10776 Session 2022
B2 OVERHEAD LINES
PS3 - Environmental and Safety Aspects from OHL

Refurbishment of sectionalizing posts on 245 kV towers for a reduced visual impact and an increased line resilience

Andrea VALANT, Dario POLINELLI, Francesco PALONE(*), Luca BUONO, Roberto SPEZIE

Terna S.p.A.
Italy
andrea.valant@terna.it, dario.polinelli@terna.it, (*)francesco.palone@terna.it, luca.buono@terna.it, roberto.spezie@terna.it

SUMMARY

Pylon-installed disconnectors are typically used on medium and low voltage levels for improving the operational flexibility of distribution networks. These pole-mounted switches are also present in some HV sub-transmission and EHV transmission backbones; on the Italian Transmission Network for instance, they have been installed on tapped lines, mostly before the standardization and nationalization process in the 60's, to allow to disconnect power plants (for instance on hydro-electric backbones) or users for maintenance purpose.
Those disconnectors are typically manually operated; neither a power source nor a telecommunication channel are present on the sectionalizing posts, which are often located in remote areas such as mountain environments.
The ageing of such equipment, as well as more challenging requirements in terms of grid flexibility, prompt the need for new and more resilient solutions. Considering these requirements, the Italian TSO Terna has developed a new concept for a pylon-installed switching equipment, called OMP (i.e. "Organo di Manovra su Palo" meaning "Pole-mounted Switchgear").
The aim of the OMP is to transform the sectionalizing posts into independent switching substations, equipped with circuit breakers, disconnectors, measurement transformers, protection relays, telecommunication systems and station service transformers. In practice, the replacement of the existing disconnectors with OMPs will allow the same operational flexibility of a normal single busbar substation. On top of that, this Terna patented solution can use standard SF_6 equipment and protection systems, so that a multi-vendor approach is possible.
The installation of circuit breakers and protection relays allows for the prompt identification and disconnection of the faulted line section only, leading to substantial advantages in terms of security and continuity of supply for the loads and to a better exploitation of the renewable resources connected to the HV transmission grid through "T" junctions.
Resilience to the very challenging environmental conditions (low temperatures, snow, ice) and reduced visual impact were the two main drivers for the development of the project.
As a first step, new dead-end towers were designed, with reduced visual impact and the very same footprint of existing pylons. The design of the new towers allows for the installation of a SF_6-insulated

switching equipment directly on the trellis, within the volume of the top hamper, and for mounting protection relays and auxiliary systems still on the tower, at a lower height.
A safe and easy access to all equipment is ensured by means of ladders, rails and fall arresters, allowing for a safe operation and maintenance. Proper selection of clearance distances and a dedicated grounding system design enable a safe operation of the OMP.
The paper deals with Terna's OMP project. In particular, it describes the motivations of the project; the design of the new dead-end pylon, including the clearance calculation for the HV SF_6 insulated equipment and the installation of the first OMP units in a challenging alpine environment, with a specific focus on the construction method sand the grounding system.

KEYWORDS
Overhead lines, Environmental impact, Resilience, Grid flexibility, Pole-Mounted Switchgear, Tapped Lines.

I. INTRODUCTION

According to Europe agreements regarding climate change and environmental impact, an economy with net-zero greenhouse gas emissions is expected by 2050 [1]; the energy transition aiming to fulfil Europe requirements will involve both Transmission and Distribution System Operators. An increase of connection requests for renewable energy resources and more challenging consumption profiles are expected. To face up the future challenging of Italian network, Terna detects an innovative technical solution for user connections, able to guarantee high flexibility and smooth insertion in the environment. The Italian HV Transmission System presents several T-junctions for user connections, typically for rated voltage between 132 kV and 150 kV (see Figure 1). A more resilient and flexible solution, called in-out connection, is instead reported in Figure 2, able to ensure power supply in case of maintenance or faults on electric backbone [2].

