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(71) Applicant *(for all designated States except US)*: **TESUCO SERVICES (PTY) LTD** [ZA/ZA]; 11 Pomona Road, Cnr Hawthorne Avenue, Pomona, 1619 Kempton Park (ZA).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **DA PONTE, Manuel dos Santos** [PT/ZA]; 282 Pleiades Avenue, Waterkloof Ridge, 0181 Pretoria (ZA). **GRZESIAK, Lech Marian** [PL/PL]; Gsiorowskiego 26a/1, PL-01-483 Warszawa (PL). **KASZEWSKI, Arkadiusz** [PL/PL]; Lukowska 1/108, PL-04-474 Warszawa (PL). **PODKOWA, Piotr** [PL/ZA]; 534 Denmar Place, Garsfontein, 0042 Pretoria (ZA).

(74) Agent: **HAHN & HAHN INC. C. MICHAEL; C. BERNDT; V.C. WILLIAMS; P.C.R. VENTER; J.F. LUTEREK; C. MICHAEL**; 222 Richard Street, Hatfield, 0083 Pretoria (ZA).

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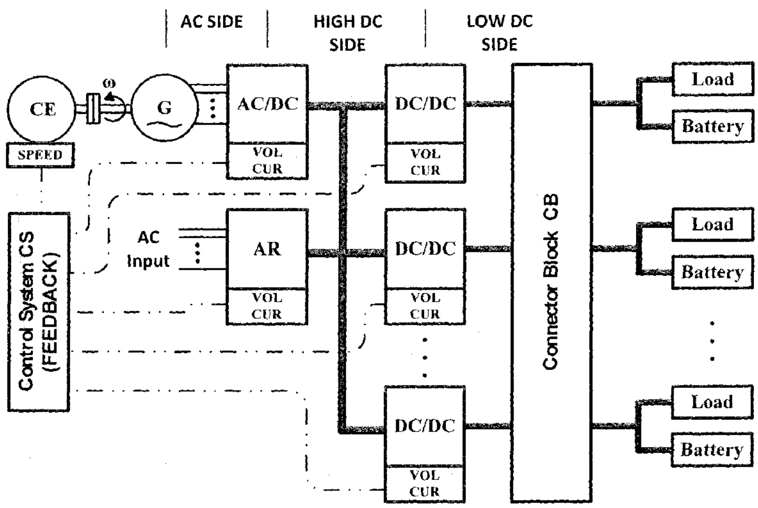

Fig: 38 Block diagram of the power system with three reconfigurable DC outputs

(57) Abstract: The invention relates to a power system comprising a first power source from a power grid with an AC multi-phase input and a second power source being a variable speed generator, which are respectively capable of supplying power to a DC link, wherein the first power source is connected to a first input power converter being provided as an active rectifier and wherein the second power source is connected to a second input power converter, further comprising at least one output converter being connected to the DC link to supply power to a load, wherein a control system is connected to the first input power converter, the second input power converter and the output converter, which controls the flow of energy from the power grid's AC input to the DC link, the flow of energy from the generator to the DC link and the flow of energy from the output converter to the load, so as to predominantly utilize all the available energy from the grid. The invention further relates to a method for operating such a system.

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TITLE OF INVENTION: POWER SYSTEM AND METHOD FOR OPERATING A POWER SYSTEM

INTRODUCTION

This invention relates to a power system. More particularly, this invention relates to power system for supporting a communication system, in particular a telecommunication system located in a remote area. Furthermore, the invention relates to a method for operating a power system.

BACKGROUND TO THE INVENTION

In recent years, many telecommunication operators increased their areal coverage by building more and more base stations. Base stations are usually mounted as a cellular radio tower. Nowadays, most cellular networks comply with the GSM standard for mobile communication. The base stations include equipment for sending a receiving radio signals from a user's cell phone. For continuous operation of the base stations, it is therefore required to provide a reliable power source which supplies the necessary electronic equipment of the base stations.

Power supplies for base transceiver stations usually include a connection to the power grid and an additional back-up generator unit which provides power in case the power available from the grid is lost or unstable or abnormal. In a typical configuration, a control unit attached to the back-up generator monitors the status of the grid and switches the generator to its on-state, when generator power is needed.

A suitable generator has been described in EP 0 947 042 B1, which is incorporated into this specification by reference. In this document, a sophisticated hybrid generator set is disclosed which comprises an engine/generator or another controllable electrical source which provides a variable voltage electrical output. This output is rectified and fed to a DC to DC converter, the output (VDC) of which is monitored by a control circuit. The output of this converter, the generator converter, serves as an intermediate DC output, which typically is used to power an inverter to generate an AC output or DC to DC converter to generate a DC output in order to supply power to one or more external loads. The use of the generator converter isolates the intermediate DC output from the generator output, and allows the generator set to operate efficiently over a wide engine/generator speed range, according to load demand.

One potential problem associated with the above described scheme is that back-up generators are often controlled according to a specific grid voltage window with low and high voltage limits which dictated when the grid voltage is abnormal. When the input voltage of the grid is outside this voltage window, the generator will switch on in order to produce power for the base transceiver station. This can lead to the situation that the generator is used more frequent than what is really necessary.

One reason for this could be that the voltage window settings allow only for small variations of the input voltage of the power grid. Another reason is that in a three phase power connection, sometimes only one phase is in an abnormal state and therefore in principle there would be power available. However, the available power from the grid is not used because the missing or abnormal voltage on even one phase already triggers the generator to be switched on. This leads to unnecessary generator operation which results in shorter maintenance intervals and higher fuel consumption than is necessary.

On many occasions, the electronic equipment used at the base transceiver station is supplied by a single company and includes electronic modules which require similar or identical power supply connections. For example, electronic modules are available which require a DC voltage of 24 V or of 48 V. Different manufactures, however, provide their modules with different power requirements. For example, some manufactures require the positive voltage to be earthed while others specify that the negative voltage should be earthed. In certain cases base transceiver stations also include equipment which operate from single or three phase AC voltage, e.g. air conditioning units and pumps.

Accordingly, the usage of electronic equipment from different suppliers often requires complicated power supply solutions which are not only more expensive to purchase but also more expensive to operate and maintain. Furthermore, it is not always possible to exchange units from different suppliers in case of a failure as the power requirements are not compatible.

It has therefore been found that there is a need in the art to provide a power system which is easier to maintain and consumes less fuel for the generator. This is in particular important when the power system is installed in a remote area, for example in the rural part of Africa.

OBJECTS OF THE INVENTION

It is an object of this invention to provide a universal power supply system that can be easily configured for various power requirements where multiple outputs can be provided wherein two galvanically isolated DC outputs with different voltages supply DC loads with different power requirements and an optional AC output that can supply AC loads.

It is further an object of the present invention to provide regulated high frequency transformers with reconfigurable DC outputs in a power system, which overcome, at least partly, the disadvantages associated with existing prior art solutions.

It is also an object of the present invention to provide regulated high frequency transformers with reconfigurable DC outputs in a power system, which are both novel and involves an inventive step.

Furthermore, it is an object of the present invention to provide a connector block suitable for integrating into a power system, which overcomes, at least partly, the disadvantages associated with existing prior art solutions.

In this respect, it is also an object of the present invention to provide a connector block suitable for integrating into a power system, which is both novel and involves an inventive step.

SUMMARY OF THE INVENTION

Thus, according to a first aspect of the invention, there is provided a power system comprising a first power source from a power grid with an AC multi-phase input and a second power source being a variable speed generator, which are respectively capable of supplying power to a DC link, wherein the first power source is connected to a first input power converter being provided as an active rectifier and wherein the second power source is connected to a second input power converter, further comprising at least one output converter being connected to the DC link to supply power to a load, wherein a control system is connected to the first input power converter, the second input power converter and the output converter, which controls the flow of energy from the power grid's AC input to the DC link , the flow of energy from the generator to the DC link and the flow of energy from the output converter to the load, so as to predominantly utilize all the available energy from the grid.

According to an embodiment of the invention, the output converter comprises at least one DC/DC converter which is converting the DC voltage at the input to a specified voltage at the output for supplying a DC load.

According to a further embodiment of the invention, the output converter comprises at least one DC/AC converter being connected to the DC link and converting the DC voltage at the input to an AC voltage at the output for supplying an AC load.

According to a further embodiment of the invention, the power grid comprises a three-phase AC input.

According to a further embodiment of the invention, the generator is capable of delivering a single phase or a multi-phase, preferably three-phase, AC output with the second input power converter being an AC/DC converter.

According to a further embodiment of the invention, the output converter provides a feedback voltage signal and a current signal to the control system so as to control the operation of the converter.

According to a further embodiment of the invention, the output converter is provided with a high frequency transformer with rectified outputs and a filter-, preferably a LC-filter, for supplying a DC load or is provided with an inverter for supplying an AC load.

According to a further embodiment of the invention, the control system comprises for each phase a grid supply voltage sensor to provide a signal to a source controller which monitors the grid voltage for each phase.

According to a further embodiment of the invention, the source controller compares each signal from the voltage sensors to a minimum and a maximum instantaneous voltage thresholds and a minimum and a maximum RMS voltage thresholds so as to provide for each phase an output binary signal for controlling a pulse width calculator and PWM signal controller.

According to a further embodiment of the invention, the pulse width calculator and PWM signal controller respectively function as gates to prevent switching of transistors of the first input power converter when a source voltage of a phase is outside a window being defined by the voltage thresholds.

According to a further embodiment of the invention, the source controller further monitors DC link voltage to control the generator output power, preferably by adjusting an engine speed of the generator, and to control the active rectifier to continue drawing power from all available phases that are within the window being defined by the voltage thresholds .

According to a further embodiment of the invention, the power system is further comprising energy storage means, preferably a battery, a capacitor or a combination of both, to power the load and the system in case there is no power available from the grid or the generator.

According to a further embodiment of the invention, at least two galvanically isolated outputs are connected to a respective load via a connector block.

According to a further embodiment of the invention, the connector block comprises a multilayered assembly with layers made out of material with suitable mechanical and electrical insulation properties and embedded connector bars, preferably comprising an electrical conducting metal or metal alloy such as copper, which form part of an electrical circuit that produces the outputs.

According to a further embodiment of the invention, the power capability of the first output is appropriately rated to supply a first load and the power capability of the second output is appropriately rated to supply the second load.

According to a further embodiment of the invention, the layers and the embedded connector bars of the connector block are reconfigurable so that different combinations of layers having series and parallel connections can be realised.

According to a further embodiment of the invention, positive or negative terminals of each output may be connected to ground independently.

According to a further embodiment of the invention, the connector block comprises multiple layers being provided as embedded connector bars for connecting the rectified output of the transformers to provide a first and a second output, which can be configured according to desired output polarities and power requirements by rearranging the embedded connector bars or by reconnecting the rectified output of the transformers.

According to a further embodiment of the invention, an output configuration at the first output and at the second output is achieved, which can be selected to be 6 VDC, 12 VDC, 24 VDC, 48 VDC, 400 VDC or any other prescribed value.

According to a further embodiment of the invention, an output with negative or positive earth at the first or the second output may be achieved.

According to a further embodiment of the invention, an output configuration at the first output and at the second output is achieved, which can be 5 kW, 10 kW, 15 kW, 300 kW or any other prescribed value.

According to a further embodiment of the invention, the first and second outputs are provided at the same output terminals with the same polarity so that the output connections are made on the same terminals.

According to a further embodiment of the invention, the connector block comprises a base plate and an interconnecting layer, wherein the interconnecting layer is selected according to a desired configuration of the outputs and the base plate is paired with the respective interconnecting layer to make up the connector block with the respective output configuration.

According to a further aspect of the invention, there is provided a universal power supply system that can be easily configured for various power requirements where two galvanically isolated outputs with different voltages supply loads with different power requirements, comprising a plurality of output power modules being connected to a multilayered assembly comprising layers made out of material with good mechanical and electrical insulation properties and embedded connector bars which form part of an electrical circuit that produces the outputs.

The plurality of output power modules may each comprise a high frequency transformer with its respective rectifiers and an LC filter.

Three output power modules may be used.

A primary winding of the high frequency transformer may be powered by any DC source and regulated high frequency inverters.

Galvanically isolated secondary windings and rectifiers may be used to produce two separate DC outputs which are reconfigurable to supply DC loads with different power requirements, namely the first output and the second output.

The power capability of the first output may appropriately be rated to supply the first load.

The power capability of the second output is appropriately rated to supply the second load.

The first output and the second output may respectively be filtered by an LC filters.

The first output and the second output may respectively be connected to a multilayered assembly comprising layers made out of material with suitable mechanical and electrical insulation properties and embedded connector bars which form part of the electrical circuit that produces the outputs.

The layers and embedded copper bars may be designed so that various electrical circuits can be realised with different combinations of layers, each with appropriately placed copper bars that make connections vertically and horizontally to complete the desired circuit.

Additionally, either the positive or negative terminals of each output may be connected to ground independently.

According to a second aspect of the invention, there is provided a method for operating a power system, which includes the steps of connecting a power grid with AC multi-phase inputs to an active rectifier and connecting a variable speed generator to an input power converter, which are respectively capable of supplying power to a DC link, providing at least one output converter being connected to the DC link to supply power to a load, wherein the active rectifier, the input power converter and the output converter are controlled to predominantly utilize all the available energy from the grid by monitoring the voltages on the multi-phase grid inputs and the DC link.25. The method according to claim 24, wherein a normal and an abnormal status of the voltages of the multi-phase input are determined so as to enable or to at least partially disable the active rectifier to operate adaptively to abnormal conditions in which one or more of the phase voltages of the grid power are outside a predetermined window.

According to an embodiment, the source controller controls how many source voltages are connected to the system and if any source voltage is determined to be abnormal, it disables the respective leg in the active rectifier such that only the signals controlling transistors which correspond to the phase with the abnormal voltage are blocked or disabled in order to continue drawing power from the other source voltage or voltages which are considered to be in the normal state.

When any source voltage changes status from abnormal to normal, the active rectifier will stop operating for a predetermined time in order to activate a start-up sequence and the system then resumes operation and draws power from all voltage sources which are in the normal state so as to utilize all the available energy from the grid.

The control system CS will detect a fall in DC link voltage caused by the imbalance of power flowing into and out of the DC link, and then activate a start-up sequence of the generator in order to operate the generator at an optimum speed, thereby balancing the power demanded by the load with the power supplied by the grid and the generator operating in parallel.

When the control system detects a rise in DC link voltage such that the DC link voltage rises above a second threshold, which is marginally higher than the first threshold, the generator speed will be reduced so that if the load demand is reduced to the point where the engine is operating at minimum speed for a predetermined time period, the generator stop sequence will be activated.

According to a further embodiment of the invention, the two power sources operate cooperatively in three modes of operation: first power source operating alone when all grid source voltages are normal or when the available power from one or two grid source voltages is sufficient to meet the load power demand; second power source operating alone and supplying power to the load when all grid voltages are abnormal; and first and second power source supplying power to the load concurrently when the grid voltage sources alone are not able to supply all the power required by the load.

Accortding to a further aspect there is provided regulated high frequency transformers with reconfigurable DC outputs in a power system, wherein a first transformer and a second transformer are connected in series to produce and a third transformer operates independently which are powered through the primary winding by inverters and the secondary windings of transformers are arranged as two identical windings connected so as to form two outputs and a centre tap which are connected through diodes and coils to a connector block such that the secondary windings of the transformers and their respective diodes are connected to form a full wave two diode rectifier circuit.

A control system may provide control outputs to connect or disconnect the loads at the first output and second output respectively.

A supply voltage may be monitored by a sensor which provides a corresponding signal to control system such that if the voltage is within the limits of two predetermined thresholds, that is the design operating window for the system's supply voltage, it will start to operate.

The inverters may operate together to supply a variable voltage to the primary windings of the transformers respectively.

Each inverter may employ a full wave bridge topology comprising four IGBTs.

The inverters may operate according the same inverter control scheme in which the pulse with is varied between a predetermined maximum on-time and a predetermined off- time so that current in the primary windings is controlled so as to maintain an output voltage on the secondary side according to a predetermined value.

The voltage of the secondary side of the transformer may be measured after rectifiers and LC filters.

The current may be controlled by increasing or decreasing the pulse width in response to a PWM signal generated by the control system.

According to a further aspect of the invention, there is provided a connector block having multiple layers in which connections are made horizontally inside the layers and vertically up or down between the different layers, wherein layers are provided as embedded copper bars for partly connecting the rectified output of the transformers to provide a first and a second output with an earth connection, which can be configures according to desired output polarities and power requirements by rearranging the embedded copper bars.

These and other features, aspects and advantages of the invention will become better understood with reference to the following description and drawings.

DETAILED DESCRIPTION OF THE INVENTION

The invention will now be described in greater detail by way of example with reference to the following drawing in which:

Figure 1 schematically shows a block diagram of the power system according to an embodiment of the invention;

Figure 2 schematically shows a control system according to an embodiment of the invention;

Figure 3 shows in a schematic drawing an output configuration of 10 kW at 48 VDC with positive earth and 5 kW at 24 VDC with negative earth according to an embodiment of the invention;

Figure 4 shows in a schematic drawing an output configuration of 10 kW at 48 VDC with negative earth and 5 kW at 24 VDC with positive earth according to an embodiment of the invention;

Figure 5 shows in a schematic drawing an output configuration of 10 kW at 48 VDC with positive earth and 5 kW at 24 VDC with positive earth according to an embodiment of the invention;

Figure 6 shows in a schematic drawing an output configuration of 10 kW at 48 VDC with negative earth and 5 kW at 24 VDC with negative earth according to an embodiment of the invention;

Figure 7 shows in a schematic drawing an output configuration of 10 kW at 24 VDC with negative earth and 5 kW at 48 VDC with positive earth according to an embodiment of the invention;

Figure 8 shows in a schematic drawing an output configuration of 10 kW at 24 VDC with positive earth and 5 kW at 48 VDC with negative earth according to an embodiment of the invention;

Figure 9 shows in a schematic drawing an output configuration of 10 kW at 24 VDC with positive earth and 5 kW at 48 VDC with positive earth according to an embodiment of the invention;

Figure 10 shows in a schematic drawing an output configuration of 10 kW at 24 VDC with negative earth and 5 kW at 48 VDC with negative earth according to an embodiment of the invention;

Figures 11 to 27 each show respective embodiments of a connector block according to a first embodiment of the invention having connector plates in various layers for realizing different output conditions;

Figures 28 to 37 each show respective embodiments of a connector block according to a second embodiment of the invention;

Figure 38 shows a block diagram of the power system according to a first embodiment of the invention;

Figure 39 shows a block diagram of the power system according to a second embodiment of the invention;

Figure 40 shows a schematic diagram of the power system according to the first embodiment of the invention;

Figure 41 shows a schematic diagram of the power system according to the second embodiment of the invention; and

Figure 42 shows a block diagram of an active rectifier according to an embodiment of the invention.

Referring now to the drawings in particular the invention embodied therein will be described. In the drawing like reference numerals and/or component reference designators refer to like parts, unless otherwise indicated.

The apparatus is designed for applications where two galvanically isolated DC outputs are required to supply separate loads at two different voltages, e.g. 24 VDC and 48 VDC, with different power requirements, e.g. first power output of 10 kW at 48 VDC and second power output of 5 kW at 24 VDC. In certain applications, other combinations of power supply are required, e.g. 5 kW at 48 VDC and 10 kW at 24 VDC.

Three High Frequency transformers with the primary winding powered by any DC source and regulated high frequency inverters, and galvanically isolated secondary windings and rectifiers are used to produce two separate DC outputs which are reconfigurable to supply DC loads with different power requirements, namely the first output and the second output. The power capability of the first output is appropriately rated to supply the first load whilst the power capability of the second output is appropriately rated to supply the second load. The outputs are filtered by an LC filters and connected to a multilayered assembly comprising layers made out of material with good mechanical and electrical insulation properties and embedded connector bars which form part of the electrical circuit that produces the outputs. The layers and embedded copper bars are designed so that various electrical circuits can be realised with different combinations of layers, each with appropriately placed copper bars that make connections vertically and horizontally to complete the desired circuit. Additionally, either the positive or negative terminals of each output may be connected to ground independently.

Each transformer with its respective rectifiers and LC filter is referred to as the output power module. According to conventional wisdom, the two desired isolated DC outputs can be realised by two output power modules. However, to satisfy the requirements for two different voltages with different power requirements, four would be required. By using three modules a number of advantages can be realised. Firstly, four different configurations are possible with three transformers. Secondly, the three transformers can be identically the same with great advantage for manufacturing and logistical costs. Thirdly, the system can be configured for the various application requirements with no need for exchanging transformers; reconfiguration can simply be done by changing the connections, e.g. series or parallel.

The output options realisable with three 5 kW, 24 VDC transformers, T1, T2 and T3, can best be described by way of an example as follows:

T1 and T2 connected in series produce 10 kW at 48 VDC while T3 operating independently will produce 5 kW at 24 VDC. The modules utilize two diode full wave rectifiers.

T2 and T3 connected in parallel will produce 10 kW at 24 VDC while T1 operating independently will produce 5 kW at 48 VDC when supplying power through a four diode full wave rectifier bridge. The conductors of the secondary winding of the transformer T1 need to be appropriately dimensioned to carry the additional current. T2 and T3 utilize two diode full wave rectifiers.

T1, T2 and T3 connected in parallel will produce 15 kW at 24 VDC when supplying power through two diode full wave rectifiers.

T1, T2 and T3 connected in parallel will produce 15 kW at 48 VDC when supplying power through four diode full wave rectifier bridges. The conductors of the secondary winding of the transformers need to be appropriately dimensioned to carry the additional current.

It must be appreciated that there are more possibilities if less or additional transformers and rectifiers are used. Furthermore, the invention can be applied in applications with higher or lower power requirements, including applications other than the base transceiver stations.

Figure 1 shows a simplified circuit of one example of one arrangement wherein two modules with transformers T1 and T2 are connected in series to produce 10 kW at 48 VDC and the third module with transformer T3 operates independently to produce 5 kW at 24 VDC. The power source, C5, is simply a capacitor which can be charged by any DC power source, e.g. a battery, grid connected rectifier or DC generator. Transformers T1, T2 and T3 are powered through the primary winding at terminals 1 and 2 by inverters INV1, INV2 and INV3 respectively. Transistors IGBT6a, IGBT6b, IGBT7a and IGBT7b operate as inverter INV1 while transistors IGBT8a, IGBT8b, IGBT9a and IGBT9b operate as inverter INV2 and transistors IGBT10a, IGBT10b, IGBT11a and IGBT11b operate as inverter INV3.

The secondary windings of transformers T1, T2 and T3 are arranged as two identical windings connected so as to form two outputs, at terminal 3 and 5 and a centre tap at terminal 4. With reference to transformer T1, terminals 3 and 5 are connected to the anodes of diodes D3 and D4. The cathodes of D3 and D4 are connected together and via inductor L1 to terminal 3 of the connector block CB1. Terminal 4, the centre tap, is connected to terminal 1 of connector block CB1. The cathodes of diodes D1 and D2 are connected to terminal 3 and 5 respectively whilst the anodes are connected to together and to terminal 2 of connector block CB1. Diodes D1 and D2 are not used in this configuration as is evident by the fact that terminal 2 is not connected to any other point. Similarly, with reference to transformer T2, terminals 3 and 5 are connected to the anodes of diodes D5 and D6. The cathodes of D5 and D6 are connected together and via inductor L2 to terminal 5 of connector block CB1. Terminal 4, the centre tap, is connected to terminal 4 of connector block CB1. Similarly again, with reference to transformer T3, terminals 3 and 5 are connected to the anodes of diodes D7 and D8. The cathodes of D7 and D8 are connected together and via inductor L3 to terminal 7 of the connector block CB1. Terminal 4, the centre tap, is connected to terminal 6 of connector block CB1.

Connector block CB1 shows all the connections required to realise the two outputs, namely 10 kW at 48 VDC and 5 kW at 24 VDC, but does not identify the different layers. Detailed descriptions of the various layers and connections with reference to more detailed drawings are provided in the succeeding pages. The first output, 10 kW at 48 VDC, is provided at terminal 9 and 10 which are connected to the negative terminal and positive terminal of the first output capacitor, C6, respectively. Terminal 9 is connected via terminal 8 to terminal 1. Terminal 10 is connected to terminal 5. It must be noted that the secondary windings of the transformers and their respective diodes are connected to form a full wave two diode rectifier circuit.

The two output modules with transformers T1 and T2 are connected in series as follows: Starting at terminal 9, the negative terminal of the first output capacitor, is connected to the centre tap of transformer T1 at terminal 4 via terminals 8 and 1 in connector block CB1. Terminals 3 and 5 of transformer T1 are connected to the centre tap of transformer T2 at terminal 4 via diodes D3 and D4, inductor L1, terminals 3 and 5 in connector block CB1 which are connected together by an embedded copper bar. Terminals 3 and 4 of transformer T2 are connected to the positive terminal of the first output capacitor via diodes D5 and D6, L2 and terminal 5 and 10 in connector block CB1. Thus the two output modules are connected in series to produce 10 kW at 48 VDC at the first output capacitor C6. The positive output terminal 10 is connected to earth at terminal 18 via terminal 17, the positive terminal of the first 48 VDC output. The negative output terminal 9 is connected to the negative output terminal 15 via fuse F1 and the switching contact of contactor CON3, terminals 16. All the connections are made by means of the embedded copper bars electrically insulated from one another. They are depicted as thick solid lines in connector block CB1. It must be noted that connections between fuse F1 and the switching contact of contactor CON3 are not included in connector block CB1.

The second output, namely 5 kW at 24 VDC is produced at capacitor C7 as follows: Starting at terminal 11 in connector block CB1, the negative terminal of the second output capacitor C7, is connected to the centre tap of transformer T3 at terminal 4 via the copper link in connector block CB1 between terminals 6 and 11. Terminals 3 and 5 are connected to the positive terminal of the second output capacitor at terminal 12 via diodes D7 and D8, inductor L3 and terminals 7 and 13 in connector block CB1. The negative terminal of the second output capacitor, terminal 11, is connected to earth at terminal 19 via terminals 20. The negative terminal of the second 24 VDC output is provided at terminal 20. The positive terminal of the second output capacitor, terminal 12, is connected to the positive terminal of the second output at terminal 22 via fuse F2 and the switching contact of contactor CON4, and terminal 21. All the connections are made by means of the embedded copper bars electrically insulated from one another. They are depicted as thick solid lines in connector block CB1. It must be noted that connections between fuse F2 and the switching contact of contactor CON4 are not included in connector block CB1.

It is important to note that the fuse F1 and the switching contact of contactor CON3 protect and control the circuit of the first output at the negative output and not the positive output which is connected to earth. By contrast, F2 and the switching contact of contactor CON4 protect and control the circuit of the second output at the positive output. This is because the negative output is connected to earth. Thus the protection and switching is done on the output that is not earthed.

It will be shown that in all configurations, the connections are arranged so that the protection and switching is always done on the output side that is not earthed.

The two DC output circuits are controlled by Control System CS1 which receives electric power from Power Supply PS1 at 0 to +15 VDC to power the IGBT driver system DV1 and 0 to +5, +15 and -15 VDC to power the control system circuits. Power Supply PS1 is powered from an external power supply, e.g. 12 VDC battery or other voltage source.

Voltage and current signals are fed into the control system as follows:
M8, the supply voltage at capacitor C5
M15, the first output voltage at C6
M16, the second output voltage at C7
M9, the current in the primary winding of transformer T1
M10, the current in the primary winding of transformer T2
M11, the current in the primary winding of transformer T3
M12, the current in the secondary winding of transformer T1
M13, the current in the secondary winding of transformer T2
M14, the current in the secondary winding of transformer T3
M17, the current of the first output
M18, the current of the second output

The control system CS1 provides control signals to the IGBT driver system to effect switching the Isolated Gate Bi-Polar Transistors IGBTs on and off as follows:
S6a and S6b control IGBT6a and IGBT6b respectively
S7a and S7b control IGBT7a and IGBNT7b respectively
S8a and S8b control IGBT8a and IGBT8b respectively
S9a and S9b control IGBT9a and IGBT9b respectively
S10a and S10b control IGBT10a and IGBT10b respectively
S11a and S11b control IGBT11a and IGBT11b respectively

The control system CS1 also provides control outputs to switch contactors CON3 and CON4 to connect or disconnect the loads at the first output and second output respectively. The control outputs for contactors CON3 and CON4 are simply isolated relay contacts which connect the contactor coils of CON3 and CON4 with the supply voltage +12 VDC which provides power to Power Supply PS1. The contactor coil circuits are closed via the ground connections. Other power sources may be used for this purpose.

The supply voltage at C5 is monitored by sensor M8 which provides a corresponding signal to control system CS1. When power, e.g. 12 VDC, is applied to the power supply system, control system CS1 is activated. If the voltage at C5 is within the limits of two predetermined thresholds, that is the design operating window for the system's supply voltage, it will start to operate. Control system CS1 monitors the first output voltage at capacitor C6 by means of sensor M15 and the second output voltage at capacitor C7 by means of sensor M16. Inverters INV1 and INV2 operate together to supply a variable voltage to the primary windings of transformers T1 and T2 respectively. Similarly, inverter INV3 operates to supply a variable voltage to the primary windings of transformer T3.

Each inverter employs a full wave bridge topology comprising four IGBTs as follows:
Inverter INV1 is connected to transformer T1 and comprises IGBT6a, IGBT6b, IGBT7a and IGBT7b. Inverter INV2 is connected to transformer T2 and comprises IGBT8a, IGBT8b, IGBT9a and IGBT9b. Inverter INV3 is connected to transformer T3 and comprises IGBT10a, IGBT10b, IGBT11a and IGBT11b.

Fast recovery diodes are connected in parallel with each IGBT in accordance with established practice. Each IGBT is switched by the control system CS1 acting through a driver system DS1 which applies the switching signal from control system CS1 to the gate of its dedicated IGBT thereby switching the IGBT on or off. The switching frequency is typically 20 kHz, but can vary according to criteria such as the type of transistors, core material of the inductor, efficiency, output quality, size and weight.

The three inverters operate according the same inverter control scheme in which the pulse width is varied between a predetermined maximum on-time and a predetermined off- time so that current in the primary windings is controlled so as to maintain an output voltage on the secondary side according to a predetermined value. The voltage of the secondary side of the transformer is measured after the rectifiers and LC filters. The current is controlled by increasing or decreasing the pulse width in response to a PWM signal generated by the control system CS1.

Referring now to Figure 2, the control system incorporates two controllers operating concurrently. Firstly, the voltage controller compares the output voltage signal V_dc_real to a voltage reference signal V_dc_ref and outputs a signal I_L_Ref. When the voltage error (V_dc_ref minus V_dc_real) is positive, output signal I_L_ref increases and when the error is negative, the output signal decreases. The voltage controller output signal is fed into the current controller as its reference signal. The current controller compares the rectified transformer output current signal, I_L_real, to the current reference signal, I_L_ref and provides a signal, V1_ref, to adjust the Pulse Width Modulation (PWM). When the current error signal, namely the difference between I_L_ref and I_L_real is positive, signal V1_re1 causes the PWM to increase the pulse width. Conversely, when the error signal is negative, signal V1_re1 will cause the pulse width to be decreased.

The positive and negative current waveforms are realised by switching IGBT pairs in a time sequence. This is explained by using inverter INV1 as an example. IGBT6a and IGBT7b are switched concurrently to provide the positive half of the waveform. During this time, IGBT6b and IGBT7a are maintained in an off state. When the positive half of the waveform is complete, all IGBTs are maintained in an off state for a predetermined period, the dead time. After the dead time has lapsed, IGBT6b and IGBT7a are switched to create the negative half of the current waveform.

