PPE for Protection of Line Workers against AC Induction Hazards during Overhead Line Work

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1. ABSTRACT

Xcel Energy partnered with Electrostatics and BME to develop a conductive suit for protecting line workers against AC-induced current in overhead line work applications. The suits were developed and tested at the high voltage laboratory BME in Budapest and field trialed in Texas in 2022. This paper covers the main aspects of developing this new type of PPE, industry accident statistics, and experiences from the field trials in Texas. The suit can be applied for construction and maintenance activities on de-energized lines in induction corridors with temporary protective grounding (TPG) up to 765 kV.

Many lives of linemen have been lost due to AC induction throughout the years in the United States and worldwide. The PPE is meant to be used with Company TPG and IEEE 1048™ practices.

Keywords:

AC induction, induced current, electric shock, conductive clothing, electrical safety, TPG, OSHA compliance.

2. INTRODUCTION

Accidents due to exposure of overhead line workers to AC induced current on de-energized lines are a large issue in the electric utility industry worldwide. De-energized circuits may pick up induced current and voltage from adjacent live lines due to electric field coupling, magnetic field coupling, electromagnetic coupling (e.g., live RF antennas) and pose significant electrical hazards that are unbeknownst to workers. Many fatalities have been reported [1] [2].

It is an irony that de-energized work may cause such electrical hazards and high risk, but it seems that many companies can benefit from improvement of their field training and supervision to ensure that temporary protective grounding (TPG) is applied correctly and effectively. Workers should be able to identify AC induction sources, mechanisms, and be able to select adequate controls. Now, it is possible to acquire special PPE for protection against AC induction.

Field guides such as IEEE 1048™ [3] and IEEE 1246™ [4] contain ample recommendations for correct application of TPGs and elimination of hazards. However, the amount of AC induction related accidents is quite high. It seems that an multi-stage approach in which a combination of work methods, training, supervision, and PPE may be able to reduce incidents.

3. HAZARD ANALYSIS AND REGULATIONS

AC induction when working in the vicinity of live lines poses several hazards to workers. Figure 1 lists the main hazards encountered.

1. Electric shock due to:
    a. Electric field (E) coupling
        i. "Voltage divider effect" from live lines
    b. Magnetic field (B) coupling from:
        i. "Air transformer effect" from live lines
        ii. Load current in adjacent lines
        iii. Power system faults in adjacent live lines
        iv. Lightning strikes near or on adjacent live lines
    c. Electromagnetic induction due to (RF) live antennas
2. Thermal burns due to:
    a. Induced electric current circulating though the body of the employee
    b. Ignition of clothing
    c. Touching hot conductors due to RF induction
    d. Wildfires initiated by induced current on dry vegetation
3. Physical trauma due to:
    a. Falls (because of electric shock)
    b. Asphyxia
    c. Heart, tendon, and muscle damage

Figure 1 – Main AC induction hazards

OSHA requires employers to protect their employees against induced voltage and induced current hazards under 1910.269(q)(2)(iv) (and Appendix C.III.D.1) [5] and 1926.950(d)(3) [6]. The National Electrical Safety Code (NESC®) has similar requirements under Rules No. 124, 212, 223, 315, 316, 420, 422, 441, 443, 444, and 445 [7]. OSHA recognizes that if a worker is exposed to a body current of 6 mA or greater (recognized let-go threshold of current exposure for workers) [6] [7], then special controls need to be put in place to protect the person. Typically, controls are a selection of isolation, insulation, and equipotential techniques. TPGs and conductive clothing are examples of equipotential techniques. OSHA 1910.137 covers requirements for PPE and directs employers to match with the specific hazards encountered [8].

Xcel Energy conducted engineering analysis and field measurements between 2017-2019 in terms of determining what the typical ranges of induced current and voltage on de-energized lines are. It was determined that the highest expected magnitude in the system was around 40 A. Several field measurements were conducted in many transmission line corridors in MN, TX, and CO and no value was recorded above 40 A. Field measurements corroborated that induced current magnitude varies per phase, and per time of the day. The measurements were useful in terms of having a general understanding of the magnitudes but are of no significance when trying to use the information for in day-to-day operations. It is better to have the crews assume that AC induction is always present. Examples of typical scenarios are listed in Figure 2.