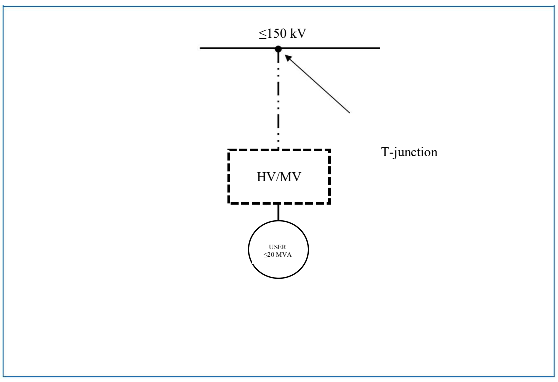

Figure 1 – Example of HV Network T-junction.

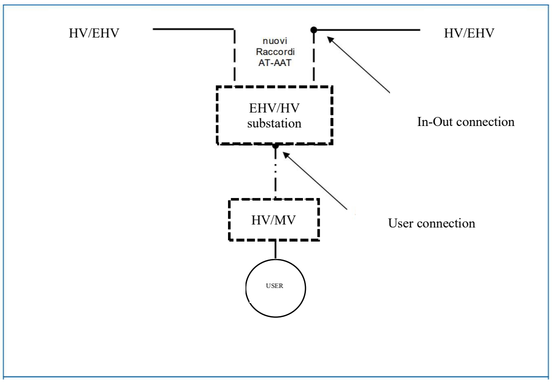

Figure 2 – Example of HV Network In-Out connection.

T-junctions were manly adopted from the second post-war period to the 1970s to connect quickly and with lower costs both traditional power plants and users. In order to ease the grid reconfiguration, T-junctions were sometimes provided with disconnectors equipped pylons, as reported in Figure 3. Manual handling disconnectors ensured a faster power supply restoration in case of maintenance or faults.

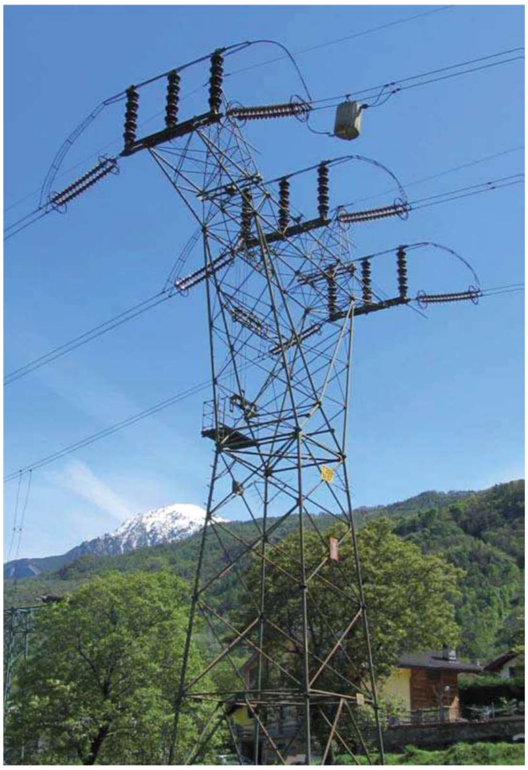
Figure 3 – Typical disconnectors installed on 220 kV "Delta" tower.

In order to simplify and speed the operation of traditional connections based on pylon-installed disconnectors up, a feasibility investigation was carried out by Terna aiming at installing HV SF6 insulated equipment on towers; the single line diagram reported in Figure 4 evidences a paramount challenging: equipment (i.e., disconnectors, circuit breakers, current and voltage transformers) and protection and control systems are installed inside the tower hamper (see Figure 5 and Figure 6, respectively), giving place to a trellis-mounted Gas Insulated Substation (GIS). An inductive voltage transformer is equipped with two winding both for protection and auxiliary system supply; a further voltage transformer is installed on the central pole to ensure a synchronized manoeuvre of circuit breakers.
The Telecommunication, Control and Protection System (TCPS) is supplied by the inductive transformer, enabling remote control by the dispatching centre. TCPS is installed inside a dedicated shelter of 9 m2 located below the SF6 insulated equipment as reported in the following Sections. In order to reduce the visual impact of the OMP tower, the shelter has been painted with an innovative camouflage as visible in Figure 6, registered at the European Intellectual Property Office EUIPO.
As visible in Figure 7, in case of fault or maintenance of the GIS equipment, the transmission line can be operated in an "emergency" mode after disconnecting the GIS equipment and installing a bypass to guarantee the HV backbone continuity.