The rectified transformer output currents are measured by means of current sensors M12, M13 and M14 for transformers T1, T2 and T3 respectively. Using the secondary circuit of transformer T1 as an example, the maximum output current is controlled according to a predetermined value by reducing the current in the primary winding of transformer T1 when the output current in the secondary winding exceeds the maximum predetermined value. In addition, the primary current of transformers T1, T2 and T3 are measured by means of current sensors M9, M10 and M11 respectively and fed into control system CS1 for purposes of over current protection in transformers T1, T2 and T3. When the transformer primary current exceeds a predetermined maximum value, control system CS1 switches off all IGBTs working in that circuit.

The circuit connections in connector block CB1 are illustrated in more detail in Figure 3. The connections are depicted in four layers which are identified as Layer 1, 2, 3 and 4 by letters A, B, C and D respectively. Different line styles are used for easy identification. The connections are identical to that of the example given in the preceding paragraphs describing Figure 1. It must be appreciated that connections are made horizontally inside the layers and vertically up or down between the different layers. Layer 1 provides the embedded copper bars for partly connecting the rectified output of the transformers to provide the two outputs, namely 48 VDC, 10 kW and 24 VDC 5 kW. The 48 VDC output is provided between points 8 and 10 and the 24 VDC output is provided between points 11 and 13. A second layer, Layer 2, provides the embedded copper bars to complete the circuit. Starting at point 8, the negative output point, it is connected to point 9 in Layer 2 and to point 1 in layer one, which is connected by a conductor to one output of transformer T1 at terminal 4, namely the centre tap. The other two output of transformer T1 are connected to the anodes of diodes D3 and D4. The cathodes of diodes D3 and D4 are connected together and to point 3 of connector block CB1. This circuit provides the rectified output of transformer T1 through inductor L1. Point 3 is connected to point 4 by a copper bar embedded in Layer 1. Point 4 is further connected by a conductor to the centre tap of transformer T2 at terminal 4.

The anodes of diodes D5 and D6 are connected to terminals 3 and 5 of transformer T2 respectively. The cathodes of Diodes D5 and D6 are connected together and to point 5 in connector block CB1 through inductor L2. Point 5 is connected to point 10 by means of a copper bar embedded in layer 1, thus completing the circuit to provide the positive output point.

As previously mentioned, a capacitor C6 is connected to points 8 and 10 in Layer 1, which is the output means for the first output. A further copper bar, embedded in layer 2 connects the positive output point at point 10 to point 17 in layer 1, the positive terminal of the first output, and point 18 in the earth layer. Thus, the positive earth connection is made. The negative output point 8 is connected to point 16 in layer 2 by means of copper bars embedded in layer 3 and an external circuit comprising a fuse and contactor contact (not shown in Figure 3, but shown in Figure 2). Point 16 is connected to point 15 in layer 2, the negative terminal of the first output.

The second output is provided at capacitor C7 (not shown in Figure 3, but shown in Figure 1) connected to points 11 and 13 in layer 1. Starting at point 11, the negative output point of the second output, an embedded copper bar connects point 11 to point 6 in Layer 1, which is connected to the centre tap of transformer T3 at terminal 4 by means of a copper conductor. Terminal 3 and 5 are connected to the anodes of diodes D7 and D8. The cathodes of diodes D7 and D8 are connected together and to point 7 in layer 1 of connector block CB1 through inductor L3. Point 7 is connected to point 13 by means of a copper bar embedded in layer 1, thus completing the circuit to provide the positive output point.

As previously mentioned, a capacitor is connected to points 11 and 13 in Layer 1, which is the output means for the second output. A copper bar embedded in layer 2 connects point 13 to point 12. The positive output at point 12 is connected to point 21 in layer 2 by means of copper bars embedded in layer 3 and an external circuit comprising a fuse and contactor contact (not shown in Figure 3, but shown in Figure 2). Point 21 is connected to point 22 in layer 2, the positive terminal of the second output. The negative output point 11 of the second output is connected to point 20, the negative terminal of the second output, in layer 1 by means of a copper bar embedded in layer 2, and to point 19 in the earth layer. Thus the second output is provided with an earth connection at the negative terminal.

Examples of other configurations are shown in Figures 4, 5, 6, 7, 8, 9 and 10 as follows:
Figure 4 shows an output configuration of 10 kW at 48 VDC with negative earth and 5 kW at 24 VDC with positive earth;
Figure 5 shows an output configuration of 10 kW at 48 VDC with positive earth and 5 kW at 24 VDC with positive earth;
Figure 6 shows an output configuration of 10 kW at 48 VDC with negative earth and 5 kW at 24 VDC with negative earth;
Figure 7 shows an output configuration of 10 kW at 24 VDC with negative earth and 5 kW at 48 VDC with positive earth;
Figure 8 shows an output configuration of 10 kW at 24 VDC with positive earth and 5 kW at 48 VDC with negative earth;
Figure 9 shows an output configuration of 10 kW at 24 VDC with positive earth and 5 kW at 48 VDC with positive earth; and

Figure 10 shows an output configuration of 10 kW at 24 VDC with negative earth and 5 kW at 48 VDC with negative earth.

The connector block configuration shown in Figure 3 is given in more detail in Figure 11, which shows a practical implementation of the multi layered connector block system and is designated as CB1.

The various components that make up the connector block shown in Figure 3 and 11 are as follows:
Layer 1 comprises the plate with copper bars that connect the rectified transformer outputs of T1 and T2 in series to realise a 10 kW output at 48 VDC. It also provides the connections for the 5 kW output at 24 VDC. It is identified as Item No. 5 in Figure 11 and shown in Figure 18.

Layer 2 comprises two separate plates identified as Items No. 6, the positive earth connecting plate for the 48 VDC output which is shown in Figure 23, and No.2, the negative earth connecting plate for the 24 VDC output which is shown in Figure 22. These plates also complete the connections of the rectified transformer outputs and to Layer 3.

Layer 3 comprises the plate that links the rectified transformer outputs and the output terminals via a fuse and contactor contact circuit. It is identified in Figure 11 as Item No. 1 and shown in Figure 25.

Layer 4 is the base plate with the earth plate and earthing bars and is identified in Figure 11 as Item No. 9. More detail is shown in Figure 26.

An additional layer, the connector block cover is shown in Figure 11 and identified as Item No. 8. The plate simply provides the mechanical means to fix the connecting copper bars for the first output (48 VDC) and second output (24 VDC) capacitors. It also incorporates the copper bars for connecting to the centre tap of transformers T1, T2 and T3. More detail is shown in Figure 27.

Practical implementation of the system shown in Figure 1 and Figure 3 are described in the succeeding paragraphs with reference to Figures 11, 19A, 19B, 21, 23 and 25.

Figure 11 shows the connector plates in the various layers as follows:
Item No. 1 is the contactor plate and makes up layer 3. Figure 25 shows the contactor plate and copper bars, copper bushes and isolating bushes in relation to the connecting points identified in Figure 3. Item No. 2 is one of two earthing plates, namely the plate that connects the negative terminal of the second output to earth, which makes up layer 2. Figure 21 shows the earthing plate and copper bars in relation to the connecting points identified in Figure 3. Item No. 6 is the second earthing plate, namely the plate that connects the positive terminal of the first output to earth, which completes layer 2. Figure 23 shows the earthing plate and copper bars in relation to the connecting points identified in Figure 3. Item No. 5 is the plate for the configuration of 10 kW at 48 VDC and 5 kW at 24 VDC and makes up layer 1. Figures 19A and 19B show the contactor plate and copper bars in relation to the connecting points identified in Figure 3. Item No. 9 is the base earthing plate. See also Item "A" in Figure 26. Item No. 8 is the cover plate for mounting the output capacitors. More detail is shown in Figure 27.

Starting again at point 8 in Item No. 5 (Layer 1 in Figure 11), the negative output point, it is connected to point 9 in Item No. 6 of Figure 1 (Layer 2) and to point 1 in Item No. 5 (layer 1), which is connected by a conductor to one output of transformer T1 at terminal 4, namely the centre tap. The other two output of transformer T1 are connected to the anodes of diodes D3 and D4. The cathodes of diodes D3 and D4 are connected together and to point 3 of Item No. 1 by means of bus-bar (E). This circuit provides the rectified output of transformer T1 through inductor L1. Point 3 is connected to point 4 by a copper bar (B) embedded in Item No.5. Point 4 is further connected by a conductor to the centre tap of transformer T2 at terminal 4.

The anodes of diodes D4 and D5 are connected to terminals 3 and 5 of transformer T2 respectively. The cathodes of Diodes D5 and D6 are connected together and to point 5 in Item No. 1 through inductor L2 by means of bus-bar (F). Point 5 in Item No. 1 is connected to point 10 in Item No. 5 by means of a vertical connection to a copper bush at point 5 in Item No. 2 and a further vertical connection to point 5 in Item No. 5, and a horizontal connection by means of copper bar (C) embedded in Item No.5, thus completing the circuit to provide the positive output point. As previously mentioned, a capacitor is connected to points 8 and 10 in Item No. 5, which is the output means for the first output. The cover plate, Item No. 8 is used to mount the output capacitor on copper bars (A and B), which are vertically connected to points 8 and 10 in Item No. 5 by means of copper bushes (H and I) respectively.

A further copper bar (B), embedded in Item No. 6 (layer 2) vertically connects the positive output point at point 10 in Item No. 5 to point 10 in Item No. 6 which is linked horizontally to point 17 in bus-bar (B) of Item No. 6 and further vertically connected to point 17 in bus-bar (G) of Item No.5 (layer 1) thereby making available the positive terminal of the first output at bus-bar (G). Similarly, point 8 in Item No.5 is vertically connected to point 8 in copper bar (C) of Item No. 6 which links point 8 and 9 horizontally.

A vertical connection links point 9 in Item No. 6 to point 9 in bus-bar (A) of Item No. 1 where it connects to the external circuit with the fuse and contactor contact and returns to Item No. 1 via bus-bar (B) at point 16. It is further vertically connected to point 16 in copper bar (D) of Item No. 6 which horizontally links point 16 to point 15 and to copper bar (F) at point 15 in Item No. 5 by means of a vertical connection. Thus the negative output of the first output is made available at bus-bar (F) and the positive output of the first output is available on bus-bar (G) in Item No. 5. The positive output of the fist output at point 17 in bus-bar (G) is horizontally linked to point 18 which is vertically connected to copper bush (H) in Item No. 1 and again connected to earth plate (A) in Item No. 9 thereby earthing the positive output of the first output.

The second output is provided at capacitor C7 (not shown in Figure 3, but shown in Figure 1) connected to points 11 and 13 in Item No. 5 (layer 1). Starting at point 11, the negative output point of the second output, an embedded copper bar (D) links point 11 to point 6 of Item No. 5 (Layer 1), which is connected to the centre tap of transformer T3 at terminal 4 by means of a vertical connection with copper bus-bar (G) in Item No.8. Terminal 3 and 5 are connected to the anodes of diodes D7 and D8. The cathodes of diodes D7 and D8 are connected together and to point 7 in bus-bar (E) of Item No. 5 (layer 1) through inductor L3. Point 7 is linked to point 13 by means of a copper bar (E), thus completing the circuit to provide the positive output point. Point 13 in Item No.5 is vertically connected to point 13 in copper bar (D) of Item No. 2 which links point 12 and 13 horizontally. A vertical connection links point 12 in Item No. 2 to point 12 in bus-bar (C) of Item No. 1 where it connects to the external circuit with the fuse and contactor contact and returns to Item No. 1 via bus-bar (D) at point 21. It is further vertically connected to point 21 in copper bar (E) of Item No. 2 which horizontally links point 21 to point 22 and to copper bar (I) at point 22 in Item No. 5 by means of a vertical connection. Thus the positive output of the second output is made available at bus-bar (I) in Item No. 5.

As previously mentioned, a capacitor C7 is connected to points 11 and 13 in Item No. 5, which is the output means for the second output. The cover plate, Item No. 8 is used to mount the output capacitor on copper bars (C and D), which are vertically connected to points 11 and 13 in Item No. 5 by means of copper bushes (H and I) respectively. A further copper bar (B), embedded in Item No. 2 (layer 2) vertically connects the negative output point at point 11 in Item No. 5 to point 11 in Item No. 2 which is linked horizontally to point 20 in bus-bar (C) of Item No. 2 and further vertically connected to point 20 in bus-bar (H) of Item No.5 (layer 1) thereby making available the negative terminal of the second output at bus-bar (H).

Thus the positive output of the second output is made available at bus-bar (I) and the negative output of the second output is available on bus-bar (H) in Item No. 5. The negative output of the second output at point 20 in bus-bar (C) is horizontally linked to point 19 which is vertically connected to copper bush (I) in Item No. 1 and again connected to earth plate (A) in Item No. 9 thereby earthing the negative output of the second output.

It must be appreciated that several combinations of plates in Layer 2 will provide various earthing combinations. Figure 12 shows a configuration of the apparatus described above using a different plate, namely Item No. 7 by which means the negative terminal of the first output, 10 kW at 48 VDC, is connected to earth by means of bus-bar (K) at point 14 in Item No. 5 which is connected to earth base plate (A) in Item No. 9 through bus-bar s C and D shown in Figure 26. The negative terminal of the second output at bus-bar (H) in Item No. 5 is vertically connected to point 11 in copper bar (C) of Item No. 2. Point 11 is linked to point 20 and 19 by copper bar (C). Point 19 is vertically connected to copper bush (I) at point 19 in Item No. 1 which in turn is vertically connected to the earth base plate (A) in Item No. 9. Thus this configuration provides a first output with negative earth and a second output with negative earth. Other combinations are possible as shown in Figures 13 and 14.

In addition, a different configuration of the two outputs is shown in Figures 14, 15, 16, 17 and 18. In this configuration, transformer T1 operates to provide the first output of 5 kW at 48 VDC while transformers T2 and T3 are connected in parallel to provide a second output of 10 kW at 24 VDC. It must be noted that secondary winding of transformer T1 is rectified by means of a four diode full wave rectifier bridge instead of the two diode bridge rectifier used in the apparatus described in detail in the preceding paragraphs. The four diode rectifier enables the transformer to produce a rectified output of 48 VDC without any need to change the windings.

In any of the configurations of the apparatus described above, the first and second outputs are always provided at the same output terminals with the same polarity so that the output connections are always made on the same terminals, e.g. a 48 VDC battery and a 24 VDC battery.

The connector block configuration shown in Figure 3 is also given in more detail in Figure 28, which shows a practical implementation of an alternative multi layered connector block system and is designated as CB2

Connector block CB2 comprises a base plate and only one layer, the interconnecting layer. There are eight different plate assemblies, one for each of the eight configurations. The base plate is paired with the interconnecting layer which comprises one of the eight plate assemblies to make up the connector block with the respective output configuration.

The base plate is shown in Figure 28 and designated as Item No 9. It comprises a plate made from insulating material with embedded copper bars that provide the connections between the rectified transformer outputs and the interconnecting layer. It also includes copper bars that provide the connections that link the rectified transformer outputs with the power output terminals via the external fuse and contactor circuits similarly to that of

Connector Block CB1. An embedded bush provides the connection to earth. More details are shown in Figure 37.

The various plates in the interconnecting layer that mate with the base plate, described in the preceding paragraph, to provide the different configurations as per Figures 3 to 10 and in Figure 28 are as follows:

Item No 1 represents the circuit arrangement in Figure 10 and is shown in more detail in Figure 29. It comprises three plates made from insulating material with embedded copper bars and bushes that connect the rectified transformer outputs of T1 to realise the 48V, 5 kW, Negative Earth power output, and the rectified outputs of transformers T2 and T3 in parallel to realise the 24 V, 10 kW, Negative Earth power output; Item No 2 represents the circuit arrangement in Figure 9 and is shown in more detail in Figure 30. It comprises three plates made from insulating material with embedded copper bars and bushes that connect the rectified transformer outputs of T1 to realise the 48V, 5 kW, Positive Earth power output, and the rectified outputs of transformers T2 and T3 in parallel to realise the 24 V 10 kW Positive Earth out; Item No 3 represents the circuit arrangement in Figure 6 and is shown in more detail in Figure 31. It comprises three plates made from insulating material with embedded copper bars and bushes that connect the rectified transformer outputs of T1 and T2 in series to realise the 48V, 10 kW, Negative Earth power output, and the rectified outputs of transformer T3 to realise the 24 V, 5 kW, Negative Earth power output; Item No 4 represents the circuit arrangement in Figure 5 and is shown in more detail in Figure 32. It comprises three plates made from insulating material with embedded copper bars and bushes that connect the rectified transformer outputs of T1 and T2 in series to realise the 48V, 10 kW, Positive Earth power output, and the rectified outputs of transformer T3 to realise the 24 V, 5 kW, Positive Earth power output; Item No 5 represents the circuit arrangement in Figure 8 and is shown in more detail in Figure 33. It comprises three plates made from insulating material with embedded copper bars and bushes that connect the rectified transformer outputs of T1 to realise the 48V, 5 kW, Negative Earth power output, and the rectified outputs of transformers T2 and T3 in parallel to realise the 24 V 10 kW Positive Earth power output; Item No 6 represents the circuit arrangement in Figure 3 and is shown in more detail in Figure 34. It comprises two plates made from insulating material with embedded copper bars and bushes that connect the rectified transformer outputs of T1 and T2 in series to realise the 48V, 10 kW, Positive Earth power output, and the rectified outputs of transformer T3 to realise the 24 V, 5 kW, Negative Earth power output; Item No 7 represents the circuit arrangement in Figure 4 and is shown in more detail in Figure 35. It comprises three plates made from insulating material with embedded copper bars and bushes that connect the rectified transformer outputs of T1 and T2 in series to realise the 48V, 10 kW, Negative Earth power output, and the rectified outputs of transformer T3 to realise the 24 V, 5 kW, Positive Earth power output; Item No 8 represents the circuit arrangement in Figure 7 and is shown in more detail in Figure 36. It comprises three plates made from insulating material with embedded copper bars and bushes that connect the rectified transformer outputs of T1 to realise the 48V, 5 kW, Positive Earth power output, and the rectified outputs of transformers T2 and T3 in parallel to realise the 24 V 10 kW Negative Earth power output.

Practical implementation of the system shown in Figure 1 and Figure 3 are described in the succeeding paragraphs with reference to Figures 28, 34 and 37.

Connections between the Base Plate and the Interconnecting Plate are made by bolting them together at the connection points.

Starting at point 1 on bus-bar B embedded in Item No. 6 (Interconnecting Layer), the negative output point, it is connected to point 1 on bus-bar (A) in Item No. 9 (Base Plate). A conductor connects point 1 on bus-bar (A) in Item No. 9 to one output of transformer T1 at terminal 4, namely the centre tap. The other two outputs at terminals 3 and 5 of transformer T1 are connected to the anodes of diodes D3 and D4. The cathodes of diodes D3 and D4 are connected together and to point 3 on bus-bar (C) in Item No. 9 via inductor L1. This circuit provides the rectified output of transformer T1. Point 3 on bus-bar (C) embedded in Item No. 9 is connected to point 3 on bus-bar (D) embedded in Item No. 6. Points 3 and 4 are linked together by bus-bar (D) in Item No. 6. Point 4 in Item No. 6 is connected to point 4 on bus-bar (D) in Item No.9, which is further connected by a conductor to the centre tap of transformer T2 at terminal 4.
The anodes of diodes D5 and D6 are connected to terminals 3 and 5 of transformer T2 respectively. The cathodes of Diodes D5 and D6 are connected together and to point 5 in Item No. 9 through inductor L2 by means of bus-bar (E). Point 5 in Item No. 9 is

connected to point 5 on bus-bar (E) in Item No. 6, thus completing the circuit to provide the positive output point. As previously mentioned, a capacitor **C6** is connected to points 1(negative connection) and 5 (positive connection) Item No. 6, which is the output means for the first output.

Points 5, 6 17, 20 and 28 on bus-bar (E) , embedded in Item No. 6 are linked together thereby making available the positive terminal of the first output at point 17 on said bus-bar (E), which is earthed by means of Point 28 on the same bus-bar (E)

The negative output at point 1 is linked to point 25 on bus-bar (B) in Item No. 6 where it is connected to bus-bar (M) which is vertical orientated and links point 25 to point 30 in the said bus-bar (M) where it connects to the external circuit with the fuse and contactor contact connected in series and returns to bus-bar (L) in Item No.9 at point 29. It is further vertically linked to point 24 in copper bar (L) of Item No. 9 where it is connected to point 24 on bus-bar (H) embedded in Item No. 6. Point 24 and 15 in bus-bar (H) are linked together. Thus the negative output of the first output is made available at point 15 on bus-bar (H) and the positive output of the first output is available at point 17 and earthed at point 28 on bus-bar (E) in Item No. 6.

Starting at point 6, the negative output point of the second output, on bus-bar (E) in Item No. 6 is connected to the centre tap of transformer T3 at terminal 4 by means of a conductor. Terminal 3 and 5 are connected to the anodes of diodes D7 and D8. The cathodes of diodes D7 and D8 are connected together and to point 7 on bus-bar (F) in Item No. 6 through inductor L3. Point 7 is linked to point 26 by means of bus-bar (F), thus completing the circuit to provide the positive output point. The positive output at point 7 is linked to point 26 on bus-bar (F) in Item No. 6 where it is connected to Bus-bar (H) which is vertical orientated and links point 26 to point 31 in the said bus-bar (H) where it connects to the external circuit with the fuse and contactor contact connected in series and returns to bus-bar (J) in Item No.9 at point 32. It is further vertically linked to point 27 in copper bar (J) of Item No. 9 where it is connected to point 27 on bus-bar (G) embedded in Item No. 6. Point 27 and 22 in bus-bar (G) are linked together. Thus the positive output of the second output is made available at point 22 on bus-bar (G) and the negative output of the second output is available at point 20 and earthed at point 28 on bus-bar (E) in Item No. 6.

As previously mentioned, a capacitor **C7** is connected to points 6 (negative connection) and 7 (positive connection) Item No. 6, which is the output means for the second output.

Points 5, 6 17, 20 and 28 on bus-bar (E), embedded in Item No. 6, are linked together thereby making available the negative terminal of the second output at point 20 on said bus-bar (E), which is earthed by means of Point 28 on the same bus-bar (E).

It must be appreciated that connector block CB2 is mechanically and electrically less complex than connector block CB1. There are a number of alternative options in applying the principle of the reconfigurable connector block. The connector block may include options with more or less transformer circuits as may be required by the specific application. Furthermore, the transformer circuits may include a plurality of output windings which can also be connected to a reconfigurable connector block that will provide the outputs as may be required by the application. For example, two transformers of similar or different capacity with dual windings can be connected to a reconfigurable connector block which can connect the windings in series or parallel provide different voltages at the outputs, similarly to that which was achieved by the example shown in Figure 1 and Figure 3. Furthermore, a combination of multiple transformers with single or multiple windings can be used to realize a plurality of configurations.

The diesel generator and power supply system combines a diesel engine, permanent magnet alternator and digitally controlled electronic power conversion system to produce high quality electric power with exceptional fuel efficiency and reduced emissions. It incorporates an optional power grid interface module and the capability to manage energy flow from the grid and/or engine according to site conditions so as to deliver electric power at the lowest possible cost.

Importantly, wide variations in supply voltage are tolerated by a grid interface module, the grid converter, and current is drawn from any or all available phases. Although the ideal situation is when all three phases are present, the system can operate on only one or two phases. Current will be drawn from the grid according to load demand up to the current carrying capacity of the cables or supply transformer.

Any shortfall in supply power will be met by the diesel generator and the generator converter, which can operate and supply power concurrently with the grid converter. Engine speed is automatically adjusted to match engine output power to load power demand, thereby optimizing engine performance under all levels of load demand in real time. This is realized by the electronic power converter system and the load adaptive variable speed engine control system, which optimizes engine operation to achieve outstanding fuel efficiency along with very low exhaust emissions (thus environment-friendly).

Figure 38 shows the simplified block diagram of the complete power system with outputs for DC power requirements. There are two power sources which supply power to a DC link, indicated by the heavily bolded thick lines and identified as "High DC Side". The main power supply is provided by the multi-phase Grid and is identified as the "AC Input". It is connected to the first input power converter, Active Rectifier (AR) which controls the flow of energy from the Grid's AC input to the DC link. Active rectifiers are well known in the art. The back-up power is provided by a variable speed generator comprising a multi-phase permanent magnet Generator G coupled to a combustion engine CE that feeds power into the second power converter, AC/DC which in turn controls the flow of energy to the DC link. The operation of this power source is described in EP 0 947 042 B1. There are three DC/DC converters which feed off the DC link and convert the high DC voltage at the High DC Side to a lower voltage at the Low DC Side to supply power to DC loads and battery banks. The operation of these DC/DC converters has been described in the preceding paragraphs. Each converter provides feedback Voltage VOL and Current CUR signals to a Control System CS that controls the operation of all the converters and the speed adjustment of combustion engine CE.

Figure 39 shows the block diagram of the system in Figure 38 with an additional converter which inverts the DC power to provide AC power to AC loads in addition to the DC power outputs. Depending on the power requirements of a particular application, the AC output may supply auxiliary power to smaller loads while the DC outputs supply main power to the larger loads. If the main or larger load requires AC instead of DC power, the AC output will supply the main power to the larger loads while the DC outputs will provide auxiliary power to the smaller DC loads. The output converters can be arranged in various configurations to suit specific power requirements in any application. For example, AC power is required and there are no DC loads, the output converter will simply be a single or three phase inverter, depending on the application. There are many inverter topologies and associated control systems known in the art, and so no details of the AC output converters are provided.

Figure 40 shows the basic schematic diagram of a working example of the system shown in Figure 38. Active Rectifier AR is connected to a three phase grid supply, namely Phase A, Phase B, Phase C and Neutral. A three phase generator is connected to converter AC/DC. Two low voltage outputs are provided by three regulated high frequency transformers with rectified outputs and filters as described in the preceding paragraphs.

Figure 41 shows the basic schematic diagram of a working example of the system shown in Figure 39. Active Rectifier AR is connected to a three phase grid supply, namely Phase A, Phase B, Phase C and Neutral. A three phase generator is connected to converter AC/DC. Two low voltage DC outputs are provided by three regulated high frequency transformers with rectified outputs and filters as described in the preceding paragraphs. A third AC output is provided by a single phase inverter DC/AC. Depending on the power requirements, inverter DC/AC could also be a multi-phase inverter.

As the power sources are well known in the art, the detailed operation of the generator system and the Active Rectifier are not described. The operation of the output DC/DC converters have been described in detail. The DC/AC converter, also referred to as an inverter is also well known in the art. However, unique and novel control schemes are presented for input converters Active Rectifier AR and generator converter AC/DC and the cooperative operation between Active Rectifier AR, Generator Converter AC/DC and combustion engine CE.

Figure 42 shows the block diagram of the control system for Active Rectifier AR. Grid supply voltage sensors 1a, 1b and 1c provide signals to the source controller 7 which monitors the Grid (source) voltages in Phase A, B and C respectively and provides an output binary signal E for controlling Pulse Width Calculator 8 and PWM Signal Controller 9 respectively. Source controller 7 is not used in active rectifiers which are known in the art. Pulse width calculator 8 and PWM signal controller 9 are modified to receive signal E and used as described in the succeeding paragraphs. Grid supply voltage sensors 1a, 1b and 1c also provide signals to current controllers 6a, 6b and 6c. Phase Lock Loops PLL 4a, 4b and 4c provide signals to current controllers 6a, 6b and 6c. Grid (source) current sensors 2a, 2b and 2c provide signals to three current controllers, namely 6a, 6b and 6c respectively. DC link voltage sensor 3 provides a signal to DC voltage controller 5 which in turn provides three signals to current controllers 6a, 6b and 6c. With the exception of source controller 7, the modified pulse width calculator 8 and the modified PWM signal controller 9, this control system arrangement is typical of that used in active rectifiers which are state of the art.

In the present invention, source controller 7, pulse width calculator 8 and PWM signal controller 9 incorporate additional functions which provide new features in the control system that enable active rectifier AR to operate as described in the preceding and succeeding paragraphs.

The output signals from current controllers 6a, 6b and 6c are fed into pulse width calculator 8 as voltage reference signals VAref, VBref and VCref. It provides four output voltage signals, VlegAref, VlegBref , VlegCref and VlegNref which correspond to the pulse width for each phase and neutral. These four signals are fed to PWM signal controller 9 which in turn provides two control signals for each leg of active rectifier AR, namely signals A and A, signals B and B, signals C and C, and signals N and N. Referring now also to Figures 40 and 41, each of these pairs of signals provides control signals for the top and bottom transistors of each phase and neutral respectively. For example: signals A and A provide signals for controlling transistors TA and T A in the active rectifier AR leg which corresponds to phase A; similarly, signals B and B for controlling transistors TB and T B in the leg corresponding to phase B; signals C and C for controlling transistors TC and T C in the leg corresponding to phase C; and signals N and N for controlling transistors TN and T N in the leg corresponding to Neutral.

Source controller 7 compares the voltage signals from sensor 1a, 1b and 1c to minimum and maximum instantaneous voltage thresholds, Vmin and Vmax , and minimum and maximum RMS voltage thresholds, Vminrms and Vmaxrms . It provides a binary signals E to pulse width calculator 8 and PWM signal controller 9 respectively which function as gates to prevent switching the transistors when any of the source voltages are abnormal.

If the source voltage of any phase is less than the predetermined minimum threshold and higher than the predetermined maximum threshold of that voltage, then the voltage quality is considered to be abnormal and the respective leg in active rectifier AR should be off. It follows that if the source voltage is 0 or missing, the voltage quality would be considered to be abnormal. Similarly, if the input voltage of all the phases are less than the predetermined minimum thresholds and higher than the predetermined maximum threshold of the source voltages, then all the legs in active rectifier AR should be off. Source controller 7 provides an output signal E which corresponds to the number of voltage sources connected to the system and the input (source) voltage quality. This signal provides binary information, namely 1 or 0, for each source voltage. For example, the binary number 111 signifies that all input voltages (A, B and C) are present and within the window for normal voltage which is determined by the predetermined minimum and maximum voltage thresholds. A binary number of 1 signifies that the corresponding source voltage is normal. A binary number of 0 signifies that the corresponding source voltage is abnormal. Thus the binary signals fed into pulse width calculator 8 and PWM signal controller 9 function as gates. A signal with a binary number of 1 will not affect the pulse width calculator while a binary number of 0 will cause the corresponding output signal to be reduced to zero. Similarly, a signal with a binary number of 1 will not affect the PWM signal controller 9 while a binary number of 0 will cause the corresponding output signal to be disabled, thereby allowing or disallowing switching of the transistors by blocking the output signals from PMW signal control 9. There are eight possible combinations of binary signals for the working examples shown in Figures 40 and 41: 000 signifies that all three phases are abnormal; 001 signifies that phases A and B are abnormal whilst phase C is normal; 010 signifies that phase A is normal, phase B is abnormal and phase C is normal; 100 signifies that phase A is normal, phases B and C are abnormal; 011 signifies that phase A is abnormal, phases B and C are normal; 101 signifies that phase A is normal, phase B is abnormal and phase C is normal; 110 signifies that phases A and B are normal, phase C abnormal; 111 signifies that all phases are normal.

In addition to binary signal E received from source controller 7, the pulse width calculator 8 receives 3 voltage reference signals similarly to the corresponding signals provided in the control system of active rectifiers which are state of the art, namely the output signals from current controllers 6a, 6b and 6c. Typically, the output signals of the current controllers 6a, 6b and 6c provide information about the instantaneous voltage which should be produced by active rectifier AR in relation to the magnitude and real time. Pulse width calculator 8 processes the information provided by the output signals from 6a, 6b and 6c and provides four output signals to PWM signal controller (phase A, phase B, phase C and neutral) which are proportional to the pulse width. As previously mentioned, these output signals are conditional upon the gate control of the binary signal

E received from the source controller. The PWM signal controller converts these signals to Pulse Width Modulation (PWM) signals A, A, B, B, C, C, N, N, which control the switching of the top and bottom transistors in each leg of active rectifier AR which corresponds to phases A, B and C and neutral. Again, these output signals are conditional upon the gate control of binary signal E as previously mentioned.

