Med-TSO
TeasiMed2 project

Workshop Report

"Resilient Grids in the Mediterranean - Mitigating Climate Risks in Electricity Infrastructure"

Co-funded by the European Union

Abstract

This report gives an overview of the Workshop organised by Med-TSO "Resilient Grids in the Mediterranean – Mitigating Climate Risks in Electricity Infrastructure" at the TERNA Academy in Rome on 12 June 2024.

This event addressed the growing challenges posed by climate change and extreme weather events on electricity infrastructure, bringing together experts from Med-TSO members to share knowledge and discuss practical solutions.

Acknowledgements

Med-TSO acknowledges the participating Members of the Association for their substantial contributions to the workshop "Resilient Grids in the Mediterranean."

Particular thanks to TERNA, whose role in hosting the event and presenting innovative resilience strategies was instrumental. The insights and case studies provided by RTE (France), IPTO (Greece), and ELES (Slovenia) significantly enriched the discussions.

The collaborative efforts and shared expertise of these TSOs were crucial in addressing the discussion about climate-related challenges to electricity infrastructure.

Finally, we thank all the participants for their active contribution to the event.

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Abbreviation list

- TSO: Transmission System Operator
- DLR: Dynamic Line Rating
- LSA: Line Surge Arresters
- NTC: Net Transfer Capacity
- PPRI: Flood Risk Prevention Plans
- REGULATION (EU) 2019/941: Regulation of the European Parliament and of the Council on risk-preparedness in the electricity sector

1. Executive Summary

The Mediterranean region is one of the most vulnerable areas in the world to the impacts of climate change, experiencing a significant rise in temperatures, increased frequency of extreme weather events, and shifts in precipitation patterns.

These climatic changes pose serious threats to the power systems in the area. As temperatures rise and weather patterns become more erratic, the resilience of electricity infrastructure is increasingly tested.

The power grids in the region face heightened risks from heat waves, droughts, and intense storms, which can lead to widespread disruptions of electricity supply. Furthermore, the accelerated development of renewable energy sources adds complexity to the management of the grid, due to weather-dependent nature of RES. Ensuring the reliability and stability of power systems in the Mediterranean under these changing conditions requires robust strategies and collaborative efforts focused on enhancing grid resilience and mitigating climate risks.

Starting from this context, the Association   organised a workshop in the frame of TEASIMED 2 project to explore the climate-related threats to power system operation and the adaptation and mitigation strategies that TSOs can put in action.

The workshop. titled "Resilient Grids in the Mediterranean" and held on June 12, 2024 in Rome, Italy, was the kick-off of the activities promoted by the Association to address the issue of electricity infrastructure resilience in the Mediterranean region. The primary objective of the workshop was to identify, assess, and develop strategies to mitigate the risks associated to climate change, thereby enhancing the resilience of power grids. This event was hosted by TERNA, the Italian electricity transmission system operator, bringing in Rome experts and stakeholders from various Mediterranean countries.

The workshop featured three main sessions, each focusing on different aspects of resilience in power grids. The first session aimed to provide participants with a common background understanding of climate change, including tools and data used to assess its impact on the electricity infrastructure. This session included case studies from France, Slovenia, Italy, and Greece, highlighting specific climate-related threats, such as storms, extreme heat waves, wildfires, flooding, landslides, and icing.

The second session was dedicated to TERNA's innovative approach for increasing the resilience of power grids against climate change. This session introduced a new probabilistic risk-based methodology developed by TERNA to assess and improve the resilience of power systems. This methodology involves the use of specific climatological models, vulnerability assessments, and contingency analysis to evaluate and enhance the resilience of grid infrastructure.

The third and final session explored various adaptation strategies implemented by transmission system operators (TSOs) to build more resilient power systems in response to climate-related threats. This session covered the influence of climate change on grid design, maintenance, and operation, with contributions from experts representing different TSOs.

The workshop provided a platform for sharing knowledge and discussing practical solutions to enhance the resilience of power grids in the Mediterranean region. It aimed to foster collaboration and exchange of best practices among TSOs, supporting the development of robust strategies to safeguard electricity infrastructure against the adverse effects of climate change.

2. Session 1 – Understanding Climate Change and its threats to the Electricity Infrastructures

The first session aimed to provide insights into the ongoing and future impacts of climate change on power systems and to discuss methodologies for integrating climate data into power system studies.

2.1. Understanding climate change and how to take it into account in power system studies?

The opening of the Session was presented by Laurent Dubus from RTE (France) that is also the convener of the Expert Team Climate at ENTSO-E

Current Climate Trends and Causes

Global temperatures have shown a significant upward trend over the past 140 years. This increase is intricately linked with the frequency and intensity of natural disasters. Historical data and climate models indicate a direct correlation between rising global temperatures and the occurrence of extreme weather events.