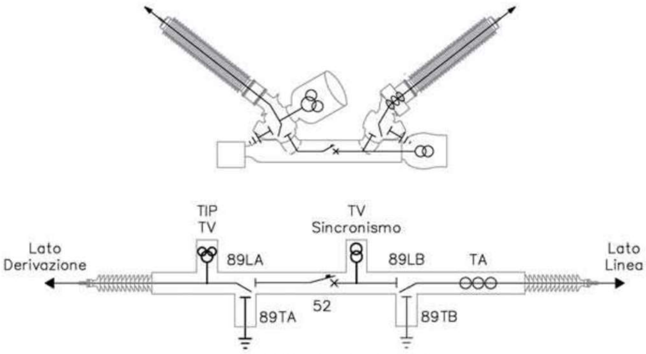

Figure 4 – Single line diagram.


Figure 5 – HV SF_6 insulated equipment on tower.

Figure 6 – Shelter camouflage.


Figure 7 – OMP arrangements (bypass mode) in case of fault or maintenance.

The main advantages of the proposed solution are related to flexibility and maintainability; indeed, circuit breakers in concert with the protection and telecontrol systems allow a quick and safe network reconfiguration both in case of fault and normal operation [3]. If two OMPs are installed on the HV backbones close to the T-junction (Figure *8*), scheduled maintenances on HV backbone branches can be carried out without interrupting user energy supply. Furthermore, in case of fault between one terminal substation and the OMP, circuit breakers will be able to isolate the faulted branch, as reported in Figure 8 with no interruption to the user supply thanks to its continuous connection to the other terminal substation. The increasing of power supply continuity and power quality related to the OMP solution will decrease user damage risk and TSO penalties according to national power quality regulation [4]. The main advantages of OMP solutions compared to pylon-installed disconnectors are reported in Table I.

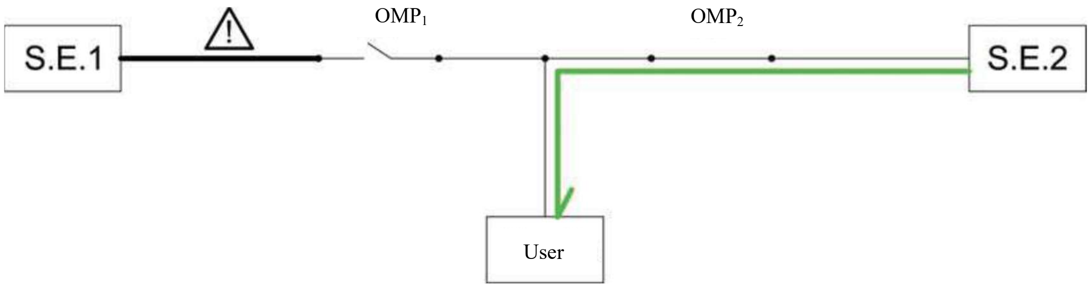

Figure 8 – Example of circuit breaker OMP arrangement after a fault between one terminal substation (i.e. SE1) and OMP (D1).

Scheduled maintenance	Fault on backbone
Time response.	Automatic fault detection.
Network flexibility.	Higher power supply continuity.
Power supply continuity.	Lower user economic losses.
Scheduled maintenance independent from users.	Lower TSO penalties according to power quality regulation.
Increased RES production.	Increased RES production.

Table I – Main advantages of OMP solution compared to pylon-installed disconnectors.

