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Protection of Power Personnel from Electrocution despite Procedural Lapses

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Abstract: A persistent and grave threat to power personnel is fatalities due to electrocution. Despite stringent safety procedures and instructions given to power crewmen, often the directives are ignored, and fatalities occur. This happens when workers succumb to psychological pressures, to exhibit daring, customer demands for instantaneous restoration of power or misplaced priorities, regional specialties and electrical reasons that cause induction, and back-feeding of power from unknown quarters. In this paper some observed phenomena that lead to fatalities are analyzed. Some solutions are briefly described and a hardware solution is suggested to address the main problem of induction, though due to varied reason. The inherent simplicity in its logic design and ingenuity in its implementation with a fail-safe feature incorporated in its operation make the proposed device deserving of future improvements. It was implemented by the authors to appreciable levels of success.

1 Introduction

The power sector workmen in Kerala are working under a non-perceptible, but constant threat to their life. The menace is latent because the reasons are less technological than due to other causes. They are psychological pressures and needless bravados, lopsided societal concerns and priorities, an organizational hierarchy conducive neither to observing nor to reporting of possible risks, regional climatic specificities etc. Though several life-saving gadgets are on hand while working on power conductors, the crew are often ignorant about their usage or availability. Almost always the crew is unwilling to use them in the company of their peers, despite the knowledge that these equipments and safety procedures are meant to save their own lives. The youngsters, both supervisors and crew, are ridiculed when they try to insist on following safety procedures or devices.

Another tragic recurrence is of casualty, even when safety devices are being used due to working on multi-fed points without isolating all sources of feedback of power. This is mostly because of the general outcry against interruptions, especially during peak viewing times. The concern for the utility crew pales in comparison with the exigency of power restoration and the comforts electricity brings, in the public minds. Back-feeding and rampant use of inverters admits electric power in the distribution system, where it is not suspected to be and is reported to have caused fatalities.

Another matter brought to light, is that the workmen have practical competence but are not taught to observe and report anomalies. The site and maintenance supervisors are either very young engineers who have just graduated and are still learning from the workmen, or people who have gone up the promotion ladder after taking a diploma and at times, the sub-engineers who may be trade certificate holders. The aptitude or confidence to observe and analyze effects of electrical phenomena, regional specialties, climate or infrastructure induced anomalies are definitely lacking, and experience with calamity does not teach, only sends alerts to avoid such situations, altogether. Neither the desire nor need for postmortem of the incident and reporting glitches, exist. There is no personnel infrastructure; no thoroughly trained, pointedly educated, experienced and duly constituted dedicated bodies to unearth problem areas and thereafter find solutions via the research interests and knowledge content of engineering colleges are in place. Induction and accumulated charges are not partial to utility workmen only. Uninformed and other innocent souls are also sometimes the victims of the unpredictable flowing of charges.

The motivation for this paper is just such an incident, more than two years back, when one of the authors bore agonizing witness to the death by electrocution of two personnel. One loss was of a valued workman in KSEB and the other was of an industrious and efficient fire-brigade officer. He came to the rescue, but fell an innocent victim to electrocution. The KSEB victim had been asked, on this occasion too, to use safety devices and quoted experience in favour of going on to climbing on the transmission tower without adequate precautions. The objective of this paper is to throw light on some observations and studies that the authors have made to prevent or check such fatalities. Hence in this paper, reference is made mostly to the electrical and general engineering knowledge acquired by the authors, and bases on an understanding of power line constructions prevalent in KSEB, in our neighbourhoods. The paper is the outcome of analysis of the strengths of the prevalent system and practices. The design considerations attempt to minimize its weaknesses. The opportunities that are tapped, are afforded by a highly interconnected power system. The alternatives or filtered out methodologies are based on knowledge that can circumvent the threats that lapses pose. The expectations from the publication of this paper, is to alert the public regarding the need for a more focused study on the recurrence of fatalities, the need for a emphatic analysis of all possibilities, the necessity for a sharing of problems with the up-coming engineering college students and for design of compact and effective circuits such that even an iota of oversight or some unfortunate negligence is not answered with death.

2 Some observed phenomena leading to fatality

The authors have observed that there is a case of induction of voltage on metallic bodies near to lines. This is more so at peak time under the high voltage line particularly during highly humid conditions. An experience to be reported is that of an open umbrella, with spread-out spokes getting a physical lift on a highly humid night under a 220 kV line at Chalakkudy, in Thrissur. In Kerala, high humidity is a norm rather than an exception and will result in breaking down the dielectric strength of air. This results in the conduction of charges down to the earth, if a path is provided. Statistics shows that almost all the accidents that led to the death of workmen during work, on high voltage lines were due to induction of the charges and the unofficial study reveals that the accidents occurred either due to improper grounding or while removing the earth connection.

