Protective Jumpering

OSHA Speaks

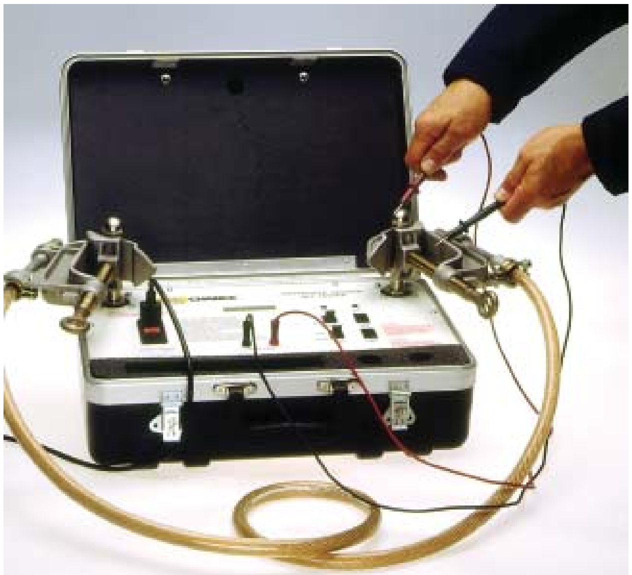
Grounding for worker safety has long been used in the utility industry. In the past it was often considered a simple subject with a straight forward approach in its application to work practices. Over the years, utilities developed a variety of protection schemes. Some are not adequate any longer. Many systems have been upgraded to higher voltages or carry more current.

January 1994 OSHA issued sweeping rules that now govern both construction and maintenance of generation, transmission and distribution. The ruling, OSHA 1910.269 [11], now places strict requirements and accountability on utilities. Rules that govern training, equipment selection and use. Rules that are having a major impact upon electricity suppliers.

What effect do the OSHA rulings have on grounding? Section M, of OSHA 1910.269 requires lines to be de-energized when work is being performed and outlines procedures to be followed and equipment to be used. Section N requires safety protective grounding equipment SHALL (mandatory) be capable of carrying the maximum fault current at a work site [4] [10], for the time necessary to clear the fault. Workers must be trained in the use of this equipment and preferred methods of connection are given. A strong implication is that this equipment must be maintained to keep it in a condition that meets these requirements, something often overlooked in the past.

What makes this subject complicated for some is the attitude that a protective jumper is just a piece of cable with two clamps on the end. Yes, that's true, but jumper selection and use is the difficult part. Consider the recommended protection method, the creation of an equipotential zone. For example, an equipotential zone can be created by placing a protective jumper in parallel with the

...new mandatory regulations govern selection and use of safety protective jumper equipment.



worker at the work site. The function of the jumper is to carry the fault current, bypassing the worker.

The allowable resistance of the protective ground can be higher for low values of available fault current than for very large values and still maintain the same voltage across the worker. Also, fast backup circuit protective devices remove the body current faster allowing a somewhat higher body current to flow and still achieve a level of protection.

Although substantial research has been conducted to determine the reaction of the human body to various levels of current, no single value can be given as a safe level for all situations. Research has determined that the body's reaction is dependent upon the time duration as well as the magnitude of the current flow[1] [2] [7] [8]. Other variables to consider are: the protective grounding method employed[3], the fault current available[4], the assumed body resistance of the protected worker[1] [5] along with his weight[3] and the level of protection being sought by the user.

To meet OSHA requirements in selecting a jumper, three variables must be considered:

(1) Available fault current at work sites
(2) Amount of time the fault current can flow
(3) Level of safety to be provided

Values of each variable may differ from utility to utility or even from work site to work site. Ultimately the safety department of the using utility must give due consideration to the variables which affect the degree of worker safety that utility desires to achieve. Once the variables are defined, the equations discussed later can be used to establish the maximum resistance value for protective grounds issued to workers for use in a predefined area.

The first two variables are self explanatory and values should be available from the engineering department. The level of safety to be provided refers to a company's choice of maximum body current allowed to flow, or stated another way, the maximum voltage that can be developed across a worker's body during an accidental energized condition with protective grounds installed. Since there is no agreement within the industry on what constitutes a "safe" protection level, each utility MUST define what it considers "safe."

Charles Dalziel, a noted researcher, has published charts which are widely used in the industry today [1][2][3][4]. He determined that the average perception current, the least current detectable by the body, to be 1.2 milliampere and the average let-go threshold to be 9 milliaperes [1][6]. He further determined that 99.5% of those receiving shocks will not go into heart fibrillation if the shock current, for a specified duration, is below the value calculated by[1][3][9]:

Equation 1

$$I = K / (\sqrt{t})$$

Where:

I = Current flowing through body's chest cavity, in milliamperes

t = Duration of current flow, in seconds

K = A constant related to the electric shock energy 165 for a 165 lb. man.

