

# A New Technology for Termite-Proof Underground Cables

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**Abstract**—Globalization and the intensification of the export of goods sometimes imply the arrival of alien species of insects dangerous for human health and sometimes for infrastructures. Termites inhabiting tropical and equatorial countries pose a high risk of damage to electrical infrastructure, directly buried cables especially. This paper addresses common conditions and effects caused by termites' attacks on buried cables, and related innovative protection measures for cable manufacturing. This protection has proven to make cables highly resistant to these attacks.

**Index Terms**—Termites, MV cables, electrical infrastructure, cable tests, Nylon, Polyphthalamide, glass fiber, sheath.

## I. INTRODUCTION

Subterranean termites can cause harm to various materials, including numerous plastic items [1]. The vulnerability of plastics to termite infestation varies depending on their chemical composition, level of hardness, and surface texture. The resistance of plastics to termites can be enhanced by employing physical and chemical modifications, such as adjusting the number of plasticizers, incorporating inert fillers or insecticides, or enclosing them behind a physical barrier.

The economic consequences of termite-induced harm to plastics, such as plastic-coated underground communication, power lines, and pipes, can be substantial. In [2], the authors report that termites have been inflicting significant harm to 138-kV subterranean wires. They generate punctures in the PVC layer covering the cable. As a result, the corrugated metal sheath is left uncovered, finally triggering a corrosion process that results in oil seepage in the soil.

A substantial amount of insulating oil being removed from the cable affects the performance of the insulation and can lead to a short circuit. For numerous applications, especially in renewable energy plants [3]–[7] where the continuity of operation is paramount for guaranteeing business revenue, it often becomes necessary to utilize more expensive alternatives, such as polyamides (e.g., Nylon). However, a specific substance may demonstrate resistance only against some species of termite, not providing general protection.

This article examines issues encountered in the operation of subterranean medium voltage (MV) 30 kV cables within

1 GWp photovoltaic plant in Brazil, with a particular focus on insulation failures resulting from termite infestation. Possible actions and remedies to be taken in the short term are discussed. A new type of MV cable with an innovative Polyphthalamide sheath reinforced by 45% glass fiber has been developed and successfully tested on site.

## II. BIOLOGICAL ASPECTS

### A. Biological premises and local scenario

Termites are heterometabolous insects belonging to the Neoisoptera or Isoptera clade within the larger Order Blattodea (cockroaches and related taxa; previously considered a distinct Order, the Isoptera). Termites are common insects that consume wood and other plant materials rich in cellulose. The animals may break down and process cellulose using symbiotic microorganisms found in their colon and midgut, mainly flagellate Protista, Bacteria, and fungus. Most of the 3100 described species are distributed in tropical and subtropical countries, with only a few species reaching northwards or southwards the intermediate latitudes of the temperate areas [8], [9].

Environmental factors such as rainfall, vegetation type, temperature, and altitude affect local termite species diversity. These factors have been proven to impact the diversity of termites in a particular area. Several of the best-known species can build large and striking termite mounds that stand out on the horizon of vast prairies, savannahs, and other open environments, foraging workers looking for trees, trunks, stumps, wood fragments and cellulose available in the surroundings, and looking for food around the termite mounds, through the excavation of long tunnels in the ground, even at a distance of hundreds of meters from the central core of the termite mound itself.

The main core of these nests hosts the so-called “royal couple,” including a fertile male and the queen, who, following an initial nuptial flight, lose their wings after their mating flights; eventually, the queen will land and look for a suitable place to begin the new colony. Millions of eggs can be later produced by a single queen, even for several years, and an individual termite mound in certain species can host up to millions of specimens (including workers, soldiers, and members of other castes, when present).

Some groups of termites, however, can build entirely subterranean nests, again finding trees, trunks, wood fragments, wooden artifacts, cellulose, and stumps available in the surroundings and looking for them by excavating long tunnels in the soil. These specialized species start from a subterranean or semi-subterranean nest (including the “royal couple”), usually placed at the base of living trees, standing trunks, large stumps, and occasionally inside small artificial cavities.