II. DESIGN CRITERIA

In order to minimize possible technological risk, Terna has started from standard HV SF6 insulated equipment available in supplier catalogues, to adapt layout and line diagram for trellis installation. For instance, double wounding inductive voltage transformers have been installed on each phase and the length and orientation of each pole have been studied to fit the tower top hamper. Concerning the electrical parameters, Table II reports the specifications for the first Terna installation on a 220 kV HV Overhead Line. GIS equipment before installation is reported in Figure 9.

If compared to GIS substation, SF6 insulated equipment connected directly to phase conductors of an Overhead Line has high risk to be stressed by transient overvoltages due to shielding failure back-flashover rate [5]; therefore, to guarantee a safe operation of the GIS equipment, surge arresters are installed between phase conductors and equipment bushing terminals at both ends as reported in Figure 10 and Figure 11 [6]. Transient lightning simulations have been performed in ATP-EMTP to estimate the expected overvoltages considering two possible grounding connection of surge arresters:

- directly on the top of tower structure;
- with a dedicated 120 mm2 grounding conductor, connected to the tower grounding system.

Detailed tower and grounding system models for transient studies have been developed to take into account the effect of reflection and attenuation of transient overvoltage. According to the consideration above, simulation results evidence that, although both grounding arrangements ensure safe operation of equipment, lower overvoltages are expected if grounding connection of surge arresters is realized directly on the top of tower structure.

Figure 9 – HV SF_6 insulated equipment before installation.

Rated voltage:	220 kV
Maximum continuous operating voltage:	245 kV
Power Frequency:	50 Hz
Rated current:	4 kA
Rated Breaking Current:	50 kA
Rated power frequency withstand voltage:	460 kV
Lightning impulse withstand level (LIWL):	1050 kV

Table II – Main characteristics of HV SF_6 insulated equipment used for the OMP prototype.

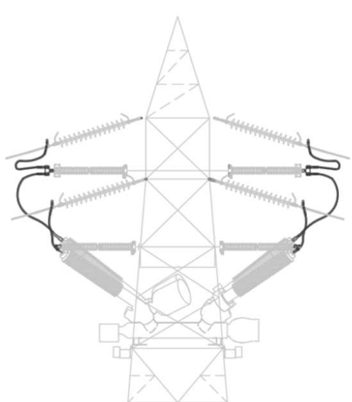

Figure 10 – OMP line surge arresters (lateral profile).

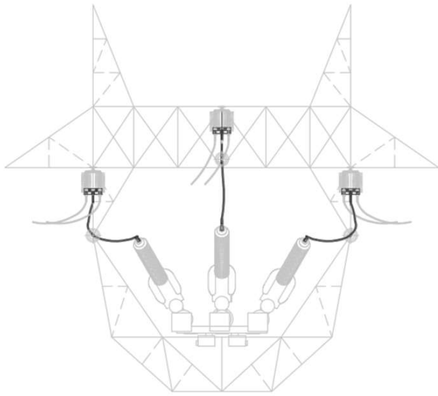

Figure 11 – OMP line surge arresters (front profile).

As reported in previous Section, OMP is provided with both equipment and auxiliary systems for protection and control purposes; three phase line diagram of OMP low voltage section is reported in Figure 12.

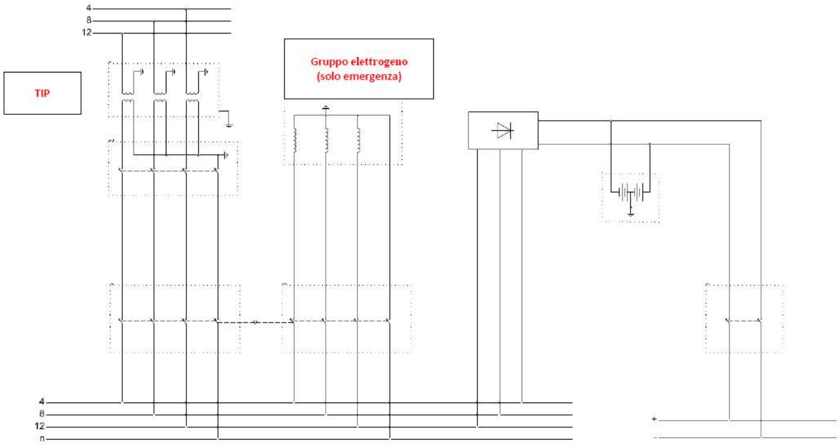

Figure 12 – Three phase line diagram of OMP low voltage section.