Generally, active rectifier AR operates similarly to the active rectifiers known in the art, but the additional Source controller 7, modified pulse width calculator 8 and modified PWM signal controller 9 enable the unique and novel operating regime of active rectifier AR to be realized. The feature whereby the normal and abnormal status of the source voltages are determined by source controller 7 and the resulting actions of pulse width calculator 8 and PWM signal controller on output to allow or disallow the switching of the transistors in active rectifier AR enables it to operate adaptively to the onerous conditions encountered in developing countries where the grid supply voltage or voltages are often not in accordance with the established standards. This control system and unique feature are not known in the art.

Source controller 7 decides how many source voltages (phases) are connected to the system and their status. If any source voltage is determined to be abnormal (missing or outside the allowable window), it disables the transistor signal for the respective leg in active rectifier. Only the signals controlling the transistors which correspond to the phase with the abnormal voltage are blocked or disabled. The active rectifier continues to draw power from the other source voltage or voltages which are considered to be in the normal state. The operation is seamless and fully automatically controlled. When any source voltage changes status from abnormal to normal, active rectifier AR will stop operating for a predetermined time. It will then activate the startup sequence which is similar to that of the known active rectifiers. The system then resumes operation and draws power from all voltage sources which are in the normal state. This enables the active rectifier to utilize all the available energy from the grid, which is usually the cheapest source of electricity.

As previously mentioned, the load power requirement may well exceed the available power at any given moment. In this instance, control system CS will detect a fall in DC link voltage caused by the imbalance of power flowing into and out of the DC link capacitor, which supplies power all the converters that are connected to the DC link. When the voltage falls below a predetermined threshold, the first threshold, the startup sequence of the load-adaptive variable-speed generator CE and G will be activated. The operation of this generator system is described in detail in European Patent No. EP 0 947 042 B1. This generator will operate at the optimum speed which is required to generate the power required to maintain the DC link voltage at the predetermine first threshold, thereby balancing the power demanded by the load with the power supplied by the Grid and the generator operating in parallel. When control system CS detects a rise in DC link voltage such that the DC link voltage rises above a second threshold, marginally higher than the first threshold, the generator speed will be reduced in accordance with the control system described in the aforementioned patent. This control system is included in Control System CS. Thus the generator will strive to maintain the DC link voltage at the first threshold level. If the load demand is reduced to the point where the engine is operating at minimum speed for a predetermined time period, the generator stop sequence will be activated. This would mean that the grid source voltage or voltages are able to supply the power required to meet load demand and achieve a balance between the power supplied to the DC link capacitor and the power drawn from it by the load. At this point, active rectifier AR will maintain the DC link voltage at the level of the second threshold.

Control system CS includes the unique control system shown in Figure 42 and the control system for the load adaptive generator described in European Patent No. EP 0 947 042 B1. The combination of these two control systems enable the two power sources, namely the grid and the generator to operate cooperatively in three modes of operation: grid supplying power to the load through active rectifier AR operating alone when all grid source voltages are normal or when the available power from one or two grid source voltages is sufficient to meet the load power demand; generator is operating alone and supplying power to the load through converter AC/DC when all grid voltages are abnormal; grid and generator are supplying power to the load concurrently when the grid voltage sources are not able to supply all the power required by the load. It must be appreciated that it is possible for the grid to supply full rated power and for the generator to supply its full rated power concurrently. In this instance, the two power sources could aggregate their capacity and supply substantially higher power than either of their individual capacity.

As previously stated, the DC loads used in the system shown in Figures 38, 39, 41 and 42 include battery banks. The stored energy in the batteries is used to power the load and tied the system through when there is no power available from the grid or the generator. The system can also be modified to operate without batteries connected to the DC loads by utilizing an energy storage system such as sufficiently large capacitor or an energy storage system as described in EU Patent No. EP 0 947 042 B1.

Two independent and galvanically isolated outputs are provided by regulated high frequency transformers and rectifiers, the output converters. The outputs are reconfigurable in terms of voltage and/or power as described above. The two outputs are also reconfigurable for positive or negative earthing individually. Additionally, in certain cases the main power requirement is for AC power supply. In this instance, the three DC/DC output converters can be replace by one or more single phase or three phase inverters to produce the required AC outputs. Such a solution would not benefit from the reconfigurable features of this patent, but would nevertheless utilize the features related to the input converters.

Although only certain embodiments of the invention have been described herein, it will be understood by any person skilled in the art that other modifications, variations and possibilities of the invention are conceivable. Such modifications, variations and possibilities are therefore to be considered as falling within the spirit and scope of the invention and hence forming part of the invention as herein described and/or exemplified.

CLAIMS

What is claimed is:

1. A power system comprising a first power source from a power grid with an AC multi-phase input and a second power source being a variable speed generator, which are respectively capable of supplying power to a DC link, wherein the first power source is connected to a first input power converter being provided as an active rectifier and wherein the second power source is connected to a second input power converter, further comprising at least one output converter being connected to the DC link to supply power to a load, wherein a control system is connected to the first input power converter, the second input power converter and the output converter, which controls the flow of energy from the power grid's AC input to the DC link , the flow of energy from the generator to the DC link and the flow of energy from the output converter to the load, so as to predominantly utilize all the available energy from the grid.

2. The power system according to claim 1, wherein the output converter comprises at least one DC/DC converter which is converting the DC voltage at the input to a specified voltage at the output for supplying a DC load.

3. The power system according to claim 1 or 2, wherein the output converter comprises at least one DC/AC converter being connected to the DC link and converting the DC voltage at the input to an AC voltage at the output for supplying an AC load.

4. The power system according to any of claims 1 to 3, wherein the power grid comprises a three-phase AC input.

5. The power system according to any of claims 1 to 4, wherein the generator is capable of delivering a single phase or a multi-phase, preferably three-phase, AC output with the second input power converter being an AC/DC converter.

6. The power system according to any of claims 1 to 5, wherein the output converter provides a feedback voltage signal and a current signal to the control system so as to control the operation of the converter.

7. The power system according to any of claims 1 to 6, wherein the output converter is provided with a high frequency transformer with rectified outputs and a filter-, preferably a LC-filter, for supplying a DC load or is provided with an inverter for supplying an AC load.

8. The power system according to any of claims 1 to 7, wherein the control system comprises for each phase a grid supply voltage sensor to provide a signal to a source controller which monitors the grid voltage for each phase.

9. The power system according to claim 8, wherein the source controller compares each signal from the voltage sensors to a minimum and a maximum instantaneous voltage thresholds and a minimum and a maximum RMS voltage thresholds so as to provide for each phase an output binary signal for controlling a pulse width calculator and PWM signal controller.

10. The power system according to claim 9, wherein the pulse width calculator and PWM signal controller respectively function as gates to prevent switching of transistors of the first input power converter when a source voltage of a phase is outside a window being defined by the voltage thresholds.

11. The power system according to claim 10, wherein the source controller further monitors DC link voltage to control the generator output power, preferably by adjusting an engine speed of the generator, and to control the active rectifier to continue drawing power from all available phases that are within the window being defined by the voltage thresholds .

12. The power system according to any of claims 1 to 11, further comprising energy storage means, preferably a battery, a capacitor or a combination of both, to power the load and the system in case there is no power available from the grid or the generator.

13. The power system according to any of claims 1 to 12, wherein at least two galvanically isolated outputs are connected to a respective load via a connector block.

14. The power system according to claim 13, wherein the connector block comprises a multilayered assembly with layers made out of material with suitable mechanical and electrical insulation properties and embedded connector bars, preferably comprising an electrical conducting metal or metal alloy such as copper, which form part of an electrical circuit that produces the outputs.

15. The power system according to claim 13 or 14, wherein the power capability of the first output is appropriately rated to supply a first load and the power capability of the second output is appropriately rated to supply the second load.

16. The power system according to any of claims 13 to 15, wherein the layers and the embedded connector bars of the connector block are reconfigurable so that different combinations of layers having series and parallel connections can be realised.

17. The power system according to any of claims 13 to 16, wherein positive or negative terminals of each output may be connected to ground independently.

18. The power system according to any of claims 13 to 17, wherein the connector block comprises multiple layers being provided as embedded connector bars for connecting the rectified output of the transformers to provide a first and a second output, which can be configured according to desired output polarities and power requirements by rearranging the embedded connector bars or by reconnecting the rectified output of the transformers.

19. The power system according to any of claims 13 to 18, wherein an output configuration at the first output and at the second output is achieved, which can be selected to be 6 VDC, 12 VDC, 24 VDC, 48 VDC, 400 VDC or any other prescribed value.

20. The power system according to any of claims 13 to 19, wherein an output with negative or positive earth at the first or the second output may be achieved.

21. The power system according to any of claims 13 to 20, wherein an output configuration at the first output and at the second output is achieved, which can be 5 kW, 10 kW, 15 kW, 300 kW or any other prescribed value.

22. The power system according to any of claims 13 to 21, wherein the first and second outputs are provided at the same output terminals with the same polarity so that the output connections are made on the same terminals.

23. The power system according to any of claims 13 to 21, wherein the connector block comprises a base plate and an interconnecting layer, wherein the interconnecting layer is selected according to a desired configuration of the outputs and the base plate is paired with the respective interconnecting layer to make up the connector block with the respective output configuration.

24. A method for operating a power system, which includes the steps of connecting a power grid with AC multi-phase inputs to an active rectifier and connecting a variable speed generator to an input power converter, which are respectively capable of supplying power to a DC link, providing at least one output converter being connected to the DC link to supply power to a load, wherein the active rectifier, the input power converter and the output converter are controlled to predominantly utilize all the available energy from the grid by monitoring the voltages on the multi-phase grid inputs and the DC link.25. The method according to claim 24, wherein a normal and an abnormal status of the voltages of the multi-phase input are determined so as to enable or to at least partially disable the active rectifier to operate adaptively to abnormal conditions in which one or more of the phase voltages of the grid power are outside a predetermined window.

26. The method according to claim 24 or 25, wherein the source controller controls how many source voltages are connected to the system and if any source voltage is determined to be abnormal, it disables the respective leg in the active rectifier such that only the signals controlling transistors which correspond to the phase with the abnormal voltage are blocked or disabled in order to continue drawing power from the other source voltage or voltages which are considered to be in the normal state.

27. The method according to any of claims 24 to 26, wherein, when any source voltage changes status from abnormal to normal, the active rectifier will stop operating for a predetermined time in order to activate a start-up sequence and the system then resumes operation and draws power from all voltage sources which are in the normal state so as to utilize all the available energy from the grid.

28. The method according to claim 27, wherein the control system will detect a fall in DC link voltage caused by the imbalance of power flowing into and out of the DC link, and then activate a start-up sequence of the generator in order to operate the generator at an optimum speed, thereby balancing the power demanded by the load with the power supplied by the grid and the generator operating in parallel.

29. The method according to claim 28, wherein, when the control system detects a rise in DC link voltage such that the DC link voltage rises above a second threshold, which is marginally higher than the first threshold, the generator speed will be reduced so that if the load demand is reduced to the point where the engine is operating at minimum speed for a predetermined time period, the generator stop sequence will be activated.

30. The method according to any of claims 24 to 29, wherein the two power sources operate cooperatively in three modes of operation: first power source operating alone when all grid source voltages are normal or when the available power from one or two grid source voltages is sufficient to meet the load power demand; second power source operating alone and supplying power to the load when all grid voltages are abnormal; and first and second power source supplying power to the load concurrently when the grid voltage sources alone are not able to supply all the power required by the load.

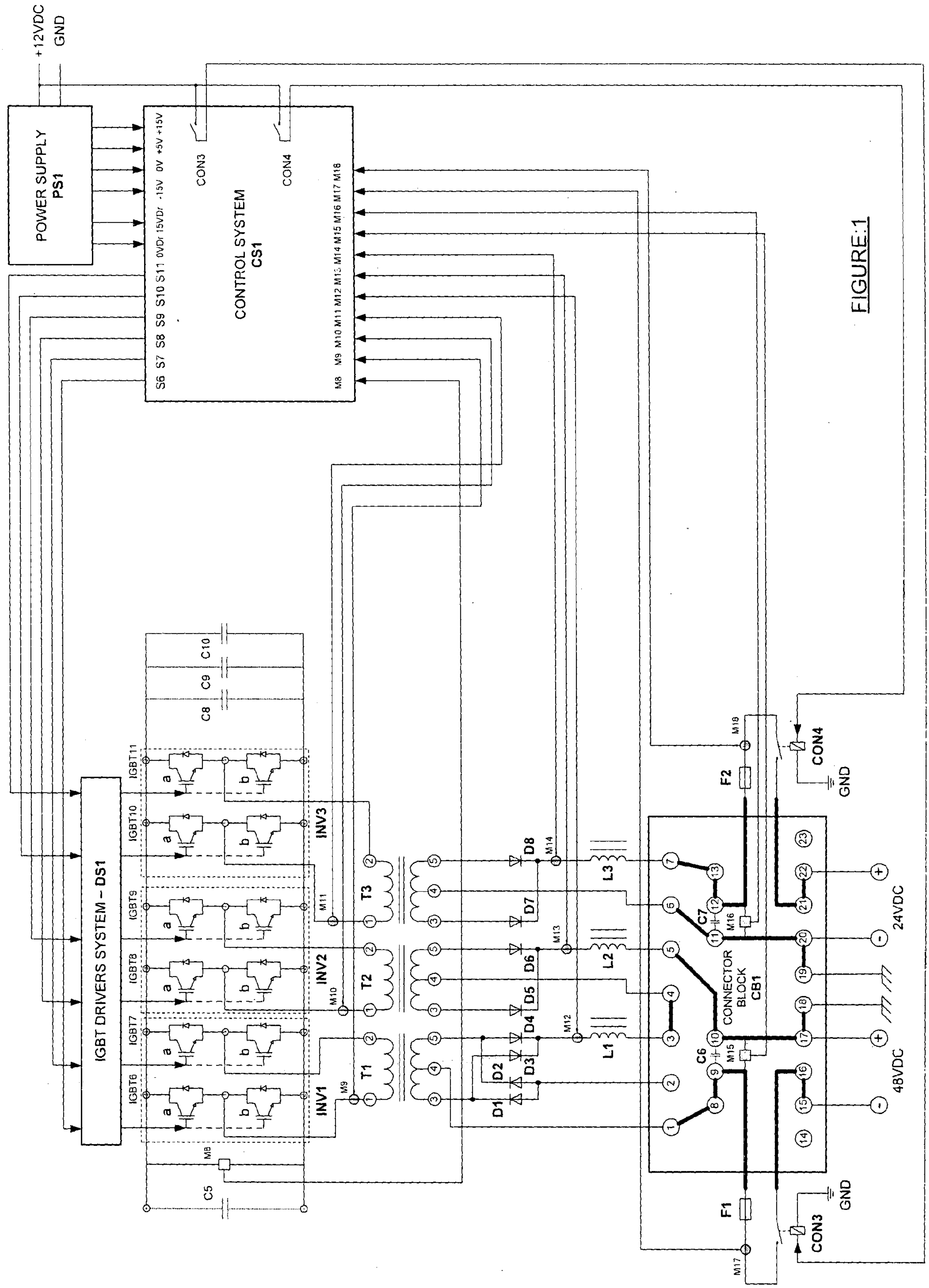

+12VDC
GND
POWER SUPPLY
PS1
CONTROL SYSTEM
CS1
S6 S7 S8 S9 S10 S11 0VDr 15VDr -15V 0V +5V +15V
CON3
CON4
M8 M9 M10 M11 M12 M13 M14 M15 M16 M17 M18
IGBT DRIVERS SYSTEM – DS1
IGBT6
IGBT7
IGBT8
IGBT9
IGBT10
IGBT11
INV1
INV2
INV3
C5
C8
C9
C10
T1
T2
T3
D1
D2
D3
D4
D5
D6
D7
D8
L1
L2
L3
C6
C7
F1
F2
CONNECTOR
BLOCK
CB1
48VDC
24VDC
GND

FIGURE:1

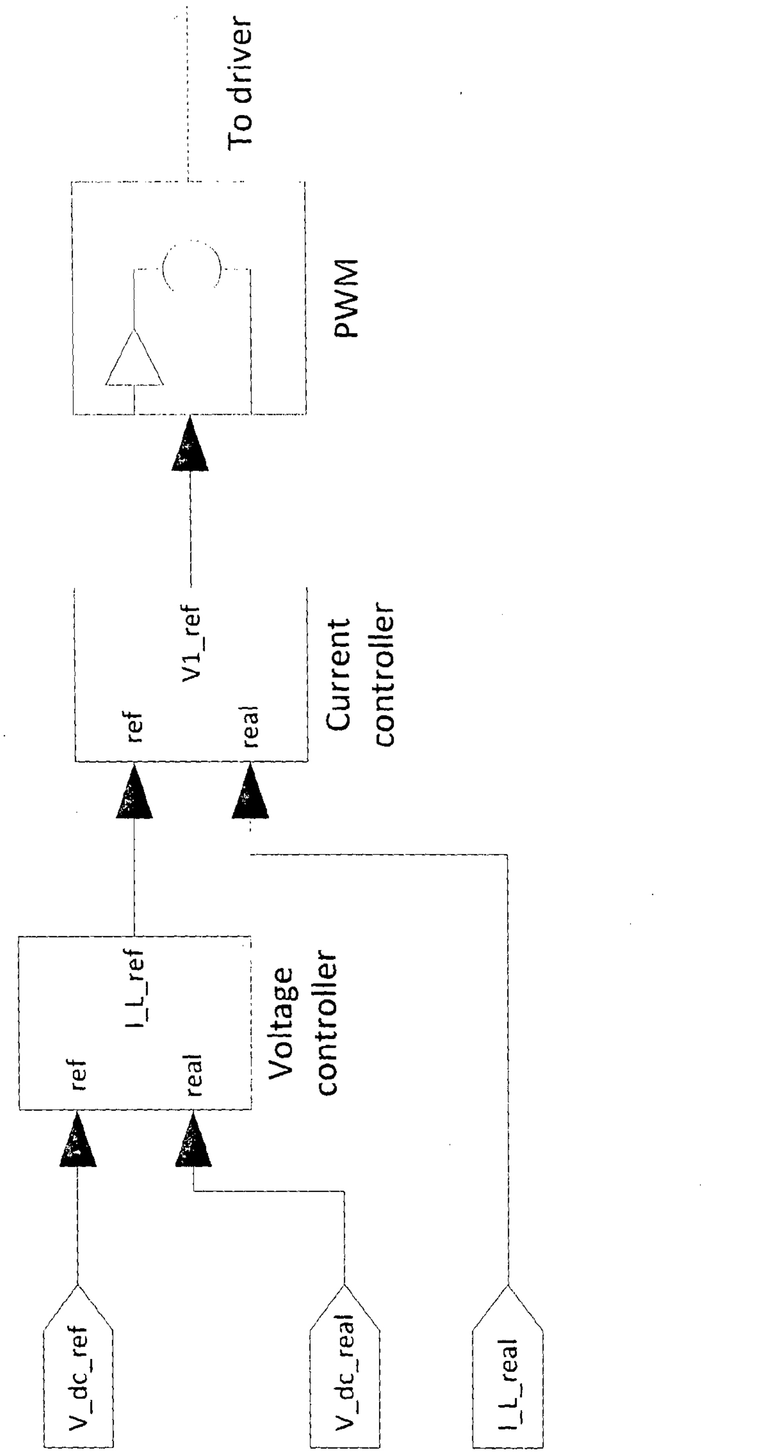


Figure: 2 Output Voltage and Current Control

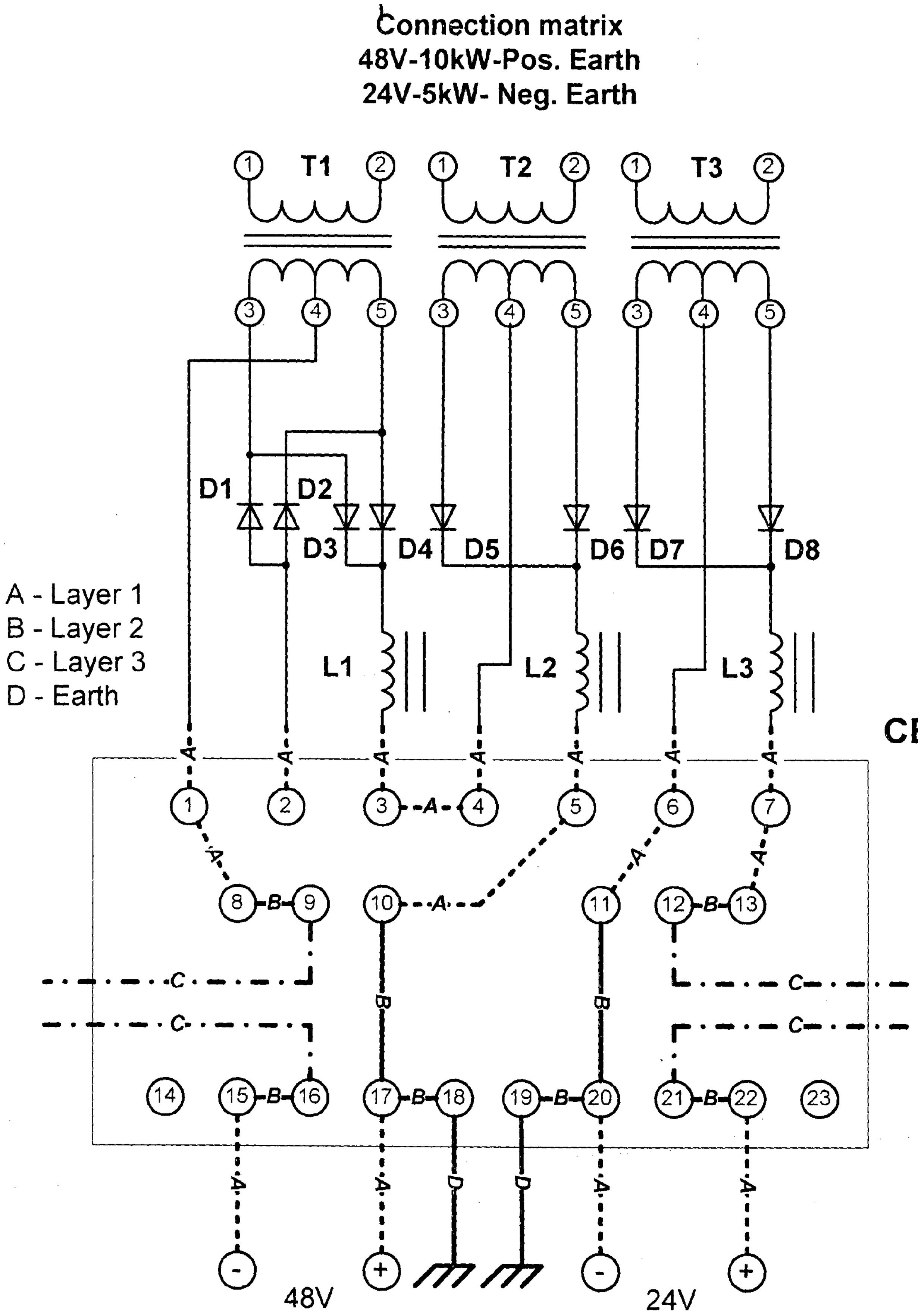

Connection matrix
48V-10kW-Pos. Earth
24V-5kW- Neg. Earth
T1
T2
T3
D1
D2
D3
D4
D5
D6
D7
D8
L1
L2
L3
A - Layer 1
B - Layer 2
C - Layer 3
D - Earth
CB
48V
24V

Figure. 3

Connection matrix
48V-10kW-Neg. Earth
24V-5kW- Pos. Earth

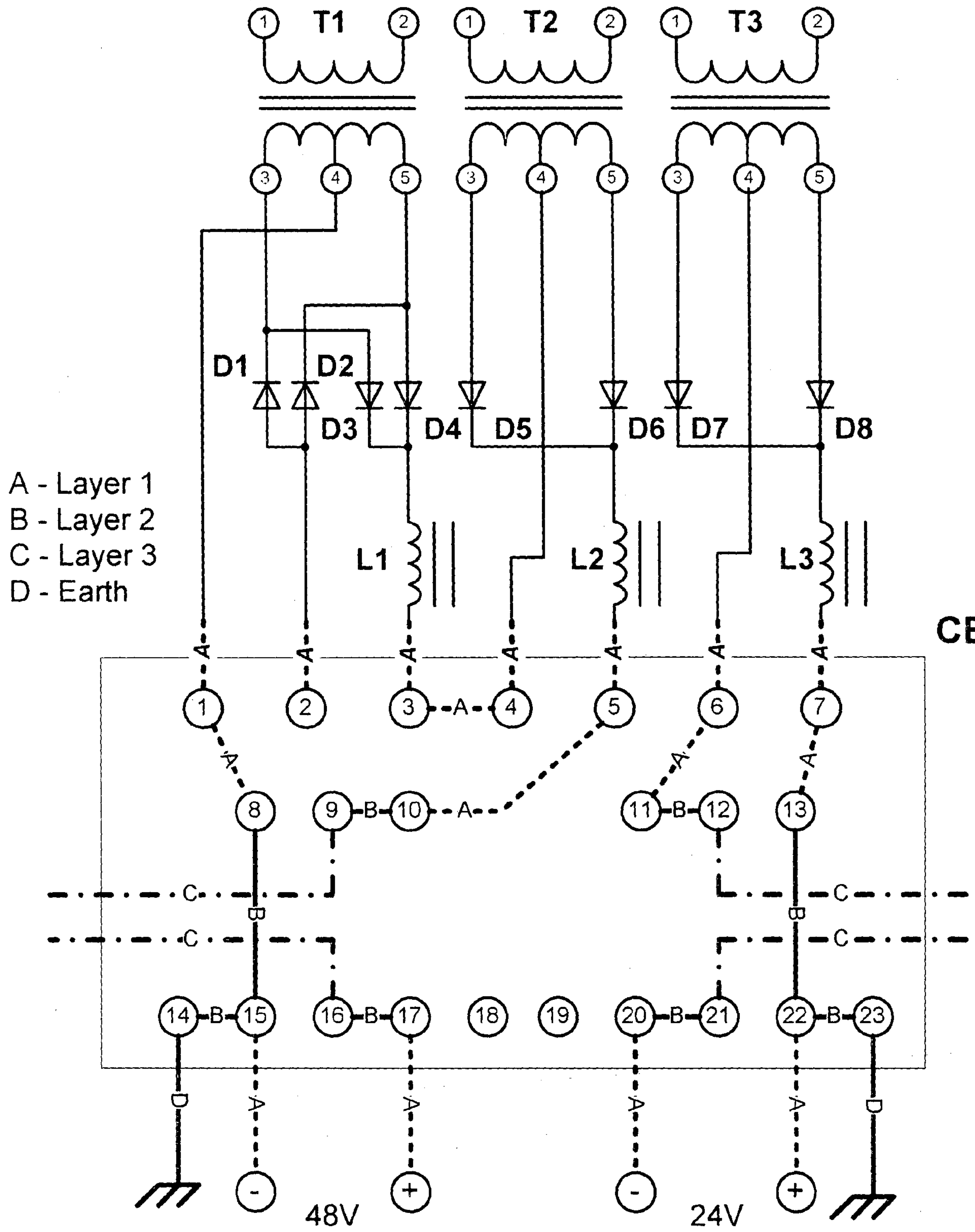


Figure. 4

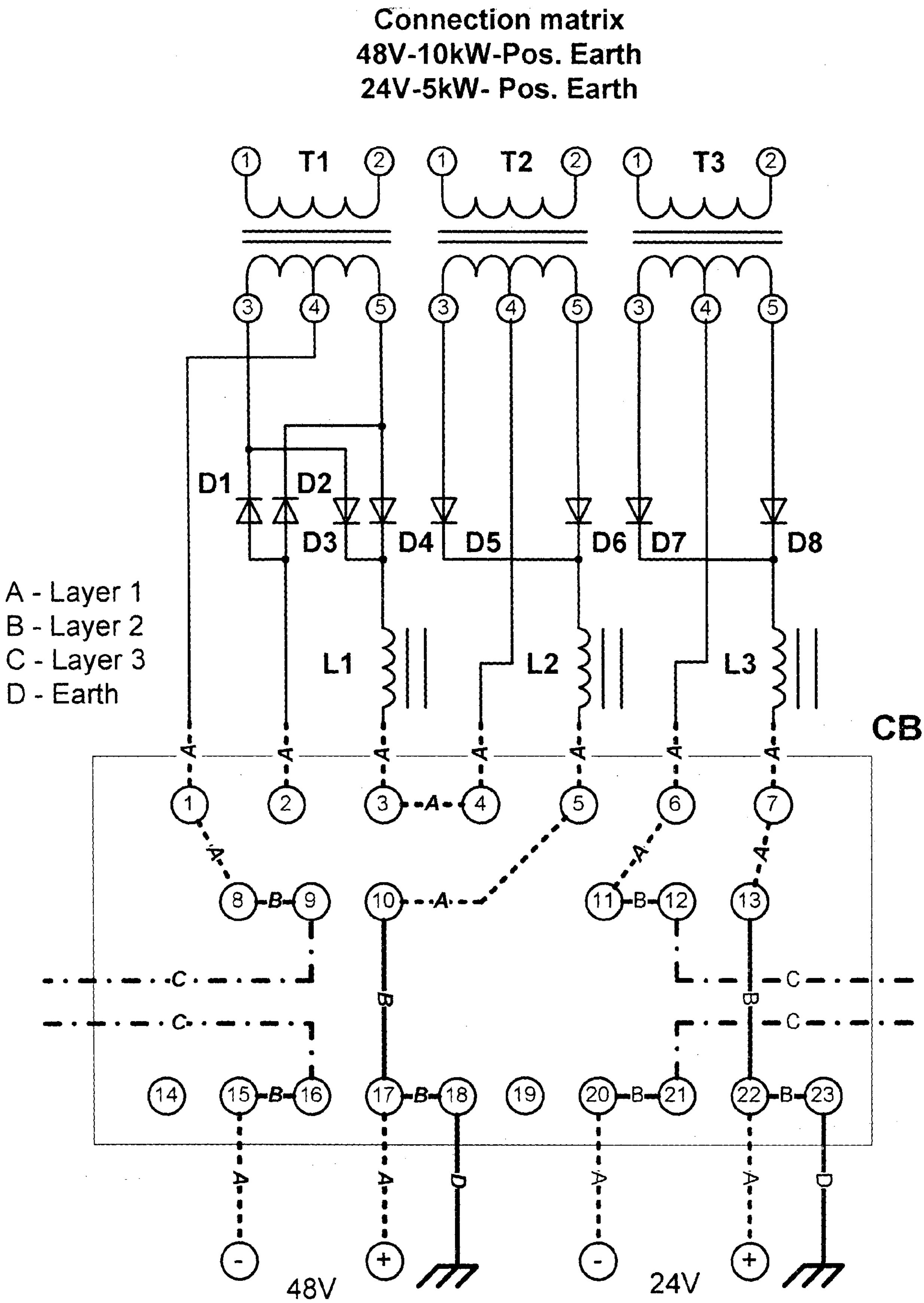

Connection matrix
48V-10kW-Pos. Earth
24V-5kW- Pos. Earth
T1
T2
T3
D1
D2
D3
D4
D5
D6
D7
D8
L1
L2
L3
CB
A - Layer 1
B - Layer 2
C - Layer 3
D - Earth
48V
24V