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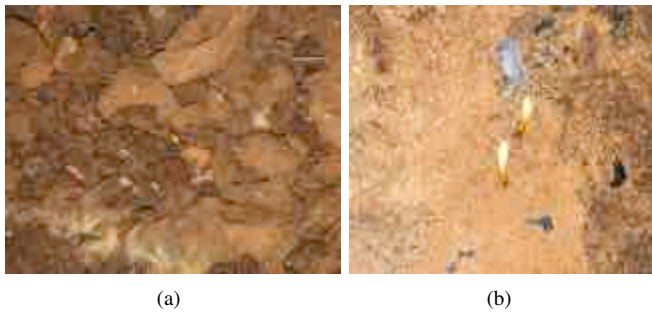


Fig. 1. Apterous adults (workers and soldiers) of the subterranean termite *Coptotermes testaceus*.

The species involved in the cable attacks in Brazil, as inferred from a close examination of the available photographic documentation (and as recently confirmed by local entomologists), has been identified [10] as *Coptotermes testaceus* (Blattodea, Neoisoptera, Rhinotermitidae), a native Neotropical (South and Central American) species widespread [10]–[12] in open tropical and subtropical habitats throughout Brazil, Venezuela, Peru, Ecuador, Bolivia, northwards to central Mexico (see Fig. 1). This species belongs to the above-discussed group of “subterranean termites,” also known as “underground heartwood termites,” which are frequently recognized as pests, chiefly in wood plantations and other man-influenced habitats [13]–[15].

The damaged electric cables do not represent a food source for termites. However, when occasionally met in the ground, termites usually circumvent the hardest materials (commonly those up to the value 3-4 of the heuristic Mohs scale) while trying to bore or at least test or taste the relatively softer materials (such as most of the plastic substances, including polyethylene, Styrofoam, and several others, and even some soft metals such as lead or copper), in order to search for potential ligneous substances beyond the encountered obstacle. The attacked cables can, therefore, be even severely damaged, with phenomena of electric dispersion, undermining the efficiency of the cables themselves, causing the need for their continuous repair and maintenance [13], [16], [17].

### B. Possible solutions to prevent, circumvent or solve the problem

The repeated occurrence of damages on underground electrical, telephone or network communications cables by subterranean termites is a well-known and long-known phenomenon [12], [13], [16], [18], [19], mainly in South-East Oriental Region, Australia, tropical and subtropical Africa, and South America, where termites in general, and specifically the subterranean termites, show their highest levels of biodiversity and species richness [8], [9], [19].

To prevent attacks and the consequent damages, several different solutions have been thus far proposed [13], [16], [17].

*Additional protective metallic sheaths* (usually iron or aluminum) cover and surround the driver portion of the cables and their outer plastic sheath. They provide good mechanical protection from the termites’ attacks. The drawbacks are high costs for cable construction and potential severe electric

induction phenomena, especially when dealing with medium-to high-voltage cables.

*Encasing the cables in concrete or surrounding them with precast concrete during installation* provides an extra protective layer that shields and encloses the wires’ core and outer plastic sheath. They provide excellent mechanical protection from the termites’ attacks. The drawbacks are the high costs for cable laying, additional problems in future repair and maintenance activities, and attacks and damages made by certain species of subterranean termites (including *Coptotermes*), which can be prevented only by meticulous sealing of each prefabricated concrete piece, including the inspection wells.

*Additional protective “hard” plastic sheaths* (usually particularly hard types of nylon-12) cover and surround the driver portion of the cables and their outer plastic sheath. The advantages are good (although not always complete) mechanical protection against the termites’ attacks and sustainable additional costs for cable construction. The drawbacks are that attacks and damages made by certain species of subterranean termites (including *Coptotermes*) can only be strongly reduced but rarely eliminated.

