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(54) Title: POWER SUPPLY SYSTEM FOR SEGMENTED LOADS

(57) Abstract

A power supply system (Fig. 2) which is comprised of multiple sets of power supplies (set 1, 2 and 3); each set having an output terminal (OT1, 2, and 3) for furnishing load current at a certain voltage; and a respective load (L1, L2 and L3) connected to the output terminal of each set; wherein a variable resistor means (20a, 20b, 20c) is provided which selectively interconnects the respective output terminals (OT1, 2 and 3) of said sets to each other; said variable resistor means (20a, 20b, 20c) including a means (e.g., Fig. 5) for varying the conductance between any two of said output terminals such that the conductance increases from zero mhos by a predetermined small step and thereafter gets progressively larger, and vice versa.

$\underline{t=t0}$

$I_1=+400\sim\frac{550+450+1400}{6}\sim$ eq.1

$I_2=I_1\sim$ eq.2

$I_3=I_1\sim$ eq.3

$I_4=+250\sim 400\times 2-550\sim$ eq.4

$\underline{t=t1}$

$V_1<V_2\ \&\ V_3\sim$ eq.5

$\therefore PS_2\ \&\ PS_3$ try to supply all $I\sim$ eq.6

$(550+450+1400)\div 4=600\sim$ eq.7

$600>500\sim$ eq.8

$I_2=I_3=500\sim$ eq.9

$I_4=-150\sim(500)(4)-450-1400\sim$ eq.10

$I_1=(500-150)\div 2=200\sim$ eq.11

$\underline{t=t2}$

$R_{20a}\rightarrow 50\mu\Omega\sim$ eq.12

V_{20a} increases to $(150)(50\mu\Omega)=7.5mV\sim$ eq.13

$2\Delta V_{max}=20mV\sim$ eq.14

$\therefore 7.5mV$ is ok $\sim$ eq.15

$\underline{t=t3}$

$R_{20a}\rightarrow 200\mu\Omega\sim$ eq.16

$V_{20a}\rightarrow(150)(200\mu\Omega)=30mV\sim$ eq.17

$2\Delta V_{max}=20mV\sim$ eq.18

$\therefore I_4=(20mV)\div(200\mu\Omega)=-100\sim$ eq.19

$I_1=(550-100)\div 2=225\sim$ eq.20

$I_2=I_3=\frac{(450+1400+100)}{4}=487.5\sim$ eq.21

$\underline{t=t4}$

$R_{20a}\rightarrow 4000\mu\Omega\sim$ eq.22

$I_4=(20mV)\div(4000\mu\Omega)=-5\sim$ eq.23

$I_1=(500-5)\div 2=272.5\sim$ eq.24

$I_2=I_3=\frac{(450+1400+5)}{4}=463.75\sim$ eq.25

$\underline{t=t5}$

$R_{20a}-00\sim$ eq.26

$I_4=0\ (\Delta I_4=5)\sim$ eq.27

$I_1=550\div 2=275\sim$ eq.28

$I_2=I_3=\frac{(450-1400)}{4}=462.5\sim$ eq.29

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POWER SUPPLY SYSTEM FOR SEGMENTED LOADS

BACKGROUND

This disclosure relates to power supply systems which furnish DC current at a certain voltage to electrical loads; and more particularly, it relates to such power supply systems in which the loads are segmented and the power supply system has redundancy.

Typical electrical loads for such power supplies are integrated circuits. They are usually packaged on printed circuit boards which have power and ground pins as well as multiple input/output pins for receiving and sending signals. Hundreds of these boards are often included in a single electronic system, such as a large data processing system or a large communications system. Multiple backplanes are commonly provided to hold the boards in groups of 10 to 20 and send signals between them, and each backplane has its own power and ground buses.

One way to provide power to such a multiple backplane system is to cable the power buses of all the backplanes together, and to connect them to a set of power supplies which operate in parallel to share in furnishing the total load current. Also, a redundant supply (i.e., an extra supply) can be included in such a system so that if any one power supply fails, the electronic system can still operate. This type of power supply system, including a redundant supply, is described in United States Patent 4,698,738 by J. Miller and J. Walker which is assigned to the present assignee.

However, in a multiple backplane electronic system, it is often desirable to have the backplanes and their supplies segmented (electrically isolated) from each other. Such segmenting enables the supplies for just one backplane to be turned off while the supplies and the circuitry of the remaining backplanes continue to operate. For example, large data processing systems often contain multiple digital computers, each of which is housed on a different backplane. When the circuitry in one of those computers fails or needs to be upgraded, it is desirable to be able to power down just the backplane of that one computer so that the repair or upgrade can be made while at the same time, the remaining computers continue to operate. However, with the above referenced power supply system, this cannot be done because there, power cannot be independently applied to and removed from the individual backplanes.

One way to solve the above problem is to not connect the power buses of the backplanes together, and to provide a separate set of power supplies (such as those of the referenced power supply system) for each backplane. But in that case, a separate redundant supply would also have to be provided for each backplane; and that would substantially increase the cost of the system. For example, consider an electronic system of FIG. 1 which has three loads L_1, L_2, and L_3. Suppose further that load L_1 requires two power supplies 1A and 1B to furnish its load current; load L_2 requires just one power supply 2A to furnish its load current; and load L_3 requires three power supplies 3A, 3B, and 3C to furnish its load current. In that case, a total of six power supplies are required to furnish the needed load current, but an additional three redundant supplies R (one for each load) are also required to provide redundancy. Thus, redundancy increases the cost of the system by 50%.