2.1 Induction related fatalities

A major occurrence of induction is found in the double circuit lines and in the multiline structures. The multi-voltage lines are also highly dangerous areas to work in. In the case of LT/HT structures, while working on LT lines, induction of charges from the HT lines, we believe can cause casualty to the workmen. The movement of clouds is also an influential factor leading to induction. (The lead author has studied this in detail since the day the earlier mentioned electric accident took place, because he had observed a heavy moisture laden cloud. On that day that jeopardized the life of the man, after working for some time on the tower, he had shown discomfort and had then laid down on the cross- arm and died as also the fire officer who went up to rescue him.). If induction happens in the middle of a task and the person comes into contact with a field, he may fall; compound the consequence of the accident. Similar is the case with induction of charges in cables.

The defects in grounding can again result in electrocution. While working on seemingly dead conductors, the movement of clouds can introduce charges on them and is found to be enough to cause the working person to get electrocuted due to conduction, if there is any fault in the grounding set-up, nearest to him. Similar is the case, when work is being carried out on one dead line of a double circuit arrangement. The value of voltage induced by the live conductor on the dead conductor is measured and found to be somewhat above 100V and is quite sufficient for causing electrocution.

While induction may be suspected to be the cause of electrical accidents to workmen in the vicinity of power conductors, nothing can be proved when the victims do not live to tell the tale. This need not be the case when electric fields are created by cable capacitances, since they are not unduly affected by passing clouds or high rate of change of flux linkages that do not leave any evidences.

2.2 Electric field related fatalities

Though safety procedures are observed to be followed diligently while workings with cables, both underground and overhead, (mainly aerial bunched conductors), accidents reportedly occur, repeatedly. It is noted that fatality is due to the discharge of charges in lieu of cable capacitance. As per procedural manuals, work should be started only after isolating the conductor from accumulated charges. For this earthing is done on both sides of the working point. In the case of underground cables, whenever there is maintenance or breakdown work to be done, the feeder is switched off at first and earthed at both ends. This means that the feeder gets earthed at both the substations. Still there will be induced voltage due to trapped charges in the cable. Since both ends are earthed the cable acts as a capacitor holding the charges which sometimes gives rise to voltage values at killer levels when cables extend to several kilo-metres even though there is an earthing shield that is running throughout the cable. We teach and learn constant charge theorem but fail to see its practical significance.

When there is work in the overhead or underground cables, it is earthed at both the substations. Then the worker is engaged somewhere in between these two earthed points. As the cable is having length of several kilometres, the capacitance of the cable is also of high value and the charge may not have been completely discharged. So the person when working in between, will come into the electric field of the cable capacitor and will form an earthed path, leading to ground discharge of the cable, through him. Charging and discharging currents flow through the earthing sheath. The cables that are short in length, need to be joined which is an added danger as described above. Each continuous run of the cable when isolated from the sending end side may act as an individual capacitor. Also, in the cable with several joints, each segment will act as an individual capacitor and the resultant parallel connection leads to an enhanced value of the capacitance, with several booster stations.

2.3 Other reasons

Another common danger is misjudgement based on acquired or deduced information that a line is dead. Trusting that a particular line is dead, from end to end, the working team may approach a tower or pole. But at an unsuspected length in between, power feed orientation may have changed. When there are unplanned, unpublished and vulnerable areas of inter-connection, when there are several feed points, when orientation of the phases of intercepting feeders, change to left or right side of the tower as it passes through long distances, especially in forest areas, the distinguishing marks and methods for checking the status of feeders reduce. This is mainly due to a lack of an overall picture or a highly comprehensive understanding of the entire system.

Added to this, communication from the supervisors to the work men atop the tower/pole is not always effective as the distance and ambient noises cause the voices to blur. So even if there are chances to avoid the mishap, via ground intervention, lack of modern and hands-free means of conveying the information, has also resulted in fatalities.

Day after day valuable lives are lost and statistics shows that on an average two persons die by electrocution per day in Kerala. After these electrical accidents are reported, the only thing that governments can do is to provide some monetary compensation and to nail the blame on hapless officials who were unfortunate enough to be present and witness this gruesome death. This serves no good other than to have more shirked responsibilities, blame games and loss of morale by enthusiastic youngsters. Hence it is strongly recommended that automated measures are examined and implemented for circumventing human errors and lapses.