Figure. 5

Connection matrix
48V-10kW-Neg. Earth
24V-5kW- Neg. Earth

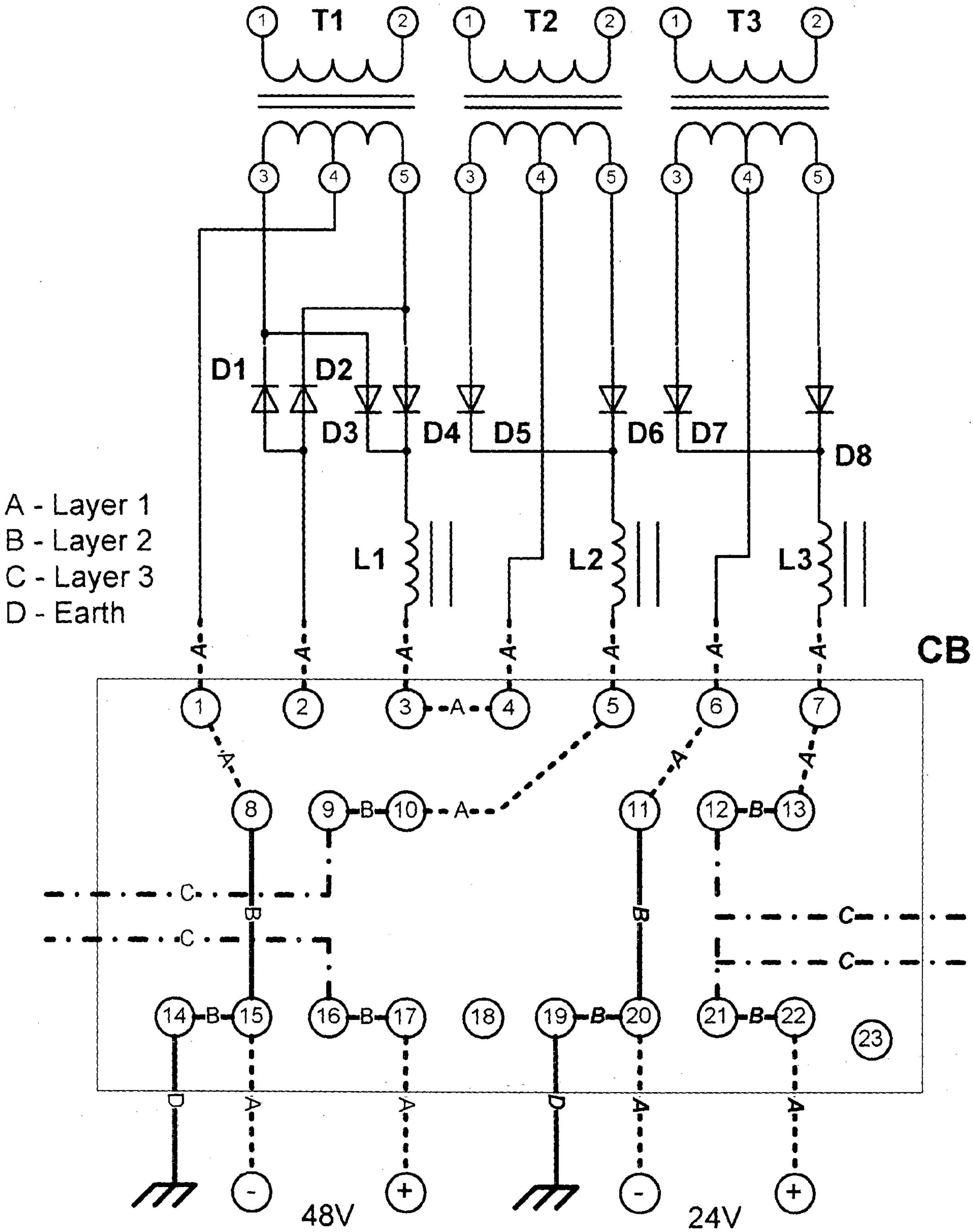


Figure. 6

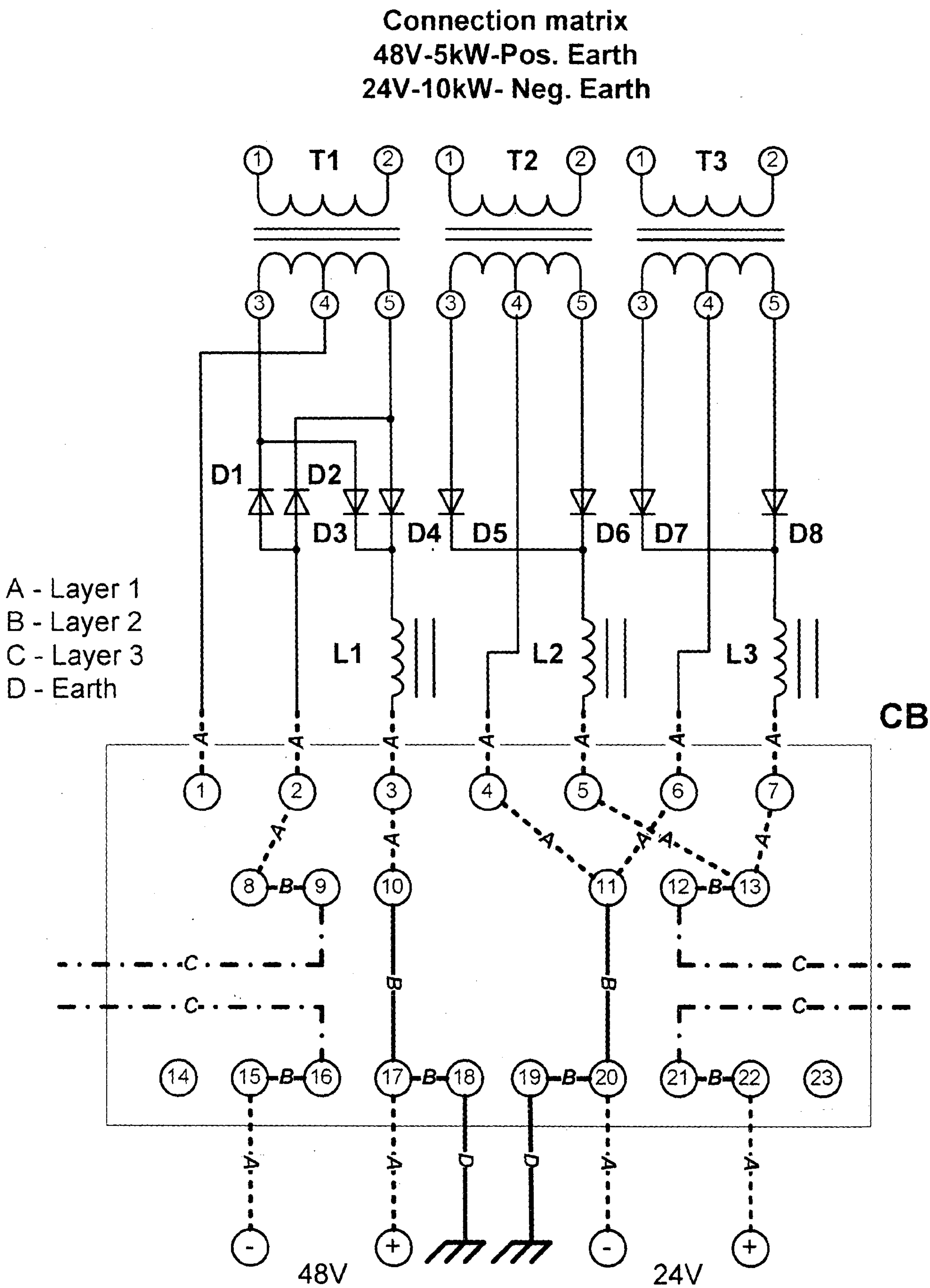

Connection matrix
48V-5kW-Pos. Earth
24V-10kW- Neg. Earth
T1
T2
T3
D1
D2
D3
D4
D5
D6
D7
D8
L1
L2
L3
A - Layer 1
B - Layer 2
C - Layer 3
D - Earth
CB
48V
24V

Figure. 7

Connection matrix
48V-5kW-Neg. Earth
24V-10kW- Pos. Earth

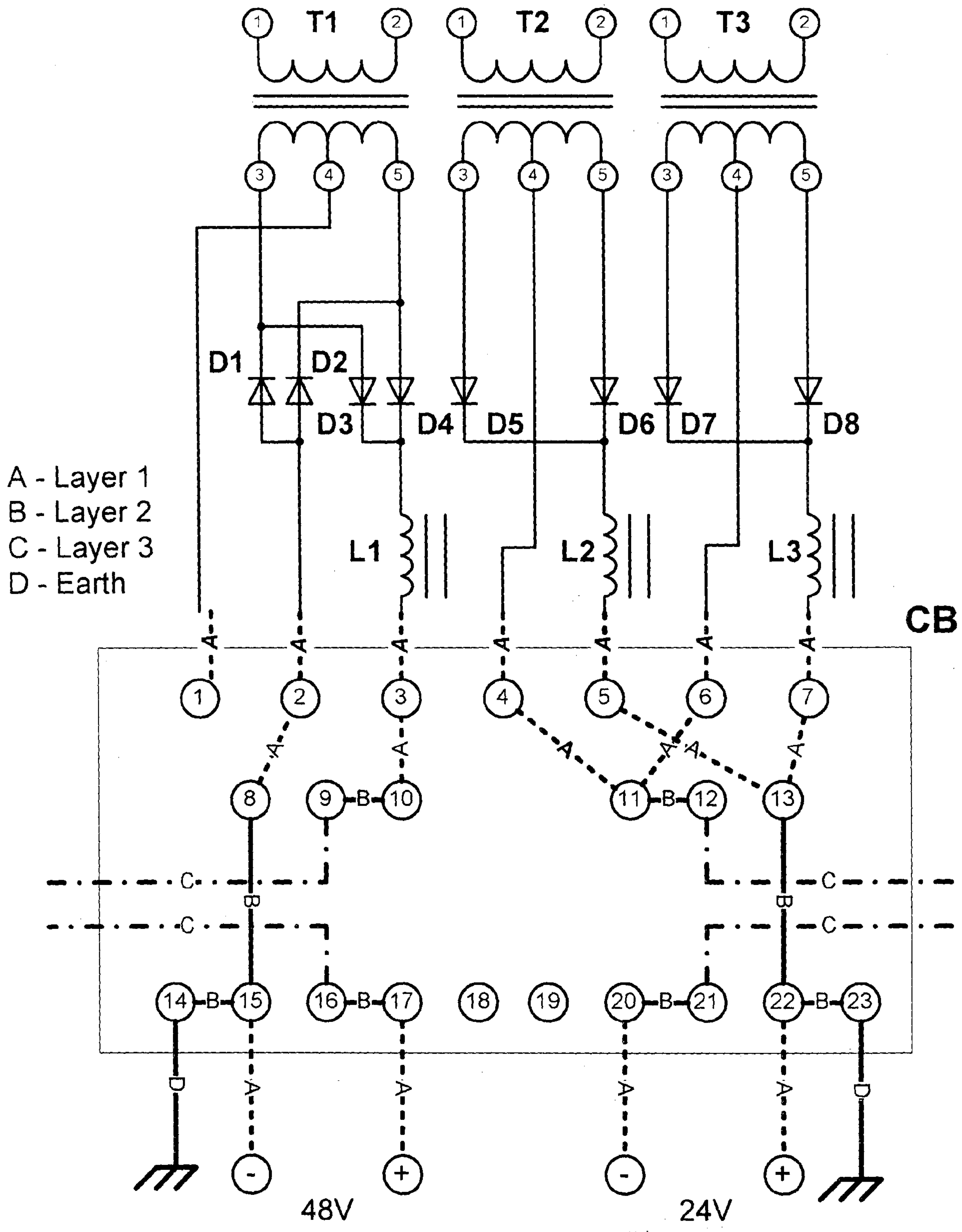


Figure. 8

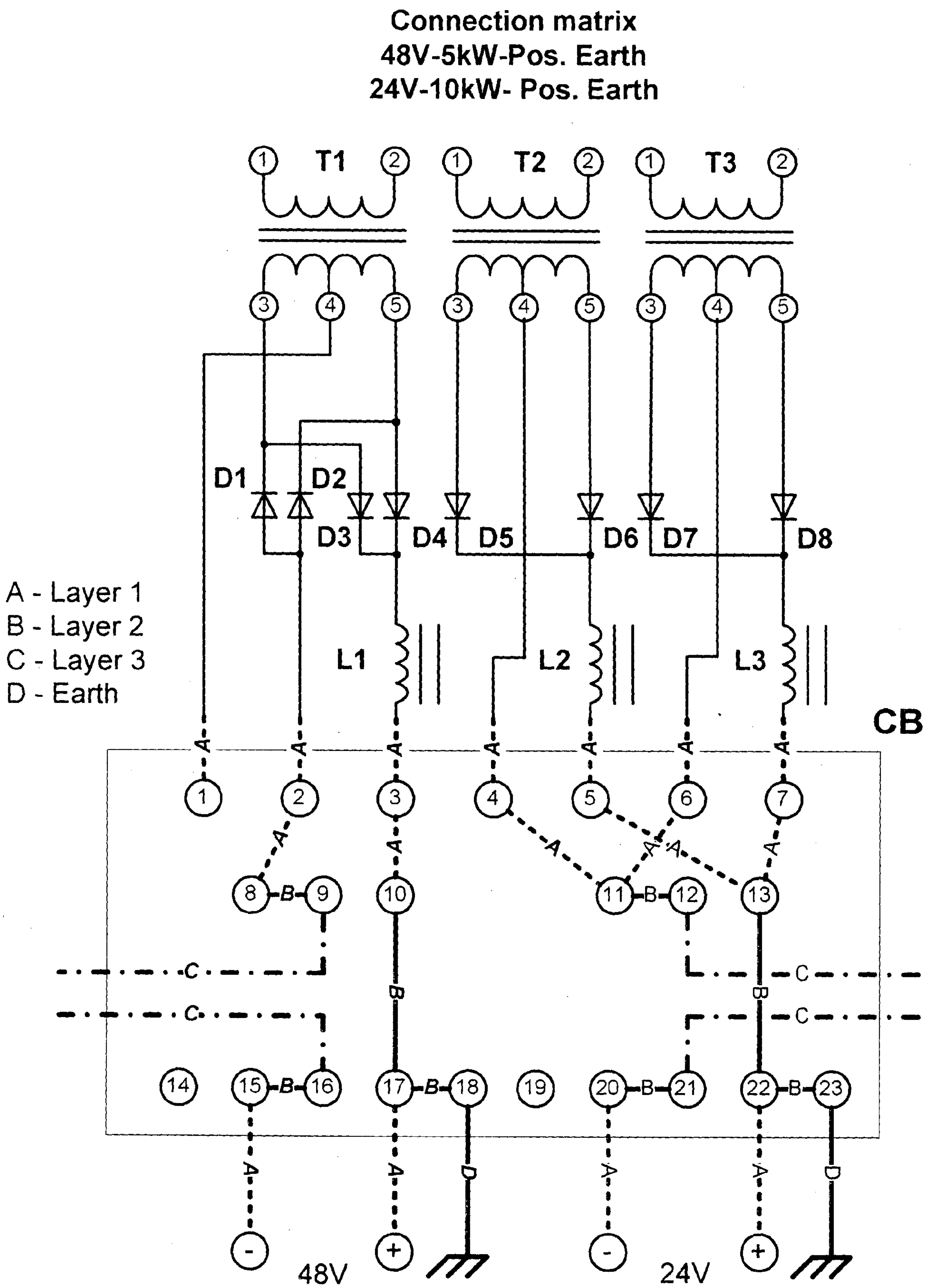

Connection matrix
48V-5kW-Pos. Earth
24V-10kW- Pos. Earth
T1
T2
T3
D1
D2
D3
D4
D5
D6
D7
D8
L1
L2
L3
A - Layer 1
B - Layer 2
C - Layer 3
D - Earth
CB
48V
24V

Figure. 9

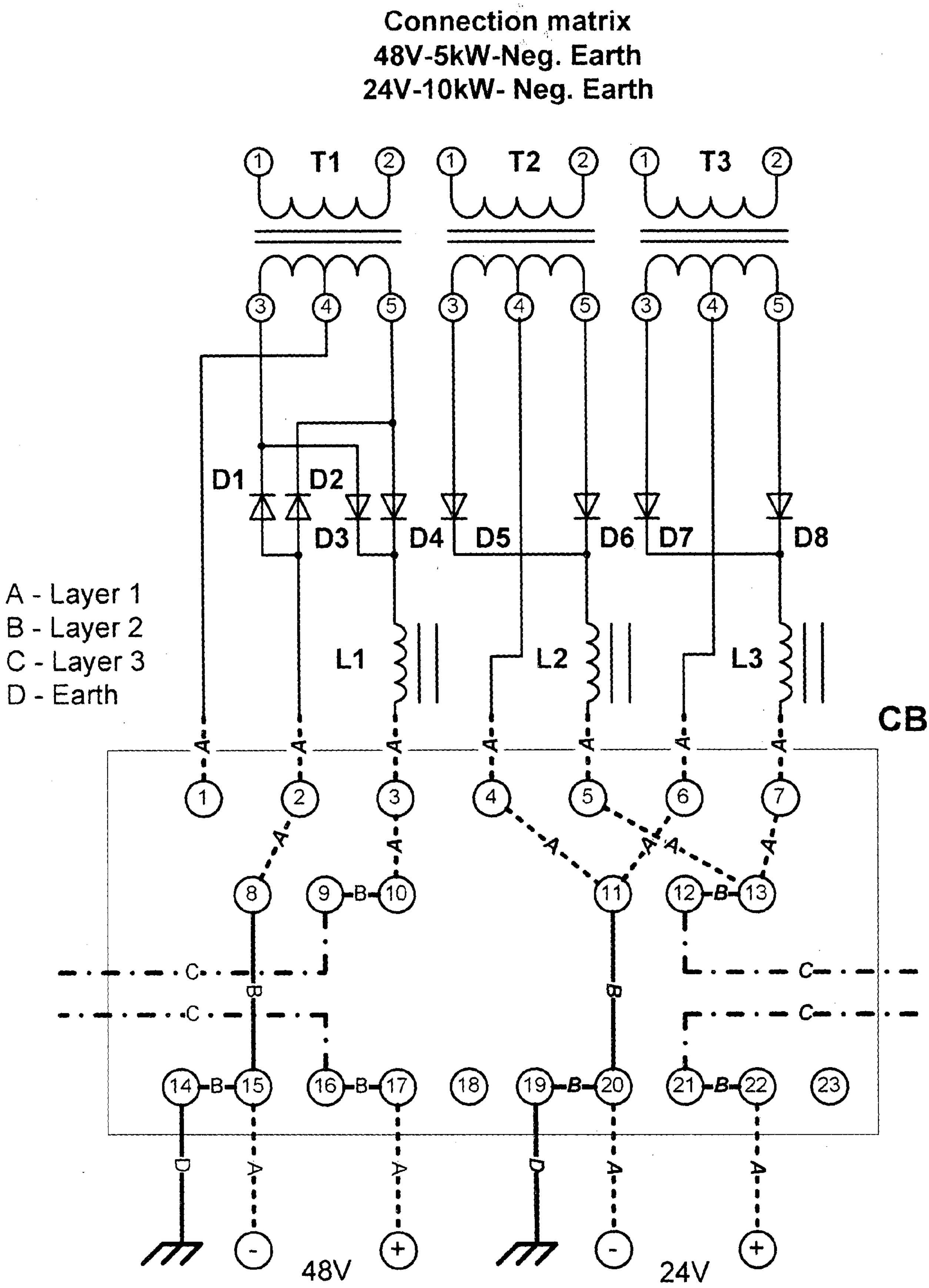

Connection matrix
48V-5kW-Neg. Earth
24V-10kW- Neg. Earth
T1
T2
T3
D1
D2
D3
D4
D5
D6
D7
D8
L1
L2
L3
A - Layer 1
B - Layer 2
C - Layer 3
D - Earth
CB
48V
24V

Figure. 10

ITEM NO.	DESCRIPTION
1	CONTACTOR PLATE
2	24V NEG EARTH
3	24V POS EARTH
4	24-10 PLUS 48-5
5	48-10 PLUS 24-5
6	48V POS EARTH
7	48V NEG EARTH
8	COVER PLATE
9	BASE EARTH PLATE

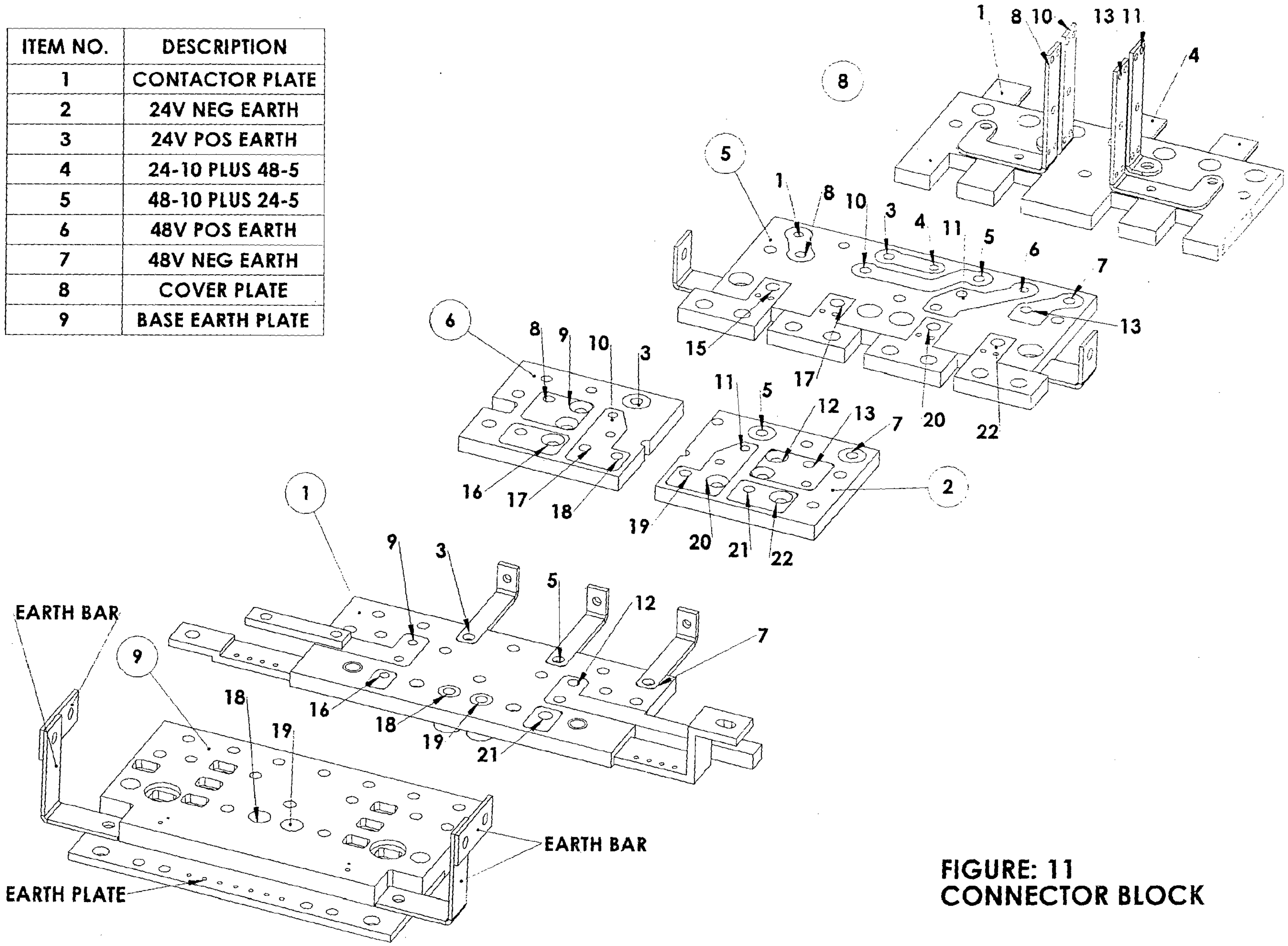


FIGURE: 11
CONNECTOR BLOCK

ITEM NO.	DESCRIPTION
1	CONTACTOR PLATE
2	24V NEG EARTH
3	24V POS EARTH
4	24-10 PLUS 48-5
5	48-10 PLUS 24-5
6	48V POS EARTH
7	48V NEG EARTH
8	COVER PLATE
9	BASE EARTH PLATE

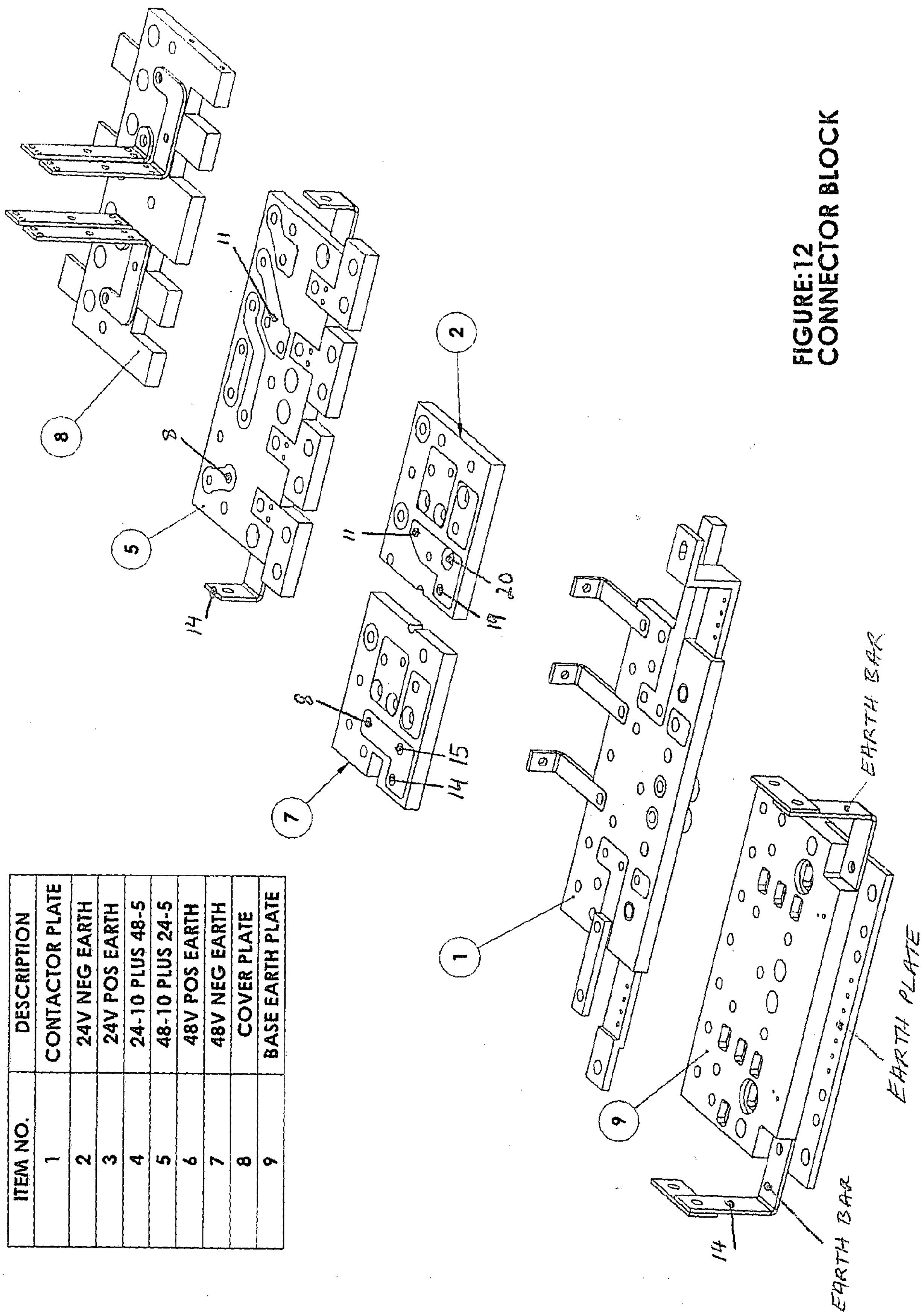


FIGURE:12
CONNECTOR BLOCK

ITEM NO.	DESCRIPTION
1	CONTACTOR PLATE
2	24V NEG EARTH
3	24V POS EARTH
4	24-10 PLUS 48-5
5	48-10 PLUS 24-5
6	48V POS EARTH
7	48V NEG EARTH
8	COVER PLATE
9	BASE EARTH PLATE

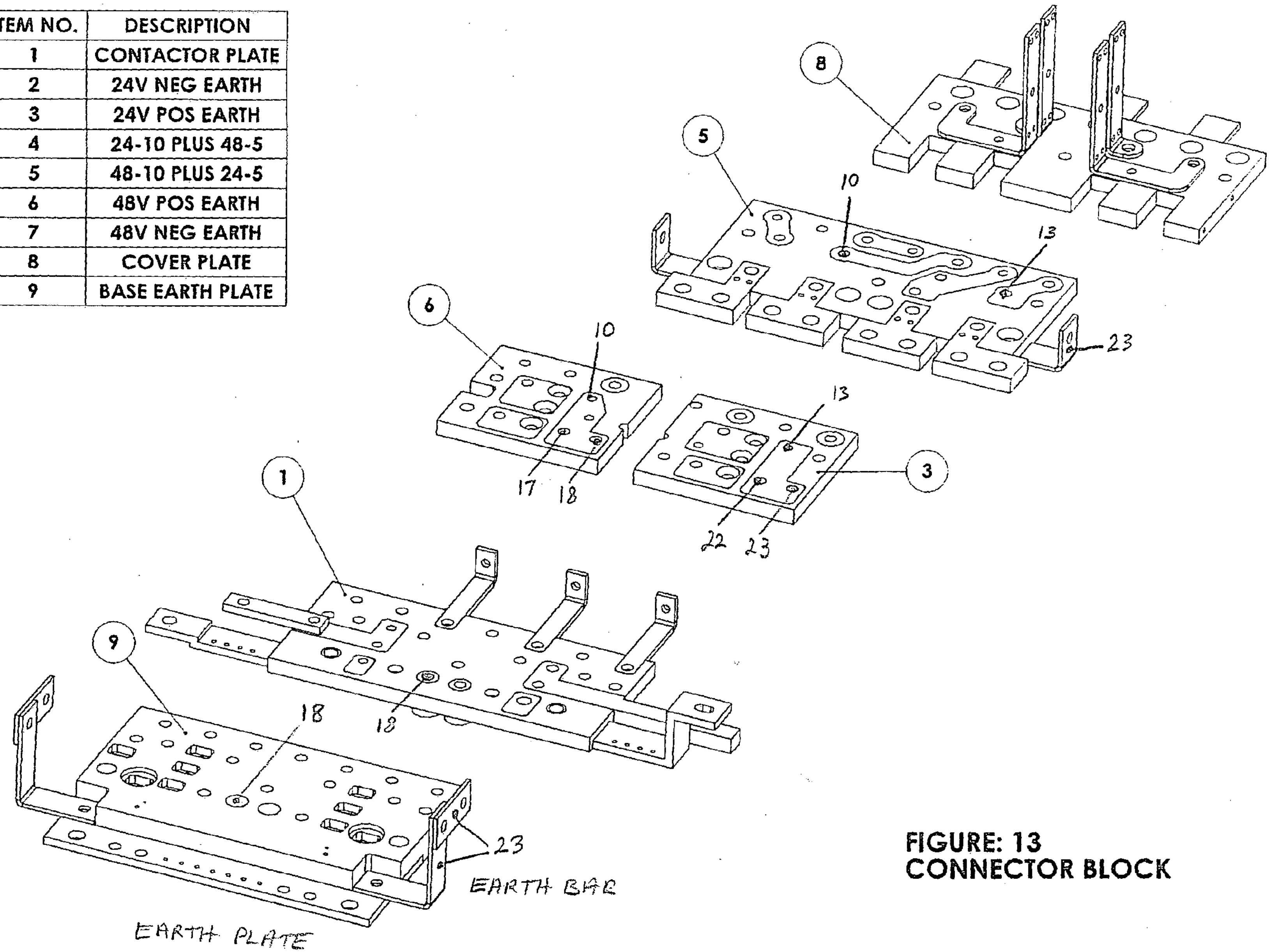


FIGURE: 13
CONNECTOR BLOCK

ITEM NO.	DESCRIPTION
1	CONTACTOR PLATE
2	24V NEG EARTH
3	24V POS EARTH
4	24-10 PLUS 48-5
5	48-10 PLUS 24-5
6	48V POS EARTH
7	48V NEG EARTH
8	COVER PLATE
9	BASE EARTH PLATE

