CIGRE PARIS 2022

HELLENIC CABLES | Member of CENERGY HOLDINGS

Study Committee B1

Insulated Cables

10703_2022

Effect of semi-conducting jackets on the performance of three-core armoured power cables

Andreas I. CHRYSOCHOS* Dimitrios CHATZIPETROS* Dimitrios N. KOSSYVAKIS* Vasileios L. KANAS*
Konstantinos PAVLOU* Konstantinos TASTAVRIDIS* George GEORGALLIS*

*Hellenic Cables, Greece

Motivation

- Effect of semi-conducting (SC) jackets on the thermal performance of 3C armoured cables used in offshore wind farms, often being of long route lengths
- IEC 60287-1-1: No reference to the above effect on current rating of SL-type, wire armoured cables
- Existing literature: Finite element (FE) studies and measurements give some indication of the effect
- Present study: Investigate the effect via the electromagnetic (EMT) representation of the cable, accounting for its distributed nature

Method/Approach

- Existing FE models and measurements may give some evidence of the SC effect:
    - Plus: Realistic representation of a cable length, including any 3D effects
    - Minus: Does not account for the distributed nature of the cable, due to short length (in practice impossible to measure over 50-100 m)
- Existing EMT cable models: Pipe-Type (PT) representation
    - Plus: Includes the distributed nature of the cable via successive pi-equivalents at power frequency
    - Minus: PT cable does not account for 3D effects stemming from the existence of helices
- Suggested cable model: Take advantage of state-of-the art FE Short-Twisted (ST) models and EMT approach via *Js*-method
    - Plus: Considers the distributed nature of the cable including 3D effects due to helices

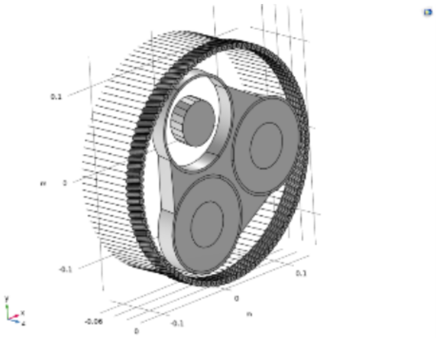

Figure 1: Cable geometry imported in 3D FE ST models used to derive the pul series impedance matrix ***Z*** via *Js*-method.

Js-method and EMT incorporation

Self and mutual elements of Z: $Z_{ij} = \frac{V_i}{I_j} = \frac{J_{S_i}}{\sigma_i I_j}$

where V_i the pul voltage drop, J_{S_i} the source current density and σ_i the conductivity of layer i.

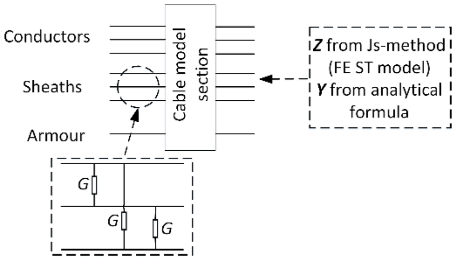

Figure 2: Cable modelling approach in EMT program. Shunt conductance *G* is the key parameter (reversed sheath to sheath resistance).

Study Committee B1

Insulated Cables

10703_2022

Effect of semi-conducting jackets on the performance of three-core armoured power cables

(continued)

System under study

- 3x2500 mm^2 Al conductor 220 kV export cable
- Total length of 20 km
- Shunt conductance $G \geq 5$ S/km
- To look into more detail, the following are examined:
  - Capacitive and inductive mechanisms, separately
  - Solid and single-point bonding schemes

Numerical results – Capacitive coupling

- Solid bonding
- Insulating jacket: The capacitive current returns solely through sheath
- SC jacket:
  - Mutual cancellation happens, though not perfect
  - A noticeable current (~20 A at the ends) still exists
  - Inductive effect of capacitive conductor current
- Similar conclusions for single-point bonding

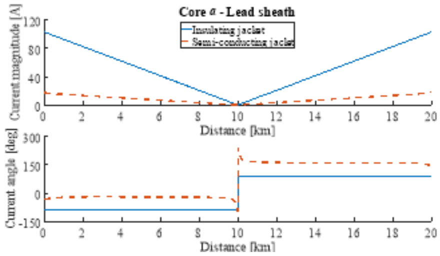

Figure 3: Cable in solid bonding. Current profile in lead sheath of core *a* under capacitive coupling.