According to ITU-T K.97 [7], equipotential connections must be guaranteed in order to ensure lower insulation stress in case of overvoltages related to lightining currents flowing along the OHL tower. Therefore, AC/DC low voltage cable screens and conductive mass have been connected to tower grounding system.

III. FIRST OMP INSTALLATION

The first two OMPs were installed along a 220 kV OHL in Aosta Valley located in North-West of Italy (Figure 13) as replacements of existing towers equipped with standard air insulated disconnectors as shown in Figure 3. The aim was to increase the flexibility of the OHL and ease maintenance planning by decoupling it with the users maintenance schedule.

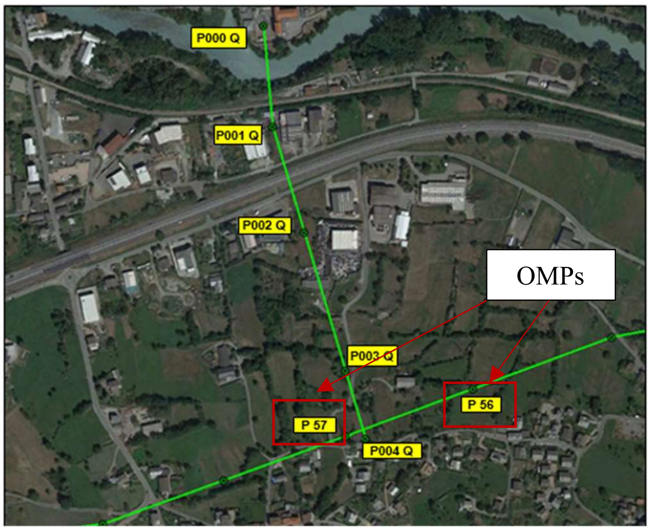

Figure 13 – First installation of 220 kV OMPs between Chatillon and Villeneuve substations.

Environmental impact has been analysed by Terna to identify the best technical solution for the T-junction refurbishment. The OMP layout ensures a substantial invariance in magnetic and electric field emissions even if compared to standard 220 kV triangular configuration Terna towers.
In terms of footprint, two alternative gas insulated substations are compared to the OMP solution in Figure 14; the installation of the OMP ensures a 97% footprint reduction with respect to the smallest ground-located solution of Figure 14b.

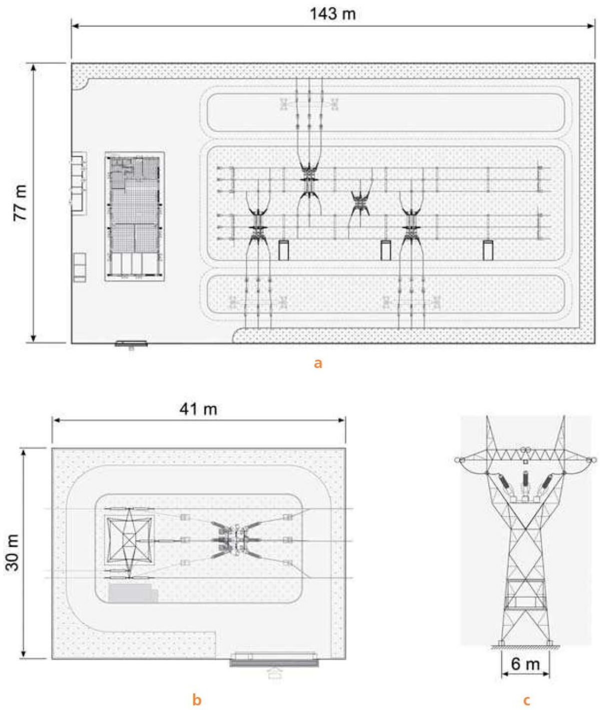

Figure 14 – Footprint comparison between a) GIS substation, b) ground-installed GIS near to tower and c) OMP solution.