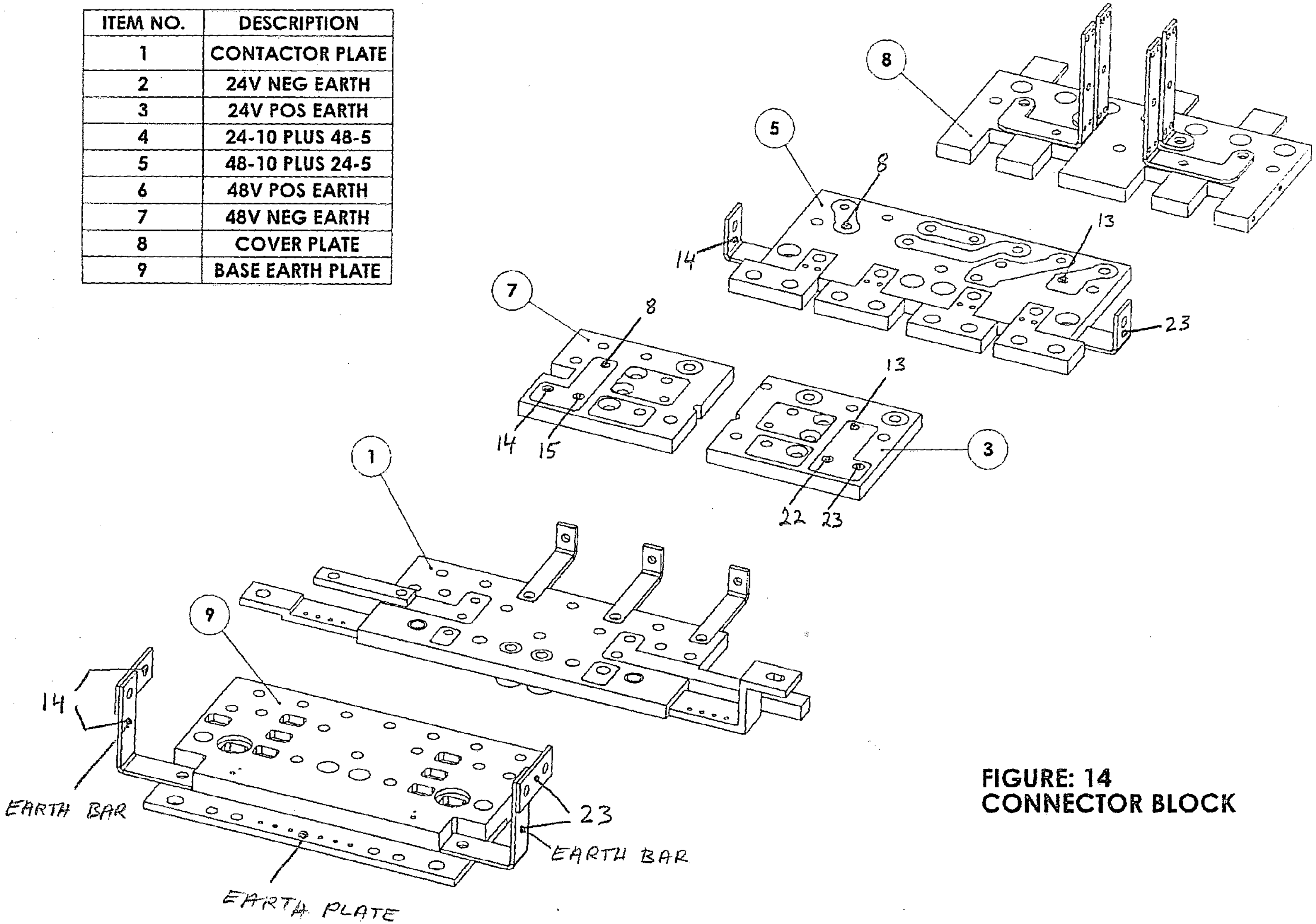


FIGURE: 14
CONNECTOR BLOCK

ITEM NO.	DESCRIPTION
1	CONTACTOR PLATE
2	24V NEG EARTH
3	24V POS EARTH
4	24-10 PLUS 48-5
5	48-10 PLUS 24-5
6	48V POS EARTH
7	48V NEG EARTH
8	COVER PLATE
9	BASE EARTH PLATE

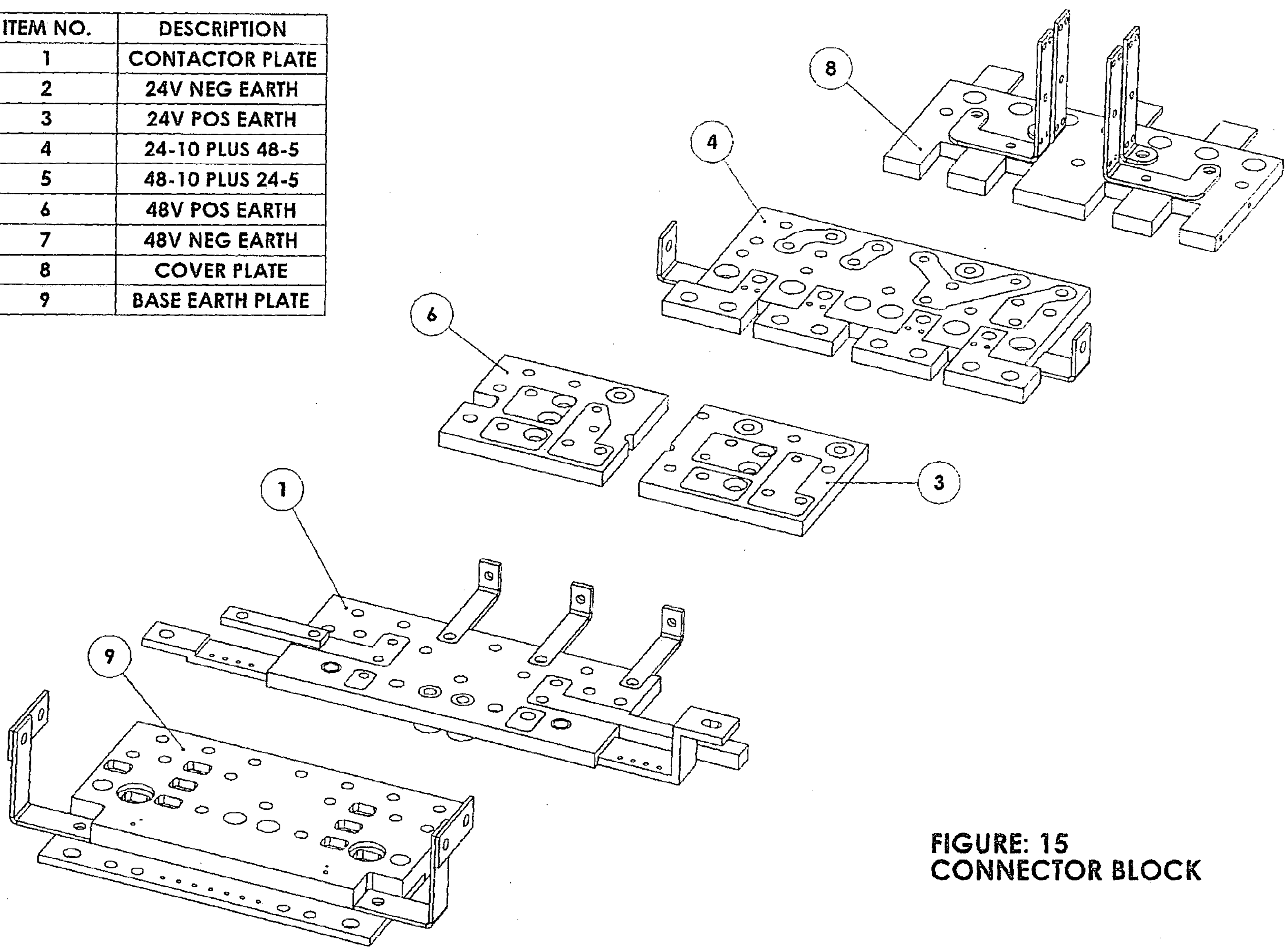


FIGURE: 15
CONNECTOR BLOCK

ITEM NO.	DESCRIPTION
1	CONTACTOR PLATE
2	24V NEG EARTH
3	24V POS EARTH
4	24-10 PLUS 48-5
5	48-10 PLUS 24-5
6	48V POS EARTH
7	48V NEG EARTH
8	COVER PLATE
9	BASE EARTH PLATE

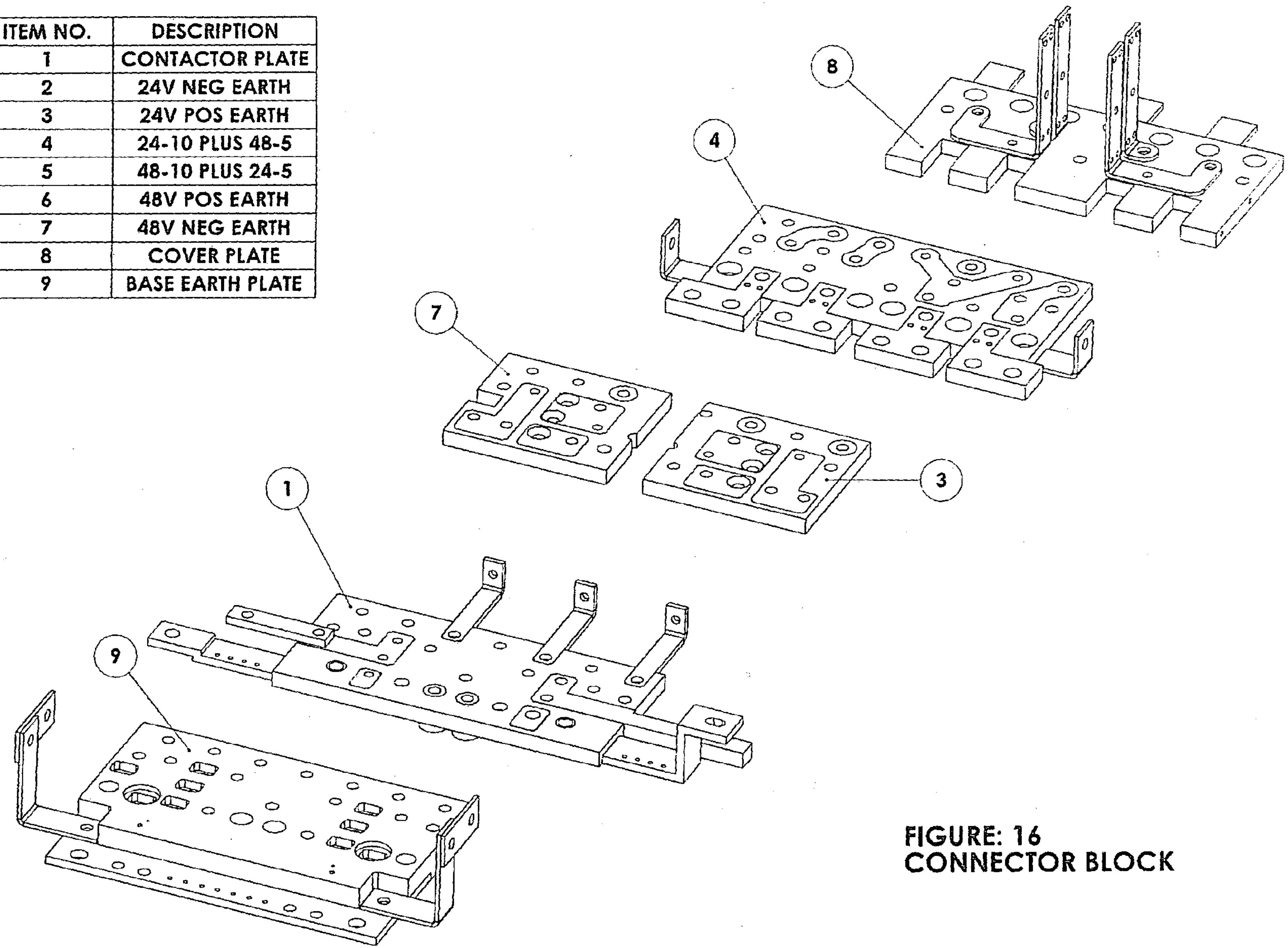
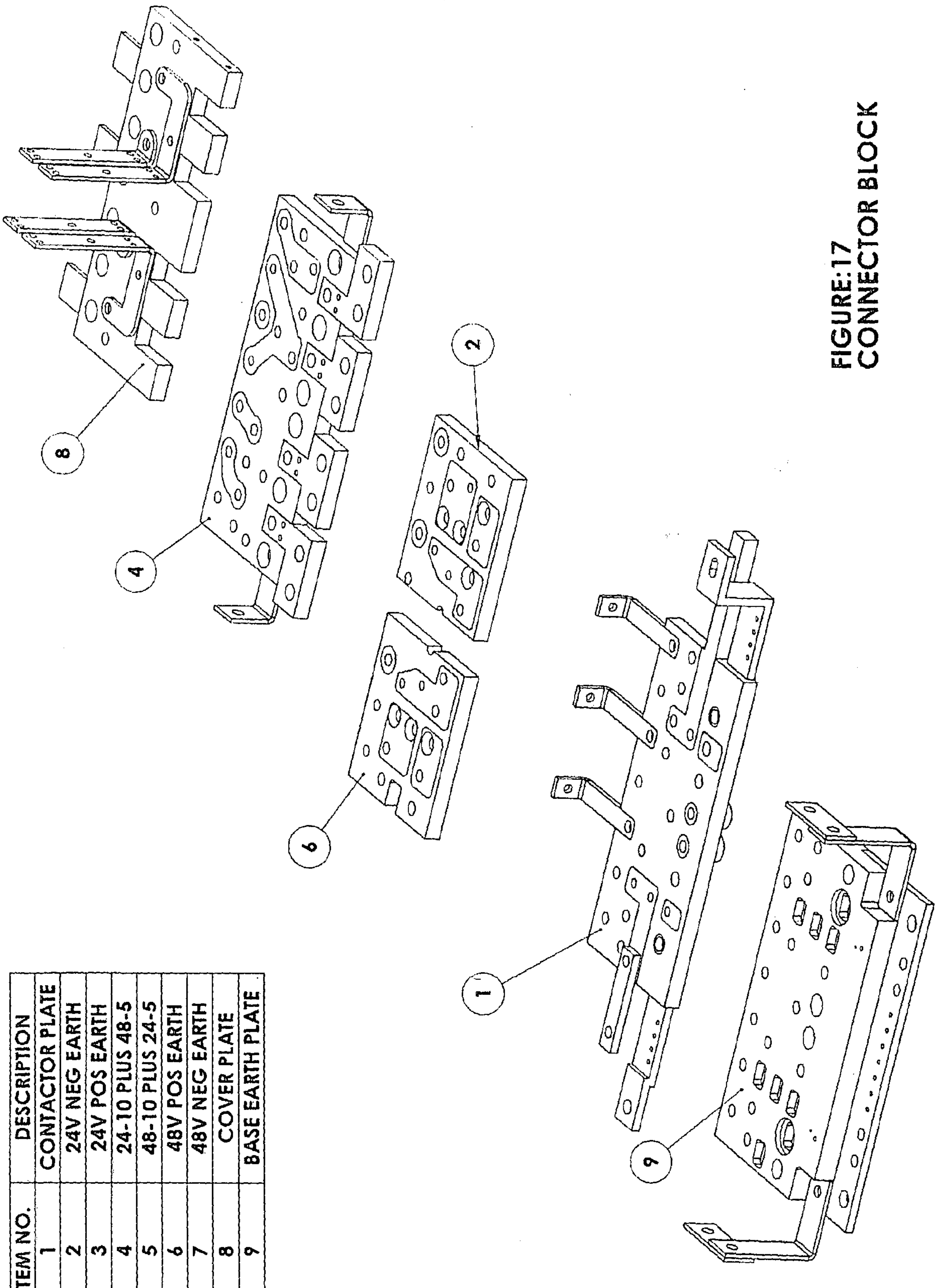


FIGURE: 16
CONNECTOR BLOCK



ITEM NO.	DESCRIPTION
1	CONTACTOR PLATE
2	24V NEG EARTH
3	24V POS EARTH
4	24-10 PLUS 48-5
5	48-10 PLUS 24-5
6	48V POS EARTH
7	48V NEG EARTH
8	COVER PLATE
9	BASE EARTH PLATE

FIGURE:17
CONNECTOR BLOCK

ITEM NO.	DESCRIPTION
1	CONTACTOR PLATE
2	24V NEG EARTH
3	24V POS EARTH
4	24-10 PLUS 48-5
5	48-10 PLUS 24-5
6	48V POS EARTH
7	48V NEG EARTH
8	COVER PLATE
9	BASE EARTH PLATE

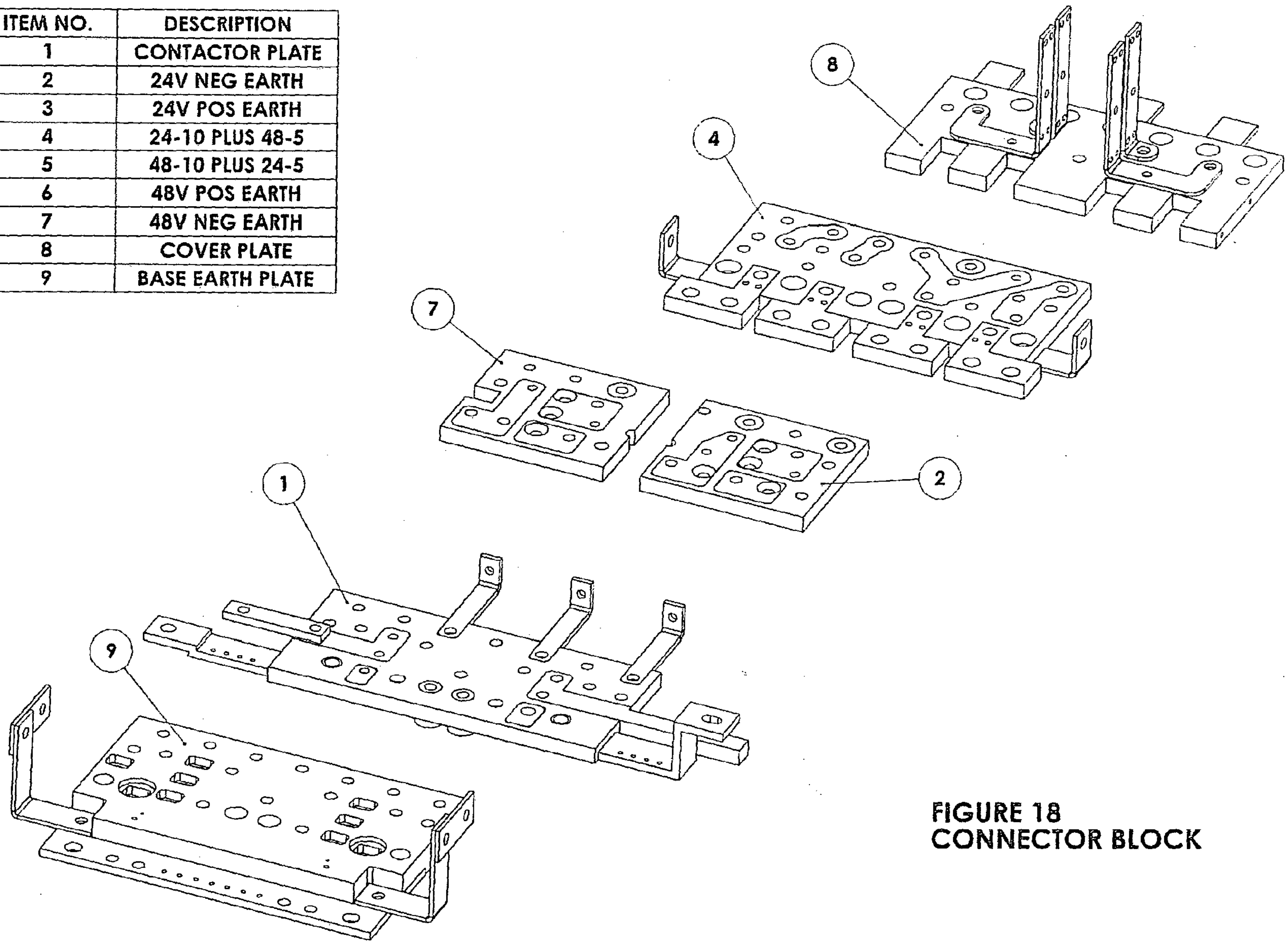
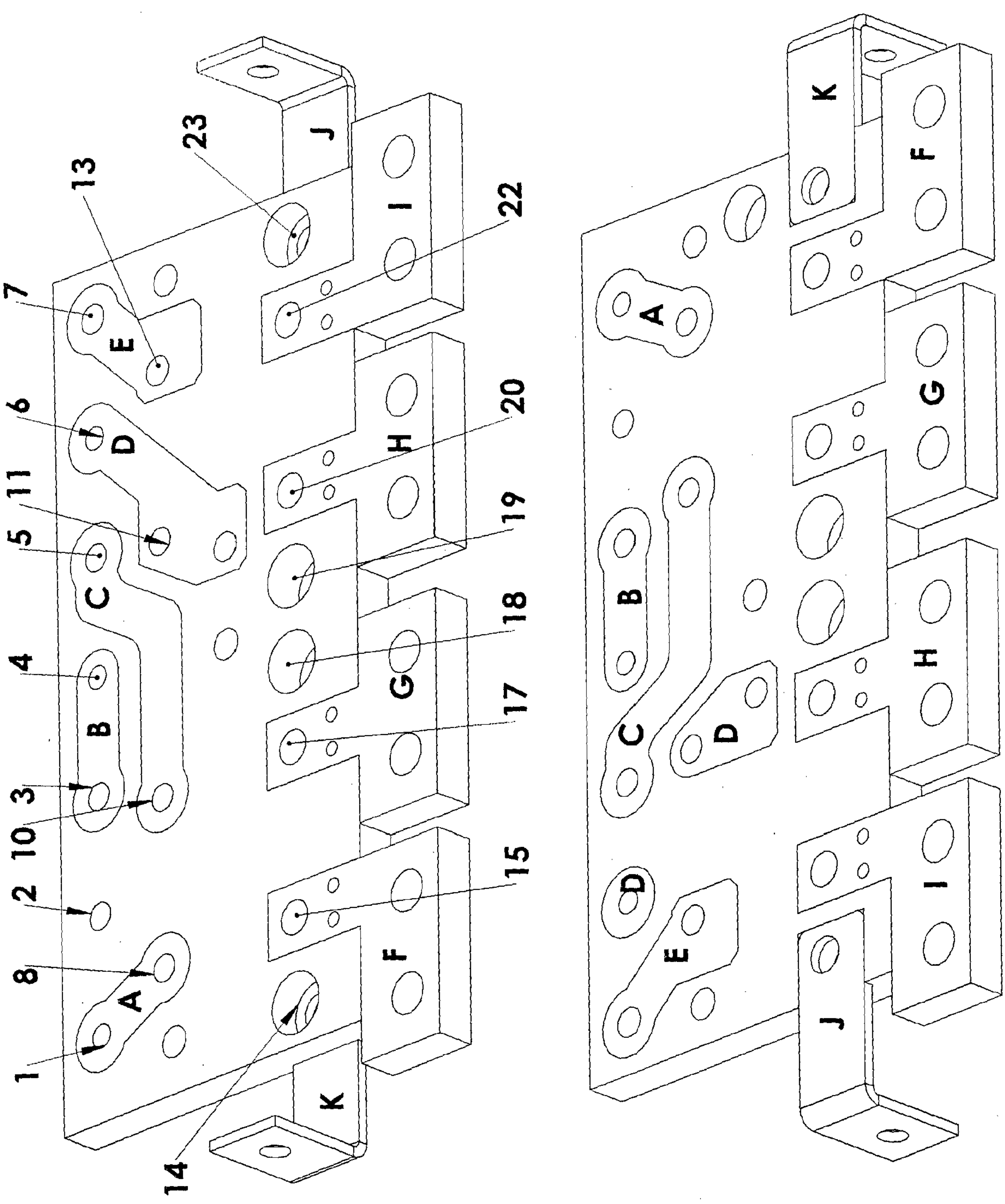


