
CHAPTER 24

PARALLEL OPERATION OF VOLTAGE-STABILIZED POWER SUPPLIES

24.1 INTRODUCTION

Stabilized-voltage power supplies, both switching and linear, have extremely low output resistances, often less than $1\text{ m}\Omega$. Consequently, when such supplies are connected in parallel, the supply with the highest output voltage will supply the majority of the output current. This will continue until this supply goes into current limit, at which point its voltage will fall, allowing the next highest voltage supply to start delivering current, and so on.

Because the output resistance is so low, only a very small difference in output voltage (a few millivolts) is required to give large current differences. Hence, it is impossible to ensure current sharing in parallel operation by output voltage adjustment alone. Generally any current imbalance is undesirable, as it means that one unit may be overloaded (operating all the time in a current-limited mode), while a second parallel unit may be delivering only part of its full rating.

Several methods are used to make parallel units share the load current almost equally.

24.2 MASTER-SLAVE OPERATION

In this method of parallel operation, a designated master is selected, and this is arranged to provide the voltage control and drive to the power sections of the remainder of the parallel units.

Figure 1.24.1 shows the general arrangement of the master-slave connection. Two power supplies are connected in parallel. (They could be switching or linear supplies.) Both supplies deliver current to a common load. An interconnection is made between the two units via a link (this is normally referred to as a P-terminal link). This terminal links the power stages of the two supplies together.

The master unit defines the output voltage, which may be adjusted by VR2. The slave unit will be set to a much lower voltage. (Alternatively, the reference will be linked out, LK1.) The output of amplifier A1' will be low, and diode D1' is reversed-biased. Q3' will not be conducting, and the drive to Q2' will be provided by Q3 in PSU1 via the P-terminal

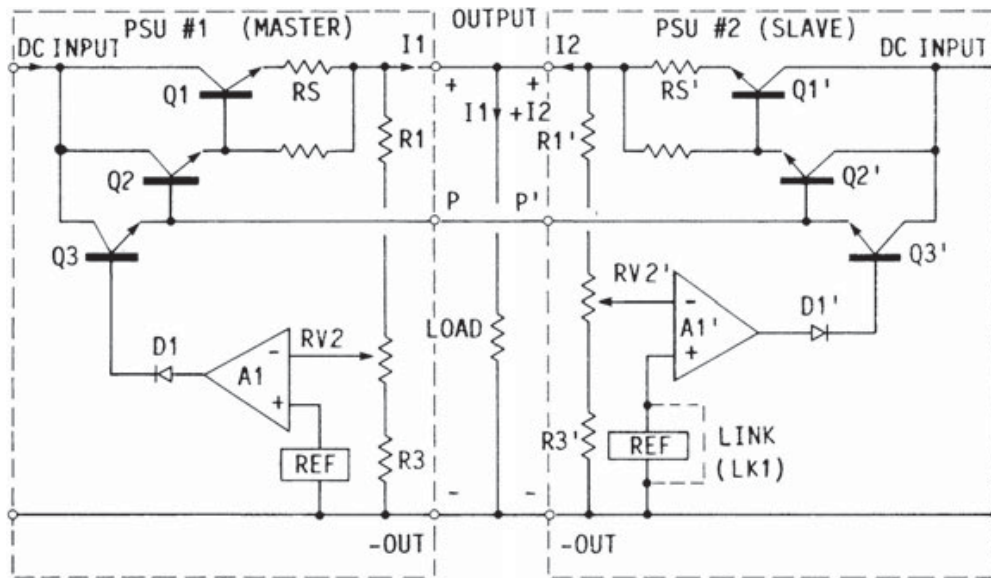


FIG. 1.24.1 Linear voltage-stabilized power supplies in master-slave connection.

link. The drive transistor Q3 must have sufficient spare drive current to provide the needs of all the parallel units; hence there is a limit to the number of units that can be connected in parallel. Drive accommodation is normally provided for a minimum of five parallel supplies.

In this arrangement, the slave supplies are operating as voltage-controlled current sources. Current sharing is provided by the voltage drop across the emitter sharing resistors R_s and R_s' . The current-sharing accuracy is not good because of the rather variable base-emitter voltages of the power transistors. A sharing accuracy of 20% would be typical for this type of connection.

The major disadvantage of master-slave operation is that if the master unit fails, then all outputs will fail. Further, if a power section fails, the direct connection between the two units via the P terminal tends to cause a failure in all units.

24.3 VOLTAGE-CONTROLLED CURRENT SOURCES

This method of parallel operation relies on a principle similar to that of the master-slave, except that the current-sharing P-terminal connection is made at a much earlier signal level in the control circuit. The control circuit is configured as a voltage-controlled current source. The voltage applied to the P terminal will define the current from each unit, the total current being the sum of all the parallel units. The voltage on the P terminal, and hence the total current, is adjusted to give the required output voltage from the complete system. Figure 1.24.2 shows the general principle.