*Additional protective plastic sheets containing repulsive or toxic substances*, or biologically active substances regulating the termites reproduction, cover and surround the driver portion of the cables and their outer plastic sheath. The advantages are discreet (although not complete) chemical protection against the termites’ attacks and intermediate costs for cable construction. However, they can only reduce but rarely eliminate attacks and damages made by certain species of subterranean termites (including *Coptotermes*), and can cause potential ecological damage to the local environment and biodiversity.

*Mechanical removal and destruction of all termite nests and mounds* surrounding cable burial areas are another possible solution. The advantages are decent (although not complete) protection against the termites’ attacks, at least temporarily (months to a few years following the intervention), and intermediate costs for intervention. The drawbacks are that attacks and damages can only be reduced and delayed but rarely eliminated, and additional costs for visual or remote-sense detection of the termite mounds surrounding cable burial areas since a suitable place to begin the new colony will be again colonized in the future by other flying funder royal couples, thus repeating the problem [20]. In addition, ecological damage to the local environment and biodiversity are possible.

*The massive use of insecticide chemicals* (e.g., Cypermethrin) in the soil surrounding underground cable sites is possible. The solution provides discreet (although not complete) short-term chemical protection against the termites’ attacks and low to intermediate costs for intervention. However, due to the chemicals’ dilution during rainy seasons, interventions must be repeated frequently, with additional and repeated costs. They provide severe and hardly acceptable ecological damages to the local environment and biodiversity (chiefly ground, ground waters, and running waters; most insecticides kill beneficial insects, and the targeted insects and fishes seem to be highly susceptible). Additionally, insects frequently

exposed have quickly developed resistance to Cypermethrin and other chemical insecticides, often rendering the solution ineffective.

Another solution is moving and laying the cables to a greater depth (1.5-2 meters) in the ground, significantly decreasing the possibility of meeting the potential feed tunnels of the local termites. The solution dramatically reduces the potential attacks, but higher costs are necessary for cable laying and future repair and maintenance.

A last solution is moving and laying the cables above the ground surface, thus nearly nullifying the possibility of underground attacks by local termites. The solution provides an almost complete reduction of the potential attacks. However, cables would be exposed to sunlight and atmospheric agents, as well as to possible acts of vandalism or exploring activities by rodents and other mammals, generating further repair and maintenance problems. Furthermore, with high costs, it is necessary to have a cover from all sides with prefabricated concrete during the cable laying, creating an additional protective hard sheath that covers and surrounds the cables' driver portion and their outer plastic sheath.

### C. Integrative or alternative proposals

Among those listed above, the second solution is likely the best now available. However, costs could be prohibitive in the current economic scenario and generate problems for future repair and maintenance. The third solution represents a perfect compromise. However, the best solution, according to the authors, once the costs and technical feasibility have been assessed in detail, could be the use of industrially already available electric cables protected by an additional sheath of Nylon-12 or PPA (Polyphthalamide) reinforced by 30-45% glass fiber or carbon fiber before they are laid. The advantages are the total or almost complete reduction of potential termite attacks and, therefore, of subsequent repair and maintenance costs. The drawback is that these cables exhibit higher costs when compared to the cost of regular electrical cables.

A similar solution that is already industrially available and originally designed to protect underground optic fiber cables from small rodents could be using protective socks made of glass fiber for underground cables, which are functional in preventing rodent attacks. However, their actual level of protection against termites still needs to be explored and verified.

A good integrated solution to the present-day problems occurring at Complexo Fotovoltaico São Gonçalo – Piauí (see Fig. 2) could likely be a combination (chosen by the client based on economic cost assessments) of relatively low-cost differentiated actions, as follows:

- Accurate identification of the precise points where termite attacks occurred along the entire path of the underground cables.
- Carrying out environmental photos of the points thus detected to verify the possible presence of trees, trunks, stumps, or clusters of roots within a radius of about 100 m from the cables themselves.

