Study Committee B2

OVERHEAD LINES

10152_2022

Development of a novel conductive garment for protecting linemen against transmission line induction

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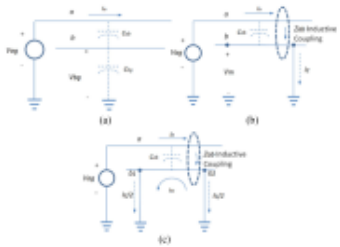
Motivation

- Electric and magnetic field induction pose a hazard to linemen working in transmission line corridors.
- This poster presents the concept of a new conductive suit that can be used for protecting transmission line workers from AC induction hazards.



source: Wu, Xuan & Meisner, David & Stechschulte, Kyle & Simha, Vinod & Wellman, Ronald & Thakur, Manish & Posey, Kenneth & Dimpfl, Scott. (2019). Induced Voltage & Current Simulations, Safety Criterion, and Mitigations for EHV Transmission Lines in Close Proximity. IEEE Transactions on Industry Applications. PP. 1-1. 10.1109/TIA.2019.2898845.

Method/Approach

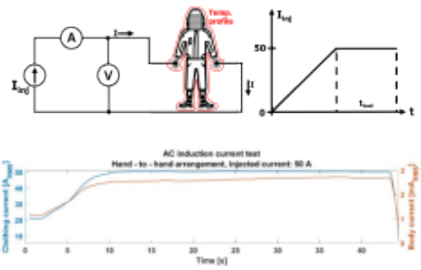
- AC induction clothing works as additional protection in the case of human error or equipment failure
  - It shunts hazardous induced current across the body (without the PPE, full current would flow through worker).
  - It lowers the magnitude of the current flowing through the worker's body below 6 mA (threshold of let-go current).
  - Clothing can conduct a high current of 50 A for a minimum of 30 seconds, without any damage of the material.

Objects of investigation

- Determination of the permissible body current magnitude
  - Threshold limit of let-go current: 6 mA
- Determination of current injection levels for laboratory inspection.
  - Maximum induced current in the field + safety factor: 50 A
- Electrical and thermal testing of conductive clothing
- Durability test of conductive garment with large number of washing cycles (50)

Experimental setup & test results

- New concept for laboratory testing of conductive suits against AC induction.



Discussion

- Temporary protective grounding (TPG) applied at the work site of the de-energized line reduces the magnitude of the induced voltage.
- Creating an equipotential zone (EPZ) around the workplace controls differences of potential between any parts of human body and, as a result it reduces current flowing through the worker.
- Studies have shown that workers make mistakes that can cause accidents; unfortunately, many AC induction related accidents are fatal.

Conclusion

- A new type of strengthened conductive clothing was developed, which can shunt body current, and protect against electric shock.
- Thermoelectric heating effect is controlled and kept under the temperature limit that could lead to a 2nd degree burn.
- Flame resistant clothing
- Laboratory testing concept was developed in the framework of ASTM WK 70226:
  - Destructive type testing
  - Non-destructive acceptance and periodical tests

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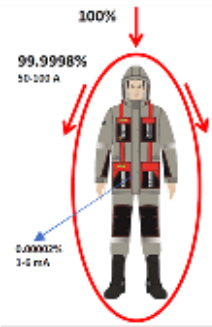
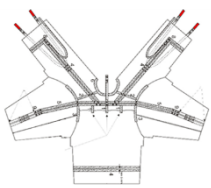
Statistics of AC induction accidents

- Statistics (BLS) show 81 AC induction accidents between 1985 and 2021 in the USA.
- Involved 93 workers in total. 33 workers were survivors (35%), and 60 workers were fatalities (65%).
- 89% of the accidents happened due to applying TPG incorrectly or not installing it at all.

Conductive clothing for AC induction protection

- AC induction clothing works as an additional safety factor in the case of human error:
  - Minimizes the level of current flowing through the worker's body down to 6 mA (threshold of let-go current)
    - Hand-to-hand; hand-to-feet; foot-to-foot
    - Protects for other body exposures
  - Ability to conduct high AC induced current of 50 A for a minimum 30 seconds, without any damage of the material
  - Handling of thermoelectric heating while current flows through the suit.