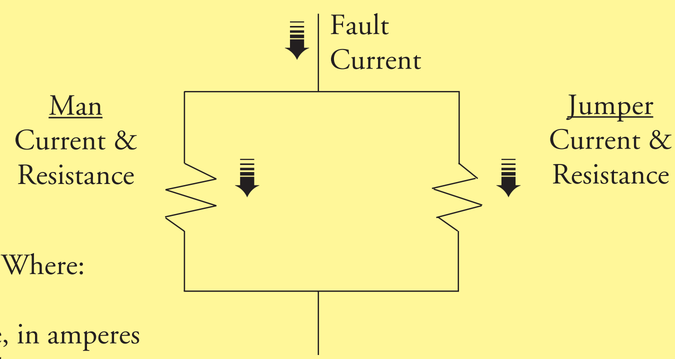
Ventricular fibrillation thresholds, with time dependency, may occur above:

0.03 second shock - 1,000 milliamperes

3.00 second shock - 100 milliamperes

In the development of an equipotential zone, a jumper is placed in parallel with the worker. Many standards and reference literature use 1,000 ohms as the worker's body resistance+. While this may not be totally correct, it provides a basis for calculations.

Equation 2



$$I_m = I_f \times [R_j / (R_j + R_m)]$$

Where:

I_m = Current through the man, in amperes

I_f = Available fault current at the work site, in amperes

R_j = Resistance of the parallel jumper, in ohms

R_m = Resistance of the worker, in ohms

Equation 2 can be rearranged to calculate the maximum jumper resistance, for a given set of conditions. It becomes:

Equation 3

$$R_j = R_m \times [I_m / (I_f - I_m)]$$

Consider the following as an example of the selection of an adequate protective jumper by a hypothetical utility.

- Maximum available fault current in the work area = 12,000 amp. RMS
- Breaker maximum operation time = 20 cycles (0.333 sec.)
- Workers weight and body resistance = 165 lbs. and 1,000 ohms
- Utility's accepted level of safety:

  Voltage across worker, $V_{worker, max}$ = 100 volts OR

  Current through worker, $I_{worker, max}$ = 1/3 the heart fibrillation level

Heart fibrillation threshold, from Equation 1 = 286 ma.

I_{man} = 95 milliampere

Maximum jumper resistance, from Equation 3 = 8 milliohm

This is the maximum resistance regardless of jumper length. The maximum resistance allowed will guide the purchaser in the selection of clamps, ferrules and cable size. See ASTM F855 (12) for jumper material requirements. If any additional resistance is present, the voltage across the man will exceed the 100 volts allowed during a fault condition.

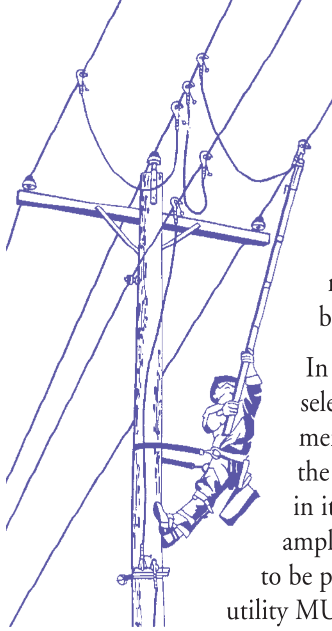
Not all utilities conduct testing or inspections to determine that jumpers remain suitable for desired protection. Those that did devised several test methods. Some passed high current through the jumper and measured the millivolt drop. Others passed current and checked for hot spots. Others performed a manual inspection only looking for broken strands or loose connections.

The typical source of high current was a current transformer (CT) operated in reverse to its normal connections. This provided the necessary current but at a very low voltage. A problem with this method is the effect of inductance which is associated with alternating current. The inductance makes the cable position during the test critical. If coiled or on a conductive surface, the inductance increases. The variation in test reading then is a function of positioning and inductance changes and is not related to the jumper's condition.

The second problem is the low test voltage. Small amounts of corrosion can affect the test but may have little affect at system voltages. For example, aluminum oxide is an exceptionally thin, high resistance coating that forms on aluminum clamps. The coating will break down at voltages seen in the field, but may indicate an abnormally high resistance during a test using a CT as a current source unless precautions are taken. It is important to ensure that the desired current is flowing, after which the millivolt drop measurements can be made. Substantial testing in high current laboratories have verified this.

Since OSHA now addresses the suitability of jumpers, the implication is that a periodic test and inspection should be planned. A reliable test uses a direct current (dc) to make millivolt drop measurements. A voltage level great enough to break down the light oxide coatings should be used, this can be in the 5 - 10 VDC range. The use of dc eliminates the problem of inductance that is associated with alternating current (ac).

Measurements should be taken end to end then at each clamp from conductor to clamp body; clamp body to ferrule; and ferrule to a few inches on the cable from the ferrule exit if necessary. It will be necessary to puncture the cable insulation to make this last measurement. The puncture should be plugged or taped afterwards. The best method of inspection for the cable portion of the jumper is still a manual inspection. For example, broken strands may not be evident during an electrical test. A sufficiently low resistance path to current flow may exist if the broken strands are in contact with each other.



In summary, new mandatory regulations govern the selection and use of safety protective jumper equipment. Substantial responsibility has been placed upon the employer for selection of equipment and training in its use. The variables to consider are fault current amplitude, duration of current flow and level of safety to be provided. The Safety Department of the using utility MUST make these determinations to assure protection against personal injury and possibly death. Guidance for this task was provided in this article and is further explained in the referenced bibliographies. ■

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