In this arrangement the main drive to the power transistors Q1 and Q1' is from the voltage-controlled current amplifiers A1 and A1'. This operates as follows.

Assume that a reference voltage REF has been set up by one of the amplifiers. (REF2 and REF2' must be equal, as they are connected by the P terminals.) The conduction of

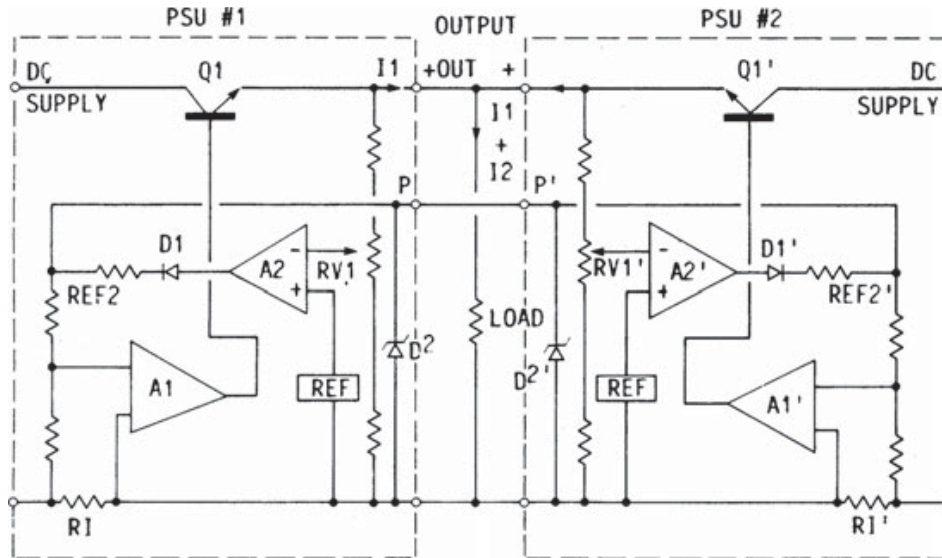


FIG. 1.24.2 Parallel operation of current-mode-controlled linear power supplies, showing natural current-sharing ability.

transistors $Q1$ and $Q1'$ will be adjusted by the amplifiers so that the currents in the two current-sensing resistors $R1$ and $R1'$ will be well defined and equal. The magnitude of the currents depends on the reference voltage on P and the resistor values.

The dominant control amplifier, $A2$ or $A2'$ (the one set to the highest voltage), will now adjust the current to obtain the required output voltage. The other amplifier will have its output diode reverse-biased.

The major advantage of this arrangement is that a failure in the power section is less likely to cause a fault in the P -terminal interconnection, and the current sharing is well defined.

This circuit lends itself well to parallel redundant operation. See Sec. 1.24.5.

24.4 FORCED CURRENT SHARING

This method of parallel operation uses a method of automatic output voltage adjustments on each power supply to maintain current sharing in any number of parallel units. This automatic adjustment is obtained in the following way.

Because the output resistance in a constant-voltage supply is so low (a few milliohms or less), only a very small output voltage change is required to make large changes in the output current of any unit.

With forced current sharing, in principle any number of units can be connected in parallel. Each unit compares the current it is delivering with the average current for all units in the total setup and adjusts its output voltage so as to make its own output current equal to the average current.

Figure 1.24.3 shows the principle used for this type of system. Amplifier $A1$ is the voltage control amplifier of the supply. It operates in the normal way, comparing the output voltage from the divider network $R3$, $R4$ with an internal reference voltage V'_{ref} and controlling the power stage so as to maintain the output voltage constant. However,