Electrical testing of conductive clothing

- Evaluation of AC induction clothing requires performing standard electrical tests.
- Test methods are described in IEC 60895:2020, and in the recently developed ASTM WK 70226.
- Tests include:
  - Fabric electric resistance, fabric shielding efficiency (SE),
  - Garment screening efficiency of electric field strength (ECC),
  - Resistance of garment components, resistance of bonding,
  - Electric current shielding of garment

Thermal performance of clothing

- Clothing evaluation includes tests for fabric flammability and ignition:
  - Conductive fabric that meets flame retardancy criteria per IEC 60895:2020 and flame resistance per ASTM F1506 are appropriate for use against AC induction.
- It is recommended that conducive clothing be arc resistant:
  - Some materials meet criteria IEC 61482-2 (tested per IEC 61482-1-1) and have an arc protective value.
  - Conductive fabrics in the marketplace are generally in range between 7 and 13 cal/cm^2 of ATPV level.

Durability test of conductive garment

- Laundering can increase the electrical resistance of conductive clothing, therefore washing cycles are applied as an aging method.
- Based on the customers requirements, it was determined that 50 washing cycles are sufficient.

Parameter	Measured value	Parameter	Measured value
Fabric resistance, no washes	0.640 Ω [b]	Garment resistance, unused, hand-to-hand	0.045 Ω [b]
Fabric resistance, 50 washes	0.780 Ω	Garment resistance, after 50 washes, hand-to-hand	0.059 Ω
Fabric SE, no washes	44.16 dB [b]	Garment resistance, unused, hand-to-foot	0.131 Ω [b]
Fabric SE, 50 washes	42.18 dB	Garment resistance, after 50 washes, hand-to-foot	0.170 Ω
Garment ECC, unused	99.99 % [c]	Body current, unused @ 50 A	2.22 mA
Garment ECC, 50 washes	99.98 %	Body current, 50 washes @ 50 A	3.90 mA [d]

[a] Hand-to-foot; [b] Per IEC 60895:2020; [c] Per IEC 60895:2020, Method 2; [d] current shielding of 99.9922%

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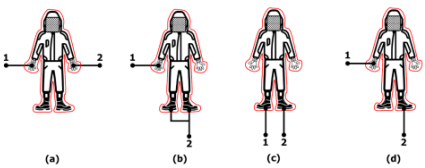
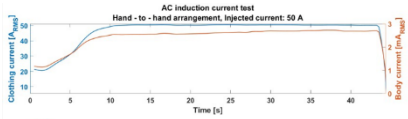
Type testing method for AC induction conductive clothing

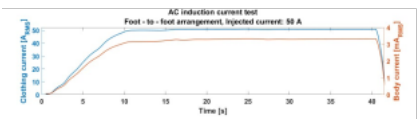
- The test determines temporary and steady state withstand to intensity in amperes and to a given time period.
- The test replicates the ability of the clothing to protect a worker when he/she establishes contact in a circuit with induced current and voltage.
- A voltage source is used for injecting a through-current on conductive clothing placed in different body configurations.
  - 50 A current level is injected.
- The test is considered a pass if the body current is within the limit and there are no visible signs of extensive body burn, there is no melting, sustained ignition, melting or dripping.
  - For body current, 6 mA is the threshold which is the limit of let-go current (to control body movement and prevent asphyxia).

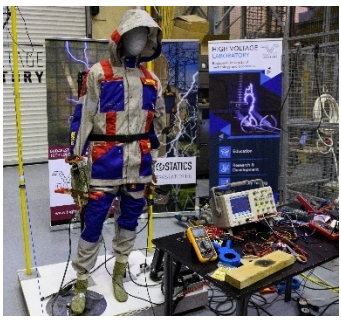
Assumed worker position

- The physiological effect of electric shock depends on the exposure time, the magnitude and the path of the current inside the human body.
- Clothing under inspection should be tested in different body configurations (a, b, c, d below).









Thermoelectric effect

- During current injection, the resistance of the suit materials cause an increase in temperature.
- During the test, thermal indicators are placed on the clothing and visual inspection is performed.
- Hot spots on the conductive fabric or other suit components did not show onsets of a 2nd degree burn (curable burn).

Conclusion

- When performing line construction and maintenance on the transmission system in the vicinity of live parts, line workers may be exposed to AC induction hazards.
- Statistics show that AC induction accidents are commonly fatal.
- A special conductive clothing was developed to protect against AC induction hazards.
- The development of a laboratory inspection procedure was introduced as there was no technical background available for laboratory testing of AC induction garments.