Once it is known that a de-energized circuit is in the vicinity of an energized line, it is very difficult to rule out the hazard of AC induction, even when the circuits run parallel for a short distance on a line section far away from the worksite. A problem is that linemen are typically taught that de-energized work is work on dead circuits. If a circuit in a multiple line transmission corridor runs together with other live circuits, even if it is not on a portion of the lines near the work site, an induced current may be produced. Even if the induced current is in the order of a few tens of milliamperes up to a few amperes, it may be lethal. For example, an induced current of 250 mA is 42 times greater than the OSHA limit of 6 mA and may be lethal.

1. Work on a double circuit tower with one circuit de-energized with TPG and the other circuit live.
2. Work on a de-energized line with TPG, and the line runs in parallel a few miles with another energized line (near or far away from the worksite)
3. Stringing conductor in a transmission corridor with other energized lines
4. Working on a de-energized line terminal inside a live substation
5. Erecting steel structures with a crane near energized lines

Figure 2 – Examples of field applications when AC induction hazards may be present.

During training it is recommended to indicate that even when a circuit is grounded it may not be dead due to the hazard of AC induction. Also, it is recommended to teach to line workers several scenarios of exposure to induced current included under Figure 2. An example of common scenarios when workers are injured are instances when the workers position themselves in series either by opening the circuit that is grounded or by trying to reposition the TPGs without the use of a live line tool. Another common scenario of accidents is when workers work on or remove hardware other than the main phase conductors (e.g., shield wires, guy wires, temporary grounding rods).

[1] has a comprehensive list of several real-life AC induction related accidents reported by OSHA that could be covered during training sessions and in safety meetings. EPRI report 1020176 [9] also contains several examples of field accidents with analysis.

4. ACCIDENT STATISTICS

There is a limited amount of field studies that cover AC induction related accidents. [1] is a comprehensive study that analyzed 36 years of reported accidents in USA in the OSHA database. The study covered 81 accidents, from which 73 occurred in overhead lines (T&D) and seven in substations. 93 workers were involved in the accidents, from which 60 people died (65% mortality rate) from electrocution due to AC induced current and the rest survived with mild to severe degree of injury.

According to [1], 37% of the accidents were due to the workers contacting the phase conductors, 27% were due to manipulating the TPG jumpers, and the rest were due to contacting other hardware (e.g., shield wires, guy wires, equipment jumpers, ground wires). 63% of the accidents were due to contact through hands. In 48% of the accidents, the TPG were applied incorrectly (e.g., without a live tool, insufficient clearance), and in 41% of the cases TPG were not present at all. 90% of the individuals were experienced workers. The results were based on OSHA recordables which include accidents were three or more employees were involved and they worked for companies with more than 10 employees, so the data is only a piece of the pie. Companies have internal data with more events, including the ones involving two or less individuals, that is not accessible to the public domain. In addition, thousands of field exposures are not even reported as the line worker may have experienced a mild or strong shock but decided to not report it.

More studies and analysis are needed in the industry including the US and other regions of the world. More regulations and awareness are necessary to reduce injuries and fatalities.

5. PHILOSOPHY OF THE SUIT AND TESTING

Conductive clothing may be used in worksites with de-energized lines and with TPGs where AC induction is present. The suits need to be specially designed for this purpose. Clothing is comprised of conductive jacket, conductive hood, conductive pants, conductive gloves, and conductive socks/boots. All components are bonded together by means of conductive straps with metallic snaps (Figure 3). The clothing needs to sustain induced current of varying magnitude for a long time such that the wearers don't experience electric shock and they are able to remove from the circuit. The suits need to have flame retardancy and adequate heat dissipation as to not create thermal burns due to thermoelectric heating. Conductive clothing provides good screening efficiency against the effect of high electric field exposure and de-energized work may be conducted near other high voltage circuits that may expose the worker over 8 kV/m [10] (in some regions, E field exposure is regulated). Lastly, the suits can be arc rated with a standard such as ASTM F1506 [11] as there are instances in which they may be used for applying TPG (arc prone activity as defined by OSHA [5] [6] [7]) or for work in the vicinity to other energized systems.