Due to vibration generated by the circuit breaker switching on/off, the OMP equipment results to be a sound source during maneuvres. Moreover, the tower could become an acoustic amplifier as a result of the higher external surface. In order to mitigate noise generation and mechanical stress to the tower, vibration dampers have been installed at the interface between equipment and tower as reported in Figure 15. A further mitigation arrangment, based on noise insulation passive shields, has been installed on the circuit breaker command cubicle as visible in Figure 16.

Figure 15 – Vibration dampers.

Figure 16 – Noise insulation passive shields mounted on the circuit breaker command cubicle.

IV. GROUNDING SYSTEM

The installation of equipment on the tower requires the grounding system to be designed according to the CEI EN 50522 standard [8]; due to the expected high short circuit current, touch voltage requirements dictate the grounding system design. Therefore, the maximum expected touch voltage near conductive mass must be lower than permissible one, according to fault time duration. Considering a 0.5 s fault time clearing, the permissible touch voltage results to be 220 V.

Soil resistivity measurements have been carried out near each OMP tower, showing an average soil resistivity of 500 Ωm; therefore, the grounding system topology has been defined according to Terna grounding system standardization [9]. The expected grounding resistance is equal to 5 Ω. Simulation results are reported in Figure 17, considering a grounding current equal to 2800 A.

The use of micropoles ensures high power frequency and impulse performances; according to Terna grounding system design, the covering of micropoles is realized with a low resistivity compound of marconite, bentonite and concrete, increasing the equivalent surface and, therefore, reducing the expected grounding resistance.

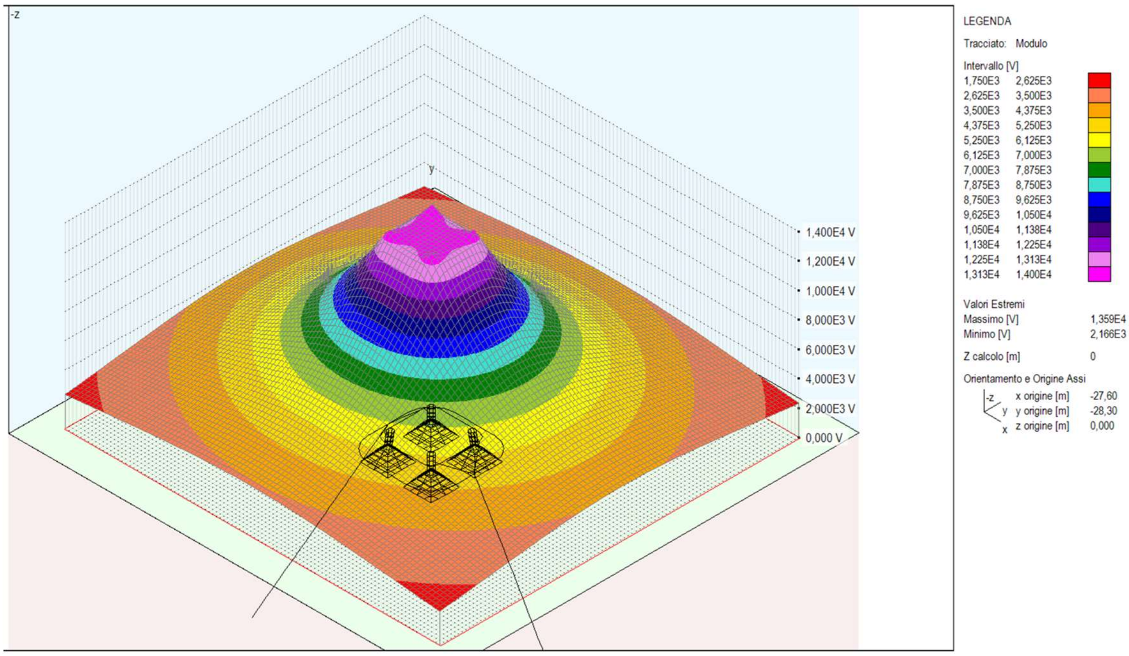

Figure 17 – Ground potential.

