate as described above in association with the configuration shown in FIG. **4**. Similarly, the inductors **460**, capacitor **462** and optional isolation transformer **464** are configured identically as described in FIG. **4** above.

[0051] Connecting the electronic transformer to the DC link **204** provides additional ride-through capability to chiller system auxiliary devices that is not available when using a conventional wound transformer. If a voltage sag occurs on the input AC power source **102**, the output voltage of the electronic transformer **108** is maintained at its rated output voltage so long as the DC link **204** is supported by the energy stored in the rotating mass of the motor **106** and the compressor **302** and/or the active converter **202**, as described above. Therefore, the operation of the chiller system is not compromised by the failure of auxiliary devices, such as the control panel, pumps, relays and contactors during voltage sags and disturbances.

[0052] While the invention has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A drive system to power a plurality of components of a chiller system having different voltage requirements, the drive system comprising:

a converter stage connected to an AC power source to receive an input AC power at a fixed input AC voltage and a fixed input frequency, the converter stage being configured to convert the fixed input AC voltage to a boosted DC voltage, the boosted DC voltage being greater than the fixed input AC voltage;

a DC link connected to the converter stage, the DC link being configured to filter the boosted DC voltage and store energy from the converter stage; and

a first inverter stage connected to the DC link, the first inverter stage being configured to convert the boosted DC voltage from the DC link to provide an output power at a variable voltage and variable frequency to a motor of a chiller system, the variable voltage having a maximum voltage greater in magnitude than the fixed input AC voltage and the variable frequency having a maximum frequency greater than the fixed input frequency;

wherein the first inverter stage is configured to reverse power flow through the first inverter stage to the DC link stage to transfer electrical power from energy stored in a rotating mass of a motor connected to the first inverter stage to maintain a voltage level of the DC link in response to a decreasing fixed input AC voltage; and

a second inverter stage connected to the DC link, the second inverter stage being configured to convert the boosted DC voltage from the DC link into an auxiliary output power source having a fixed output AC voltage and a fixed output frequency for at least one component of a chiller system, the fixed output AC voltage being less than the fixed input AC voltage; and, wherein the fixed output AC voltage and fixed output frequency of the second inverter stage is maintained in the event of a temporary decrease in the fixed input AC voltage.

2. The drive system of claim 1, wherein the converter stage is controllable to precharge the DC link.

3. The drive system of claim 1, wherein the second inverter stage is comprised of at least four power semiconductor switches configured to invert the boosted DC voltage to the fixed output AC voltage and fixed output frequency.

4. The drive system of claim 1, wherein the first inverter stage and the second inverter stage are disposed in a single enclosure.

5. The drive system of claim 1, wherein the first inverter stage and the second inverter stage are disposed in separate enclosures.

6. The drive system of claim 1, wherein the auxiliary output power source fixed output AC voltage is 120 VAC and the fixed output frequency is 60 Hz.

7. The drive system of claim 1, wherein the second inverter stage provides the fixed output AC power to a control panel and to a power distribution panel, and at least one auxiliary electrical component is connected to the power distribution panel.

8. The drive system of claim 8, wherein the at least one auxiliary electrical component is selected from the group consisting of: pumps, relays, solenoids, heaters, contactors, fans, and combinations thereof.

9. The drive system of claim 3, wherein the second inverter stage also comprises a circuit for providing a DC power source directly from the input AC power while the converter stage is precharging the DC link.

10. The drive system of claim 9, wherein the circuit of the second inverter stage includes a plurality of diodes connected to the input AC power and a diode connected to the DC link.