The suit that was developed under this initiative was funded and sponsored by Xcel Energy and Electrostatics. The designs were tested at the high voltage laboratory at BME in Budapest. The development was conducted between 2019-2022. The scope was to develop specialized PPE to reduce injuries due to AC induction hazards. As of 2019, no PPE was available worldwide to address the issue of protecting line workers when there is human or equipment failure. The rate of incidents is high in electric utility environments in the US and OSHA regulations haven't targeted this issue directly. Little regulation is in place.

A typical issue in terms of reducing injuries due to AC induction is lack of coordination between training, company procedures, field observation, supervision, and field demonstration. Many programs address AC induction hazards very little or not at all. The line workers may fail to identify field conditions in which they will be in series with the path of induced current. An example is a TPG bracket grounding condition in a double circuit transmission line where the line workers have placed the master grounds too far away. The TPGs may create an AC induction loop with the energized line which is comprised of phase conductors, shield wires, TPG jumpers and soil. A line worker in the middle may be able to partition the induction loop into two loops and become a conductive path if touching the phase conductor while standing on a grounded platform. Another example is if the worker clips a jumper on a transmission tower and when separating the jumper and becomes in series with the path of induced current.

Substation work is not exempt from AC induction hazards. Workers have lost their lives while performing line terminal work on arresters, line traps, and voltage transformers as they may remove equipment jumpers and be unaware that they are closing the ac induction loop with the transmission line that is out of service but it runs parallel with a live circuit. Another injury was reported by EPRI [9] inside a substation while an individual bridged two large bus sections on a 400 kV live substation in Europe.

The philosophy of the conductive suit is to act as a "shunt" or "personal bond" which takes the larger portion of the total induced current away from the body of the worker and makes that current flow through the conductive fabric, conductive gloves, conductive socks/boots [12]. See Figure 3. In the example, the screening of the suit allows 0.00002% (6 mA or less) of the current to flow through the worker and 98.998% (~50 A) to flow through the suit. The worker should have main protection by means of TPGs, bonding, and EPZ, and if human error occurs, the suit would be able to act as secondary protection from electric shock.

For the suit design a tolerable threshold of a body current of 6 mA was selected. One justification is IEEE 80 [13] defines tolerable current that a person can sustain, and 6 mA provides a reasonable limit. Second, 6 mA is the defined let go current per OSHA [5] [6] to which controls are needed per the employer in environments where AC induction is present. Furthermore, a safety margin was added, and the suit performance was determined based on a 30 s total time of exposure. The developers accounted to the fact that an individual may touch a conductor for several seconds and on several occasions. Also, the

30 s account for some extra thermoelectric withstand. In practice, when the line workers are in the field and they experience AC induction current when they are wearing the conductive suit, the wearer may not be able to identify or feel currents in the range between 1-10 A [14]. In the range between 10-20 A, some heating will be indicative for the worker that a current effectively is flowing through the suit and the procedure is to detach from the circuit and evaluate the condition. Some minor arcing may be noticeable when removing from the circuit.

The suits are flame resistant and arc rated per ASTM F1506 [11]. There is an IEC standard, IEC 60895 [15], that addresses conductive clothing for barehand work and vicinity work, that has flame retardancy, but it is currently not rated for carrying AC induced current and has no arc rating either. During the study, it was determined that traditional barehand suit designs have limited capacity to withstand induced current (2 to 19 A only, depending on manufacturer) and some suits even ignited and carried a flame. For that reason, AC induction must be addresses by specially designed conductive clothing.

The flame resistance ensures survivability as in case a flame occurs, it will self-extinguish and won't contribute to the extent of an injury. The [1] study found cases recorded by OSHA in which the employees clothing turned into fire due to exposure to AC induction.

The suits were tested for touch with heated fabric by following ASTM C1057 [] criteria for 30 s so second-degree burns are not sustained if the fabric overheats. Further details of the suit design can be found in [16]. An effort is ongoing in ASTM Subcommittee F18.65 (clothing for protection against electrical hazards) for the creation of a new standard specification for this type of suits and the standard is planned for release in 2024-2025.