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BRIEF DESCRIPTION OF THE DRAWINGS:

Various features and advantages of the invention are described herein in detail in conjunction with the accompanying drawings wherein:

FIG. 1 shows a power supply system which has segmented loads and redundancy;

FIG. 2 shows a preferred embodiment of a power supply system which is constructed according to the invention;

FIG. 3 is a more specific version of the FIG. 2 embodiment in which the current requirements for the loads and the current-furnishing capacities for the supplies are all specified;

FIG. 4 is a set of equations which explain the time sequence by which the FIG. 3 system operates;

FIG. 5 shows a preferred physical makeup for some of the components in the system of FIGs. 2 and 3;

FIG. 6 illustrates the operation of the FIG. 5 component; and

FIG. 7 shows the operation of the FIG. 3 system under the conditions where one power supply fails.

DETAILED DESCRIPTION

Referring now to FIG. 2, one preferred embodiment of a power supply system which is constructed in accordance with the invention will be described in detail. This power supply system includes three sets of power supplies which are hereinafter referred to as SET1, SET2, and SET3. In SET1 there are two power supplies PS_{1a} and PS_{1b}; in SET2 there is one power supply PS_{2a}; and in SET3 there are three power supplies PS_{3a}, PS_{3b}, and PS_{3c}.

Each set of power supplies has an output terminal which furnishes load current at a predetermined voltage. In FIG. 2, the output terminal of the SET1 power supplies is indicated as OT_1; the output terminal of the SET2 power supply is indicated as OT_2; and the output terminal of the SET3 power supplies is indicated as OT_3. A load L_1 is connected directly to output terminal OT_1; a load L_2 is connected directly to output terminal OT_2; and a load L_3 is connected directly to output terminal OT_3.

Each set of power supplies further includes a current-sharing circuit which operates to equalize the load current that each power supply in a set furnishes to its respective output terminal. In FIG. 1, the current-sharing circuit for the SET1 power supplies is schematically indicated by a dashed line CS_1; the current-sharing circuit for the SET2 power supply is indicated by a dashed line CS_2; and the current-sharing circuit for the SET3 power supply is indicated by a dashed line CS_3. All of the details of one suitable current-sharing circuit are given in United States patent 4,698,738; and they are herein incorporated by reference.

Now in accordance with a preferred embodiment of the invention, a connector 20 is provided which selectively connects and disconnects the output terminals OT_1, OT_2, and OT_3 of the power supply sets as they are running. In FIG. 2, connector 20 is illustrated as being comprised of three variable resistors 20a, 20b, and 20c which respectively connect output terminals OT_1, OT_2, and OT_3 to a node 20d. Each of these resistors has a conductance that increases from zero by a predetermined small step and thereafter progressively increases to a highly conductive value.

Also in accordance with the preferred embodiment, a switch 30 is provided which selectively interconnects, and disconnects, the respective current-sharing circuits of each of the power supply sets. In FIG. 2, switch 30 is shown as consisting of three single pole single throw switches 30a, 30b, and 30c which respectively interconnect the current-sharing circuits CS_1, CS_2, and CS_3 to a node 30d. When the current-sharing circuits of any two power supply sets are connected via switch 30, and the output terminals of those same two sets are connected via connector 20 through a high conductance, then the supplies of both sets equalize their output currents.

Further in accordance with the preferred embodiment, the total number of power supplies is selected such that all of the supplies together, minus any one supply, have a total current-furnishing capacity which meets the current requirements of all of the loads; and at the same time, no set of supplies is made so large as to include a redundant supply. One particular example of this is shown in FIG. 3. There, the loads L_1, L_2, and L_3 are respectively shown as requiring 550 amps, 450 amps, and 1400 amps; the SET1 power supplies have a capacity of 500+500 amps; the SET2 supply has a capacity of 500 amps; and the SET3 supplies have a capacity of 500+500+500 amps.

Now, to understand how the power supply system of FIG. 3 operates, reference should be made to FIG. 4 wherein the state of that power supply system is shown at various time instants t_0 through t_5. Initially, beginning at time t_0, all of the variable resistances 20a-20c are in their most conductive position, and all of the current-sharing switches 30a-30c are closed. Suitably, the resistance of each variable resistance at this time is less than 20 micro ohms.

Due to the above switch and resistance positions, the power supplies in all of the sets furnish equal amounts of load current. In the specific example of FIG. 3, current I_1 from each of the SET1 supplies equals 400 amps as given by equation 1. Current I_2 from the SET2 supply and I_3 from each of the SET3 supplies equals current I_1 as is given by equations 2 and 3. Switch 20a carries a current I_4 which is +250 amps as is given by equation 4.

Suppose now that the FIG. 3 system continues to operate in the above state until some sort of fault occurs in load L_1 or a feature needs to be added to L_1. Then the need arises to remove power from load L_1 so that the problem can be worked on. To that end, at time t_1, switch 30a is opened thereby stopping any current-sharing between the power supplies of SET1 and the power supplies of SET2 and SET3. As a result, the current furnished by the supplies of SET1 will stop tracking the current of the other supply sets, and a small voltage difference will occur between the output terminal of SET1 and the other supply sets.