3 The economics and the need for automated safety

The economics of having safety devices can never be compared with the probability figures of possibilities of accidents. The paradox of most such devices is that, they are on the system, inactive and non-committal, till a fault occurs, and whether it has functioned and effectively and saved the situation, is known only after the fact. Such devices cannot afford to be proactive and simulate faults or accidents. Even if an accident has never occurred at a point, one cannot avoid safety devices, and cost can never be a consideration. But there are other repercussions which are briefly discussed before the need for automated fail-safe devices are argued for.

3.1 Economics of fatalities

From an economics point of view, whenever an accident occurs, there is a natural delay in charging the conductor from substation which may extend to several hours. This leads to heavy revenue loss to the utility due to loss of load and due to loss of production hours for connected industries. This is not at all desirable in the present scenario of power crisis. Interruptions and lengthy restoration times are going to be costly in the new scenario of electricity markets. Also the durability of the conductors, both overhead and UG needs to be examined, not only in terms of costs but in terms of power evacuation capabilities as well. Otherwise, if a high voltage transmission line gets snapped, time for identification and rectification may go up by a long scale and here too, the revenue losses are aggravated. Several stories are heard regarding the difficulties faced to locate one single pin insulator, which has punctured and holds the entire distribution line in that feeder to ransom, till it is located. The other line materials like insulators, support structures, etc. are similarly vulnerable and their failure and consequent interruptions invite public ire. It might also have been observed that an angry public can and do ransack the offices of utilities, rather than the system which they do not understand and fear, if the loss of a valued life occurs. The personnel are intimidated and lay low or abscond rather than go to the office, analyse and dam the damage, even if not associated with the accident site.

3.2 Social relevance

Accidents are ugly incidents that make enemies of the crew who are field workers. Several times, they have been beaten up, though without any involvement but presence on the site. Poor knowledge, skill and analysis have also caused accidents. And human intervention cannot be expected, especially because of the spread of the power system and speed of electricity that strikes at remote, unlikely and unexpected locations and very fast.

Under these circumstances, equipment which will work without any human interface but serve to safeguard lives is inevitable both for the utility and for the valuable lives. An automatic earthing arrangement is designed here which accounts for the safety of workmen by proper earthing, automatically. It can discriminate and diagnose the dead line, forecast conductor snapping and thereby preserve life and credibility of utilities, and improve reliability and revenue stability. This device will serve as an additional safety in working on double circuit structures, multi-voltage structures, multi-circuit towers from any sort of induction charges from nearby lines, movement of clouds etc. The identification of dead line which plays a crucial factor before starting of the works can be easily diagnosed using this equipment. Also, the cable earthing can be effectively done using this equipment.

3.3 Preliminaries

Some methods preliminarily surveyed are outlined for further studies. The idea mooted is that for a three phase system, the alignment of two coils should be such that it gives a virtual short at de-energization. Whenever there is shutdown or deactivation of line due to any scheduled or unexpected cause, automatically the switch should connect the coils to short the line. So any induced currents will pass through the coil as the coil is designed accordingly. When the supply is restored the coils should resemble the connection of pressure coils in the two wattmeter method of power measurement and stand guard against the applied voltage. This would be a good idea to emulate.

4 The earthing equipment

The figure (Fig.1) shown is a scaled down prototype shown in relation to its location near to a tower. In Fig. 2 a horizontal cross section of the end view of the equipment designed for identification of deadlines, earthing of any induced voltages or currents from nearby lines, clouds etc. is given. (The green coloured balls and yellow coloured conducting springs are more in numbers than shown in the figure.) There is one more violet coloured earthing coil on the other side of the structure which can serve as a parallel path. Also this will serve as a spare circuit for earthing when one coil fails. A small pulley shaped arrangement is shown at the end of the iron body to enable free movements of the earthing coil. The unattached end of the coil will clasp on to the cross arm and the particular conductor will be earthed. Likewise every line is provided with this device and a person can work without fear of electrocution. Only the upper half remains open; .the springs are protected with a fibre body; with connecting ends remaining bare. The lower half of the equipment with the green balls is also covered with a fibre body, sealing them from dust ingress, and to prevent wear and tear and improper functioning. The lower part is having a film of oil inside, which will enable smooth movement of the balls which are made of iron in both the direction. Thus the oil gets circulated throughout the area and cooling is done naturally. This also