FIGURE 18
CONNECTOR BLOCK

FIGURE: 19A
ITEM 5



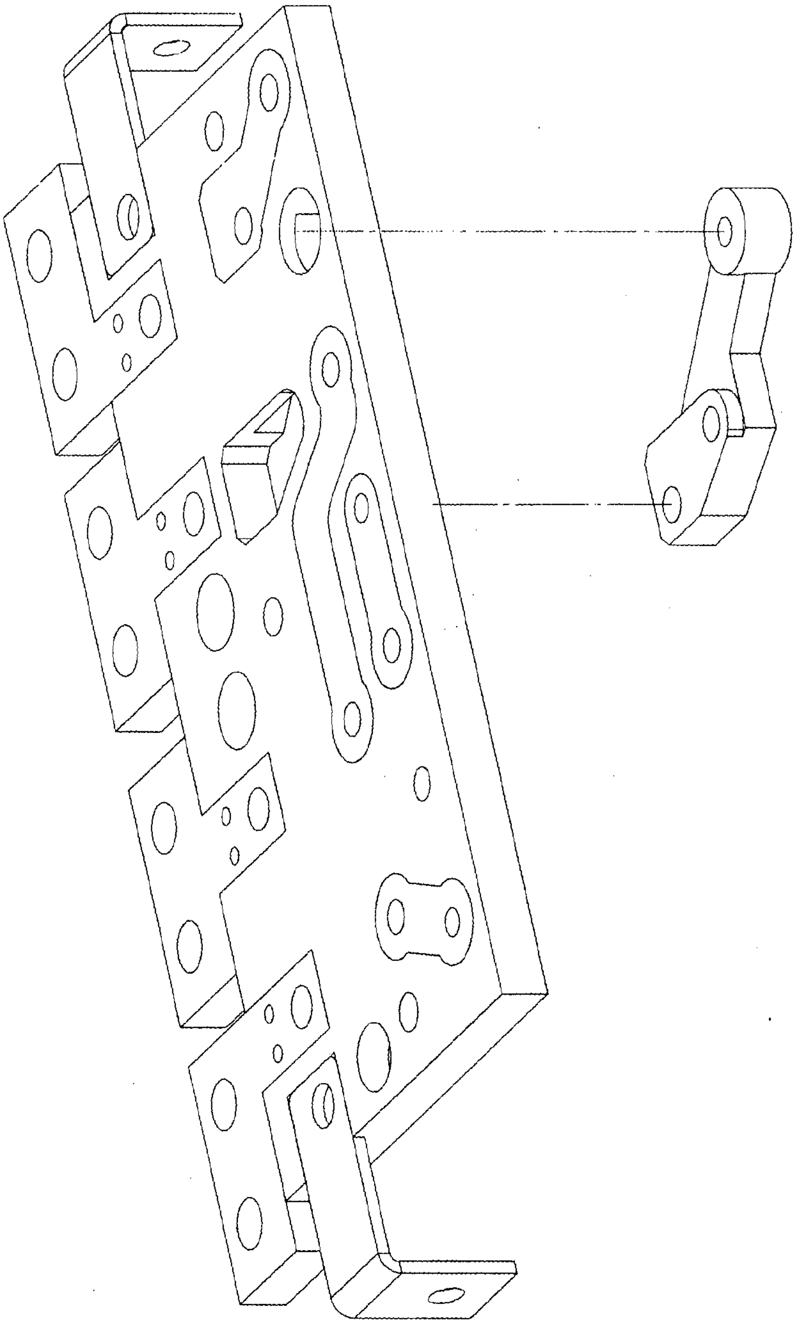


FIGURE: 19B
ITEM 5

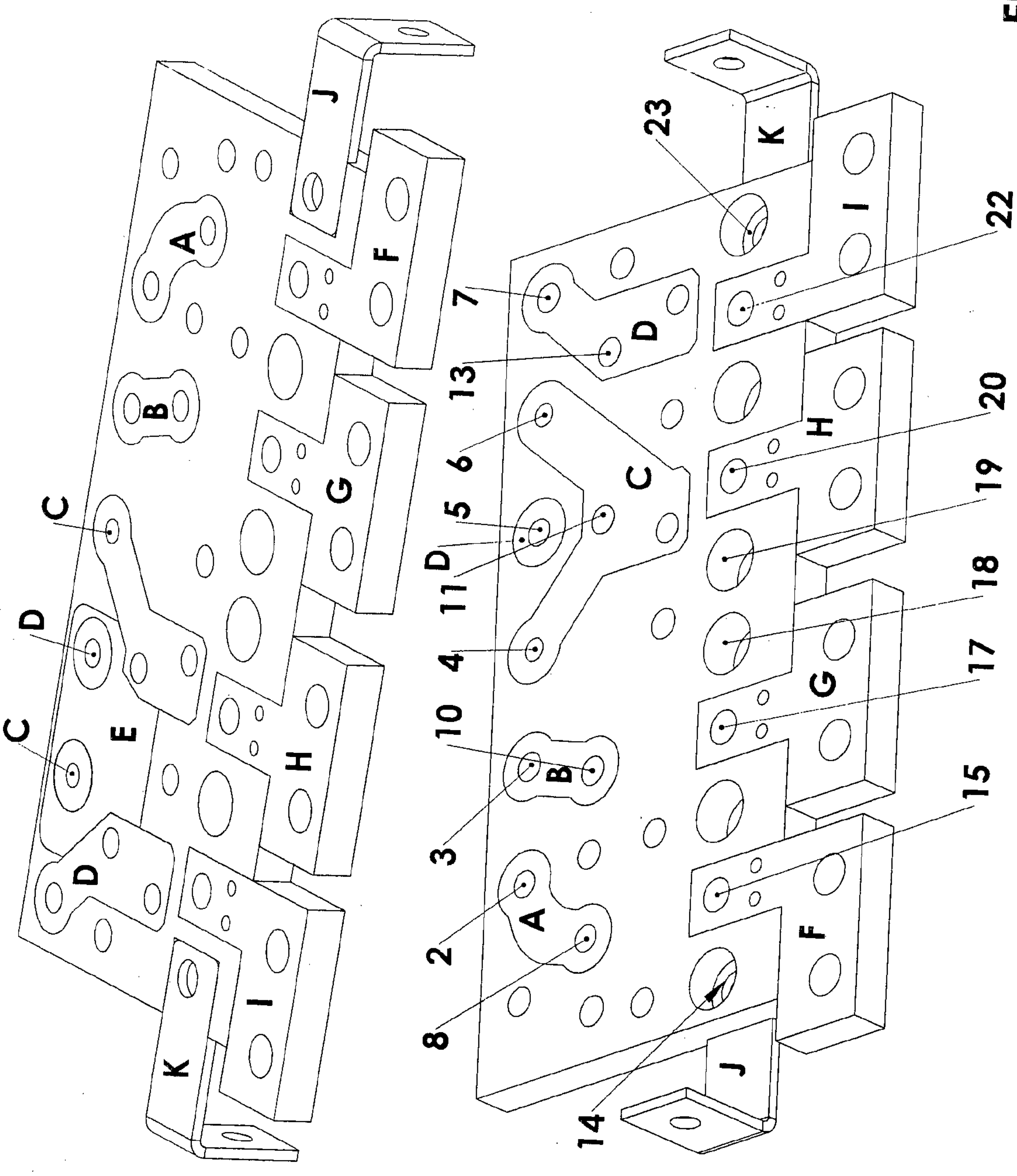


FIGURE: 20A
ITEM 4

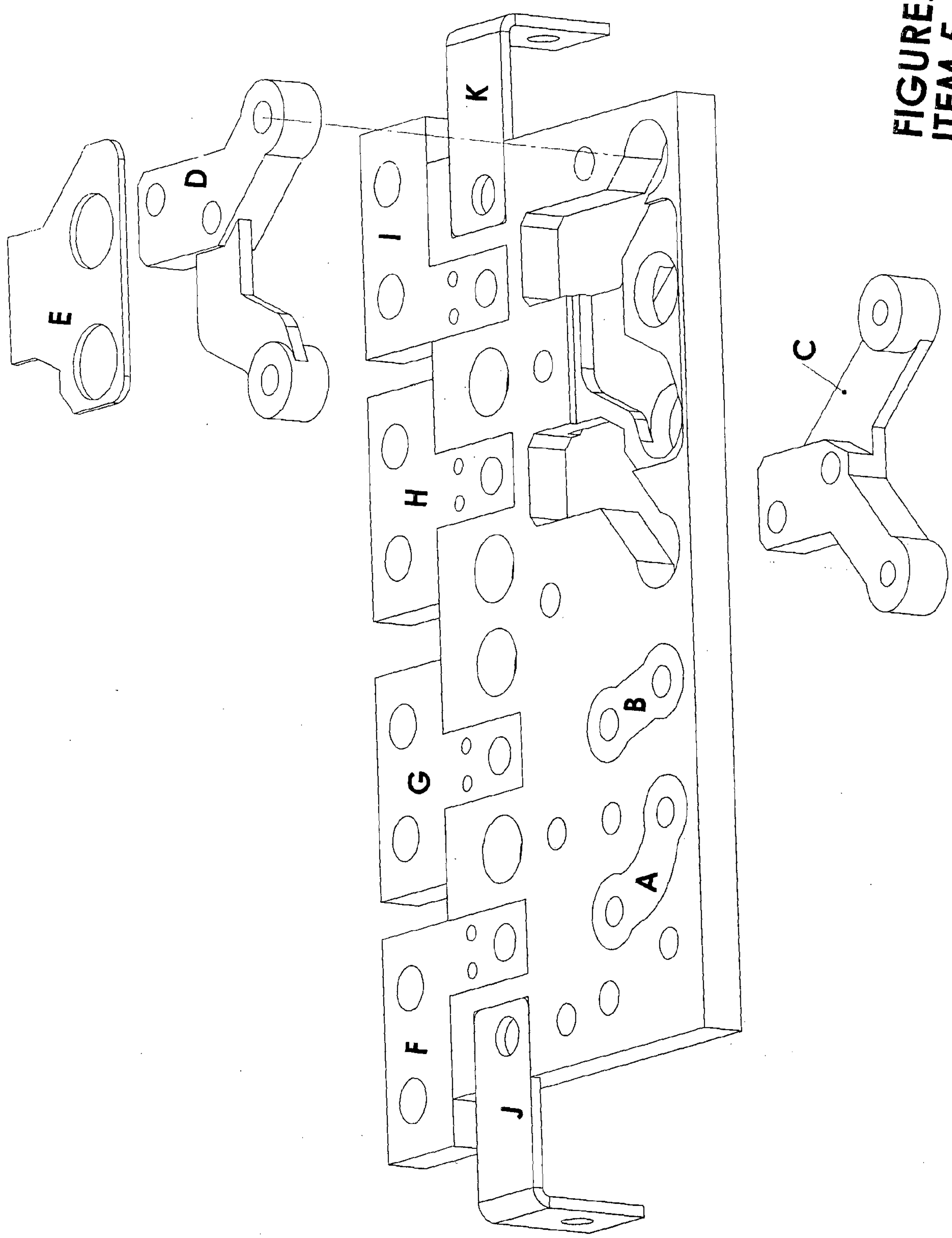


FIGURE: 20B
ITEM 5

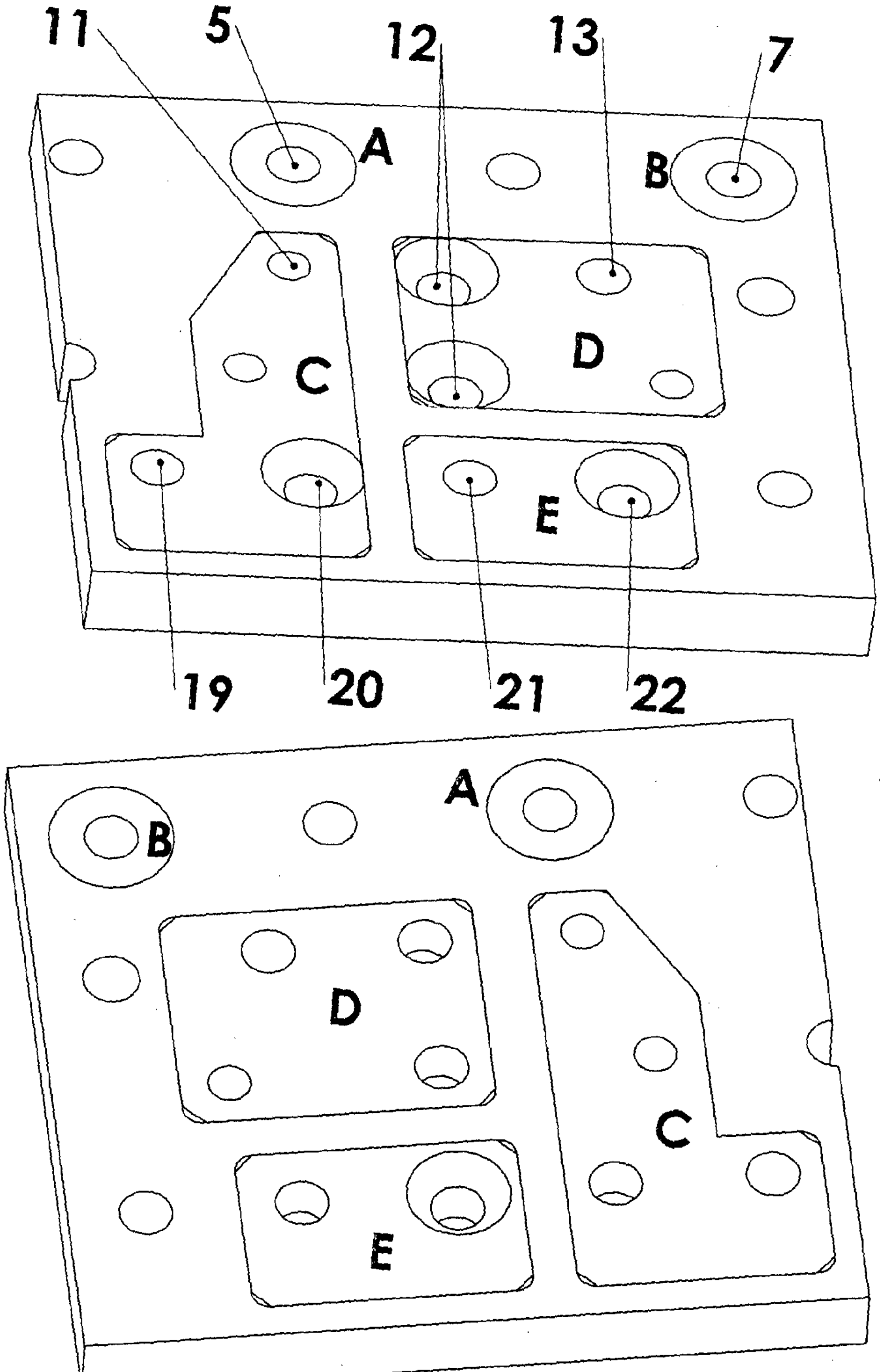
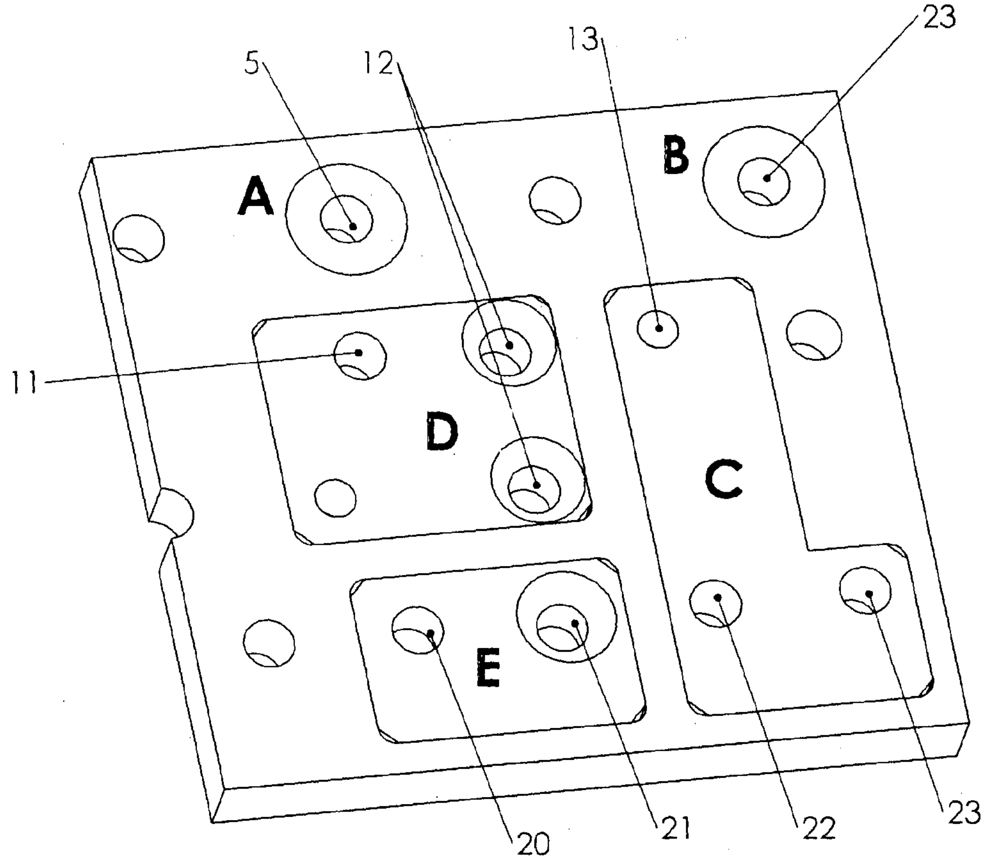