The suit design [17] requires very low electrical resistance for its components (e.g., fabrics, conductive bands) and for its finished garments (e.g., jacket, hood, pants, gloves, socks). Resistance values of the suit must be tested during production to ensure good workmanship and compliance to the design. When procured, suits come with a safety passport which includes baseline tests, and it has a sheet for logging periodic measurements of resistance during the life of the suit. It is recommended to test resistance values of the suits every 2-3 years in service. Suits must be visually inspected daily, prior to use. In the field, the line workers must conduct a continuity check with a multimeter after the visual inspection, mostly to ensure proper bonding of the suit components. Table 1 shows examples of resistance measurements of components and bonding.

Table 1 – Examples of electrical resistance measurements of an AC induction suit during in-service periodic testing

Number of washing cycles	Resistance hand-to-hand (ohm)
0 (new, unused)	0.61
10	1.62
50	3.63

NOTE – Measurements were conducted at the BME laboratory.

AC induction suits must be donned as a complete kit in order to work properly. It is important to cover this aspect during training and field demonstration. Also, in the field, it is recommended to have a "buddy check" program in which line workers once they don the suit are also checked by a coworker, and ensure suit is properly bonded and worn.

Never assume that only a large induction current can harm a person. Even a small amount of current, in the tens of milliamperes could hurt an individual. The problem with AC induction is that the time of exposure could be in the order of several seconds. There is no protection system that can disconnect the induced current. Therefore, once a person becomes in series with the induced current, the only way of disconnection is for the person to be able to self-remove from it. If the body current is large enough to cause muscle contraction, the person may suffer from the hand and limb muscles to contract and get locked in position with the conductor and not let go. Also, the current may cause asphyxia by contracting the chest muscles and/or ventricular fibrillation of the heart.

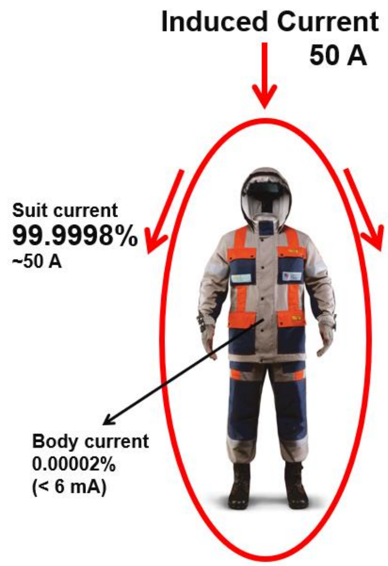

Figure 3 – Examples of how the AC induction suit helps conduct shunt induced current through conductive fabric and reduces the worker's internal body current.

Figure 4 shows an example of a laboratory test of an induction suit as tested at BME Hungary. The test shown is for injecting 50 A during 30 seconds between hand-to-hand with an AC generator. A special manikin with metallic skin is utilized which has insulators in between torso and limbs and it has a special 1000-ohm resistor in between sections which is used for measuring the voltage across and for estimating the body current. During the test, the total suit current is monitored and the body current too. A test is a pass if the body current never exceeds 6 mA during the whole duration of the test. During the test, thermal performance is measured with special cameras and there are non-reversible thermal stickers positioned inside the suit [17]. Also, the manikin is dressed in a 100% cotton shirt that is used for evaluating signs of scorching and charring which could be signs of a burn. During the test, it is not allowed for components to melt or drip, if a flame appears, it must self-extinguish. Also, burns are monitored and only a small burn area is allowed. The test is also conducted for hand-to-foot, and for foot-to-foot contact. For more technical details about the test, consult [17].

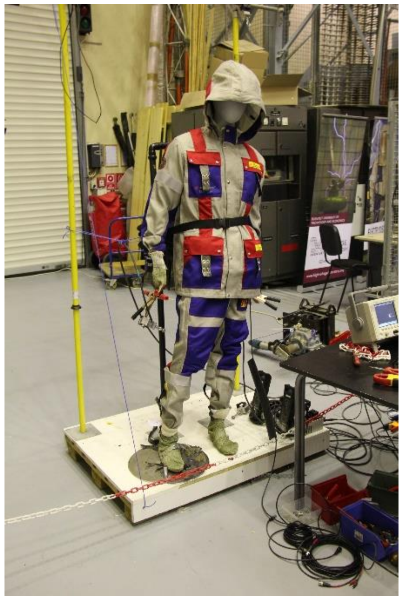

Figure 4 – Examples of a laboratory test of hand-to-hand exposure to induced current.