11. A chiller system comprising:

a refrigerant circuit comprising compressor, a condenser, and an evaporator connected in a closed refrigerant loop;

a motor connected to the compressor to power the compressor;

a variable speed drive connected to the motor, the variable speed drive being configured to receive an input AC power at a fixed input AC voltage and a fixed input frequency and provide an output power at a variable voltage and variable frequency to the motor, the variable voltage having a maximum voltage greater in magnitude than the fixed input AC voltage and the variable frequency having a maximum frequency greater than the fixed input frequency, the variable speed drive comprising:

a converter stage connected to an AC power source providing the input AC power, the converter stage being configured to convert the input AC voltage to a boosted DC voltage, the boosted DC voltage being greater than the fixed input AC voltage;

a DC link connected to the converter stage, the DC link being configured to filter the boosted DC voltage and store energy from the converter stage; and

a first inverter stage connected to the DC link, the first inverter stage being configured to convert the boosted DC voltage from the DC link into the output power for the motor, the first inverter stage also being configured to reverse power flow through the first inverter stage to the DC link stage to transfer electrical power from energy stored in a rotating mass of the motor to maintain the voltage level of the DC link stage in response to a decreasing input AC voltage; and

an electronic control transformer connected to the DC link, the electronic control transformer being configured to convert the boosted DC voltage from the DC link into an auxiliary output power source having a fixed output AC voltage and a fixed output frequency, the fixed output voltage being less than the fixed input AC voltage, wherein the fixed output AC voltage and fixed output frequency of the electronic control transformer is maintained in the event of a temporary decrease in the input AC voltage.

12. The chiller system of claim 11, wherein the converter stage is controllable to precharge the DC link.

13. The chiller system of claim 11, wherein the electronic control transformer is comprised of at least four power semiconductor switches configured to invert the boosted DC voltage to the fixed output AC voltage and fixed output frequency.

14. The chiller system of claim 11, wherein the first inverter stage and the electronic control transformer are disposed in a single enclosure.

15. The chiller system of claim 11, wherein the first inverter stage and the electronic control transformer are disposed in separate enclosures.

16. The chiller system of claim 11, wherein the auxiliary output power source fixed output AC voltage is 120 VAC and the fixed output frequency is 60 Hz.

17. The chiller system of claim 12, wherein the electronic control transformer provides the fixed output AC power to a control panel and to a power distribution panel, and at least one auxiliary electrical component is connected to the power distribution panel.

18. The drive system of claim 17, wherein the at least one auxiliary electrical component is selected from the group consisting of: pumps, relays, solenoids, heaters, contactors, fans, and combinations thereof.

19. The drive system of claim 12, wherein the electronic control transformer also comprises a circuit for providing a DC power source directly from the input AC power while the converter stage is precharging the DC link.

20. The drive system of claim 11, wherein the circuit of the electronic control transformer includes a plurality of diodes connected to the input AC power and a diode connected to the DC link.

21. An electronic control transformer for powering at least one auxiliary device associated with a chiller system, the electronic control transformer comprising:

an inverter module to convert a DC voltage to provide a fixed output AC voltage and fixed frequency to power the at least one auxiliary device;

the inverter module comprising a plurality of pairs of power switches, wherein each pair of power switches includes an insulated gate bipolar transistor connected in anti-parallel to a diode;

an input DC connection for connecting the electronic control transformer to a DC link of a variable speed drive; and

an output AC connection for connecting the at least one auxiliary device to the inverter module.

22. The electronic control transformer of claim 21 wherein the inverter module is controllable by a pulse width modulation technique.

23. The electronic control transformer of claim 21 wherein the plurality of pairs of power switches comprises two pairs of power switches.

24. The electronic control transformer of claim 21, further comprising an input AC connection for connecting to an input AC power source used to power the variable speed drive, the input AC connection also including a pair of converter diodes and a reverse blocking diode, the converter diodes configured to rectify an input AC voltage from the input AC power source to a DC voltage and the reverse blocking diode being connected between the converter diodes and the input DC connection to prevent short-circuiting a precharge circuit of the variable speed drive.

25. The electronic control transformer of claim 24, also comprising an input capacitor connected across the input DC connection for filtering the DC input and for storing electrical energy.

26. The electronic control transformer of claim 21, also comprising an input capacitor connected across the input DC connection for filtering the DC input and for storing electrical energy.

27. The electronic control transformer of claim 21, also comprising an isolation transformer connected to the output AC connection for electrical isolation of the load.

28. The electronic control transformer of claim 27, also comprising a filter circuit in series with the isolation transformer, wherein the filter circuit comprises at least one series-connected inductor, at least one parallel connected capacitor, and combinations thereof.

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