V. CONCLUSIONS

In order to face future challenges in power transmission system related to renewable energy sources spread and fast changing load consumption profiles, higher flexibility and availability must be guaranteed to existing and new HV connections.

In this scenario, Terna has developed a new concept for a pylon-installed switching equipment, called OMP. Based mainly on the adaptation of standard HV SF_6 insulated equipment, the OMP ensures higher operational standards, both in normal conditions and in case of fault on power transmission backbones. Higher flexibility is ensured by the installation of a remote-control system, supplied by inductive transformer; therefore, OMP circuit breaker con be remotely operated by Dispatching Centre for maintenance purpose. On top of that, the protection system installed on the OMP ensures a coordinate intervention of the OMPs and terminal Substations to guarantee fast and selective fault extinction.

As the GIS equipment bushing terminals are connected directly to the conductor phases of the OHL, higher insulating stresses are expected if compared to equipment installed in substations. A detailed insulation coordination design has been performed; surge arresters have been installed on the OMP tower on both ends of the SF6 equipment to ensure a safe operation. Surge arresters are installed on the low voltage side to protect distribution circuits from lightning overvoltages. An innovative grounding system, with a low earth resistance, has been defined by Terna according to soil resistivity measurement, ground lightning density and tower height.

OMP tower has lower environmental impact both in term of footprint and magnetic and electric fields if compared to standard Terna solutions for improving T-junction flexibility. Furthermore, the shelter installed on OMP tower has been painted with an innovative camouflage, reducing the visual interference of OMP tower.

BIBLIOGRAPHY

[1] European Commission, “2050 long-term strategy”, link: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy_en.

[2] Italian Grid Code, “The Transmission, Dispatching, Development and Grid Security Code governs the procedures which Terna must adopt in relationships with grid users”, link: https://www.terna.it/en/electric-system/grid-codes/italian-grid-code.

[3] R. Spezie, D. Polinelli, A. Valant, F. Palone, M. Carbone, “Organo di Manovra su Palo: una soluzione per aumentare la flessibilità della RTN”, L’Energia Elettrica, 2021.

[4] Regolazione individuale delle microinterruzioni per i clienti finali in alta e altissima tensione, 2020, [online] Available: https://www.arera.it/it/docs/20/524-20.htm.

[5] F. M. Gatta, A. Geri, S. Lauria, M. Maccioni and F. Palone, "Lightning Performance Evaluation of Italian 150 kV Sub-Transmission Lines," 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2019, pp. 1-7, doi: 10.1109/EEEIC.2019.8783851.

[6] F. M. Gatta, A. Geri, S. Lauria, M. Maccioni and F. Palone, "Tower Grounding Improvement Versus Line Surge Arresters: Comparison of Remedial Measures for High-BFOR Subtransmission Lines," in IEEE Transactions on Industry Applications, vol. 51, no. 6, pp. 4952-4960, Nov.-Dec. 2015, doi: 10.1109/TIA.2015.2448613.

[7] ITU-T K.97:2014, “Lightning protection of distributed base stations”.

[8] CEI EN 50522:2011, “Earthing of power installations exceeding 1 kV a.c.”.

[9] F. Palone, L. Buono and R. Spezie, "New grounding systems for enhancing OHL performances and reducing environmental impact," 2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2021, pp. 1-6, doi: 10.1109/EEEIC/ICPSEurope51590.2021.9584763.