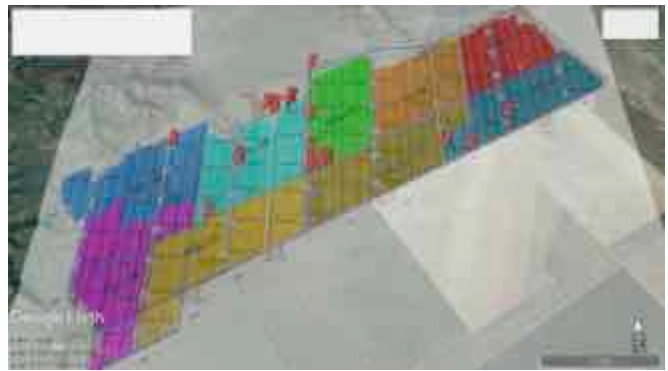


Fig. 2. Distribution of the attacks of the subterranean termites (*Coptotermes testaceus*) in Complexo Fotovoltaico São Gonçalo – Piauí.

- Ensure that all inspection wells near the termite attack points are carefully monitored along the cables to identify possible direct access points to the cable path or alternative nesting sites within the same inspection wells. If this is verified, use insecticides such as permethrin/Cypermethrin in the wells and seal them thoroughly from each side. Accurate sealing of all inspection wells should eliminate possible access points to the cable by termites or new nesting points within the same inspection wells.
- Mechanical removal of all possible woody material and termite nests present around the precise points where termite attacks occurred (as well as alternative artificial subterranean cavities) to prevent further damages and avoid further colonization by new founder termites.
- Protect only the sections of underground cables closest to residual forest areas and trees, isolated stumps, or wooden artifacts with single-layer tapes of fiberglass or carbon fiber (at least of hard nylon) or with protective socks made of glass fiber.
- Moving and laying the underground cables to greater depth (1.5-2 meters) in the ground, at least for the sections of cables closest to residual forest areas and trees or isolated stumps.
- Provide for installing several “termite traps,” already commercially available, which allow periodic monitoring of the presence of termites in the vicinity of the cables.

### D. Actions for termite attack prevention

Preliminary investigations need to be carried out on the areas in which future projects involving underground cables are foreseen to ascertain the possible or likely presence of termites in the subsoil. The presence of nesting subterranean termites can be documented in various and combined ways, including visual seeking by expert entomologists or experienced exterminator technicians around trees or wooden artifacts, the use of thermal scanners mounted on drones, or the use of specifically trained “molecular dogs” (“sniffer dogs”), able to quickly detect possible termite crowding in the subsoils, as well as in the case of several other insect taxa with conservation concern or known as pests [21]–[23].

Due to termites' nearly worldwide distribution [8], [9], [19], attacks are more likely in areas with higher termite biodi-



(a) Global pattern of termite species richness - Circles and colors indicate the number of species in each plot



(b) Global pattern of termite genera composition. Plots with similar colors share a higher proportion of species

Fig. 3. Global patterns of termite biodiversity (data from [21]).

versity, including (in relative order of importance, mainly for the presence of several subterranean termite species) tropical and subtropical South America, southern North America and Central America, southern Asia and the whole Tropical and subtropical Asia, Australia, and Southern, Central, and Eastern Africa (see Fig.3). More detailed information on global termite biodiversity patterns can be found in [8], [9], [19].

Once the actual or very probable presence of termites (mainly subterranean termites) has been documented, it will be avoided, as far as possible, to bury electrical cables in the vicinity (<100 m) of forest area residues, isolated trees, partially buried stumps in the ground, wooden artifacts, or small artificial cavities (e.g., galleries, already existing and abandoned inspection wells). In such cases, however, the cables should be buried at a depth of  $1.5 \div 2$  meters, and/or it is recommended the use of cables already available from the industry, including a protective hard nylon (e.g., nylon-12) sheath, better if reinforced by good percentages (30-45%) of glass fiber or carbon fiber.

### III. ELECTRICAL ENGINEERING ASPECTS

#### A. Brazilian project overview: electrical design

The analyzed Brazilian project consists of three large-scale photovoltaic fields that convey the produced electric energy to one substation connected to the 500 kV grid. The total rated capacity is several hundreds of megawatts. The first two fields are in operation; the third is under construction.

