

An Improved ac Power Switch

Turning ac power on and off isn't always as simple as it seems. Here's an ac power controller that is safe, reliable, long-lived, digitally controlled, and interference-free.

by Raymond A. Robertson

NEARLY EVERY TEST SET includes a device to apply ac power to the unit under test. It may be a commercially available unit, but more commonly is specially built. It is normally a box containing a power supply, a relay, and a relay driver. Some of the fancier ones include inductors to enhance the life of the relay contacts and some sort of EMI (electromagnetic interference) filtering. While these devices do the job, they generate EMI when turning on or off. Many are special, one-of-a-kind designs, and it is not only time-consuming to design and fabricate a rack-mounted box that has convenient input and output connections, but the finished product is sometimes less than ideal from the points of view of safety, reliability and electromagnetic compatibility.

The new HP Model 14570A AC Power Controller (Fig. 1) is a digitally controlled ac power line switch and distribution system that is designed to alleviate these problems. It combines the best characteristics of relays and solid-state switching devices to create an ac switching device that is safe and reliable, generates little EMI, and has a relatively long life.

The 14570A is useful in applications that require any of the following capabilities:

- Direct control of many medium-power ac devices under program control (e.g., process automation).
- Control of ac devices where generation of EMI would

cause sensitive equipment to malfunction.

- Distribution of filtered ac power to sensitive instruments.

Typical applications include production test, process control, time or temperature cycled production burn-in, and other programmed control of small-to-medium-power ac loads.

While the 14570A can be interfaced to many different controllers using standard TTL voltage levels, it was designed as an accessory for HP's 6940B and 6942A Multiprogrammers. Thus it is most easily connected to a user's application as one of many functions under the supervision of the multiprogrammer.

Design Considerations

Power relays have a typical lifetime of about 50,000 operations at full load. In a test set that takes one minute to test each unit and operates for one 8-hour shift per day, there will be over 100,000 relay operations a year. Thus a typical relay will have a life of only about one-half year. A useful life of 10 years was one of the design goals for the 14570A. Other goals were to design a safe and reliable rack-mountable unit that would be easy to connect and compatible with the 6940B and 6942A Multiprogrammers or any open-collector digital source.

We were looking for an ac switch that generates no EMI, has no losses, and can withstand long-term electrical abuse.

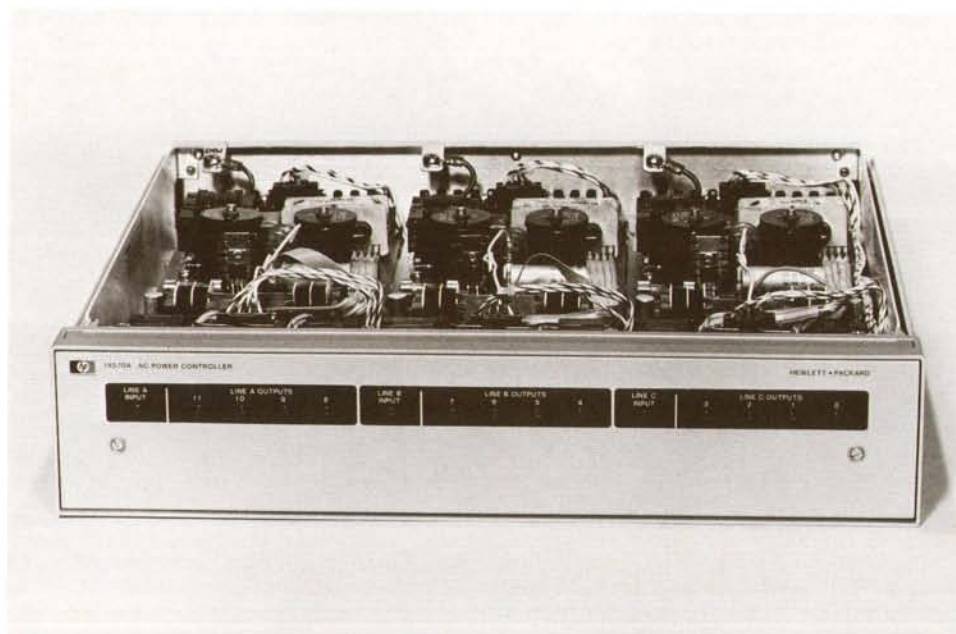


Fig. 1. The HP 14570A AC Power Controller is designed for high-reliability, low-interference automatic ac power switching in systems applications. It has 12 outputs, organized into three groups of four switches. Each group has a single 115V or 230V ac power input. Twelve TTL-compatible inputs control the 12 outputs.

To minimize EMI generation, the switch must turn on when the line voltage is zero and therefore when the load current is also zero. It must turn off when the load current is zero. Since the line voltage is not necessarily zero when the current is zero, there must be provision for the voltage across the open switch to rise gradually to the line voltage.