6. FIELD TRIALS AND TRAINING

The electric utility selected two crews for conducting field trials in TX. Specialized training was given prior [5]. The training included a theory section, review of common AC induction accidents, review of field procedures, and donning demonstration of the suits. The students had their induction suits ready during the training and were able to get familiar with their use and don them.

The field supervisor was a line worker with both live work and dead work experience. The TPG practices were discussed and the fact that the suit was going to function as secondary protection.

Figure 5 – AC induction PPE training of transmission line workers in Texas, USA

During the training, the instructors carried a demonstration in which the conductive suit is placed on top of an insulating surface, and then a current injection source is connected, and a 5 A current is injected (Figure 6). The demonstration helps the line workers understand the function of the suit and they can confirm that the suit is effectively conductive, it has very low resistance, and that all bonding is crucial for adequate performance. During the demonstration, the instructor can detach components on purpose and show the result to the students. An example is to show improper bonding between jacket and pants and the effect of increase in resistance or an open circuit which is indicative of no protection. The suits have many safety measures in the design which are explained to the workers so they can identify when they need to trouble shoot any issue encountered. It is recommended to have spare gloves in the field in case of need of replacement. It is recommended to provide two suits per employee or have spares ready at the field.

Figure 6 – Demonstration to line workers and injection of 5 A of current through the conductive suit during training in Texas, USA

Figure 7 shows examples of suit donning as given during the training of line workers.

Figure 7 – Example of training demonstration on adequate bonding between conductive suit components

The first field trial was consisted in installing two new OPGW wires under a live 115 kV line for three miles in 2022. The towers are wood H-frames with two shield wires on top. See Figure 8. Dollys had to be installed in all wood poles for stringing the OPGW wires. The OPGW wires were going to be strung in a middle location and towards both ends. A set of master TPG grounds was set in the mid span of the installation on the OPGW wires and running grounds were installed every ¼ mile on the OPGW runs.

It was expected for the OPGW wire to pick up induced current. Field measurements were performed on the OPGW wires once they were grounded, and it was recorded that the induced current at the time of measurements was about 1.5 A (about 250 times the OSHA limit). Main controls were put in place by means of TPG practices, and a backup was set with the use of conductive suits.

During the hazard assessment and risk mitigation phase of the job, it was determined that the risk of electric shock due to induction was present for the following activities:

1. Running grounds are secondary means of grounding a conductor as their contact points have very large resistance (2-5 ohm), so workers couldn't rely on their ability to count as appropriate bonding. Any voltage drop across the running grounds could produce electric shock and workers needed to ensure other low resistance grounds were in place (e.g., additional master grounds). Whenever a worker had to touch the OPGW wire, they had to ensure they had a bonding wire across points touched by the line workers.
2. OPGW had to be positioned on top of the dollys. The dolly construction had a neoprene wheel that is non-conductive, and a risk of electric shock was present if a worker contacted the OPGW and dolly metallic parts or ground. Crews were instructed to install temporary jumpers across the pole ground (which had to be bonded to the metallic frame of the dolly) and the OPGW wire before placing the wire in or out of the dolly.
3. The conductive clothing shall be used as secondary protection, meaning the workers were not instructed to skip or violate any Company TPG procedure.
4. Insulating trucks (aerial platforms) were used for the job and workers were informed that the insulating platform doesn't protect against hand-to-hand or any other in series exposure to induced current in the induced circuit. Workers must always ensure there is a metallic path (e.g., bonding jumper) if they create or close an opening in the induction current path.
5. Any splicing of OPGW required a bonding jumper across conductor ends and personnel had to be positioned in an EPZ.