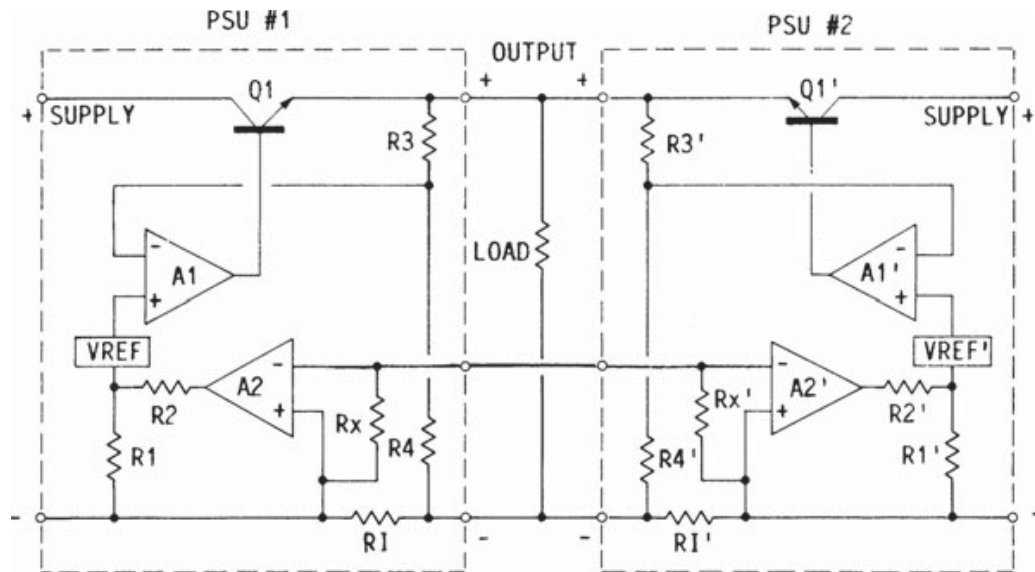


FIG. 1.24.3 Parallel operation of voltage-stabilized linear power supplies, showing forced current-sharing circuit.

V'_{ref} is made up of the normal reference voltage V'_{ref} in series with a small adjustable reference V_2 developed by the divider network R_1, R_2 from the current sense amplifier A_2 . V_2 , and hence V'_{ref} , may be increased or decreased in response to the output of amplifier A_2 . The maximum range of adjustment is limited, being typically 1% or less.

Amplifier A_2 compares the output current of its own power supply with the average output current of all the power supplies by comparing the voltage analogue across the internal current shunt R_1 with the average voltage analogue generated by all the shunts and averaged by the interconnection resistors R_x . A_2 will increase or decrease the second reference voltage V_2 , and hence the output voltage of its supply, so as to maintain its current on a par with the average.

An interconnection between the power supplies must be provided to carry the information on the average current. (This is sometimes known as a P-terminal link.)

Any number of such supplies can be directly connected in parallel. All that will be required from the supplies is that their output voltages must be adjusted to be within the voltage capture range (within 1% of the required output voltage in this example).

The major advantage of this technique for parallel redundant operation is that in the event of one power supply failing, the remaining working units will redistribute the load current equally among them without interruption to the output.

The output voltage of the combination will adjust itself to the average value of the independent units.

A more practical arrangement of this circuit principle is demonstrated in Fig. 1.24.4. This circuit has the advantage that the reference voltage can be increased or decreased as required.

The output voltage of amplifier A_2 (node A) will normally be equal to the reference voltage V_{ref} . Hence there will be no corrective action so long as the output current is equal to the average current of the combination. Under these conditions, the voltages at node B and node C are the same. If the current is not balanced, then the voltage at node B will not be the same as that at node C, and the output of amplifier A_2 will change to adjust the reference voltage. This will result in a change in output voltage and a correction in the output current, to recover a balanced condition.

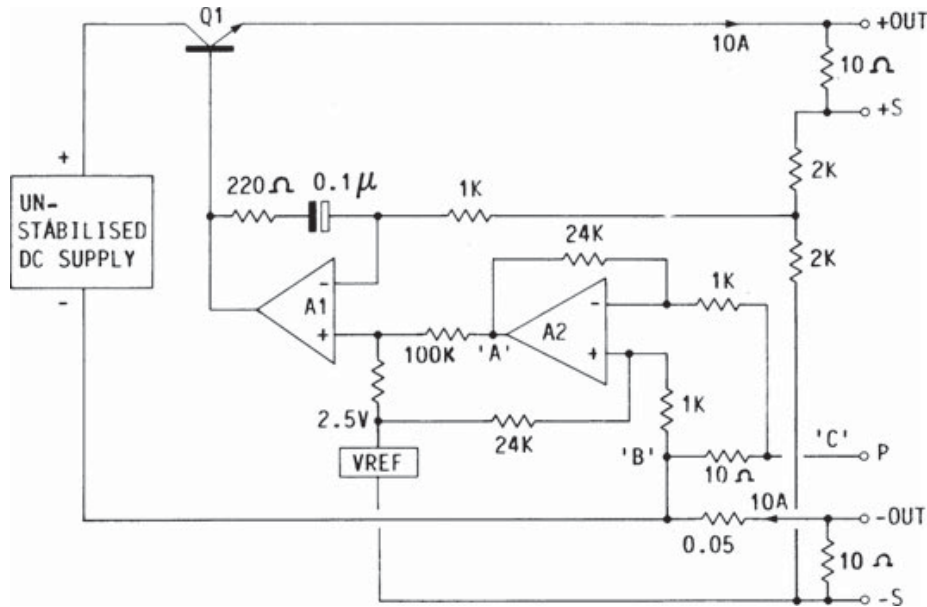


FIG. 1.24.4 Example of a forced current-sharing circuit.