The internal collection system of each photovoltaic field consists of an MV underground network composed of three single core cables, U0/U= 20/35 kV, manufacturer General Cable do Brasil (Prysmian Group), model FOREX AL BCC PE. Figure 4 shows the cable dissection view. It is possible to detect every part: core conductor (note the purchased cable



Fig. 4. MV cable dissection view.

has an aluminum core conductor instead of the copper conductor shown in the picture); semi-conductive screen; XLPE insulation; semi-conductive screen and concentric neutral; polyethylene (PE) jacket.

In each photovoltaic field, the total lengths of the cable paths are the following:

- 500 mm<sup>2</sup> single core cable: several dozens of kilometers.
- 400 mm<sup>2</sup> single core cable: a few dozens of kilometers.
- 185 mm<sup>2</sup> single core cable: few kilometers.

The rated voltage/frequency of the collection system is 34.5 kV/60 Hz. The three-phase system is grounded through a resistor limiting the single phase-to-ground short circuit current within 800 A. Several clusters compose each field: each cluster is protected against a single phase-to-ground short circuit by a protective device (multifunction protection), ensuring fault clearance in a few hundreds of milliseconds.

#### B. Termite attacks and fault development

Figure 5 represents the termite attacks and the consequent fault development. Termites bite the jacket's external surface (its thickness is 2.4 mm only), concentrating the attack on a small area until it is completely perforated. They cross the space between the copper wires of the concentric neutral, piercing the semi-conductive screen and the XLPE insulation. Soil dust and humidity pollute this hole, triggering partial discharge phenomena up to the final breakdown in the short to medium term (some days – weeks).

#### C. Actions and remedies in the short-term

1) *Tests:* To prevent faults, an immediate action is to carry out diagnostic electrical tests in the field. These tests aim to detect any weak point along each cable [24]–[26]. Each weak point due to a termite attack should introduce a low insulation resistance on the jacket and the XLPE insulation if the termite has pierced the cable deeply.

A fast and low-cost method is the “Direct Current (DC) under voltage test” to be carried out both on the jacket and the XLPE insulation. This test measures the jacket's Insulation Resistance (IR) and the XLPE insulation. These measurements can be performed using an advanced insulation tester, e.g., a high-performance digital megohmmeter.

The leading international standardization organizations have yet to issue a standard for DC undervoltage tests on MV cables, e.g., IR measurement on XLPE primary insulation of cables. However, in recent years, several utilities have performed insulation assessments of MV cables using the methods provided by IEEE Std. 43-2013 [27].



Fig. 5. MV cable attacked by termites..

Considering that the IR measurement strongly depends on the environmental temperature, a good assessment of the XLPE main insulation of cables can be performed using the following methods derived from the above IEEE standard. These methods – i.e., Polarization Index (PI) and Dielectric Absorption Ratio (DAR) measurement – involve measuring successive IR values at specified times. Being the IR influenced by environmental temperature, these procedures are not significantly affected by temperature, allowing them to be applied without the need for result corrections, provided that the test equipment remains stable during the test.

A third method, i.e., Dielectric Discharge (DD) measurement, completes the insulation assessment. Electricité de France developed this method after years of research and testing in the field. While PI and DAR tests measure the currents flowing during the charging process (from an electrical point of view, an MV cable is a capacitor having very little conductance), the DD test measures the current flowing during the discharge process.

## 2) Cable repairs:

*a) Jacket repairs:* Termite-related outages can range from brief disruptions to prolonged service interruptions, which can also affect the transmission network. Substantial sections of photovoltaic facilities may need to be connected to the grid. Aside from the annoyance and maintenance expenses, there is a risk of revenue loss until service is restored. Many termite-related failures initially manifest as phase-to-ground faults and may escalate into phase-to-phase faults.

Therefore, it is essential to determine the corrective actions. The repair method can provide advanced notice, allowing for more freedom in choosing whether to start repairs right once, postpone them for a later time, or schedule to replace the cables. If the fault is precisely identified and confined to the outer sheath, it can be exposed for repair promptly. Promptly repairing the cable circuit is crucial since a faulted distribution cable results in part of the plant being out of service.