The second trial consisted in installing one OPGW wire under a live 345 kV line in TX in 2022. The structures are metallic, weathered steel, H-frames. Insulating trucks were used for the job. The crews already had some experience gained from trial #1, and work was conducted with a little more experience. Workers were able to don the suits in less time and checks were conducted diligently. The induction current couldn't be measured onsite due to an issue with the portable ammeter, but it was not a problem as the workers assumed AC induction was present and proceeded with caution and similar methods as in trial #1.

During trial #2, the team experienced a little fire on vegetation due to the induced current path to ground through the TPG grounds. The crew was able to extinguish the fire. The procedure was modified in terms of adding awareness of the risk of initiating a wildfire due to AC induction current.

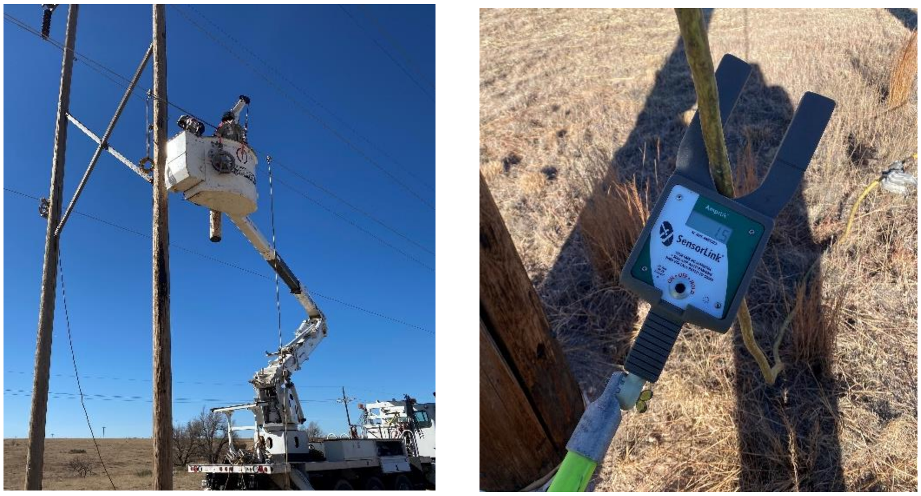

Figure 7 – Field work of installing OPGW with TPG and 1.5 A of induced current under an energized 115 kV line in Texas, USA

Currently, the electric utility approved the induction suits for wide use across the service territory. Training is ongoing in CO in 2024 and MN in 2025. Full deployment is expected at the end of 2025. Currently, the company has about 75 induction suits. Expected suit fleet is about 200 suits once fully deployed by end of 2025. Workers are instructed to use the suits as needed as part of their day-to-day activities and their site hazards and risk assessments.

More details regarding hazard and risk assessment for de-energized work, including AC induction hazards are found in [19].

7. FUTURE WORK

There is ongoing work in ASTM to develop a standard performance specification for manufacturing AC induction conductive clothing. The standard is scheduled for release in 2024. Also, the standard guide IEEE 1067 [18] for use, care, and maintenance of conductive clothing is under review and has a new section that covers AC induction protection; guide is scheduled for ballot in 2024. Lastly, IEEE 1048 [3] for TPG is under review and is scheduled for ballot in 2025.

New OSHA regulations are needed to reduce injuries and fatalities due to AC induction.

Future training courses for line workers and substation electricians of electric utilities and contractors should include AC induction hazard recognition, and mitigation through controls and PPE.

8. CONCLUSIONS

Federal regulations in the US require employers to provide protection to their workers if the induced current in the body of their workers is greater than 6 mA (defined per OSHA) [5] [6]. When working on de-energized lines and equipment, when AC induction is present from nearby energized lines, that threshold can be exceeded. Typical controls include work methods with controls such as TPG [3] and insulating protective equipment (IPE). A big problem is when there is human error or protective equipment failures. A new type of PPE was developed in conjunction with an electric utility in the US, a laboratory in Europe, and a conductive clothing manufacturer. The result is a conductive suit that provides secondary protection to workers, when they are conducting work on de-energized systems with traditional methods (e.g., TPG).