Solid-State Switches

While it is possible to build a solid-state switch that approaches the required low EMI, most commercially available solid-state switches do not perform as well as they could. The main reason is that most solid-state relays derive gate current for the switching element from the ac line. The switch can not turn on until the line voltage has risen to a level sufficient to provide enough current. A solution that is rarely implemented is to provide a separate supply for gate current.

The typical circuit for a solid-state switch is given in Fig. 2. It contains an isolation device, a gate current limiting resistor, and a solid-state switching device. In this case the isolator is an optocoupler. A small relay is sometimes used in its place. The switch in Fig. 2 uses a triac (triode ac semiconductor switch). SCRs (semiconductor controlled rectifiers) are sometimes used instead, and this results in a more rugged device but a somewhat more complicated circuit.

The circuit of Fig. 2 has some problems. The circuit is not synchronized to turn on at the zero crossing of the ac line. Although this one does not, some solid-state relays do contain a voltage detection circuit and gating to prevent the switch from firing except near the line zero. However, even in these circuits, the current to fire the triac is derived from the same source as the load current; in fact, the trigger current flows through the load. Therefore, the zero-voltage window has to be set high enough for the line voltage to exceed the drop caused by the gate voltage, the drop in the load, and the drops in the gate current limiting resistor and diode bridge. There is a further complication in that the triac has a latching current. This is the current that must flow through the triac to ensure that the current will continue to flow after the gate current has been removed. The zero-voltage window must be of sufficient magnitude to accommodate the voltage drops and yet allow the load current to exceed the latching current of the triac. Load current in an inductive load builds slowly, and triacs have a nonsymmetrical gate firing characteristic. When the zero-voltage point is set too low, a small inductive load is likely to turn on only for alternate half cycles. To guard against this, the zero-voltage window for most solid-state relays is set at 25 to 80 volts.

Solid-State Switch Operation

Triacs turn on very rapidly. If a load such as a tungsten lamp, which has a high inrush current, is turned on at moderate line voltage, there is a large rate of change of current (di/dt) in the switching device. This causes EMI and may damage the triac. Solid-state switches can withstand large current surges, but there is a limit to the di/dt that they can withstand. This is because it takes a finite length of time for the current to spread so that the whole semiconductor die can share the load current. If the current rises too rapidly, localized heating on the die can destroy the device. With the circuit arrangement of Fig. 2, the triac will turn on and off each half cycle of the 60-Hz ac line. The large di/dt results in a 120-Hz signal that is very rich in high-frequency harmonics.

On turn-off, solid-state relays perform more like an ideal switch. The triac will remain on for each half cycle until the load current is less than the latching current of the triac. When the source of the trigger current is removed, the triac will turn off at the next zero of the load current. There is a problem when the load is inductive. When the current is almost zero, the voltage may be near its peak. When the triac ceases conduction, the full line voltage may appear across the open switch almost instantaneously. This large dv/dt can be coupled through parasitic capacitance to the gate of the triac, causing it to turn on again. To guard against this dv/dt problem, an RC snubber network is placed across the switch. The value of this snubber should be tailored to the load. If the snubber impedance is too low, excessive load current will flow through it; if its impedance is too high, the triac will fire because of excessive dv/dt . In either case the load never turns off.

Solid-State Switch Protection

Solid-state relays can withstand a moderate amount of abuse from overcurrent. They will typically withstand ten times rated current for about one cycle of the ac line. Most 120Vac branch power lines can deliver in excess of 500 amperes into a short circuit. Therefore, it is difficult to select a fuse that will interrupt the line current fast enough to protect the switch in the event of a short circuit, but that acts slowly enough to avoid the nuisance of blown fuses with normal inrush current. Short-circuit protection is important because many loads have fault conditions that result in abnormally high current. A motor with a locked rotor will draw a high current, as will a lamp whose filament has burned out and falls across the support leads. It is inconvenient to have to replace the failed device and fuse, but it is even more inconvenient to have to replace a destroyed switch as well.

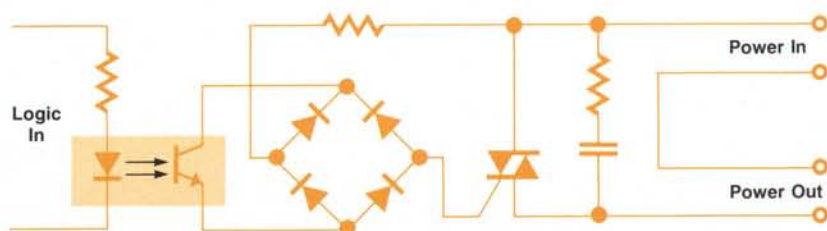


Fig. 2. Typical solid-state relay block diagram.

Triacs respond to overvoltage and to fast line spikes in the same manner; they turn on and remain on for the remainder of the line cycle. This is a problem when the triac is supposed to be off. It manifests itself as occasional half cycling. This can be an inconvenience or a safety hazard depending on the nature of the load. Not all vendors guarantee that their devices will withstand this breakover firing. Possible solutions include metal-oxide varistors across the switches for overvoltage protection, and normal-mode filters to reduce line spikes to solve the dv/dt problems.

