THE HAZARD COMPENSATOR: A NEW TECHNIQUE OF LEAKAGE HAZARD REDUCTION IN UNGROUNDED SYSTEMS

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ABSTRACT

Shock hazards of capacitive leakage in isolated electrical systems are only recently being well recognized. Dangers are increasing through growth of heart surgery and use of intracardial probes and electrodes.

Hazard reduction by better system design now produces diminishing returns, and does nothing for connected equipment leakage. Typical total system leakages are still 100 microamps or more on lateest designs, vs fibrillation levels of about 20 microamps for direct myocardial contact.

The Hazard Compensator uses a new approach, accepting leakage existing in the system, but reducing its shock hazard on accidental body contact. It drives current from ground to line equal to leakage current flowing from line to ground. This forms a closed current loop, with system leakage supplied by the compensator, thus excluding accidental body paths from the leakage loop.

Already in service, the device is applied one per system, single-circuit type where system changes are small, or multi-circuit to accomodate to changes in system leakage. It can compensate for connected equipment leakage, and be module-mounted on equipment to remove its individual hazard. Typical 20:1 hazard reduction now makes 20 microamp total system hazard index attainable.

THE CAPACITIVE LEAKAGE PROBLEM

Electrical safety in hospital operating rooms and intensive-care units is not presently being properly attained by use of isolating transformers per recommended Electrical Code practice. Capacitance between lines and ground degrades system isolation as shown in Fig. 1.

FIG.1 CAPACITIVE LEAKAGE HAZARD

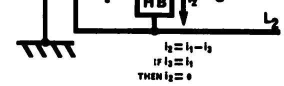

FIG.2 HAZARD COMPENSATION APPLIED TO L_1

Here, the distributed capacitance between line L_1 and ground is lumped into a single impedance Z_1, and if a human body HB is accidentally connected between L_2 and ground, a fault current will flow. In a large system, Z_1 may be quite low, and dangerous currents can flow, often in excess of the Code limit of two milliamps.

This hazard may be reduced by use of short wiring runs, thicker wire insulation of lower dielectric constant, larger conduits with fewer wires, and by using isolation transformers of low KVA rating and special low-capacitance design. These techniques can yield a typical system hazard index of about 100 microamps in a packaged system.

However, the leakage of connected loads may be much greater than this, and while the total system hazard index limit for ordinary OR's may not be exceeded, it will still be too high where heart electrodes are in use. Also, rebuilding older systems to conform to new code requirements is very costly.

HAZARD COMPENSATION - A NEW SOLUTION

The hazard compensation technique is based on the new concept of accepting the leakage prevailing on the system, provided it is not due to insulation failure or bad system practice. The effect of this leakage on an accidental ground path external to the system is then neutralized by using a hazard compensator to drive current from ground into each line equal to the leakage current flowing from each line into ground.

This is shown in Fig. 2, where a current source G produces an output current i_3 flowing from ground to some unspecified point. If the device is set up so that i_3 always equals i_1, then i_2 will equal zero. That is, i_1 and i_3 form a closed current loop, with the leakage current i_1 being supplied by current source G, rather than by the system. As body path HB is outside this current loop, it now will be unaffected by it.

As the system is symmetrical about ground, the scheme in Fig. 2 will work equally well inverted, and if the two are superimposed, the arrangement in Fig. 3 results.

Here the generator output i_3 is equal to the sum of the system leakage currents i_1 and i_2. As in Fig. 2, and using the superposition principle, a body path can be connected between either L_1 or L_2 and ground, and no leakage current can flow through it, since the leakage currents will continue to be supplied entirely by the current source G.

The current source consists of an amplifier with a high output voltage capability, and its output current is made proportional to the voltage appearing between each line and ground, as shown in Fig. 4.

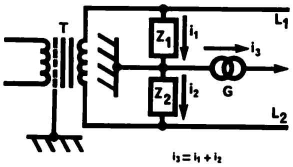

FIG.3 HAZARD COMPENSATION APPLIED TO L_1 & L_2

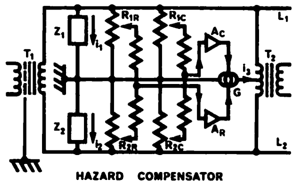

FIG. 4 HAZARD COMPENSATOR SINGLE-CIRCUIT MODEL

Here, current amplifier G receives its input from two other amplifiers, A_C and A_R. These in turn are driven by the combined signals from potentiometers connected between lines and ground. Amplifier A_C is designed to drive G to produce an output current leading the line-to-ground voltage by 90 degrees. This output is thus in phase with and proportional to the capacitive components of the system leakage, and by adjustment of R_{1-C} and R_{2-C}, this component of the output can be made exactly equal to the system capacitive leakage, regardless of line-to-ground voltage.

Amplifier A_R produces an output current in phase with the line-to-ground voltage, and R_{1-R} and R_{2-R} may be adjusted to cancel the resistive component of system leakage. Thus by proper adjustment of the four controls, virtually complete neutralization of the leakage hazard is possible.

Adjustment of the device is quite simple. No distinction is made between resistive and capacitive adjustments,the controls being simply set in turn for minimum total hazard as shown on a suitable hazard indicator. The latter may be the one installed on the isolated system, or more conveniently, a separate plug-in meter may be used which permits the hazard index of each line to be read individually.

The output of amplifier G is connected to the center-tap of the primary of the compensator's power transformer, providing a return path for the various components of the output current.

With the device adjusted for correct compensation, any change in the system leakage will upset this balance, either by adding uncompensated leakage, or by removing leakage and causing over-compensation. In most ordinary OR's, this is not serious, such changes usually being small compared to the maximum permitted system leakage. In such systems, the compensator is adjusted with the complete system energized, and without any equipment plugged in. As equipment is added, its leakage is simply added to what now appears to be a leak-free system, and the increased margin provided by the compensator virtually eliminates nuisance alarms by the hazard indicator.

Generally at least one circuit may be dropped at its circuit breaker, without causing serious over-compensation by removing part of the system leakage.

In special areas, however, a total hazard index of a few tens of microamps may be necessary, while total connected equipment leakage may be about 100 microamps. To deal with system leakage changes in such cases, the multi-circuit compensator shown in Fig. 5 is used.

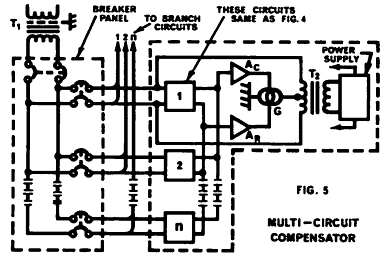

FIG. 5

MULTI-CIRCUIT COMPENSATOR

This is basically identical to Fig. 4, except that signal lines are fed in from the load side of each circuit breaker in the breaker panel. As each breaker is closed, these lines energize four potentiometers arranged as already described, and the outputs of these are combined to feed amplifiers A_C and A_R in a manner permitting completely independent adjustment.

The output of the compensator thus adjusts itself automatically to add or subtract output current and correctly maintain balance, as system leakage is added or subtracted by closing or opening panel breakers.

Changes in connected equipment may be accomodated by adjusting the balance of each circuit with the load energized. Equipment is then added to or removed from the system by operating its assigned circuit breaker rather than by unplugging it, thus maintaining system balance.

Also, major equipment items may be fitted with individual single-circuit compensators which balance the equipment leakage alone, permitting its addition to a system without degrading it.

The compensator is able to provide reduction of the leakage hazard index by a factor of 15 or 20 to one. Greater reductions are possible under controlled conditions, but such settings will be spoiled in practice by changes in system leakage due to temperature and humidity effects.