24.5 PARALLEL REDUNDANT OPERATION

The purpose of parallel redundant operation is to ensure maintenance of power even in the event of one power supply failure. In principle, n supplies (where n is two or more) are connected in parallel to supply a load that has a maximum demand that is $n-1$ of the total combination rating. Hence, if a supply fails, the remainder of the units will take up the load without an interruption in the service.

In practice, the failed supply may short-circuit (for example, the SCR over voltage crow-bar may fire). To prevent this supply from overloading the remainder of the network, the power supplies will usually be rectifier-diode OR-gated into the output line. Figure 1.24.5 shows a typical arrangement.

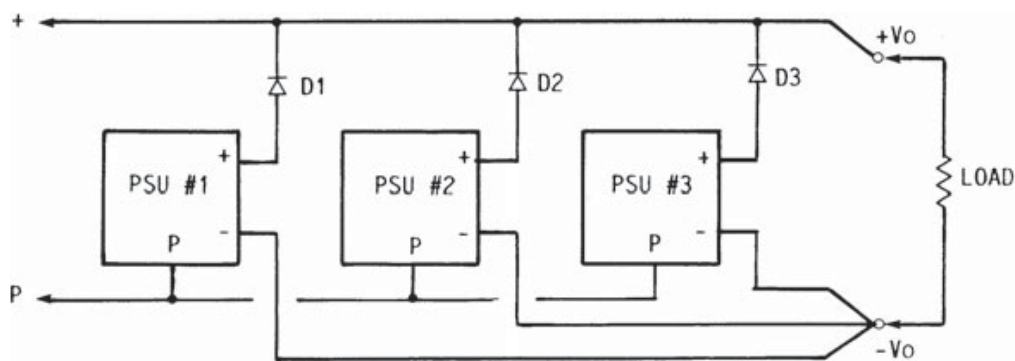


FIG. 1.24.5 Parallel redundant connection of stabilized voltage power supplies.

Remote voltage sensing is not recommended for parallel redundant operation, as the remote connections provide alternative current paths in the event of a power supply failure. If line voltage drops are a problem, then the diodes should be mounted at the load end and remote sensing taken up to the diode anode only, as shown in Fig. 1.24.6.

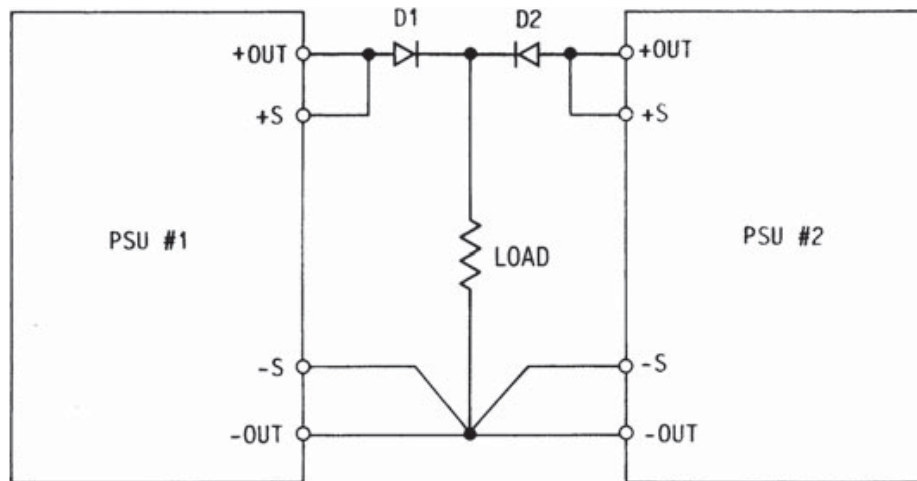


FIG. 1.24.6 Parallel redundant operation of voltage-stabilized power supplies, showing quasi-remote voltage sensing connections.

Power supplies of the forced-current-sharing type are most suitable for this type of parallel redundant mode operation, as the P-terminal link provides current sharing and does not compromise the operation if a supply fails. In fact, the technique ensures that the remainder of the supplies share the load equally, increasing their output currents as required to maintain a constant output voltage.

24.6 PROBLEMS

1. Why does operating constant-voltage power supplies in parallel present a problem?
2. What is meant by parallel master-slave operation?
3. Explain the major disadvantage of master-slave operation.
4. What is meant by forced current sharing for parallel operation?
5. What is the major disadvantage of forced current sharing?
6. What is meant by parallel redundant operation?