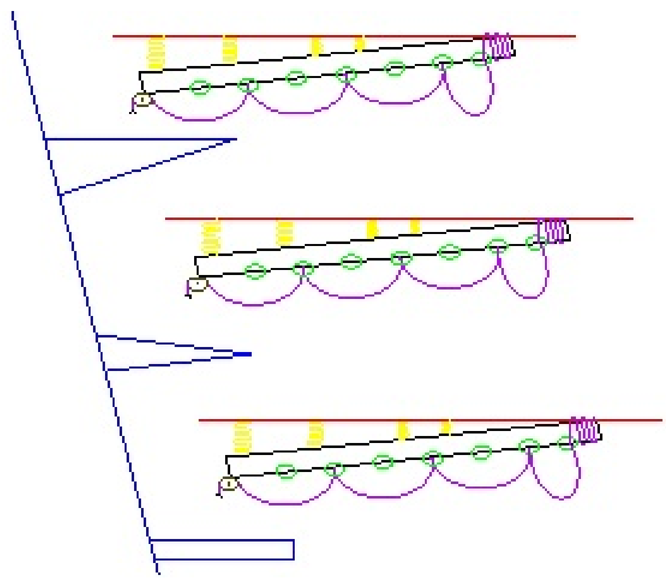

Figure 1: The arrangement of the components of the device

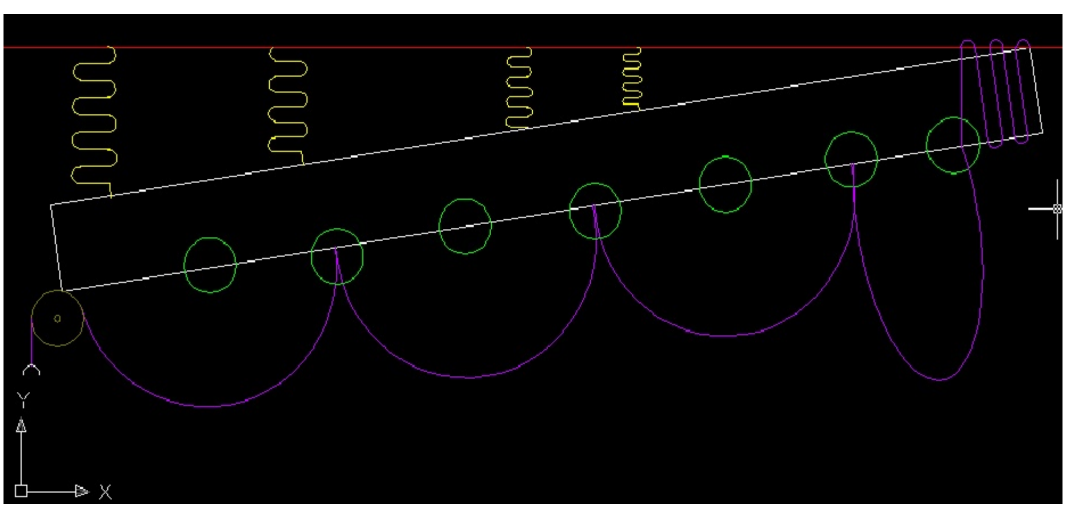

Figure 2: A horizontal cross section of the end view of the equipment

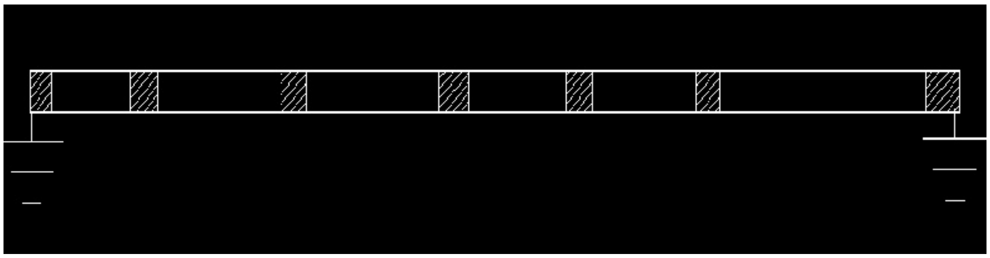

Figure 3: The earth arrangement and capacitance of cable (Case 1)

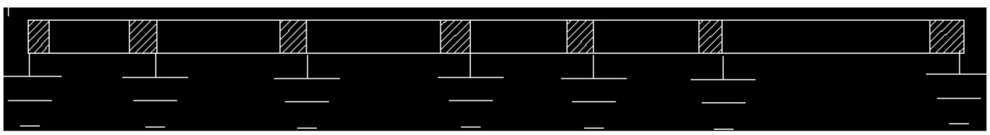

Figure 4: The earth arrangement and capacitance of cable (Case 2)

safeguards the equipment from entering into the Curie point.