FIGURE: 21
ITEM 2 24V NEG EARTH



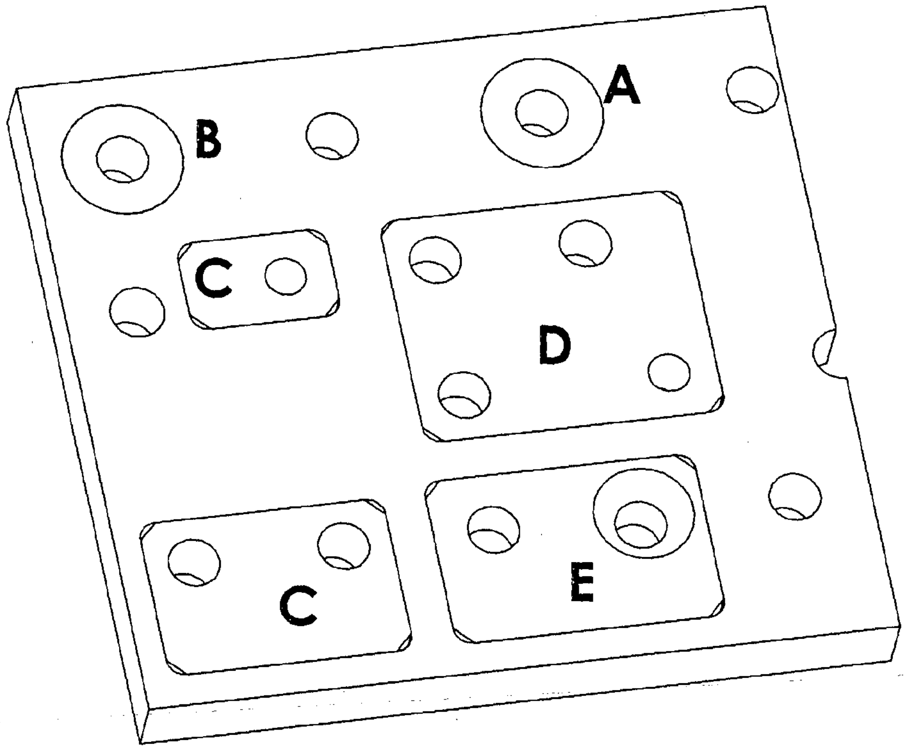


FIGURE: 22A
ITEM 3 24V POS EARTH

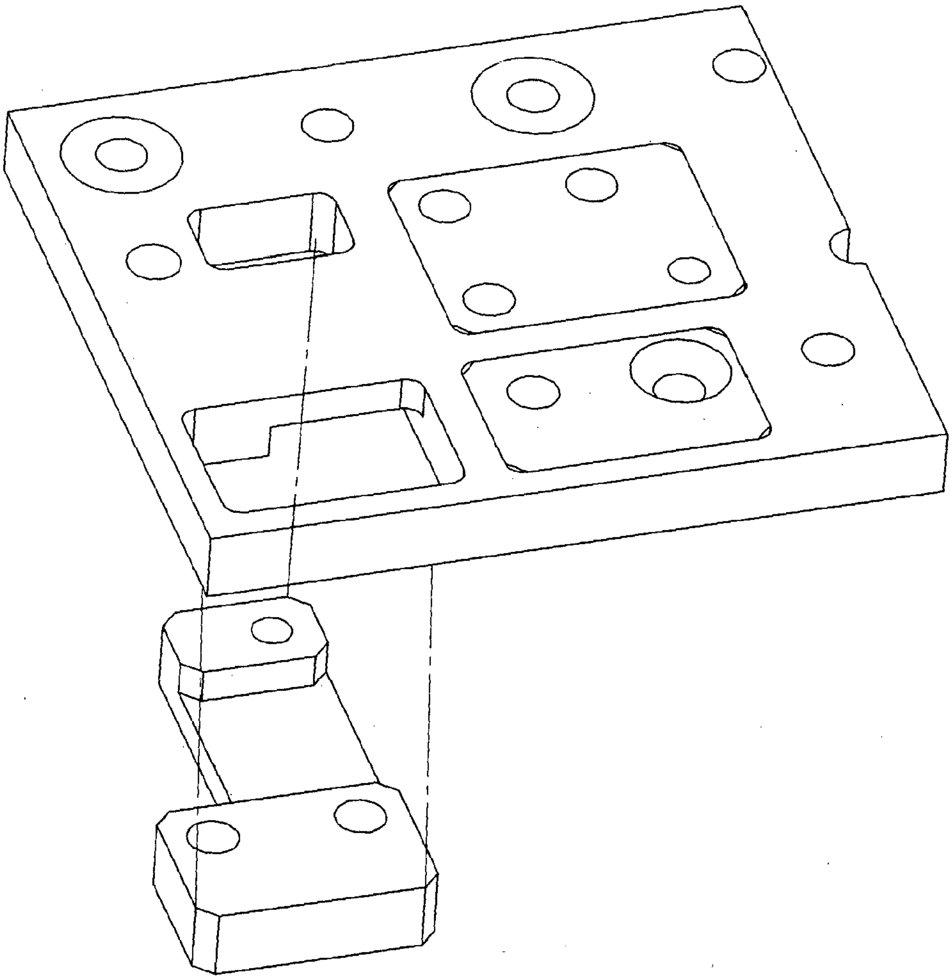


FIGURE: 22B
ITEM 3 24V POS EARTH

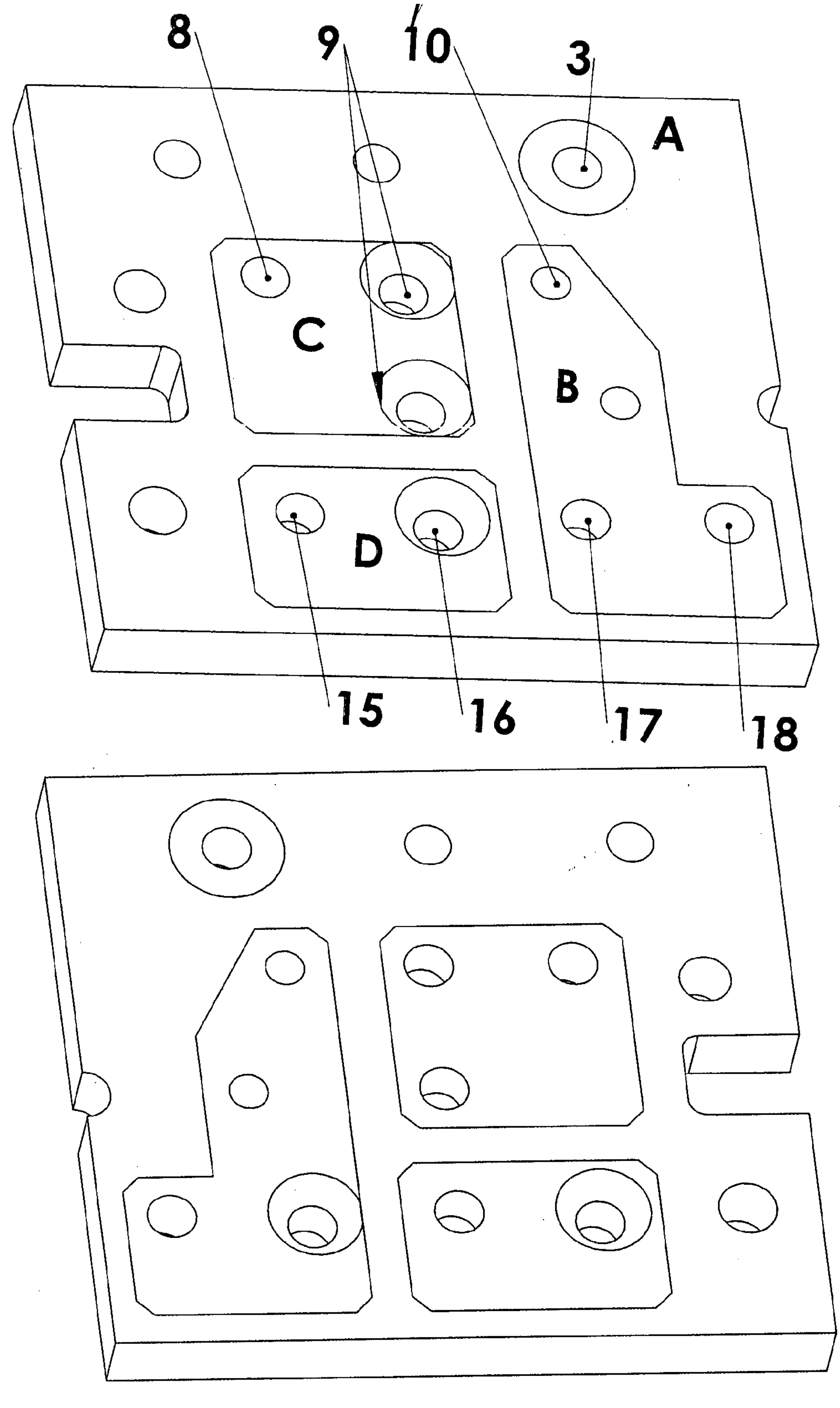


FIGURE: 23
ITEM 6 48V POS EARTH

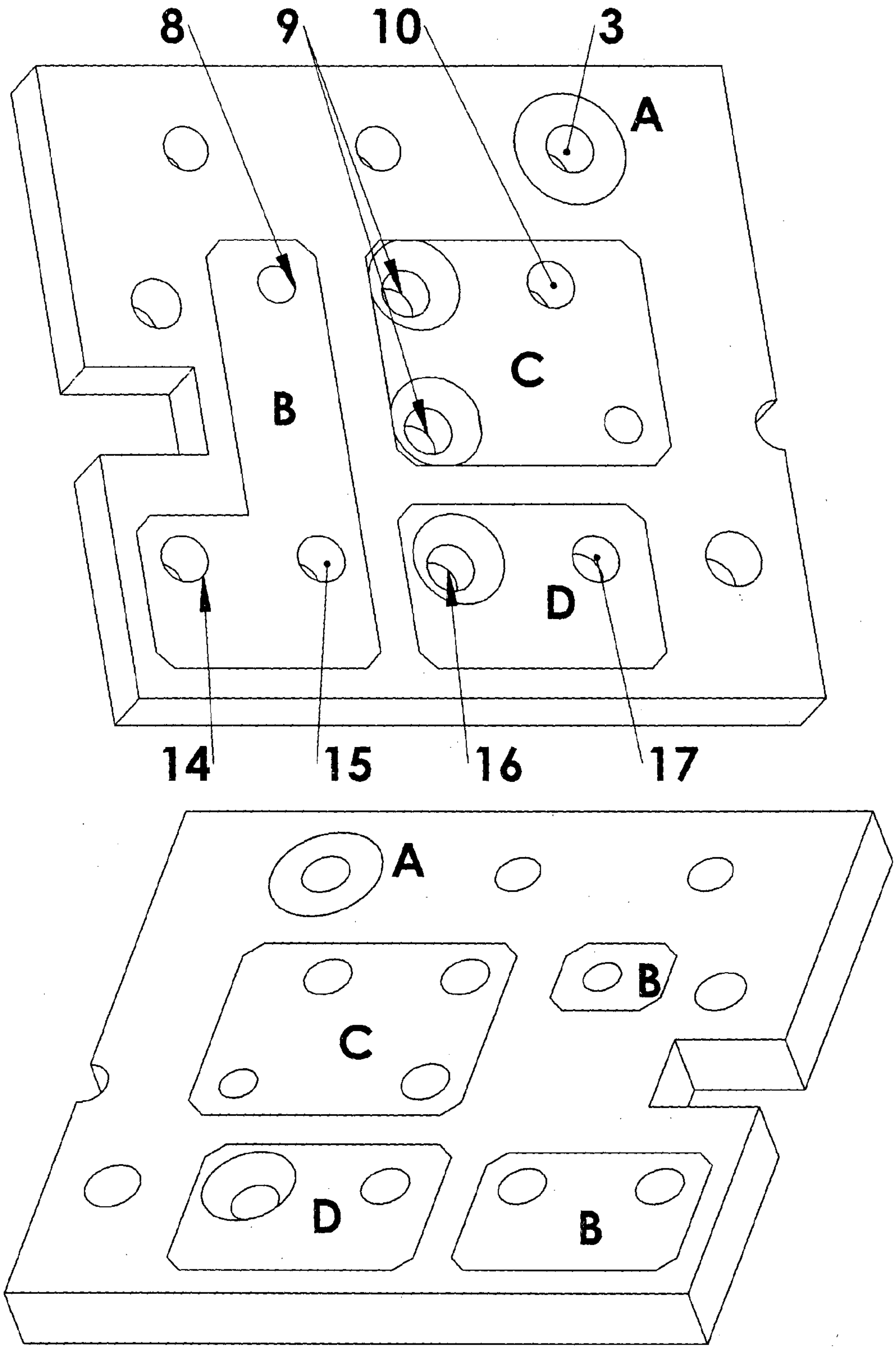


FIGURE: 24A
ITEM 7 48V NEG EARTH

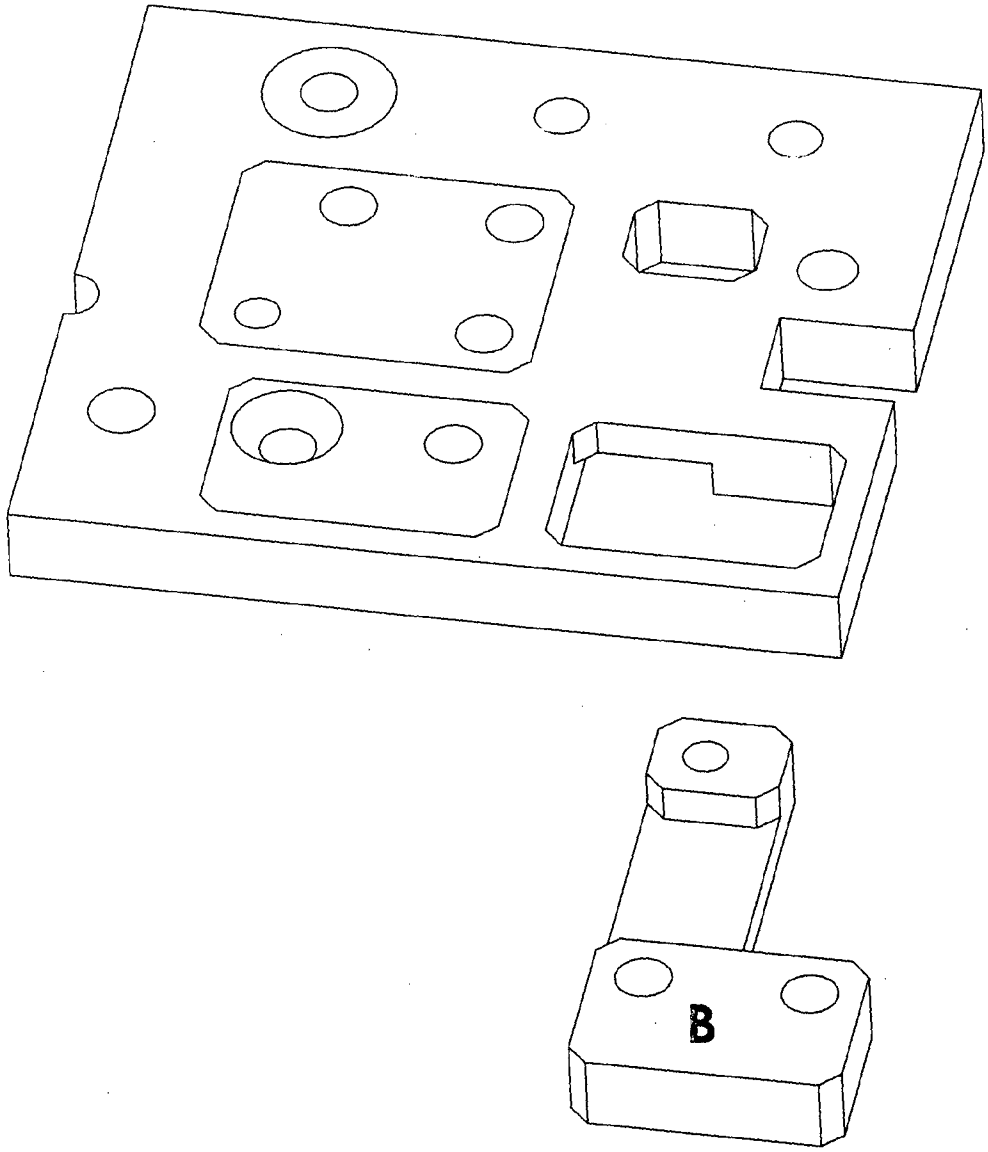


FIGURE: 24B
ITEM 7 48V NEG EARTH

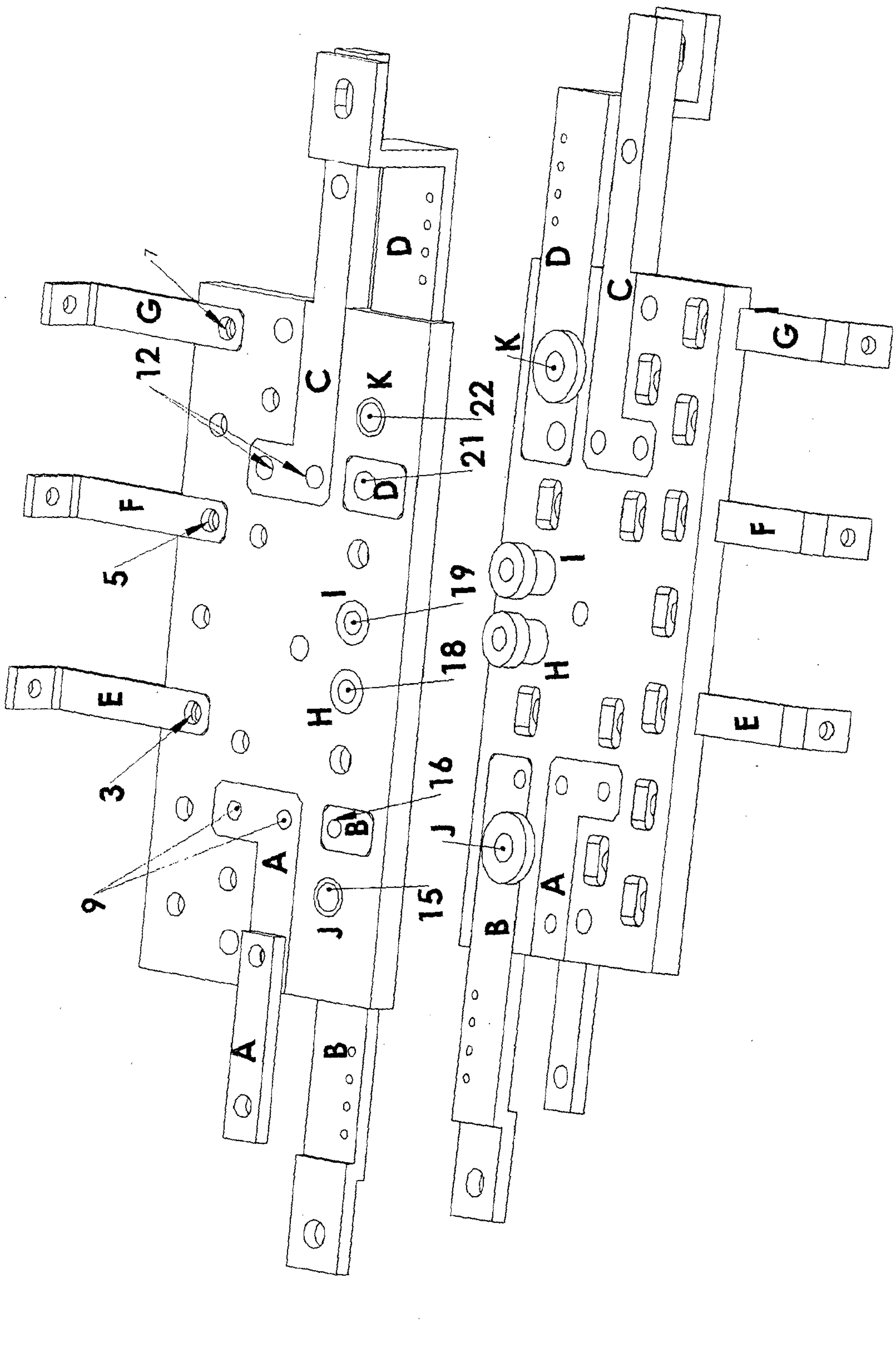


FIGURE: 25
ITEM 1 CONTACTOR PLATE

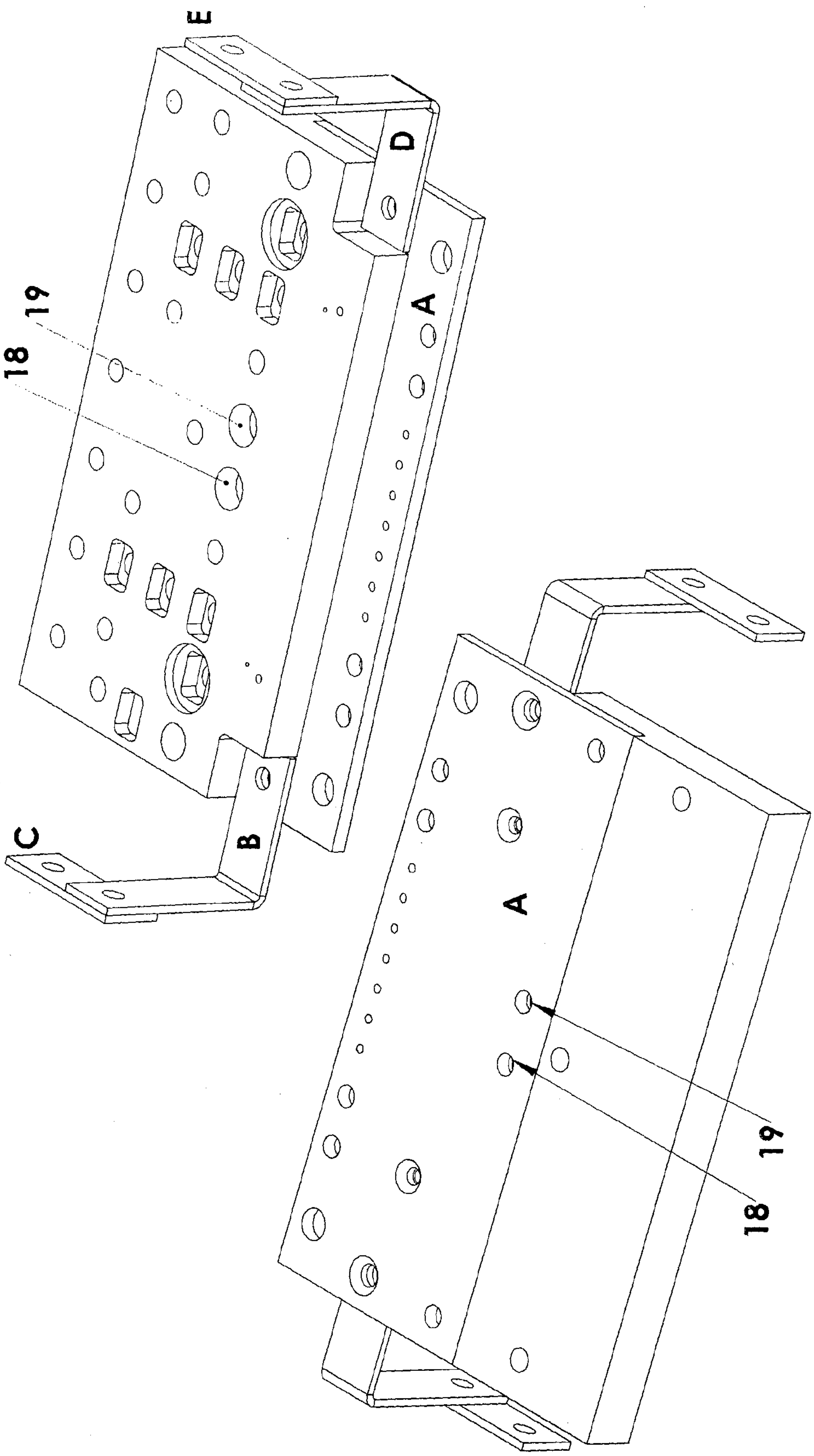


FIGURE: 26
ITEM 9 BASE EARTH PLATE

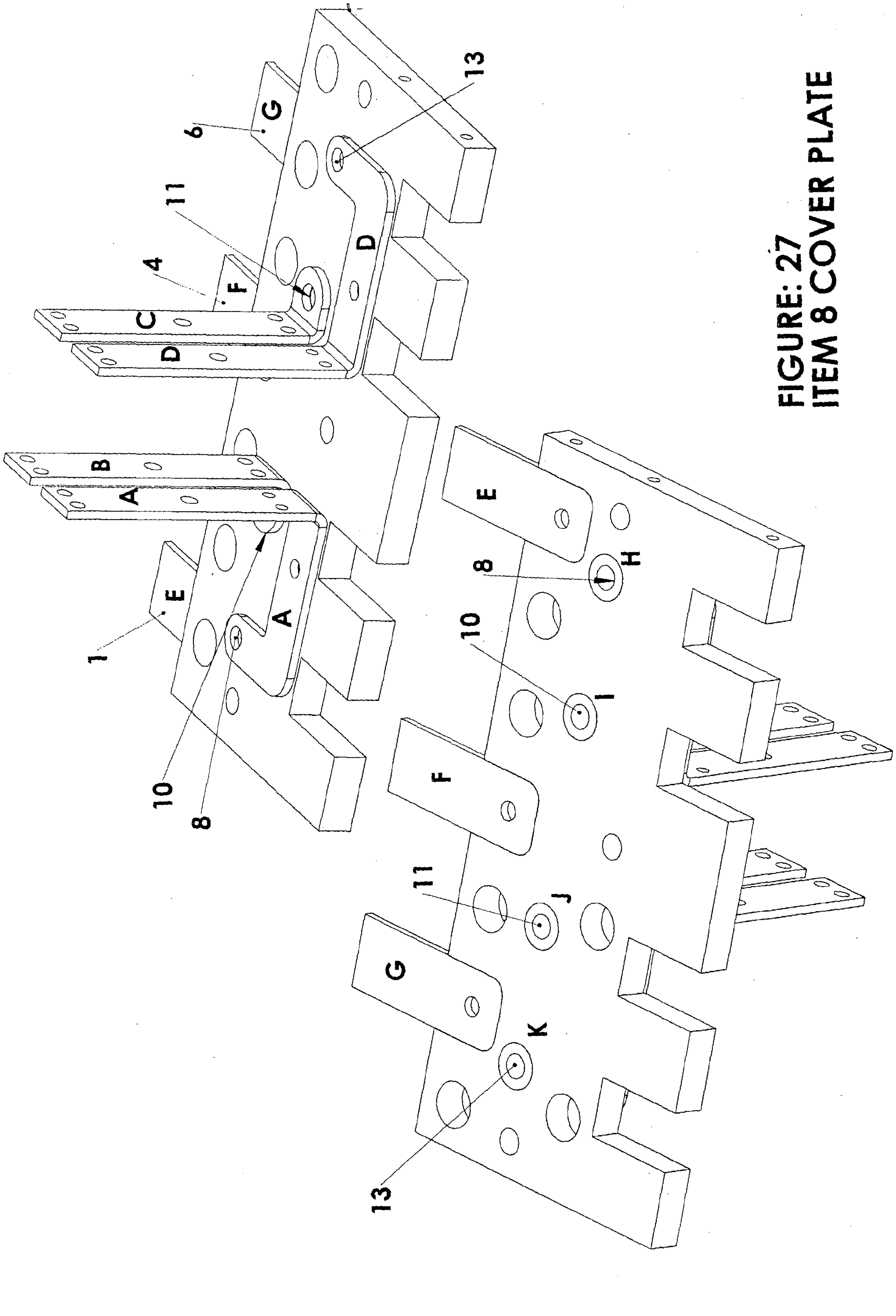


FIGURE: 27
ITEM 8 COVER PLATE

ITEM NO.	PART NUMBER	QTY.
1	48V5kW Neg Earth 24V10kW Neg Earth	1
2	48V-5kW Pos Earth 24V-10kW Pos Earth	1
3	48V-10kW Neg Earth 24V- 5kW Neg Earth	1
4	48V-10kW Pos Earth 24V-5kW Pos Earth	1
5	48V-5kW Neg Earth 24V-10kW Pos Earth	1
6	48V-10kW Pos Earth 24V-5kW Neg Earth	1
7	48V-10kW Neg Earth 24V-5kW Pos Earth	1
8	48V-5kW Pos Earth 24V-10kW Neg Earth	1
9	Connector Base Plate	1