Assume now that the voltage on output terminal OT_1 is slightly less than the voltage on output terminals OT_2 and OT_3. This is stated by equation 5. Due to the slight voltage imbalance, the SET2 and SET3 power supplies will try to furnish all of the current to all of the loads L_1,

L_2, and L_3. This is stated by equation 6. However, the power supplies of SET2 and SET3 do not have enough current-furnishing capacity to furnish all of the load current. This is shown by equations 7 and 8.

Equation 7 shows that the four supplies of SET2 and SET3 each need to furnish 600 amps in order to supply all of the load current; and equation 8 says that each supply can only furnish 500 amps. Thus, currents I_2 and I_3 will be limited to 500 amps as is given by equation 9; and the excess of that current over the requirements of loads L_2 and L_3 will equal the current I_4 through switch 20a. Thus, current I_4, as is stated by equation 10, becomes -150 amps. Load L_1 requires 550 amps; the difference between that amount and the 150 amps through switch 20a is furnished by the SET1 power supplies; and so the supplies PS_{1a} and PS_{1b} each furnish 200 amps.

Next, at time t_2, the resistance of the variable resistor 20a is slightly increased from its minimum value. For example, as stated by equation 12, the resistance increases to 50 micro ohms. Thus, if the current I_4 through resistor 20a remains unchanged, the voltage across resistor 20a will rise to 7.5 millivolts. Any rise in voltage across resistor 20a has, however, an important constraint. Specifically, the voltage across resistor 20a cannot exceed the tolerances with which the voltages can vary between the output terminals of any two power supplies.

Constant voltage power supplies have a tolerance of $\pm\Delta V$ on their output terminal voltage which is caused by the accuracy with which the constant voltage can be preset. For low voltage supplies (i.e., zero to ten volts), that voltage tolerance ΔV of any one supply typically will be ±10 millivolts. Thus the maximum voltage difference between any two supplies is $2\Delta V$ which occurs when one supply voltage is preset at nominal minus ΔV and the other supply voltage is preset at nominal plus ΔV. Typically, $2\Delta V$ has a maximum of 20 millivolts, and this is stated by equation 14. Since the 7.5 millivolt drop across resistor 20a is less than this largest preset voltage difference between the output terminals of two supplies, the state of the system as shown at time t_2 is stable and can occur.

Next, at time instant t_3, the resistance of resistor 20a is increased further to 200 micro ohms. This is stated by equation 16. Thus, if the 150 amps continues to flow through resistor 20a, the voltage drop across resistor 20a will be 30 millivolts. This is stated by equation 17. But such a 30 millivolts drop cannot occur because it is greater than the maximum tolerance that is possible between the output terminal voltage of any two supplies. Consequently, the drop across resistor 20a will be limited to that maximum or 20 millivolts. This is stated by equation 18.

Now, given a 20 millivolt maximum drop across resistor 20a while its resistance is 200 micro ohms, then the current I_4 must equal -100 amps. This is stated by equation 19, and it is less than the -150 amps that occur at times t_0, t_1, and t_2. Consequently, the power supplies of SET1 will increase the amount of current which they furnish to load L_1 as is shown by equation 20; and the power supplies of sets 2 and 3 will decrease the amount of current which they furnish as is shown by equation 21.

Next, at time t_4, the resistance of resistor 20a is further increased to 4000 micro ohms. This is stated by equation 22. As a result, the current I_4 drops even further to just 5 amps as is stated by equation 23. Thus the load current from the supplies of SET1 increase further as is given by equation 24; and the current from the supplies of SET2 and SET3 decrease further as is given by equation 25.

Finally, at time t_5, the variable resistor 20a open circuits, and so its conductance goes to zero. This is stated by equation 26. As a result, current I_4 goes from 5 amps to zero. This change in current which occurs when the resistance 20a is opened is, however, very small. Thus no hazardous sparking occurs, no data damaging RFI radiation occurs, and no data damaging sag or spike in output terminal voltage occurs. This is stated by equation 27.

Once resistor 20a is opened, the power supplies of SET1 furnish all of the current to load L_1; and the power supplies of SET2 and SET3 furnish all of the current to loads L_2 and L_3. This is stated by equations 28 and 29. In other words, load L_1 and the power supplies of SET1 have been isolated from the rest of the system.

At this point, the power supplies of SET1 can be turned off so that load L_1 can be worked on (i.e., a problem repaired or a feature added). And at the same time, the loads L_2 and L_3 can continue to operate. Allowing loads L_2 and L_3 to operate in this fashion is a very important feature since, for example, it can bring in thousands of dollars of extra billings in the case where each load is a computer in a multiprocessor data processing system.

After the work on load L_1 is complete, the system is reconnected by performing all of the above described operations in reverse order. Thus, the initial state of the system will be as given at time t_5; the next state of the system will be as is given at time t_4; etc. And, during the reconnection sequence, no hazardous sparking occurs, no data damaging RFI occurs, and no data damaging sag or spike in output terminal voltage occurs since the step in conductance is small and thus the step in load current is small.

Turning now to FIG. 5, a preferred embodiment of each of the variable resistors 20a, 20b, and 20c will be described. This embodiment includes one member 40 which has an elongated passageway 41; and it includes another member 42 which is shaped to slide into the passageway 41 and engage the passageway surfaces. Preferably there is some elasticity between the members 40 and 42 as they engage so they make intimate contact but do not wear out. Symbol "d" in FIG. 5 indicates the distance by which member 42 is inserted into the passageway 41; and the conductance between the members 40 and 42 increases as the distance "d" increases.