A possible solution could be to use heat-shrinkable wraparound insulating tubing or tap, mainly used for repairing the outer/inner sheath of cables [28], [29]. They also provide corrosion protection to the metallic parts of the cables exposed to a polluted environment. Anyway, the behavior of these components against termite attacks has never been investigated. Since the components have been conceived as wraparound sheets to repair the cable jackets, ensuring mechanical and electrical characteristics similar to the original ones of the cable, we assume that they cannot provide any additional protection against termites' attacks. Wraparound sleeves available for purchase are constructed from thermally stabilized, cross-linked, weather-resistant, halogen-free polymeric material. The sleeves have an interior coating of hot melt glue. Thermochromic paint is applied to the exterior of the sleeves.

*b) XLPE insulation repairs:* Splicing is usually avoided whenever possible; however, when the cable is essentially damaged, there could be a reason for building splices. The option is to either splice the cable or replace the entire length.

A splice refers to the joining of two or more conductors

using an appropriate connector, followed by re-insulation, re-shielding, and re-jacketing with compatible materials, all applied over a suitably prepared surface. It is recommended that splices match the rating of the cable to prevent them from reducing the cable's capacity and becoming the system's weakest point. The steps for building a splice are preparing the surface, joining conductors with connector(s), re-insulating, re-shielding, and re-jacketing.

### 3) Improvements:

a) *MV cables with Nylon termite proof jacket:* Incredible amounts of science and engineering have been involved in developing ways to protect cables from termite attacks, but these are rarely communicated to the electrical industry. Initially, efforts to prevent termite attacks included injecting soil surrounding cables with insecticide-containing substances such as DDT, Lindane, Aldrin, and Dieldrin. Nevertheless, because of the detrimental impacts of environmental pollution and the potential health hazards to workers, this activity was prohibited in numerous nations.

Research conducted by research institutes and cable industries has revealed that Nylon-12 is highly resistant to termite attacks. In some locations, including Australia, it became common practice to extrude Nylon-12 jackets over polyethylene (PE) cable sheathing. The economic viability of nylon-jacketed cable was compromised by the costs of raw materials and additional processing, which negatively impacted its overall performance. Insecticide-containing cable sheathing compounds, specifically Sevin and Lindane, were produced as substitutes for nylon. Although these poisons effectively killed termites, repeated attacks by other colony members led to premature cable failure. Additional joint research improved the termite resistance of nylon and found more cost-effective polymers with similar insect-repelling properties. Nylons 11 and 12 were shown to possess distinctive combinations of characteristics, including hardness, smooth surface finish, and flexibility. No plastic materials were found to have termite resistance similar to nylon and be flexible enough for use as cable-sheathing materials, as indicated by the research.

Where a nylon jacket is specified for insect protection, an LLDPE sheath (color orange) shall be applied over the cable core. The nylon jacket shall consist of continuously UV-stabilized black nylon (usually polyamide 12) with a radial thickness of not less than 0.8 mm. It must have a smooth, glossy surface, free from defects or scratches. There are eight types of nylons: Nylon 6; Nylon 6.6; Nylon 4.6; Nylon 6.9; Nylon 6.10; Nylon 6.12; Nylon 11; and Nylon 12. Nylon 12 is a polymer with the formula  $[(CH_2)_{11}C(O)NH]_n$ . Nylon-12 mechanical properties, such as hardness, tensile strength, and abrasion resistance, are similar to those of metallic materials known to resist termite attacks and stronger than widely used and low-cost plastic materials used to protect electric cables buried in the soil, such as standard PE (polyethylene). Additionally, all nylons (polyamide) can be reinforced with glass beads and carbon fibers to improve their mechanical and thermal performance.