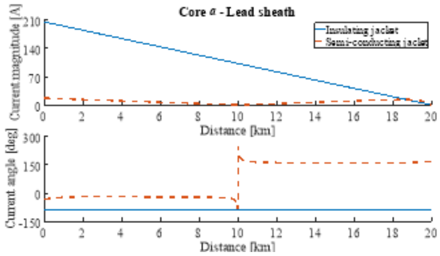

Figure 4: Cable in single-point bonding. Current profile in lead sheath of core *a* under capacitive coupling.

Numerical results – Inductive coupling

- Steady-state
  - Solid bonding: Effect of armour μ_r on sheath current
  - Single-point bonding: in SC case circulating currents are progressively developed

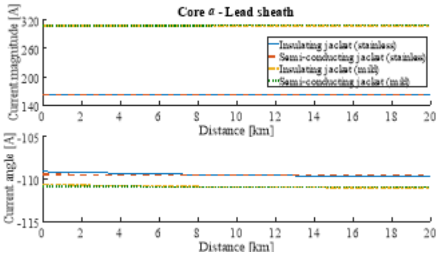

Figure 5: Cable in solid bonding. Current profile in lead sheath of core *a* under inductive coupling - mild or stainless steel wires.

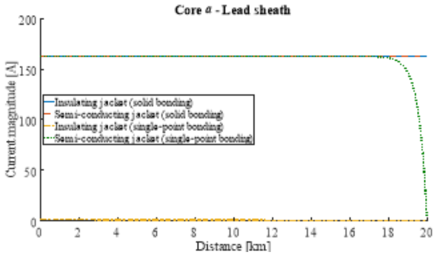

Figure 6: Cable in solid and single-point bonding. Current profile in lead sheath of core *a* under inductive coupling.

http://www.cigre.org

cigre | PARIS 2022

HELLENIC CABLES — Member of CENERGY HOLDINGS

Study Committee B1

Insulated Cables

10703_2022

Effect of semi-conducting jackets on the performance of three-core armoured power cables

(continued)

Numerical results – Inductive coupling

- Phase-to-ground short-circuit
  - The existence of SC jackets allows for short-circuit current sharing

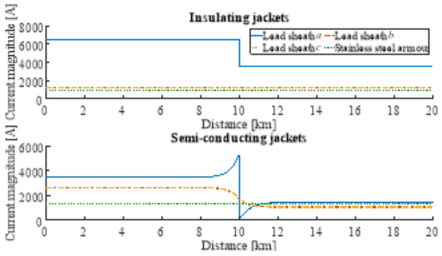

Figure 7: Cable under single-phase internal fault. Current profile in lead sheaths and armour.

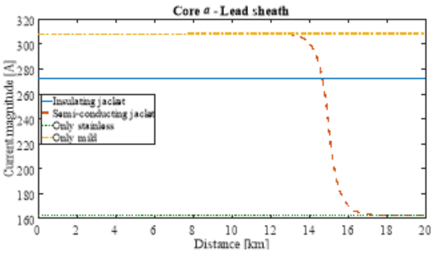

Figure 8: Connection of 2 different cables. Current profile in lead sheath of core *a* under inductive coupling.

- Connection of different cables
  - Effect of *G* on transition region
  - Increasing *G*, the transition region progressively narrows
  - Result: The final current value of each region is reached in less distance from the transition point

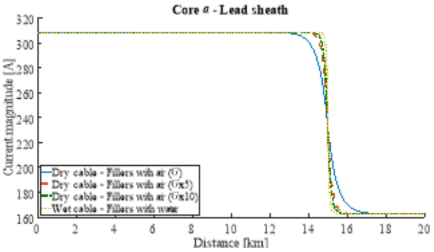

Figure 9: Connection of 2 different cables. Current profile in lead sheath of core *a* under inductive coupling. Investigation between dry and wet cable.

Discussion - Conclusion

- A more realistic EMT cable model is developed thanks to *Js*-method and FE 3D ST combination
- The thermal effect of capacitive current is currently not considered in current rating calculations (not discussed in any IEC or CIGRE document)
- Capacitive current entirely present in cables with insulating jacket, still noticeable in cables with SC jackets (imperfect mutual cancellation and inductive effect of capacitive current in conductor)
- Circulating currents in sheaths even under single-point bonding in cables with SC jackets
  - Measurement of cable loss difficult to be verified through conventional inductive EMT models
- Sharing of short-cicuit current is possible thanks to SC jackets which leads to design optimisation of metallic sheath
- Shunt conductance *G* is the key parameter
- The higher *G is,* the most optimum the thermal performance of the cable is
  - Quicker sharing of short-circuit current
  - Narrower transition region between different cable designs
  - Minimisation of extra lengths with oversized cables