As was previously explained, it is critical that the step in conductance between the members 40 and 42 is very small as those members initially engage. In the FIG. 5 embodiment, this small step is achieved by providing a beveled tip 43 on member 42. By beveling the tip 43, the surface area between the members 40 and 42 at their point of initial engagement can be made as small as desired, and thus the initial conductance between those members is reduced by a like amount.

Conductance between the members 40 and 42 increases in a nonlinear fashion until all of the tip 43 is in the passageway 41. Thereafter, the conductance between the members 40 and 42 rapidly increases in a linear fashion with the distance "d". All of this is shown in FIG. 6 by a curve 44.

Preferably, the entrance to the passageway 41 is covered with an insulator 45. This insulator 45 prevents the end of the tip 43 from being accidentally pushed flush against that portion of member 40 which the insulator 45 covers. Such accidental contact must be prevented since it would produce a large step in conductance between the members 40 and 42. Also, the insulator 45 within the passageway serves as a guide which prevents "contact bounce" from occurring between the members 40 and 42 as they initially engage.

Consider now the sequence which occurs when any one of the power supplies fails. This situation is illustrated in FIG. 7 wherein power supply PS_{3c} is shown to have failed. When a supply fails, it automatically turns itself off and acts like an open circuit. Current to the loads L_1, L_2, and L_3 is then furnished by all of the remaining power supplies which are still operating.

For the system which is illustrated in FIG. 7, each of the remaining power supplies will furnish 480 amps after supply PS_{3a} fails. This is calculated as 550+450+1400 divided by 5. Current I_4 will equal 480X2-50; current I_5 will equal 480-450; and current I_6 will be the sum of current I_4 and current I_5.

One primary feature of the above system is that in the event of a power supply failure, all of the loads will continue to operate even though no one load has an extra or redundant supply. This is very important because the alternative of adding an extra or redundant supply in each set would significantly increase the system's cost and thereby make it less competitive. Further, the addition of an extra supply in each set would decrease the system's MTBF (mean time between failure) simply because there would be more parts that might fail.

To replace the failed power supply PS_{3c}, a repairman merely needs to pull that supply out of a socket which attaches it to the output terminal and current-sharing circuit, and to insert a new supply. When that occurs, the power supply system will then revert back to the state which it had before supply PS_{3a} failed (i.e., the state which is described at time t_0 in FIG. 4).

A preferred embodiment of the invention has now been described in detail. In addition, however, many changes and modifications can be made to these details without departing from the nature and spirit of the invention.

For example, in the embodiment of FIG. 3, the power supplies of all of the sets have the same current-furnishing capacity. But as an alternative, the current-furnishing capacity of the supplies can vary from set to set and they can also vary within a set.

To illustrate this point, suppose that load L_3 in FIG. 3 only requires 1100 amps. Then, power supply PS_{3c} can be changed to have a current-carrying capacity of only 200 amps. When all of the loads and all of the supplies are operating, each supply will share in furnishing load current in proportion to its current-furnishing capacity. And when any one power supply fails, the remaining power supplies will likewise share in picking up the added load.

As another alternative, the physical makeup of the variable resistors 20a, 20b, and 20c can be modified from that which is shown in FIG. 5; however, it is critical that the initial step in conductance from zero remains small. For example, instead of having a beveled tip 43 on member 42, just a small narrow portion of the surface of passageway 41 can be made conductive at the passageway entrance; and that conductive portion can then be made progressively wider with the distance "d".

Some latitude is allowable on the maximum size of the step in conductance which occurs in the variable resistors 20a, 20b, and 20c. However, as the size of the step increases, a corresponding step in load current also occurs in each of the power supply sets; and that in turn causes a voltage sag or spike to occur at the loads. Eventually, a point is reached at which the step in current is so large that the resulting sag or spike in voltage causes the circuitry in a load to operate improperly.

So, to avoid this problem, the product $2\Delta V\Delta C$ preferably is limited to that which causes a voltage sag or spike at the loads which is less than 3% of the nominal supply voltage. Alternatively, the product $2\Delta V\Delta C$ is limited to be less than 20% of the respective current-furnishing capacity of each power supply set. Here as before, $\pm\Delta V$ is the permissible preset tolerance of the output voltage. In many cases, these constraints can be met by limiting ΔC to be less than one thousand mhos (i.e., - limiting $1/\Delta C$ to be more than 1000 micro ohms).

Note that, as was described above in conjunction with FIG. 4, a large change in load current also can occur when one of the current-sharing switches is opened or closed. In FIG. 4 at time t_1, current I_4 changed from a +250 amps to a -150 amps. But that change in current does not cause the voltage on the output terminals to go out of the regulation band; nor does it generate RFI radiation. This is because the speed with which the current change occurs is limited to the reaction time of the current-sharing circuitry of the power supplies. Typically, the total change in current would occur over 10 to 50 milliseconds. By comparison, when one of the variable resistors 20a, 20b, or 20c is opened, the current through that resistor drops to zero instantaneously.

Note also that certain other problems will occur if the current-sharing switch of a set of supplies is not opened before the variable resistor for that set of supplies is opened, and vice versa. Suppose, for example, that in FIG. 3, the variable resistor 20a is opened while the current-sharing switches 30a, 30b, and 30c are closed. When that occurs, all of the supplies will continue to try to share in furnishing the total load current, but such sharing will be impossible since resistor 20a is open. In their effort to share the load current, the power supplies of SET1 will increase their output terminal voltage and the power supplies of SET2 and SET3 will decrease their output terminal voltage. And this will continue until the terminal output voltages of all the supplies go out of regulation. Conversely, the power supply system of FIG. 3 will work, although in an unevenly stressed fashion, if the current-sharing switches 30a, 30b, and 30c always remain open. In fact, the current-sharing between the supplies of each set can be disabled, and the system will still work.