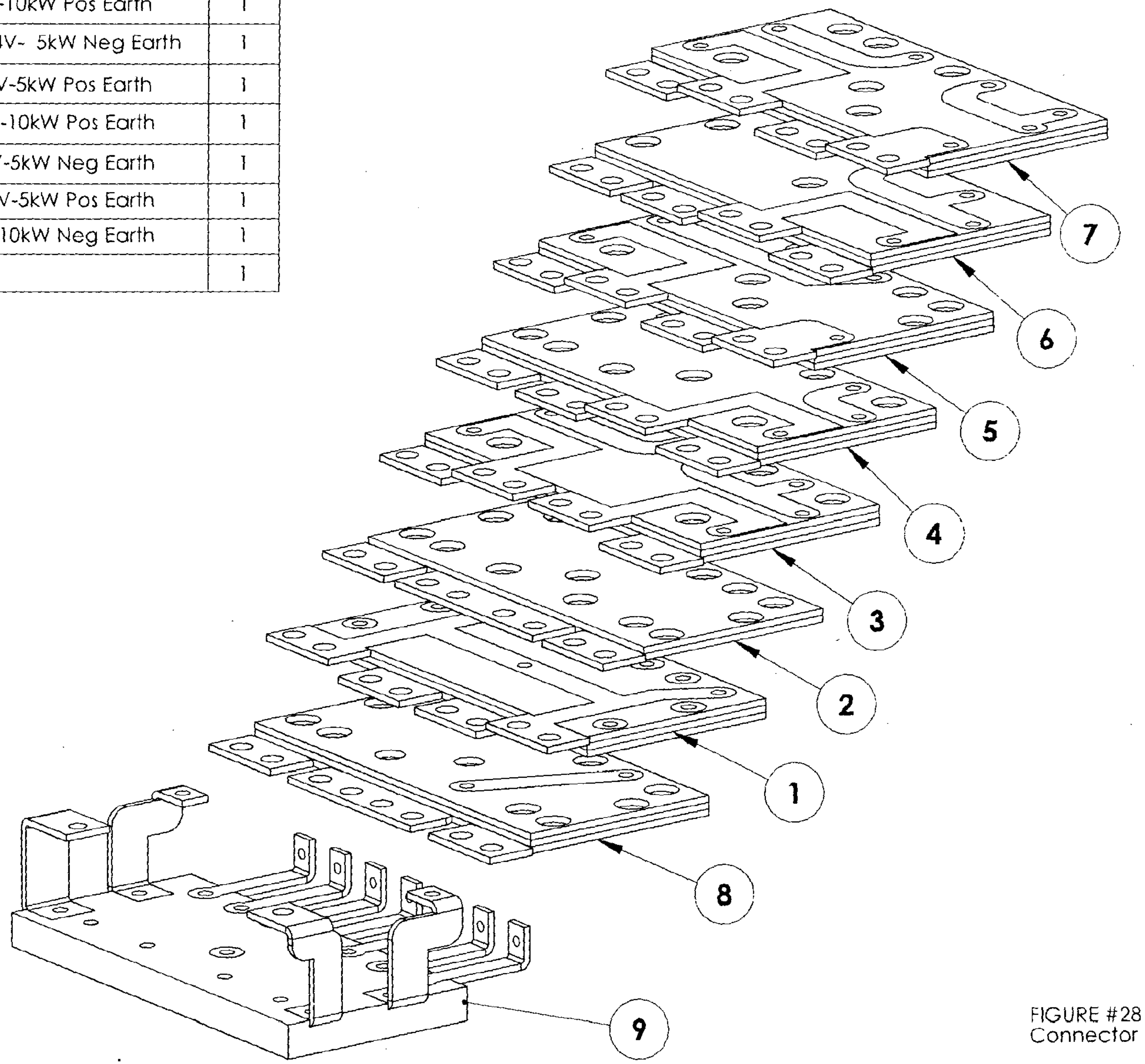


FIGURE #28
Connector Block Option #2

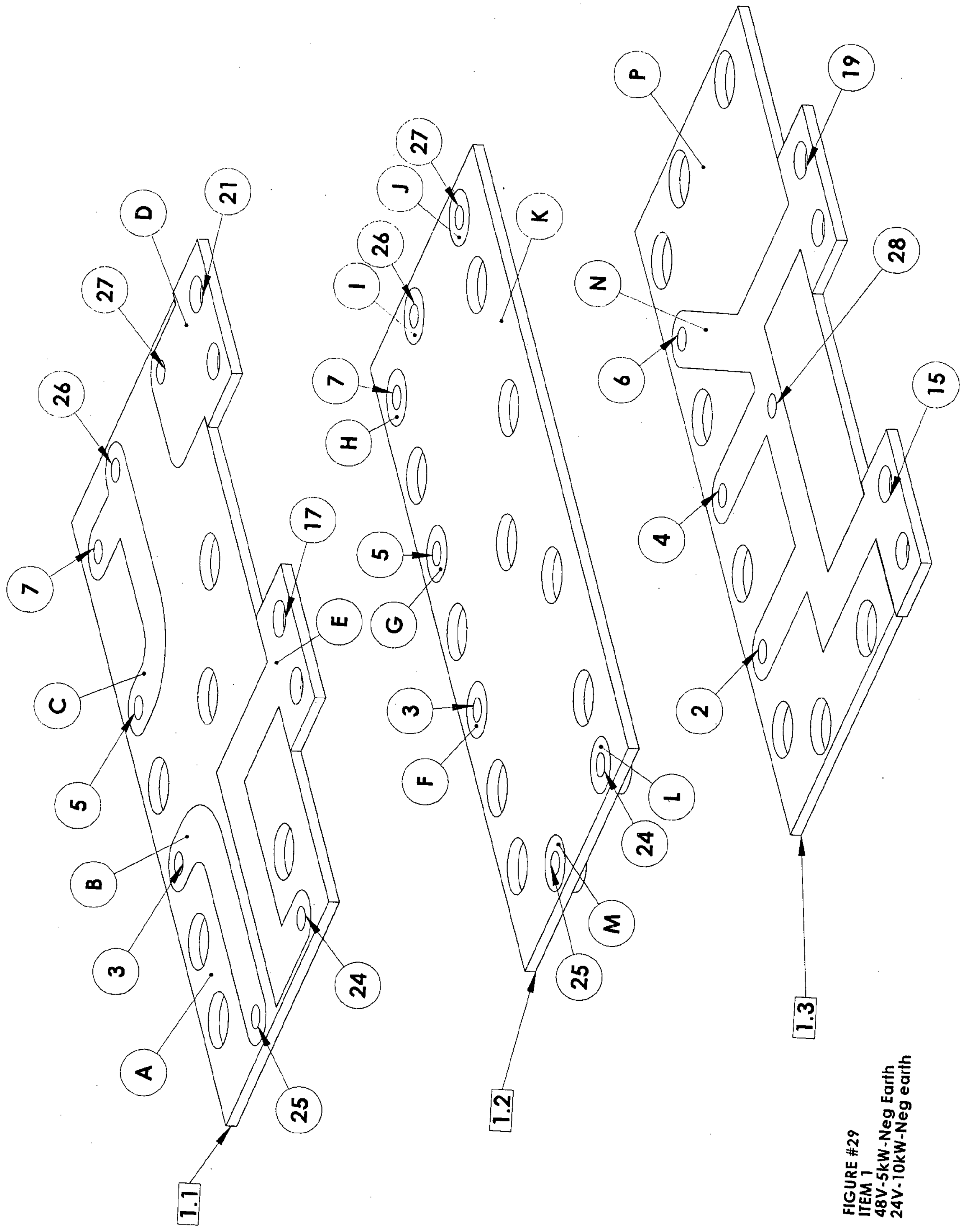


FIGURE #29
ITEM 1
48V-5kW-Neg Earth
24V-10kW-Neg earth

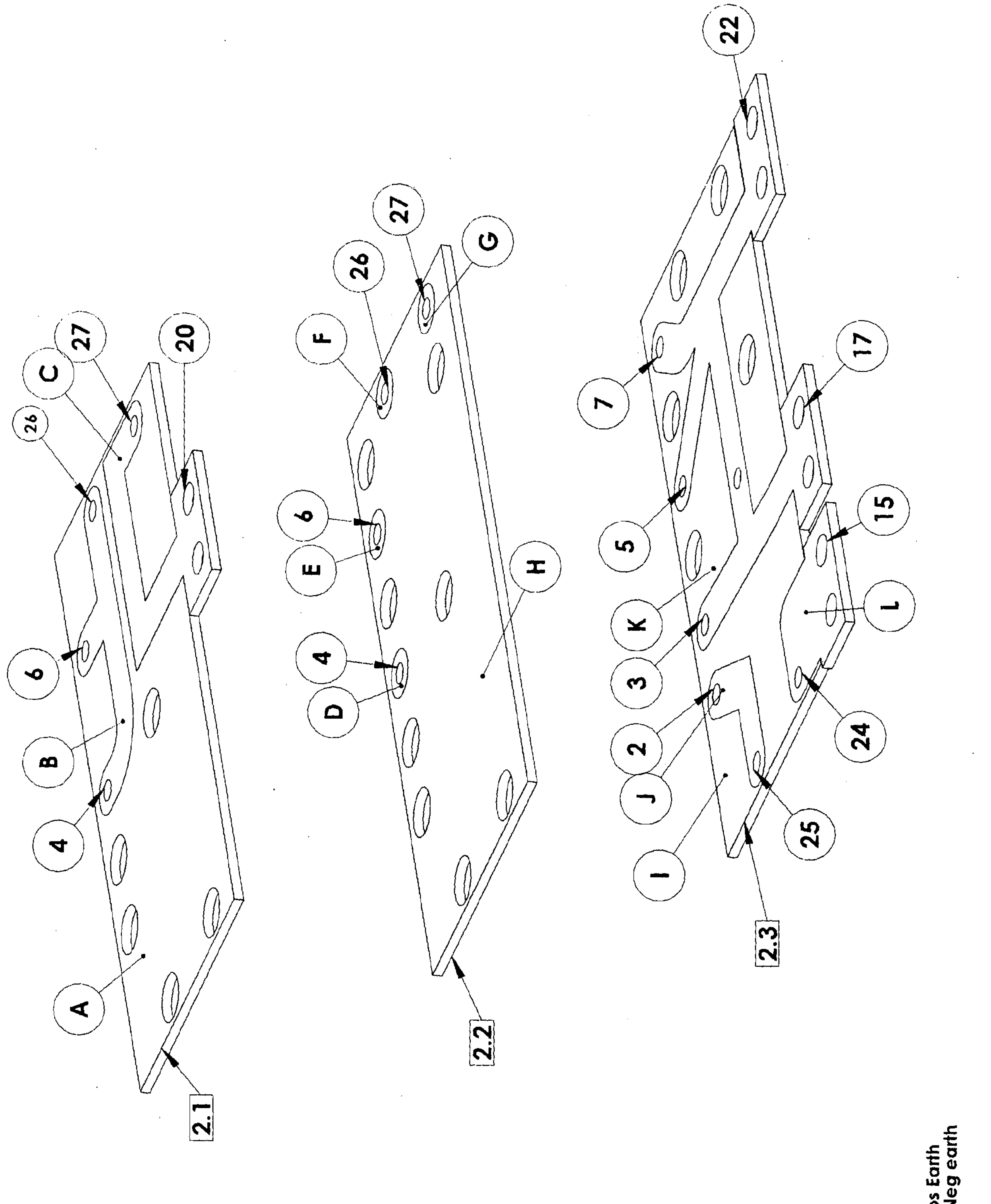


FIGURE #30
ITEM 2
48V-5kW-Pos Earth
24V-10kW-Neg earth

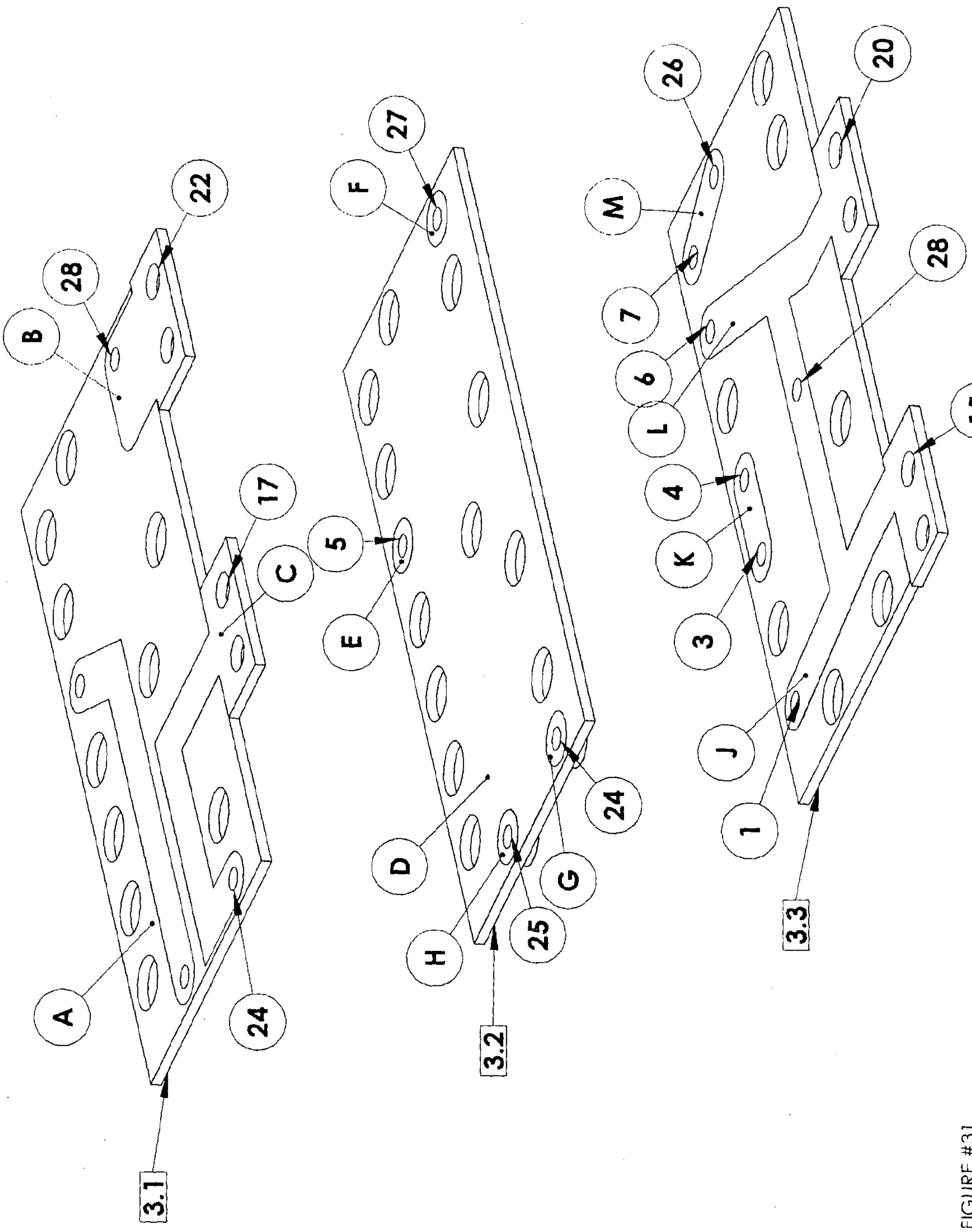


FIGURE #31
ITEM 3
48V-10KW-NEG EARTH
24V-5KW-NEG EARTH

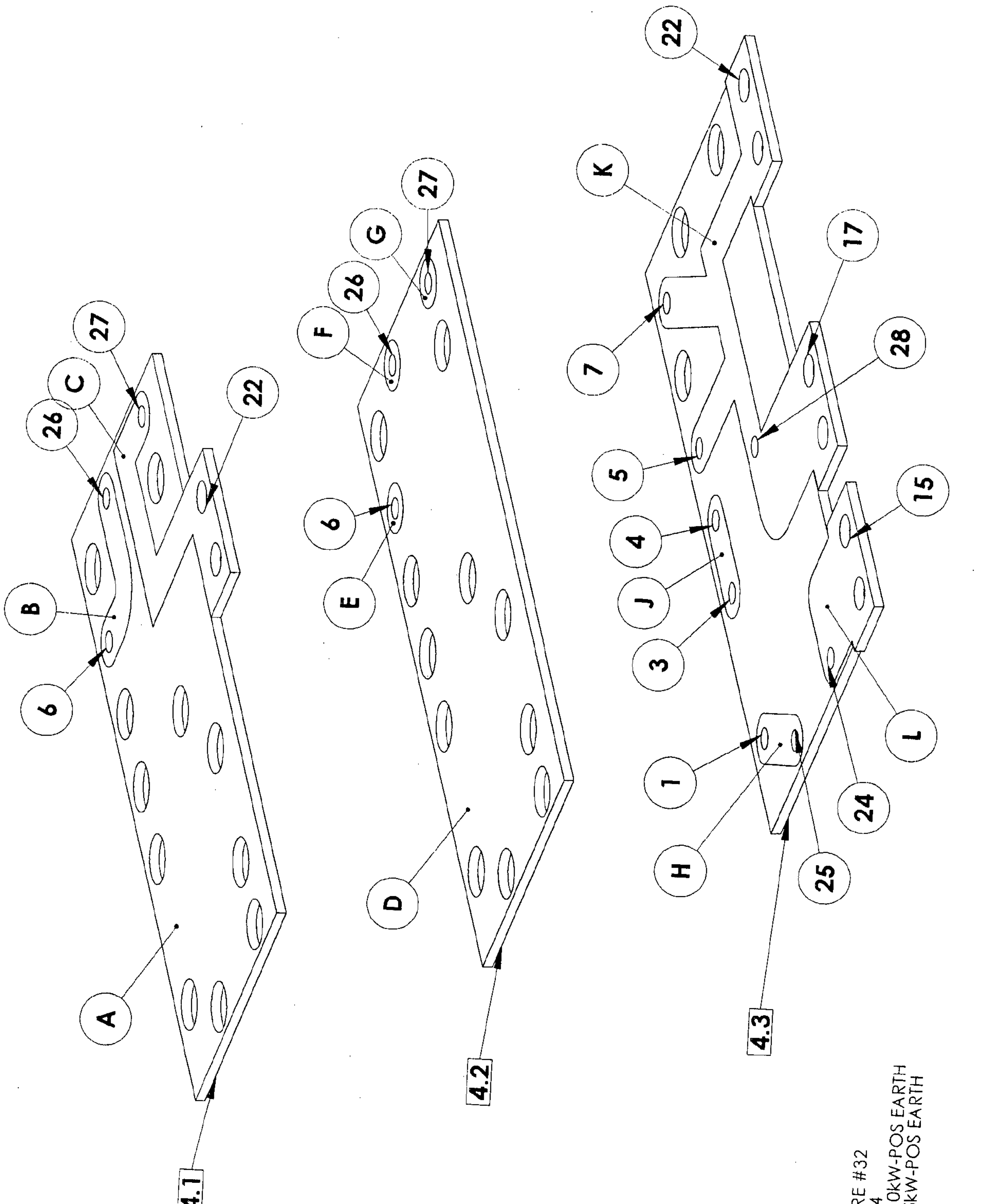


FIGURE #32
ITEM 4
48V-10kW-POS EARTH
24V-5kW-POS EARTH

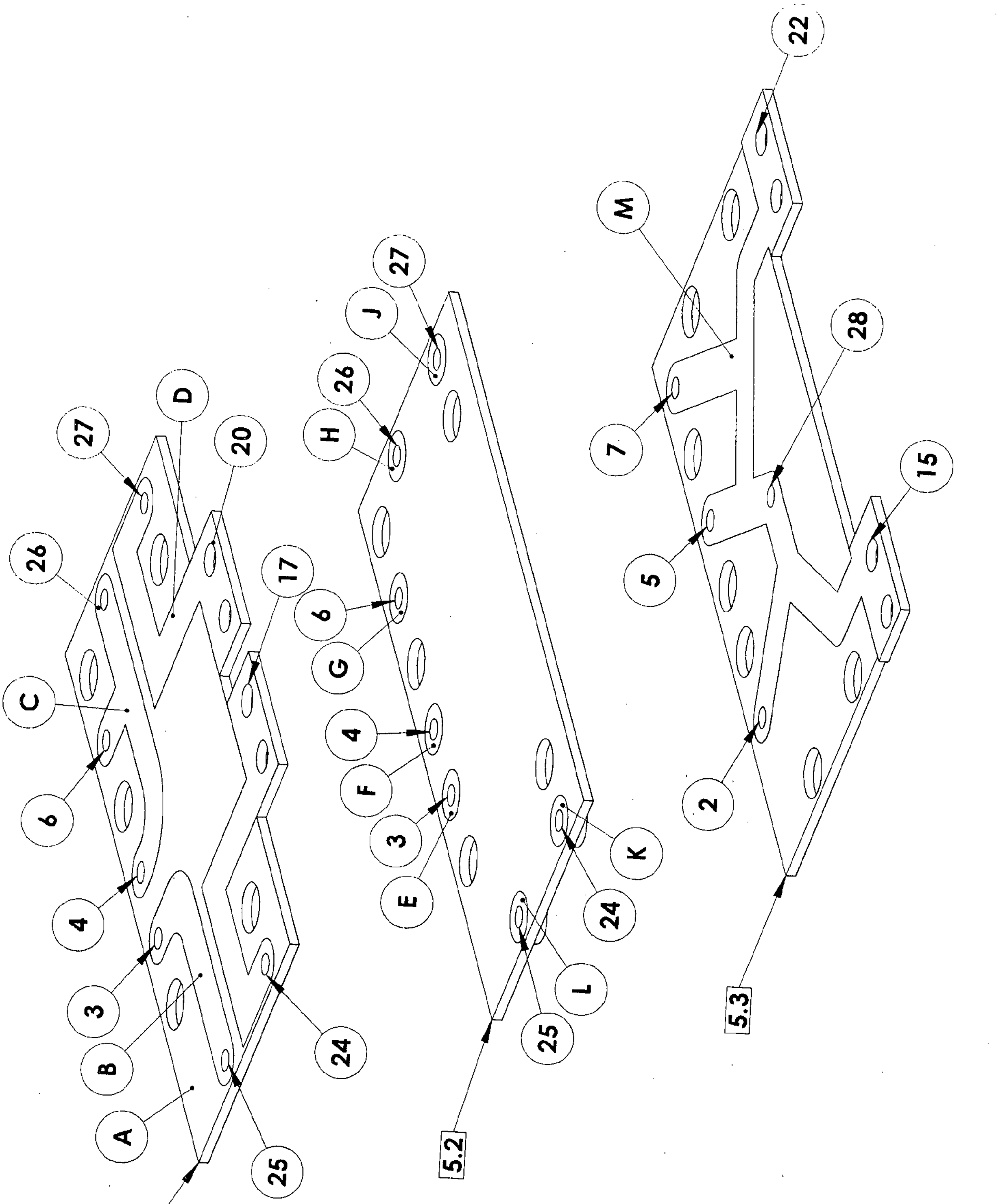


FIGURE #33
ITEM 5
48V-5kW-NEG EARTH
24V-10kW-POS EARTH

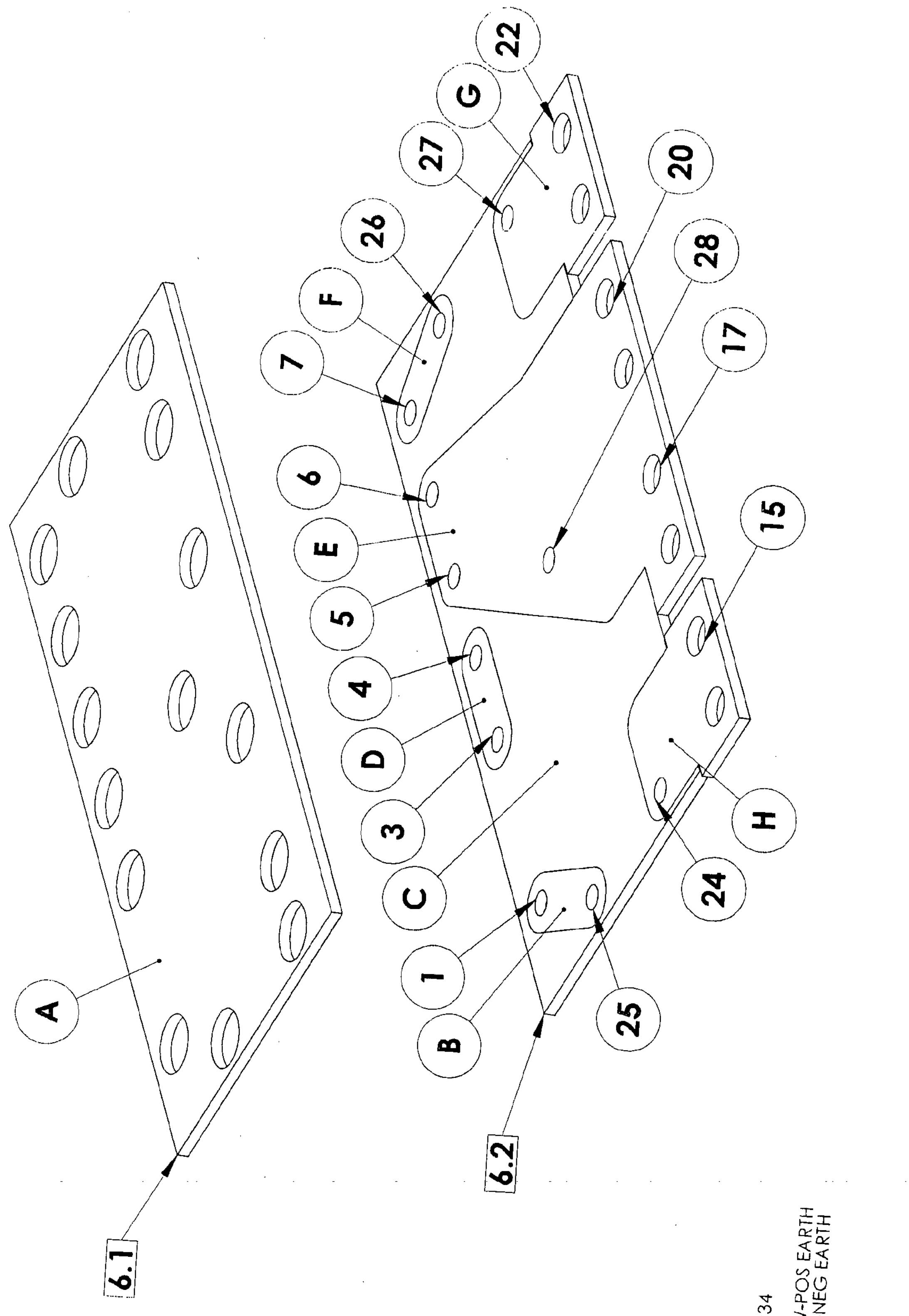


FIGURE #34
ITEM 6
48V-10KW-POS EARTH
24V-5KW-NEG EARTH

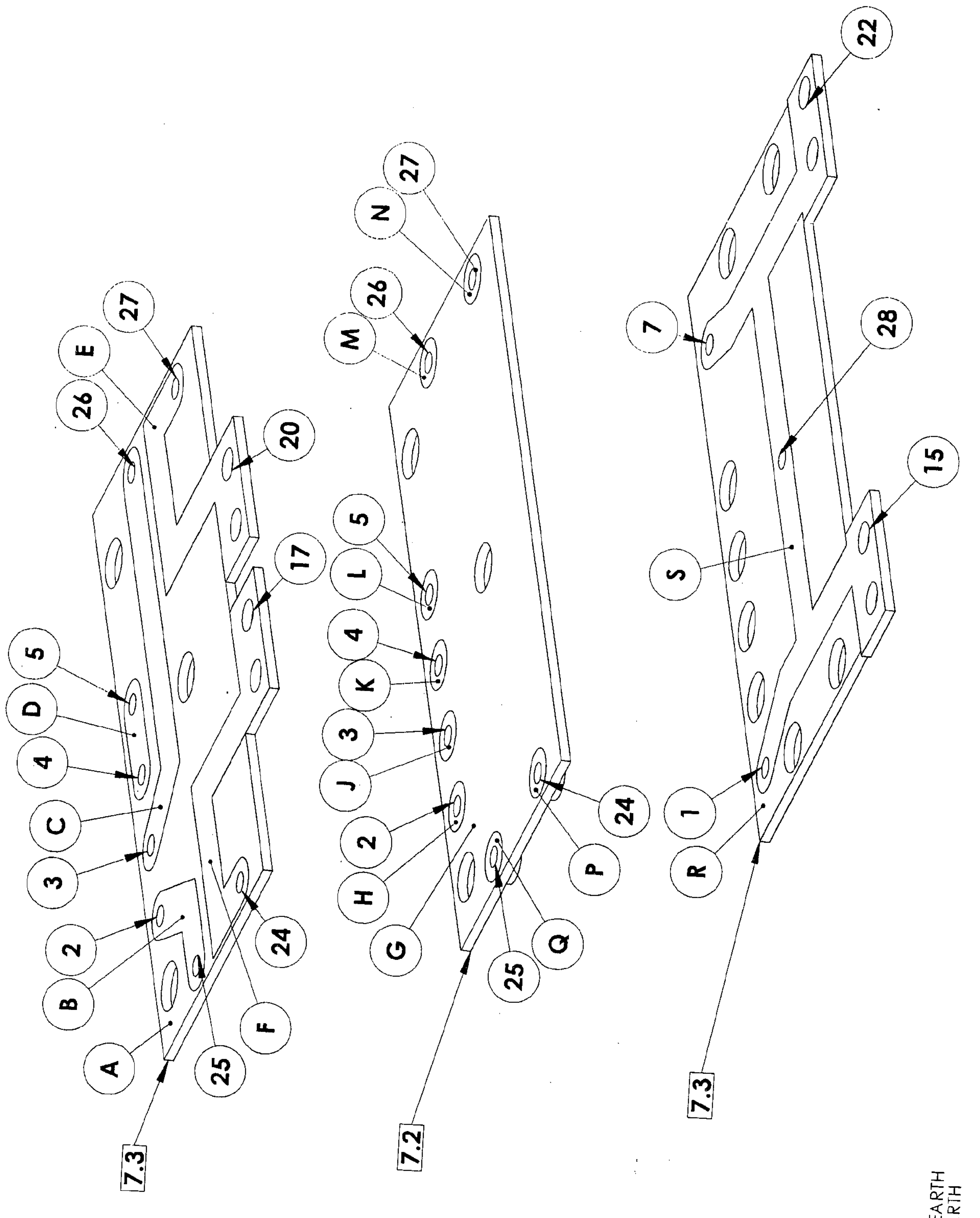


FIGURE #35
ITEM 7
48V-10kW-NEG EARTH
24V-5kW-POS EARTH

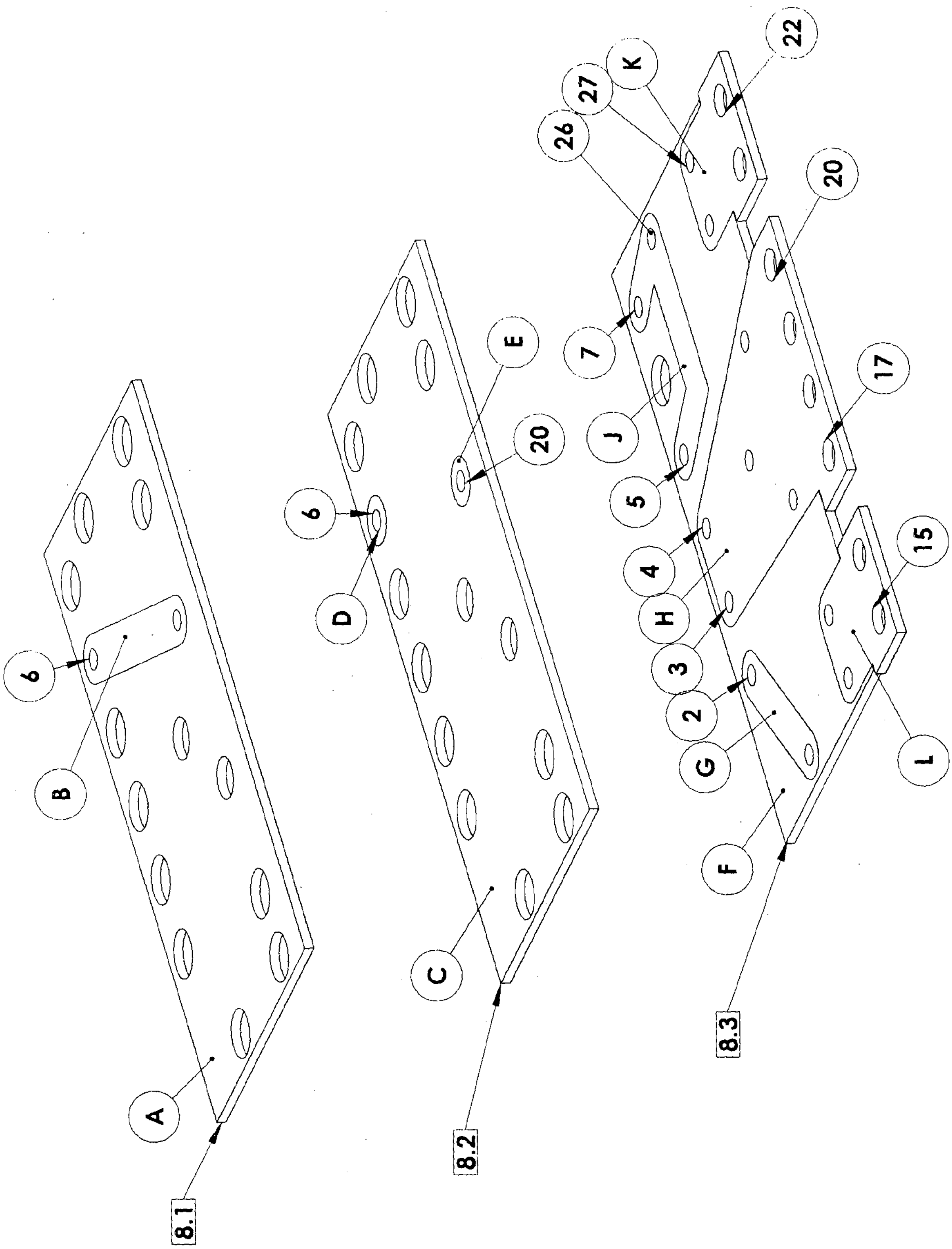


FIGURE #36
ITEM 8
48V-5KW-POS EARTH
24V-10KW-NEG EARTH

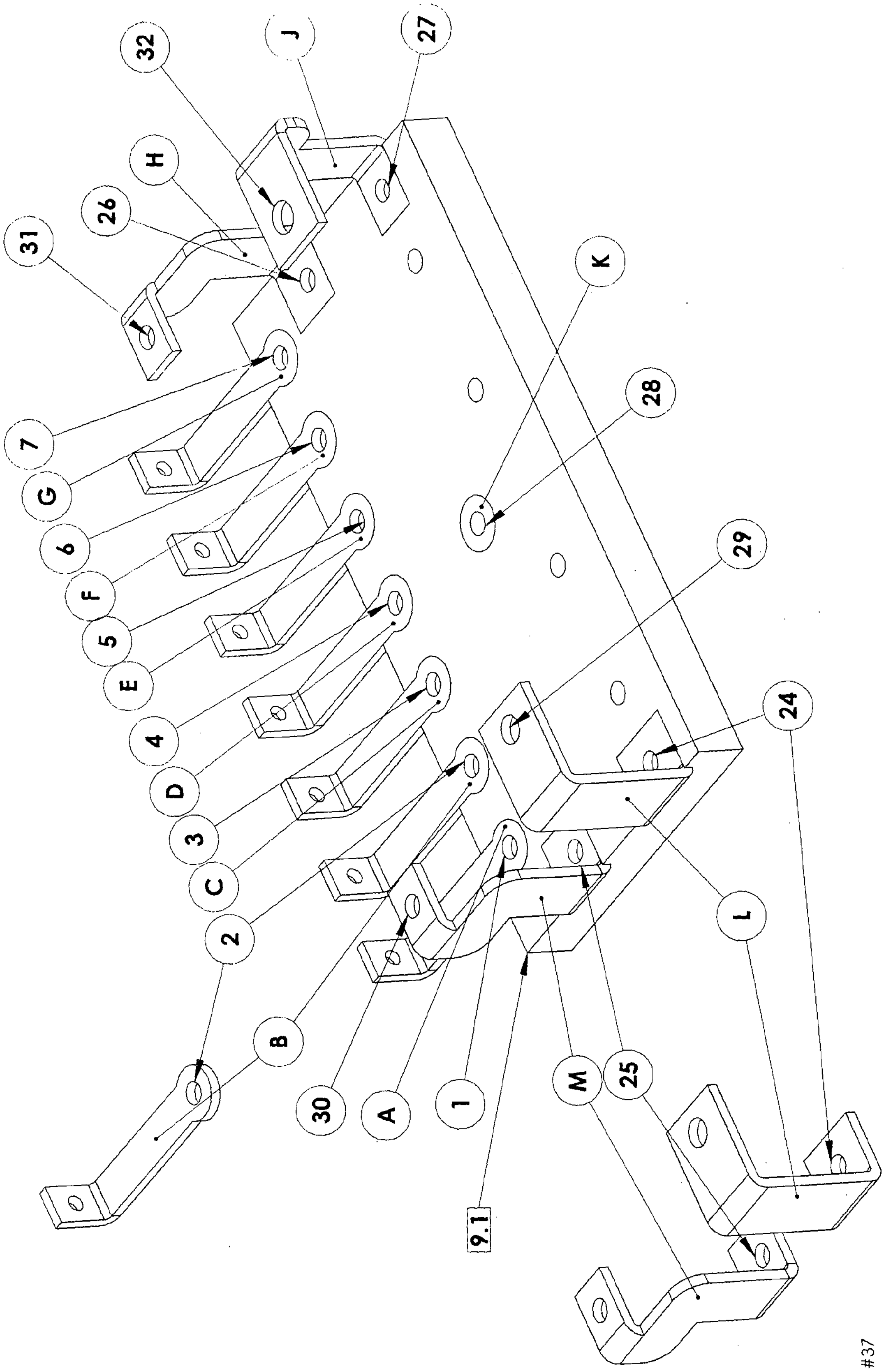


FIGURE #37
ITEM 9
Connector Base Plate

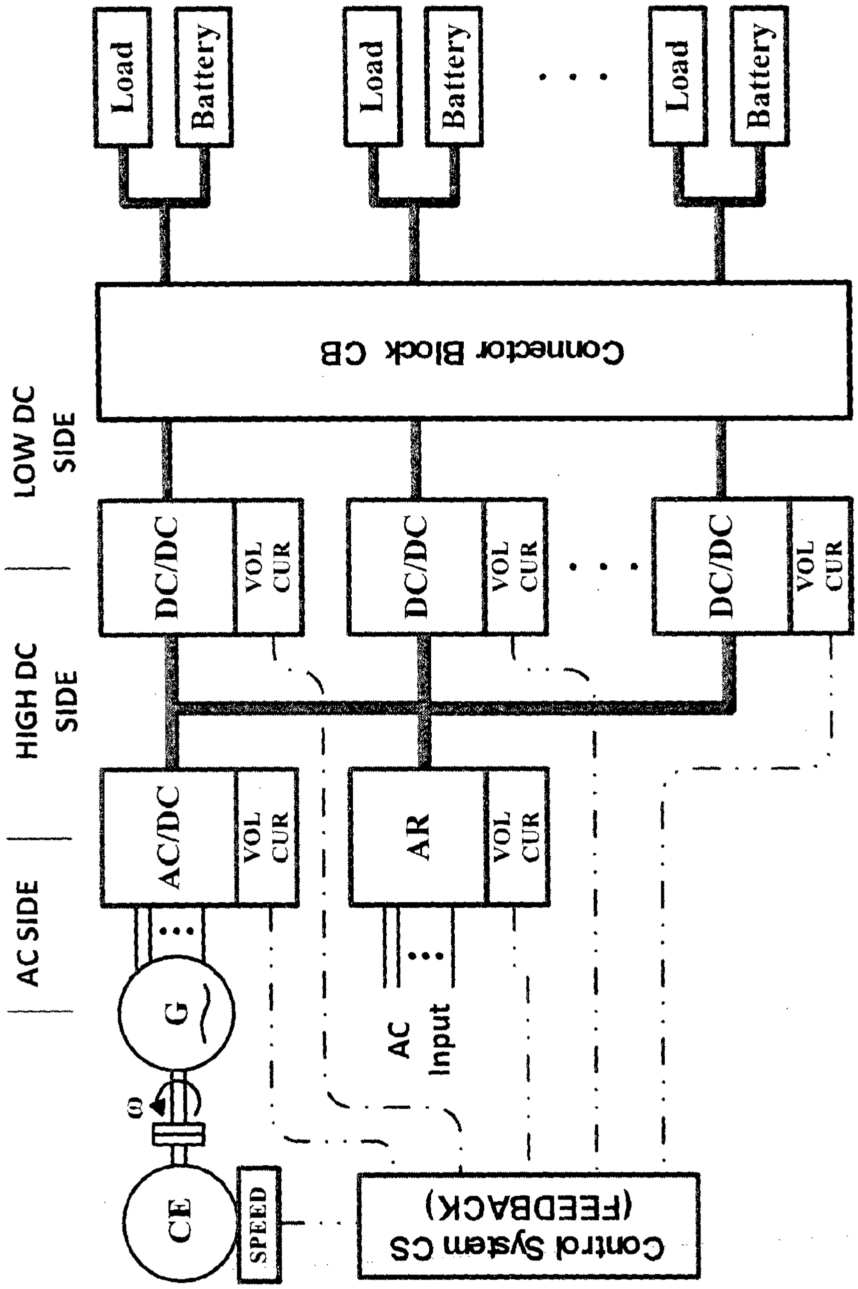


Fig: 38 Block diagram of the power system with three reconfigurable DC outputs

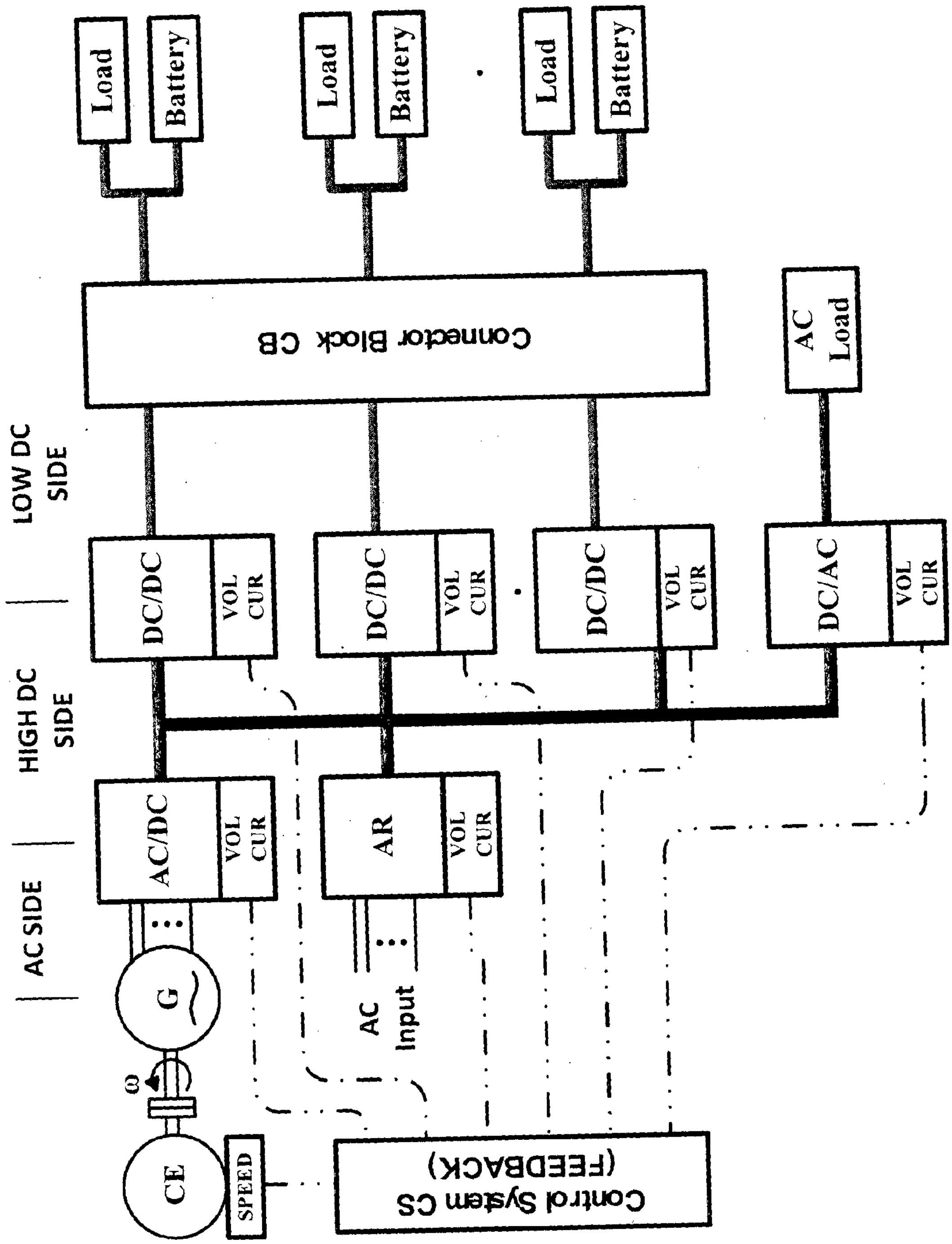


Fig: 39 Block diagram of Fig.38 with optional inverter output for AC loads

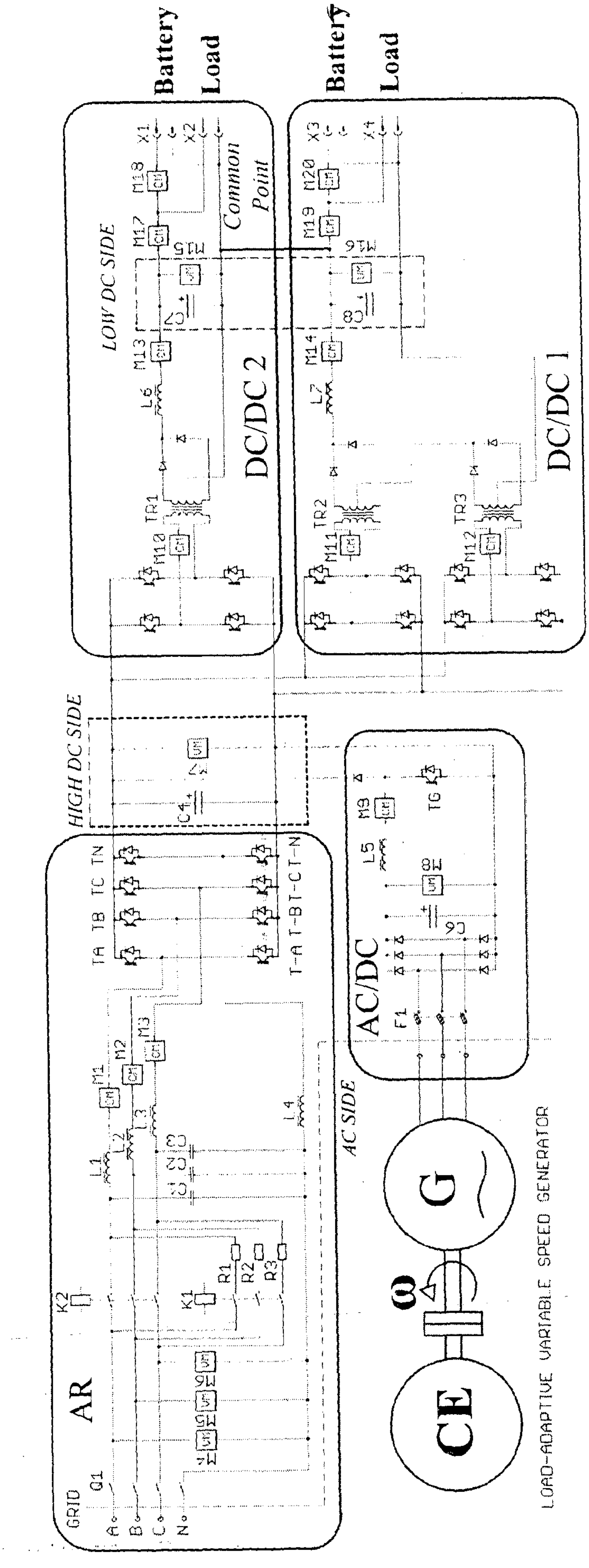


Fig: 40 Schematic diagram of power system with three reconfigurable DC outputs

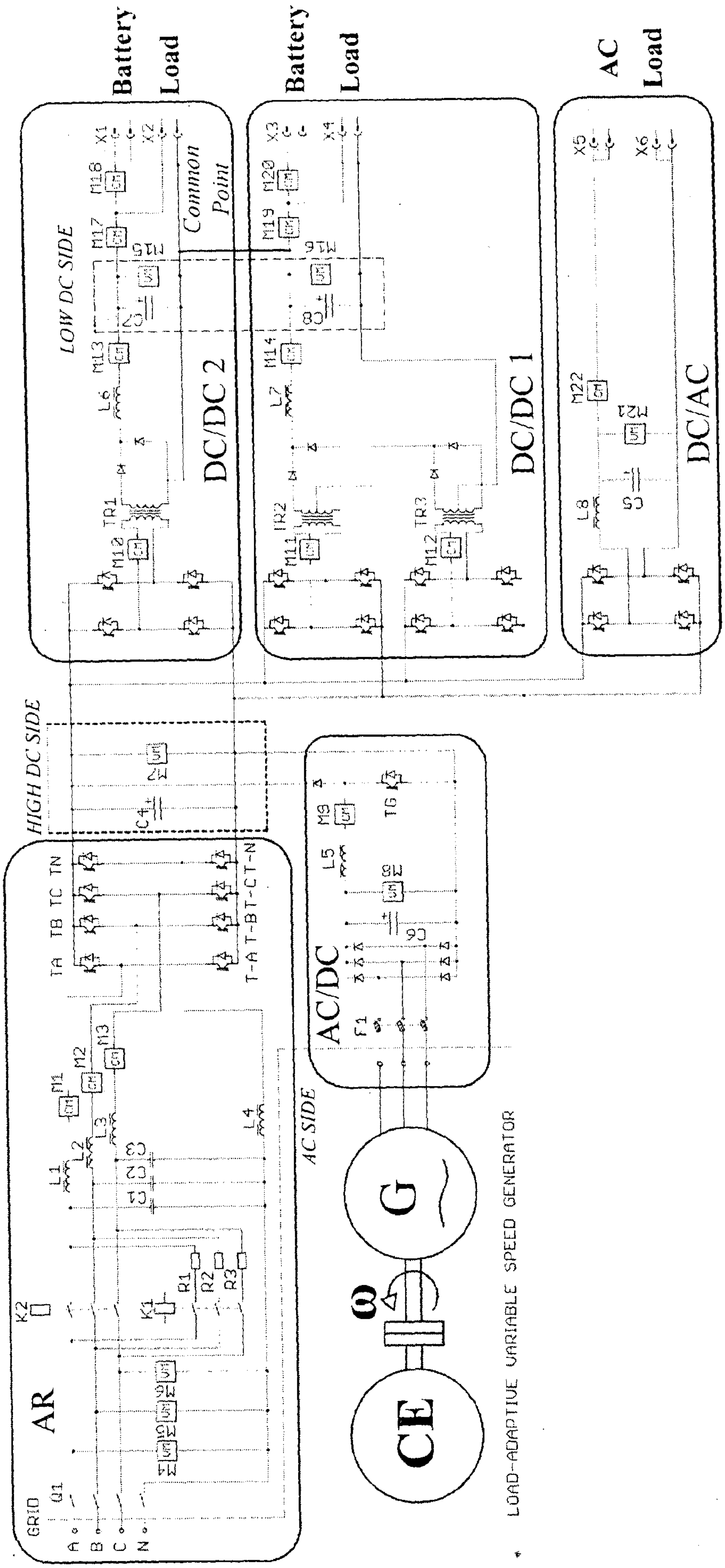


Fig: 41 Schematic diagram of power system with three reconfigurable DC outputs and optional AC output

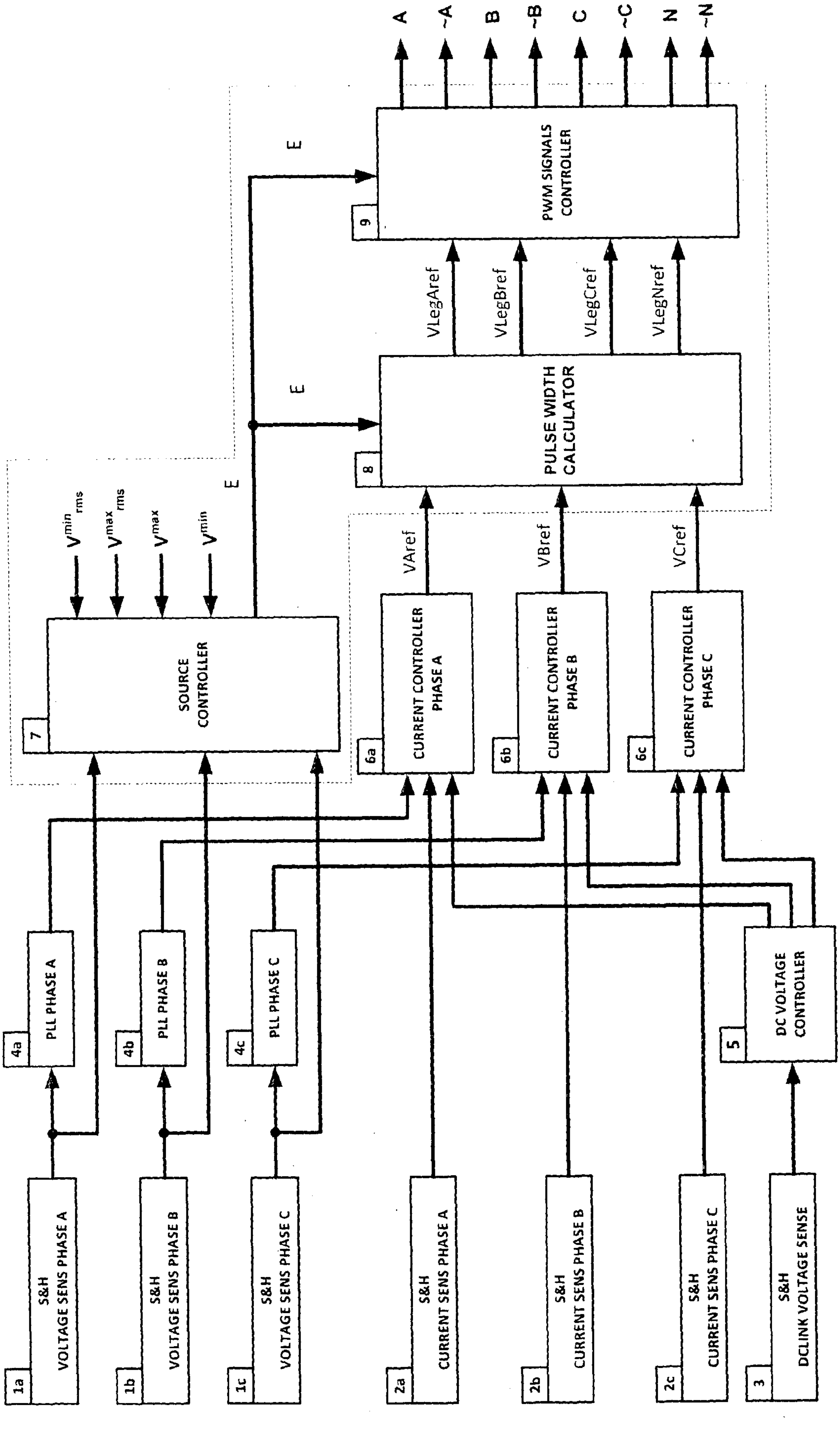


Fig: 42 Block diagram of the control system for Active Rectifier AR