4.1 Other safety features

All the tower structures are to be provided with this gadget and so if some fail, the healthy ones will suffice. The angle between the line and the equipment is designed to be not more than 4 degrees which will aid a better performance. The pulley is enclosed in a protective, oil filled cover which serves to remove obstruction to the pulley's free movement despite cables. The (violet) earthing coils are actually protected with light weight sheath and the coils are attached to the balls. When the balls move horizontally, the coil moves vertically. The identification of a dead line as well as forecasting of conductor snapping can also be easily done by using this equipment.

A major advantage of this equipment is that, no CT or PT but line voltage as in a transformer is used for its working. No additional supply is needed. The design visualizes a self-circulating lubricating system with natural cooling. The wear and tear is less with no such vulnerable parts.

4.2 Recommended use in cables

Case 1. *If the joints are not earthed (Fig. 3)*:

If the joints are not earthed, the whole assembly will act as a single capacitor and as the length of the cable becomes too high, the value of capacitance also will be of high value. So, whenever a person comes to work, even in a situation where the cable which is earthed at both the substations, a path to earth is completed through him. The hatched portions shown are the joints in the cable. So the segments, all put together, forms an individual capacitor. Hence, when the person engaged in between this set-up, forms the path for the capacitor to discharge to the earth.

Case 2. *If all the joints of the cable are earthed (Fig. 4)*:

In this condition, if all the joints of the cable are all earthed appropriately, each portion will act as an individual capacitor. This is shown in Fig. 4. In this case, the resultant capacitance increases. Though this is the generally recommended configuration, end result will be that the net capacitance of the cable rises to values higher than the above case. To make matters worse, the cable joints are not at all isolated from each other. In order to avoid the accompanying danger, the cable should be isolated from any charges.

Both the above cases can be saved using the proposed electro- mechanical switch at all such joints. This switch should be placed at each joint such that whenever the supply is turned off, these earth switches will completely isolate each cable piece in the second case, and proper earthing is provided in both the cases.

5 Working principle

The basic working principle of the equipment is based on the molecular theory formulated by Weber and Ewing. Under normal condition, (when conductor is live) the iron bar will be in the magnetic field and the intensity of magnetization is high. The conducting springs which are many in numbers will get compressed and the iron bar will be lifted up. The angle between the iron bar and the live conductor will decrease and the iron bar will get attracted to the conductor. Like this, the balls which are also many in numbers get attracted to each other, away from the pulley and the earthing coil will be on the iron bar completely. Hence the equipment as a whole is clasped onto the conductor.

Now, when the line gets switched off, the magnetizing field is removed, and only the presence of internal molecular magnetic field persists and this will nullify each other and the iron bar as a whole will be demagnetized. The compressive forces on the springs are not there and the balls will no longer remain in attraction. The iron bar will come down in gravity and the balls will move towards the pulley and hence the earthing coil starts moving vertically down through the pulley. The horizontal portion of the earthing coil gets stretched. The earthing coil will move down until it reaches to the cross arm below it and it will get attached to it. As the tower as a whole is earthed, the cross arms act as the earthed contact and when the coil reaches to this point, the concerned line also gets solidly earthed. Since each supporting structure is solidly earthed, any charge flowing will be through the earthing coil. The impedance of the earthing coil is designed to provide the easiest path towards the earth. So any sort of charge by means of induction is allowed to pass through this route towards the earth.

Now, when the line is charged; the magnetic field rises. This causes the balls to move towards the conductor, away from the pulley part. The earthing coil attached to the balls also returns. Simultaneously the springs start to compress as the iron bar gets magnetized and attracted towards the live conductor. These two movements, the movement of balls and that of the iron bar, lift the earthing coil from the cross arm. The presences of oil with pulley and ball arrangements help in reducing the frictional hindrance to the movement of earthing coil against gravity.

To identify deadlines from live ones, there is a visible clue. For a dead line the system will always appear to be earthed as the iron rod makes a large angle with the conductor and the earthing coil is seen attached to the cross arm.

6 Conclusion

If this equipment is used, electrocution via induction is completely avoided. The case studies have shown that severe electrocution is associated with the removal of earth rods. When the last earth rod is removed the person who is removing it, is trapped in the earth circuit and he becomes the victim of the electrocution. If this equipment is used, one can even use the earth rod for an assurance and can easily unplug it from the conductor without any risk. The risk of conductor snapping is also reduced if the arrangement is placed at various portion of the conductor in addition to the earthing one. Here, the resilience of the spring is adjusted such that whenever the air gap increases, the iron bar will move away from the conductor. The point of possible snapping can thus be identified easily and the conductor can be renewed and large revenue gap can be alleviated.

The equipment does not require any auxiliary supply system or any kind of excitation system. It will use the energy from the conductor itself and is a great advantage, in remote locales, of no additional power. The cost of the equipment is also very low when compared to other protection devices.

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