Note further that in order to maintain its preset output voltage, power supplies sense their actual output voltage and adjust it up or down until it equals the preset value. But that sensing can occur at the power supply output terminal, or at the load. So preferably, the terminals of the variable resistors 20a, 20b, and 20c which interconnect the power supply sets are placed at the points where the power supply sets sense their output voltage. Otherwise, the voltage across a variable resistor could exceed $2\Delta V$, and that in turn would increase the instantaneous change in current which occurs through that component when its step in conductance ΔC occurs.

In view, therefore, of all of the above, it is to be understood that the invention is not limited to the details of the illustrated embodiments, but is defined by the appended claims.

WHAT IS CLAIMED IS:

1. A power supply system which is comprised of: multiple sets of power supplies; each set having an output terminal for furnishing load current at a certain voltage; a respective load connected to the output terminal of each set; and each set further having a current-sharing circuit by which the load currents furnished from the supplies within a set are shared; wherein

all of said supplies together, minus any one supply, have a total current-furnishing capacity which meets the current requirements of all of said loads, and yet no set of supplies includes a redundant supply;

a switching means is provided which selectively interconnects, and disconnects, the respective current-sharing circuits of said sets such that the supplies of all connected sets furnish equalized load currents; and

variable resistors are provided which selectively interconnect the respective output terminals of said sets through a conductance that increases from zero by a predetermined small step and thereafter progressively increases to a short circuit, and which selectively disconnects the respective output terminals through an oppositely varying conductance.

2. A power supply system according to claim 1 wherein said predetermined small step in conductance is limited to that which produces a voltage sag or spike at said loads which is less than 3% of said certain voltage.

3. A power supply system according to claim 2 wherein each of said variable resistors includes first and second members with respective surfaces that slideably engage in selectable amounts, with the degree of said conductance increasing with the amount of engagement.

4. A power supply system according to claim 3 wherein said first member includes an elongated passageway, and said second member includes an elongated portion which slides into said passageway and engages its surface in selectable amounts to vary said conductance.

5. A power supply system according to claim 4 wherein said elongated portion has a beveled tip which minimizes the amount of initial engagement with said passageway.

6. A power supply system according to claim 5 wherein each respective load is a backplane in a computer system.

7. A power supply system which is comprised of: multiple sets of power supplies; each set having an output terminal for furnishing load current at a certain voltage; a respective load connected to the output terminal of each set; and each set further having a current-sharing circuit by which the load currents furnished from the supplies within a set are shared; wherein

all of said supplies together, minus any one supply, have a total current-furnishing capacity which meets the current requirements of all of said loads, and yet no set of supplies includes a redundant supply;

a first means is provided which selectively enables the respective current-sharing circuits of any of said sets of power supplies to operate together and share in furnishing their load currents; and

a second means is provided which selectively interconnects the output terminals of said sets through respective conductances which increase from zero by a predetermined small step and thereafter progressively increase to a short circuit, and vice versa.

8. A power supply system according to claim 7 wherein said predetermined small step in conductance is limited to that which confines any voltage sag or spike at said loads to less than 3% of said certain voltage.

9. A power supply system according to claim 7 wherein said predetermined small step in conductance is limited to that which produces a current step of less than 20% of the respective current-furnishing capacity of each set of supplies.

10. A power supply system according to claim 7 wherein said predetermined small step in conductance is limited to one thousand mhos.

11. A power supply system according to claim 7 wherein said second means includes first and second members with respective surfaces that slideably engage in selectable amounts, with the degree of said conductance increasing with the amount of engagement.

12. A power supply system according to claim 7 wherein each set of power supplies maintains said certain voltage by sensing the voltage at a node between its output terminal and its load, and wherein said variable conductances of said second means are connected at such nodes.

13. A power supply system which is comprised of: multiple sets of power supplies; each set having an output terminal for furnishing load current at a certain voltage; and a respective load connected to the output terminal of each set; wherein

all of said supplies together, minus any one supply, have a total current-furnishing capacity which meets the current requirements of all of said loads, and yet no set of supplies includes a redundant supply; and

a means is provided which interconnects the respective output terminals of said sets and selectively varies the conductance between them such that the conductance increases from zero by a predetermined small step and thereafter gets progressively larger, and vice versa.

Fig.1 (PRIOR ART)