Hardness tests based on the Rockwell scale (the Rockwell scale is a hardness scale based on the indentation hardness of a material, i.e., it determines the resistance to indentation

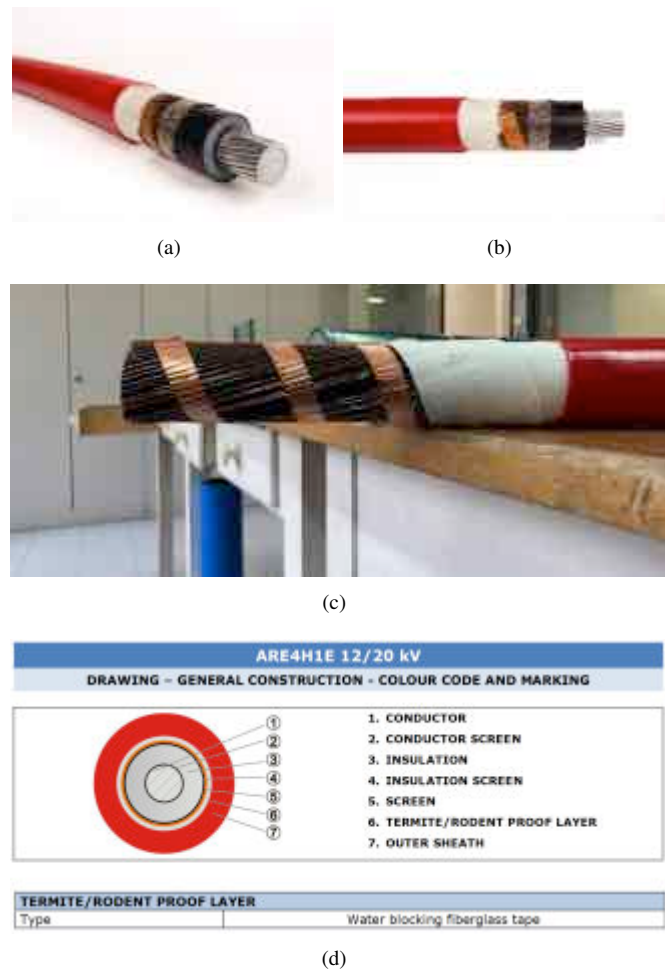


Fig. 6. MV cable with termite/rodent-proof fiberglass sheath (courtesy of Tratos).

a given material can withstand) showed that among plastic materials, the highest hardness values were obtained for PPA (Polyphthalamide reinforced by 45% glass fiber), with values around 124,000/126,000.

Nylon plastics display variable hardness, ranging from a maximum of ca. 115,000 (Nylon-12, or Nylon-6 graphite-filled or Kevlar-reinforced) to a minimum of ca. 80,000 (Nylon 6.6). The highest Nylon-12 values guarantee the best resistance to termite attacks.

### b) *MV cables with Fiberglass termite proof jacket:*

According to previous observations, Tratos has developed a new MV cable with a termite/rodent-proof fiberglass sheath (Fig. 6). As reported in Fig. 6, the cable presents the standard structure of MV cables with the addition of a termite/rodent-proof fiberglass layer. The layer is made with a double-stitched fiberglass water-blocking tape. Both tapes are made of fiberglass yarns, 272 Tex in weft (transverse yarns) and 136 Tex glass yarn used in warp (longitudinal yarns). Once the tapes have been weaved and coated with super-absorbent polymer, they are stitched together. The weight percentage of glass fiber in the tape is  $>60\%$ . Due to the presence of the super absorbent polymer, the tape also has hygro-expanding properties to prevent the passage of water (absorption capacity:

250%).

#### IV. CONCLUSIONS

The paper discusses the problem of damage due to termites in buried lines, which are usually installed in utility-scale photovoltaic plants. The insulation damages and out-of-service due to the insulation breakdowns are identified in a real case plant in Brasil. The tests needed to identify the point of failure are discussed, and possible remedies are proposed. With the contribution of Tratos, a reinforced MV cable with a termite/rodent-proof layer made of fiberglass has been conceived and produced and is now under test in the photovoltaic plant, with satisfactory results.

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