

**Figure 14.8** Simplified electric-power distribution for 115 V circuits. Power frequency is 60 Hz.

placed across the entire secondary winding; electricians do this by making connections to the two ungrounded terminals. Ordinary wall receptacles and lights operate on 120 V, obtained from either one of the ungrounded hot (black) transformer terminals and the neutral (white) grounded center tap. In addition, for health-care facilities, the National Electrical Code (NEC) for 2006 requires that all receptacles be “Hospital Grade” and be grounded by a separate insulated (green) copper conductor (Article 517-13). An additional redundant ground path through the metal raceway, conduit, or a separate cable is required for patient-care areas. Some older installations used metal conduit as the only ground conductor. Conduit grounds are generally unsatisfactory, because corrosion and loose conduit connections make them unreliable.

### PATIENTS' ELECTRICAL ENVIRONMENT

Of course, a shock hazard exists between the two conductors supplying either a 240 V or a 120 V appliance. Because the neutral wire on a 120 V circuit is connected to ground, a connection between the hot conductor and *any* grounded object poses a shock hazard. Microshocks can occur if sufficient potentials exist between exposed conductive surfaces in the patients' environment. The following maximal potentials permitted between any two exposed conductive surfaces in the vicinity of the patient are specified by the 2006 NEC, Article 517-15:

1. General-care areas, 500 mV under normal operation
2. Critical-care areas, 40 mV under normal operation

In general-care areas, patients have only incidental contact with electric devices. For critical-care areas, hospital patients are intentionally exposed to electric devices, and insulation of externalized cardiac conductors from

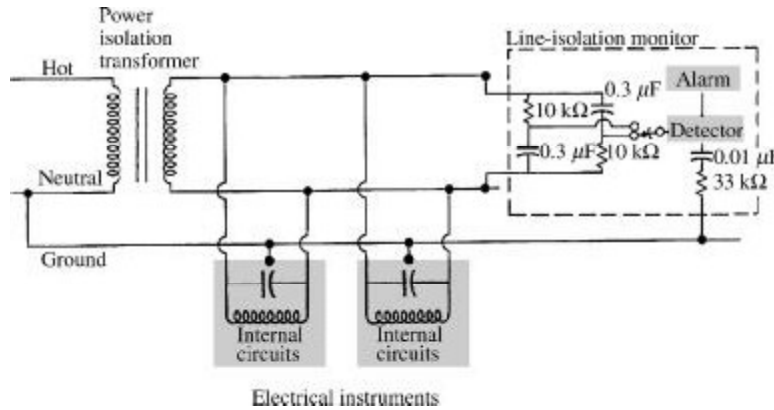
conductive surfaces is required. In critical-care areas, all exposed conductive surfaces in the vicinity of the patient must be grounded at a single patient-grounding point (Section 14.8). Also, periodic testing for continuity between the patient ground and all grounded surfaces is required.

Each patient-bed location in general-care areas must have at least four single or two duplex receptacles. Each receptacle must be grounded. At least two branch circuits with separate automatic overcurrent devices must supply the location of each patient bed. For critical-care areas, at least six single or three duplex receptacles are required for each location of a patient bed. Two branch circuits are also required, at least one being an individual branch circuit from a single panelboard. A patient-equipment grounding point (Section 14.8) is permitted for critical-care areas. For details, see NEC 70–2006, Article 517-19.

**ISOLATED-POWER SYSTEMS**

Even installing a good separate grounding system for each patient cannot prevent possibly hazardous voltages that can result from ground faults. A *ground fault* is a short circuit between the hot conductor and ground that injects large currents into the grounding system. These high-current ground faults are rare, and usually the circuit breakers open quickly. If the center tap of the step-down transformer were not grounded, then very little current could flow, even if a short circuit to ground developed. So long as both power conductors are isolated from ground, a single ground fault will not allow the large currents that cause hazardous potentials between conductive surfaces.

Isolation of both conductors from ground is commonly achieved with an *isolation transformer*. A typical isolated-power system is shown in Figure 14.9. In an isolated system such as this, if a single ground fault from either conductor



**Figure 14.9** Power-isolation-transformer system with a line-isolation monitor to detect ground faults.

to ground occurs, the system simply reverts to a normal grounded system. A second fault from the other conductor to ground is then required to get large currents in the grounds.

A continually operating *line-isolation monitor* (LIM) (also called a *dynamic ground detector*) must be used with isolation transformers to detect the occurrence of the first fault from either conductor to ground. This monitor alternately measures the total possible resistive and capacitive leakage current (*total hazard current*) that would flow through a low impedance *if it were connected* between either isolated conductor and ground. When the total hazard current exceeds 3.7 to 5.0 mA for normal line voltage, a red light and an audible alarm are activated. The LIM itself has a monitor hazard current of 1 mA. This makes the allowed fault total hazard current for all appliances served by the transformer somewhat less than 5 mA.

The kinds of corrective action that should be taken when the alarm goes off must be explained to medical personnel so that they do not overreact. The periodic switching in some line-isolation monitors produces transients that can interfere with monitoring of low-level physiological signals (ECG and EEG) and give erroneous heart rates. Or it can trigger synchronized defibrillators and aortic-balloon assist pumps during the wrong phase of the patient's heart cycle. Some LIMs avoid these problems by using continuous two-channel circuitry instead of measuring the total hazard current by switching between each line and ground.

Isolated-power systems were originally introduced to prevent sparks from coming into contact with flammable anesthetics such as ether. The NEC requires isolated-power systems only in those operating rooms and other locations where flammable anesthetics are used or stored.

## EMERGENCY-POWER SYSTEMS

Article 517 of the 2006 National Electrical Code specifies the emergency electric system required for health-care facilities. An emergency system is required that automatically restores power to specified areas within 10 s after interruption of the normal source. The emergency system may consist of two parts: (1) the life-safety branch (illumination, alarm, and alerting equipment) and (2) the critical branch (lighting and receptacles in critical patient-care areas). For additional details, see Article 517-25, 30–35.

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## 14.4 MACROSHOCK HAZARDS

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The high resistance of dry skin and the spatial distribution of current throughout the body when a person receives an electric shock are two factors that reduce the danger of VF. Furthermore, electric equipment is designed to minimize the possibility of humans coming into contact with dangerous voltages.