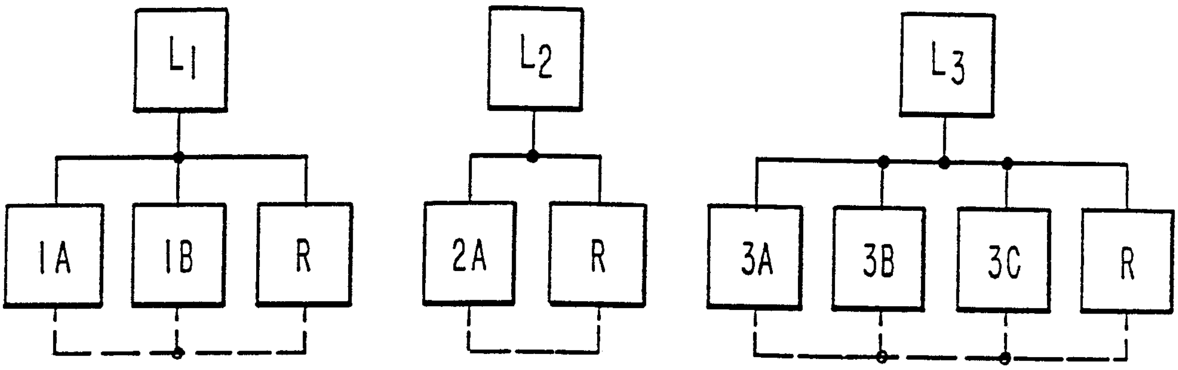


Fig.2

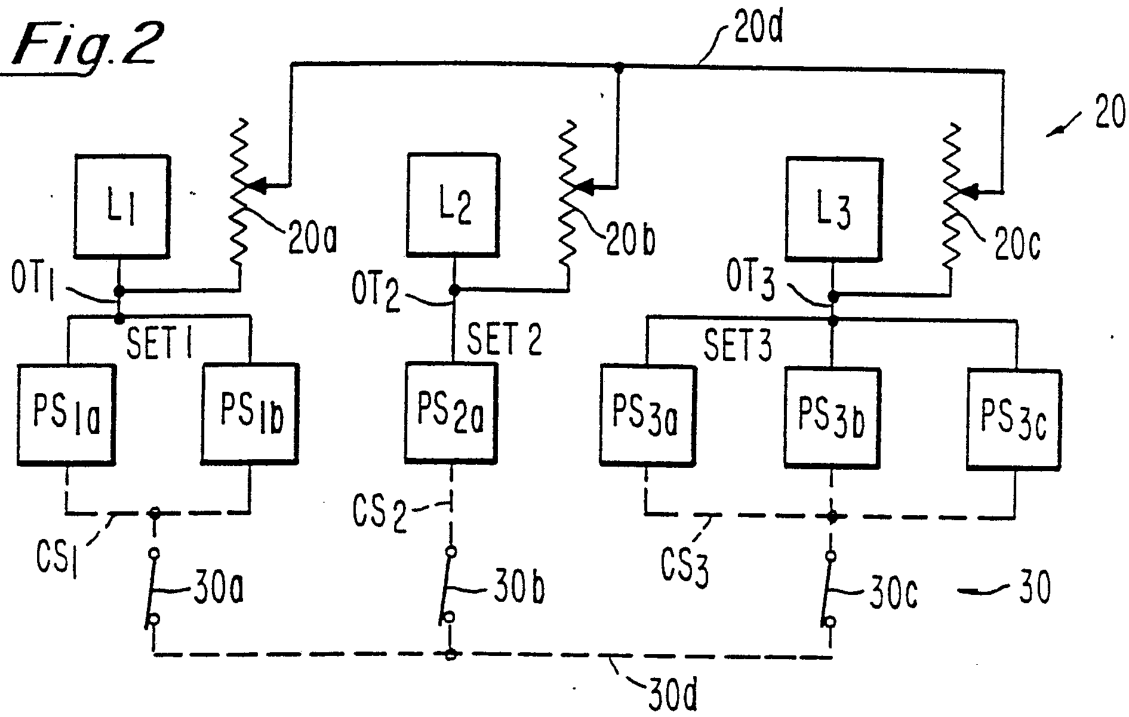


Fig.3

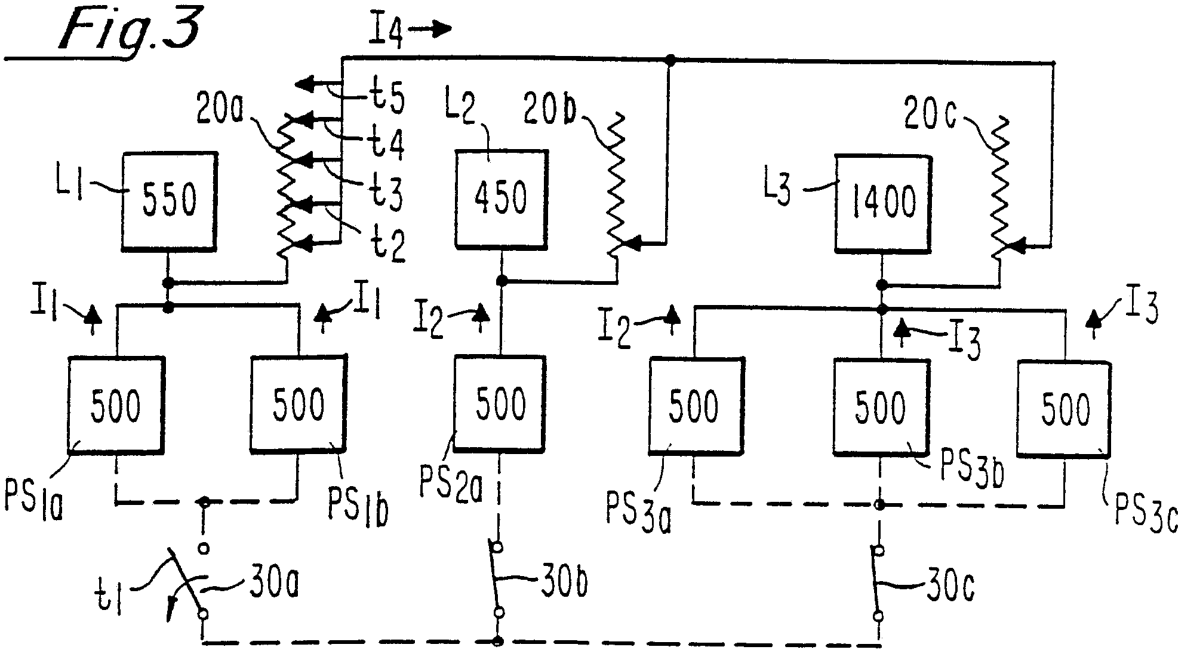


Fig. 4A

$t=t_0$

$I_1=+400 \sim \frac{550+450+1400}{6}$ ~eq.1

$I_2=I_1$ ~eq.2

$I_3=I_1$ ~eq.3

$I_4=+250 \sim 400 \times 2-550$ ~eq.4

$t=t_1$

$V_1<V_2$ & V_3 ~eq.5

$\therefore PS_2$ & PS_3 try to supply all I ~eq.6

$(550+450+1400)\div 4=600$ ~eq.7

$600>500$ ~eq.8

$I_2=I_3=500$ ~eq.9

$I_4=-150 \sim (500)(4)-450-1400$ ~eq.10

$I_1=(500-150)\div 2=200$ ~eq.11

$t=t_2$

$R20a \rightarrow 50\mu\Omega$ ~eq.12

V20a increases to $(150)(50\mu\Omega)=7.5\,mV$ ~eq.13

$2\Delta V max=20\,mV$ ~eq.14

$\therefore 7.5\,mV$ is ok ~eq.15

$t=t_3$

$R20a \rightarrow 200\mu\Omega$ ~eq.16

$V20a-(150)(200\mu\Omega)=30\,mV$ ~eq.17

$2\Delta V max=20\,mV$ ~eq.18

$\therefore I_4=(20\,mV)\div(200\mu\Omega)=-100$ ~eq.19

$I_1=(550-100)\div 2=225$ ~eq.20

$I_2=I_3=\frac{(450+1400+100)}{4}=487.5$ ~eq.21

$t=t_4$

$R20a \rightarrow 4000\mu\Omega$ ~eq.22