Accidents and fatalities from exposure to electric shock due to induced current on de-energized overhead lines and equipment are common in the US [1] and worldwide. A large number of accidents are attributed to human error, deficiencies in field procedures, training deficiencies and lack of recognition of AC induction hazards, insufficient field supervision, and company culture.

The special conductive clothing consists of a set of jacket, pants, gloves, and socks/boots that acts as a personal EPZ and electric shunt that offers a different path for induced current to flow when the person is in series with the path of the induced circuit. The suit is capable to reduce the body current under 6 mA and allow precious body control and time for the worker to decouple from the induction circuit. The suit is flame resistant and arc rated [11]. The current suit design is rated for 10 cal/cm^2. The suit can function as arc rated (AR) clothing and no additional arc rated clothing is needed to be worn underneath. It also can be used in proximity with live systems and attenuates exposure to electric field strength (E) [10] [15]. The suit that was developed was rated for 50 A of induced current for 30 seconds, and is arc rated to 10 cal/cm^2. Workers are instructed to not deviate from Company TPG practices while wearing the suit.

AC induction is unpredictable, difficult to calculate, and unreliable when measured in the field. The best approach is to assume it is present in the field and apply controls for it. Induced voltage and current varies in the circuits per phase or element, and per time of the day. A very small magnitude (in the order of milliamperes) is enough to cause injury or death to a person. Once a person experiences electric shock due to induction, there is no protection system or automatic disconnecting means available to decouple the individual. The workers must be able to remove themselves from the circuit.

Injuries and fatalities due to AC induction hazards are preventable. Controls may be implemented by means of following proper TPG company procedures. Wearing special conductive clothing brings additional protection that can account for human error and equipment failure.

More regulations are needed in the industry by OSHA, NESC, and other bodies in order to help reduce AC induction accidents and fatalities.

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10. RECOGNITION

The authors would like to recognize and thank all the transmission line workers, supervisors, managers, and laboratory technicians that participated in the development of the AC induction suit. Also, the inspiration for the creation of this new type of PPE originated from the thought and sharing of stories about the loss of loved ones, stories of survival and recovery of many line workers.

11. VITAE

Eduardo Ramirez-Bettoni graduated from Universidad de Costa Rica in 2002 with a BSEE degree. Eduardo has been a member of IEEE for 13 years. He was a substation field protection engineer between 2002-2008. He practiced consulting in substation design between 2008 and 2014 in Canada and the USA. Since 2014, he joined the Transmission and Substations Standards Department in Xcel Energy as a Consulting Engineer, and he develops design, construction, commissioning and safety standards for substation and transmission line applications. He is convenor of the IEC Technical Advisory Group in the US National Committee for TC78, and Secretary of WG15. He is also a member of Cigre B3.54, Vice Chair of IEEE T&D ESMOL Subcommittee, a member of IEEE Substations Subcommittee, Chair of IEEE Grounding and Lightning Subcommittee G0, Secretary of ASTM F18.65 Subcommittee, a member of ASTM F1506, Co-Chair of ASTM WK 70226 (conductive clothing standard specification), and a member of NFPA Flash Fire Protective Garments Committee (NFPA 2112/2113). He is a registered professional engineer in the state of Minnesota.

Bálint Németh got his MSc and PhD in the Budapest University of Technology and Economics (BME). He is working in BME as associate professor since 2015 and also as Director of the High Voltage Laboratory since 2007, and Manager of Dr. Béla Csikós Live Working Education Center. Between 2009 and 2019 he worked as developmental advisor for the MVM OVIT Ltd. He has field experience as Research and Development Project Manager in different areas such as lightning protection, dielectric insulation, transformer diagnostics, asset management for electromagnetic compatibility, industrial electrostatics, biological effects of electromagnetic fields, overvoltage and environmental protection, and live line maintenance and training. He is member and convenor of several international committees like CIGRÉ A2, B2, B2.64 WG, IEEE ESMO, IEEE 1067, ASTM, IEC TC 78, IEC 60895 as well as project leader of different EU H2020 projects like INTERFACE, FLEXITRANSTORE, FARCROSS, and ONENET. Bálint produced more than 150 publications in well-known conferences (IEEE, CIGRÉ, etc.) and more than 25 international journal papers.