Another problem with solid-state switches is the power they dissipate. Most of this power loss is caused by the voltage drop across a solid-state device in its on state. This power loss causes thermal work-hardening of the solder that holds the die to the header. This can result in increased thermal impedance that can lead to thermal runaway. Many devices are rated for as few as 25,000 thermal cycles. In an application where the solid-state relay reaches its maximum operating temperature during each on cycle, it may have a life that is only one-half as long as an electromechanical relay.

Relay Switching

Electromechanical relays have been used as ac power switches for a long time. They are close to an ideal switch when they are in either the on or the off state, but when switching, their behavior is less than ideal. A small power relay that can survive 1000 volts across its open contacts is much more common than a medium-power triac that will withstand the same voltage. The same relay might be rated at 5000 volts from coil to contacts. It is difficult to imagine a switching device that is better than a well-mated pair of relay contacts.

Relays suffer from two main problems: turning on and turning off. It is difficult to turn a relay on at zero voltage because of the several milliseconds of time uncertainty between the application of coil power and contact closure. There are also several milliseconds of bounce when the relay contacts come together. This bouncing causes rapid changes in load current, which cause severe EMI and some

erosion of the relay contacts. When the relay opens there is also a few milliseconds of time uncertainty between the removal of coil power and opening of the contacts. This makes synchronization to the line cycle impractical. When the contacts open, there is less bounce than when the contacts close, but damage to the contacts is more severe and the EMI is worse than upon closing. This seeming contradiction exists because the air gap between the relay contacts ionizes as they open. The ionized air is a good conductor and might have as low as a 30-volt drop at six amperes. The gap continues to conduct and carry almost the full load current until the line voltage nears the arc voltage. While arcing, the relay dissipates more than 100 watts of power for a few milliseconds, generates much EMI, and suffers erosion of its contacts. This results in two limitations on relays. It is common to see relays rated at 240Vac but only 32Vdc because at 240Vdc the arc will not extinguish. Also, relays are usually restricted to some slow rated switching speed such as 0.5 Hz. This is necessary to keep the average power dissipated in the gap within the physical limits of the relay. A typical medium-power relay would last for less than a minute at its rated load if switched at 30 Hz.

The 14570A Solution

From the above discussion, it can be seen that relays make pretty good switches, but physical limitations restrict what can be done to improve their performance. On the other hand, solid-state switches offer a lot of promising capability, but typical circuit implementations and their lack of ruggedness make them less than ideal. The 14570A AC Power Controller takes the best characteristics of each method to overcome the deficiencies of the other. An SCR and a relay in parallel form the switching element. The SCR makes and breaks the load current while the relay carries the load except for the first and the last few milliseconds of each on cycle. Fig. 3 is a block diagram of the 14570A.

The 14570A is an ac power distribution system. There are three independent boards in each unit. Each board has four ac power switching channels that share a common neutral line. Thus there are 12 channels per box. The ac power is fed

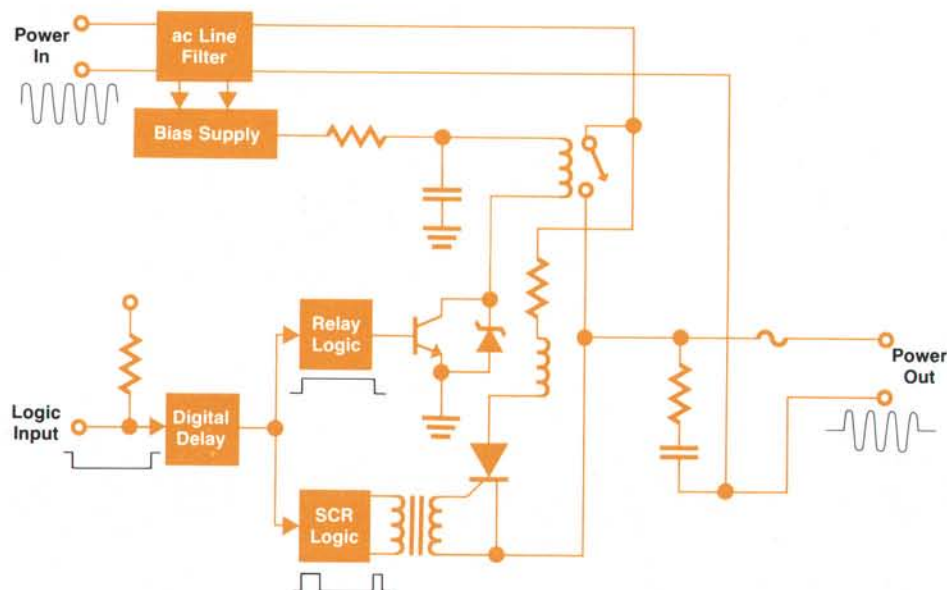


Fig. 3. 14570A block diagram. Only one of the 12 output channels is shown. Each power input serves four output channels.