$I_4=(20\,mV)\div(4000\mu\Omega)=-5$ ~eq.23

$I_1=(500-5)\div 2=272.5$ ~eq.24

$I_2=I_3=\frac{(450+1400+5)}{4}=463.75$ ~eq.25

$t = t_5$

$R_{20a} — OO \sim$ eq. 26

$I_4 = 0\ (\Delta I_4 = 5) \sim$ eq. 27

$I_1 = 550 \div 2 = 275 \sim$ eq. 28

$I_2 = I_3 \doteq \frac{(450-1400)}{4} = 462.5 \sim$ eq. 29

Fig. 4B

Fig. 4

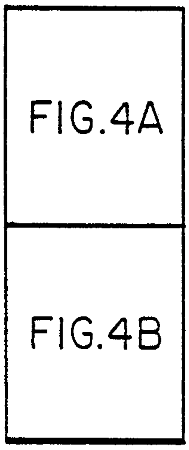


Fig. 5

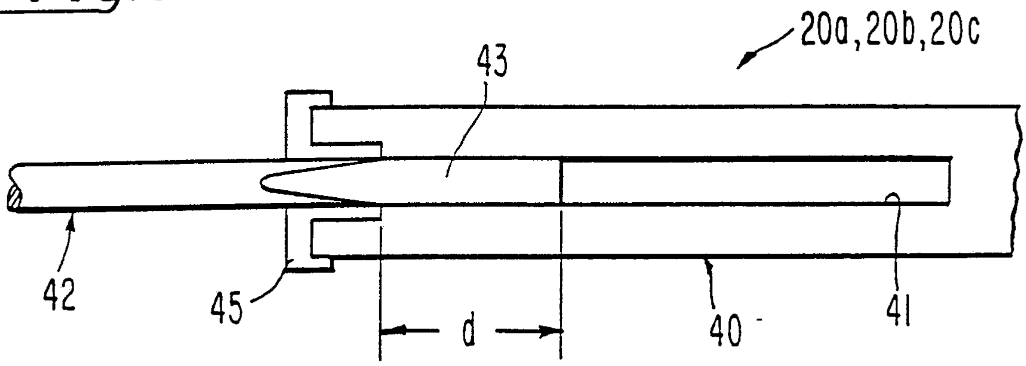


Fig.6

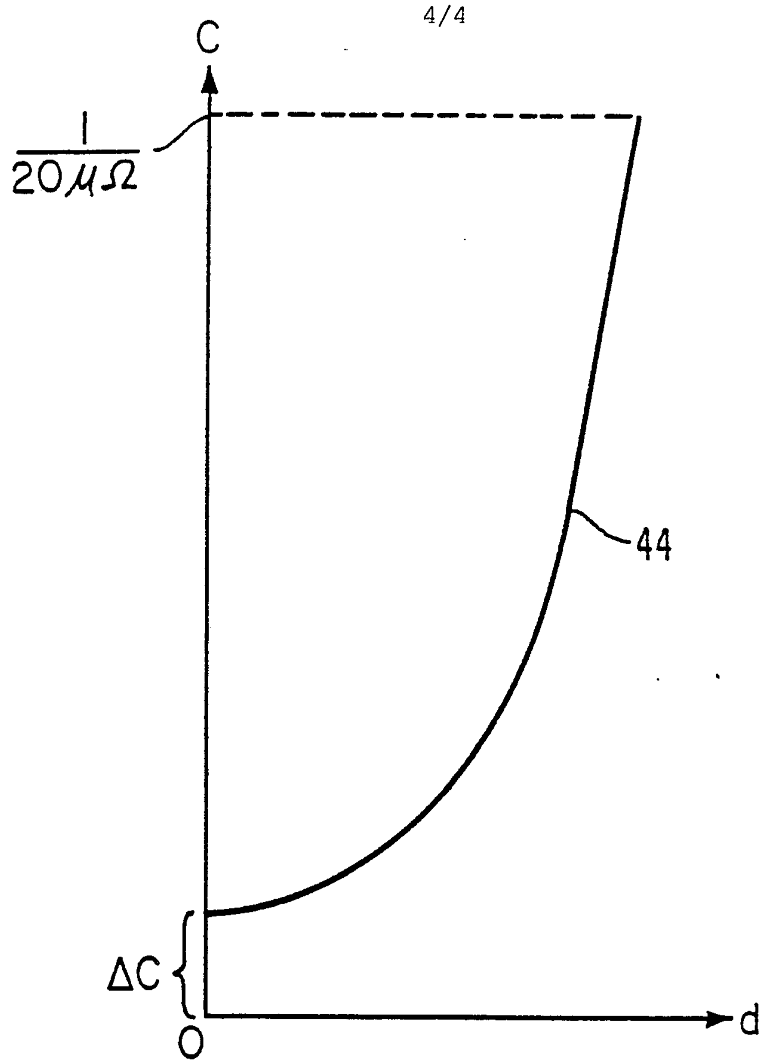
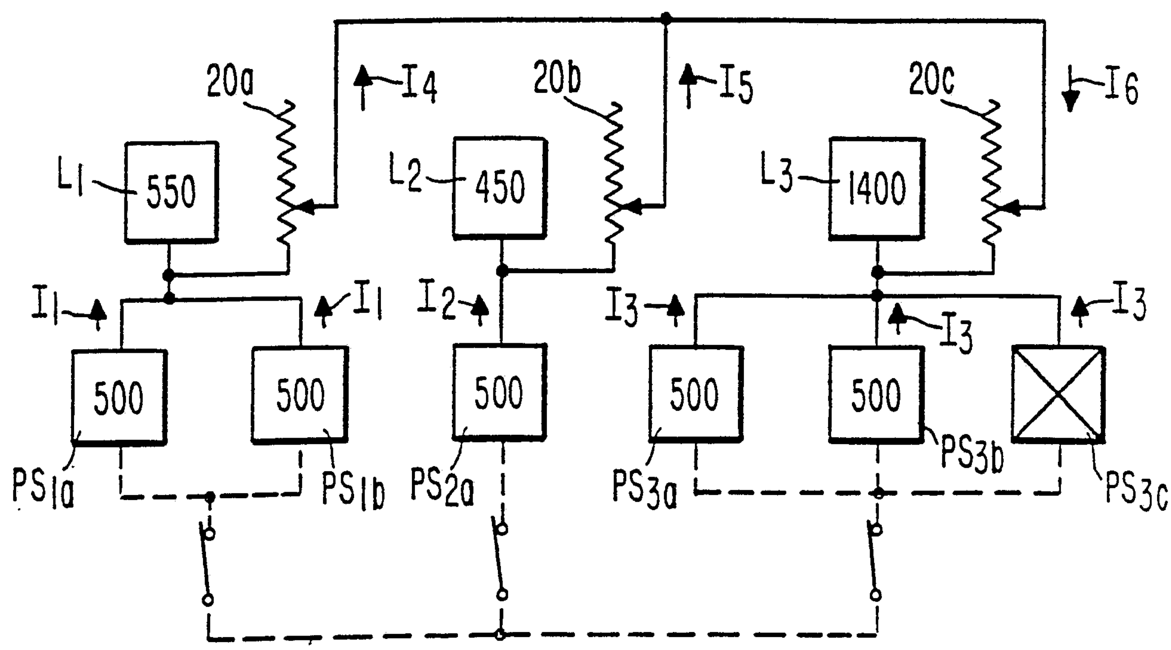

C
1
20μΩ
44
ΔC
O
d

Fig.7


20a
I4
20b
I5
20c
I6
L1
550
L2
450
L3
1400
I1
I1
I2
I3
I3
I3
500
500
500
500
500
PS1a
PS1b
PS2a
PS3a
PS3b
PS3c

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 88/03803

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC
IPC4: H 02 J 1/10,9/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC4	H 02 J

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	US, A, 4659942 (J.A. VOLP) 21 April 1987, see column 3, line 26 - column 4, line 11 --	1-13
A	US, A, 4539487 (T. ISHII) 3 September 1985, see the whole document --	1-13
A	US, A, 4651020 (T.J. KENNY ET AL) 17 March 1987, see column 2, line 35 - column 3, line 17 --	1-13

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* Special categories of cited documents: [10]

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
8th February 1989	06 MAR 1989
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	P.C.G. VAN DER PUTTEN

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. PCT/US 88/03803

SA 25402

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The members are as contained in the European Patent Office EDP file on 12/01/89
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4659942	21/04/87	NONE	
US-A- 4539487	03/09/85	DE-A- 3332727	30/05/84
		JP-A- 59099930	08/06/84
		GB-A-B- 2132040	27/06/84
US-A- 4651020	17/03/87	EP-A- 0215348	25/03/87
		JP-A- 62060436	17/03/87

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