3. Range of Tolerable Current

Effects of an electric current passing through the vital parts of a human body depend on the duration, magnitude, and frequency of this current. The most dangerous consequence of such an exposure is a heart condition known as ventricular fibrillation, resulting in immediate arrest of blood circulation.

3.1 Effect of Frequency. Humans are very vulnerable to the effects of electric current at frequencies of 50 or 60 Hz. Currents of approximately 0.1 A can be lethal. Authorities generally agree that the human body can tolerate a slightly higher 25 Hz current and approximately five times higher direct current. At frequencies of 3000- 10 000 Hz, even higher currents can be tolerated [B28], [B30][9]. In some cases the human body is able to tolerate very high currents due to lightning surges.

Detailed studies of the effects of both direct and oscillatory impulse currents are reported in the literature [B19], [B21].

Information regarding special problems of dc grounding is contained in the 1958 Report of the Conversion Substation Committee [B16]. The hazards of an electric shock produced by the electrostatic effects of overhead transmission lines are reviewed in Part 1 of the 1971 Report of the General Substations Subcommitee [B59]. Additional information on the electrostatic effects of overhead transmission lines can be found in Chapter 8 of the *Transmission Line Reference Book 345 kV and Above* (the EPRI Red Book) [B46].

3.2 Effects of Magnitude and Duration. The most common physiological effects of electric current on the body, stated in order of increasing current magnitude, are perception, muscular contraction, unconsciousness, fibrillation of the heart, respiratory nerve blockage, and burning [B53].

Current of 1 mA is generally recognized as the threshold of perception, that is, the current mangitude at which a person is just able to detect a slight tingling sensation in his hands or fingertips caused by the passing current [B21].

Currents of 1-6 mA, often termed let-go currents, though unpleasant to sustain, generally do not impair the ability of a person holding an energized object to control his muscles and release it. Dalziel's classic experiment with 28 women and 134 men provides data indicating an average let-go current of 10.5 mA for women and 16 mA for men, and 6 mA and 9 mA as the respective threshold values [B29].

In a 9-25 mA range, currents may be painful and can make it hard or impossible to release energized objects grasped by the hand. For still higher currents

9 The numbers in brackets with the prefix B refer to those of the bibliography in Chapter 20.

muscular contractions could make breathing difficult. Unlike the cases of respiratory inhibition from the much greater current mentioned next, these effects are not permanent and disappear when the current is interrupted —unless the contraction is very severe and breathing is stopped, not for seconds, but for minutes. Yet even such cases often respond to resuscitation [B25].

It is not until current magnitudes in the range of 60–100 mA are reached that ventricular fibrillation, stoppage of the heart, or inhibition of respiration might occur and cause injury or death. A person trained in cardiopulmonary resuscitation should administer CPR until the victim can be treated at a medical facility [B27].

Hence, this guide emphasizes the importance of the fibrillation threshold. If shock currents can be kept below this value by a carefully designed grounding system, injury or death may be avoided.

As shown by Dalziel and others [B26], [B29], the nonfibrilating current of magnitude I_B at durations ranging from 0.03–3.0 s is related to the energy absorbed by the body as described by the following equation:

$$(I_B)^2\, t_s = S_B \qquad \text{(Eq3)}$$

where

I_B = rms magnitude of the current through the body
t_s = duration of the current exposure in s
S_B = empirical constant related to the electric shock energy tolerated by a certain percent of a given population

A more detailed discussion of this equation is provided in Section 4.

3.3 Importance of High-Speed Fault Clearing. Considering the significance of fault duration both in terms of Eq 3 and implicitly as an accident-exposure factor, high-speed clearing of ground faults is advantageous for two reasons:

(1) The probability of electric shock is greatly reduced by fast fault clearing time, in contrast to situations in which fault currents could persist for several minutes or possibly hours

(2) Both tests and experience show that the chance of severe injury or death is greatly reduced if the duration of a current flow through the body is very brief; the allowed current value may therefore be based on the clearing time of primary protective devices, or that of the back-up protection

A good case could be made for the former because of the low combined probability that relay malfunctions will coincide with all other adverse factors necessary for an accident, as has already been described in Section 2.

If the probabilistic aspects are neglected, choice of the backup relay clearing times is more conservative since it assures greater safety margins with regard to Eq 3.

An additional incentive to use switching times less than 0.5 s results from the research done by Biegelmeier and Lee [B8]. Their research provides evidence that a human heart becomes increasingly susceptible to ventricular fibrillation when the time of exposure to current is approaching the heartbeat period, but that the danger is much smaller if the time of exposure to current is in the region of 0.06–0.3 s.

In reality, high ground gradients from faults are usually infrequent, and shocks from this cause still more so. Futhermore, both events are often of very short duration. Thus, it would not be practical to design against shocks that are merely painful and cause no serious injury, that is, for currents below the fibrillation threshold.