Human activities, particularly the emission of greenhouse gases, are the primary drivers of climate change. The main symptoms of these changes include:

- Increasing temperature, including increased frequency of occurrence and intensity of heat waves
- Wildfires
- Flooding
- Other extreme weather events

These changes pose substantial risks to power systems, impacting their resilience and operational adequacy.

Future Projections

To understand and mitigate future risks, climate modelling tools are essential. Some key resources include:

- IPCC WGI Interactive Atlas: Provides global and regional climate information, from the latest IPCC AR6 report
- Copernicus Interactive Climate Atlas: Offers detailed climate projections and data.
- WEMC Teal Tool: Delivers tailored climate and energy data for power system studies.

These tools help in projecting future climate scenarios and understanding their potential impacts on power systems.

Impacts on Power Grids

Climate change significantly affects the resilience and operational adequacy of power grids. The increased dependence on weather-sensitive renewable energy sources and the physical impacts of extreme weather events on infrastructure are critical concerns. The main threats include:

- Large-scale impacts: Cold waves, flooding, winter storms, heat waves, wildfires, and sea level rise.
- Local impacts: Sticky snow, freezing rain tornadoes, localized extreme weather events.

Climate parameters such as temperature, solar irradiation, wind speed, and precipitation are crucial for assessing power system components. These parameters influence:

- Interconnection capacities
- Hydro power generation
- Solar PV power generation
- Wind power generation
- Electricity demand, load flow patterns

Adequacy studies now need to consider complex scenarios like cold waves combined with wind droughts.

Addressing Climate Change in Power System Studies

Past climate data is no longer sufficient for future planning. Projections and advanced modelling are necessary. Tools like the Pan-European Climate Database (PECD) developed by the Copernicus Climate Change Service (C3S) for ENTSO-E are crucial for integrating climate data with energy models. The work flow for PECD involves data retrieval, bias adjustment, spatial and temporal interpolation, conversion of climate information into energy indicators, and the aggregation of energy indicators and the aggregation of energy indicators.

Conclusions

- Urgency of Transition: A strong and rapid transition to more sustainable practices is vital to address the impacts of climate change.
- Integration in Studies: Climate change considerations must be integrated into all prospective power system studies.
- Increased Dependency: Both climate change and the development of renewable energy sources increase the dependency of power systems on weather and climate conditions.
- Data Sharing: High-quality, open datasets for climate and energy are essential for coherent and relevant studies across different geographical levels and time scales.
- Data Organization: Energy data needs to be better organized and shared to build effective climate and energy models.

2.2. Climate related threats to electric power infrastructure in Slovenia

Marko Hrast (ELES) gave an overview of some cases of climate-related threats to electric power infrastructure in Slovenia. He has highlighted the concept of Resilience using Cigre's 2019 definition of power system resilience, which describes it **as the ability to limit the extent, severity, and duration of system degradation following an extreme event.**

The major climate related threats for Slovenia came from:

- **Snow and ice storms** were a significant concern, with snowstorms capable of collapsing power lines due to wet snow loads or fallen trees. Hrast discussed the ice storm of February 2014, the largest in Slovenia's history, which caused substantial operational problems and damage to both transmission and distribution networks.
- **Windstorms**, particularly the Bora winds common in western Slovenia, were another major threat. These winds can reach speeds up to 220 km/h, causing significant damage to older 110 kV lines. Hrast noted that several instances of high-speed winds in 2010, 2012, and 2015 led to severe damage to power infrastructure.
- **Flooding and landslide**s were also highlighted as critical issues. In August 2023, severe rainstorms resulted in the worst flooding in Slovenia's history, affecting several high voltage and distribution lines due to landslides and submerged substations.
- **Wildfires** posed an additional risk. Hrast mentioned the largest wildfire in Slovenia's history, which occurred in July 2022 and lasted 15 days, affecting high voltage lines. Despite the extensive fire, effective vegetation management helped minimize the damage to power infrastructure.
- **Lightning strikes** frequently cause outages and damage in Slovenia's Subalpine area, which is highly prone to heavy thunderstorms. Hrast emphasized the importance of implementing line surge arresters (LSA) to minimize outages and damage.

Recover strategy

Recovery from disasters was another crucial aspect of the presentation. Effective recovery strategies in Slovenia involve risk identification, emergency action plans, and adherence to international standards. Hrast highlighted the use of modular towers, which facilitate quick recovery and minimize downtime in case of line outages.

2.3. Operational Resilience of High Voltage Grid in Italy: managing Climate Change Effects in Real Time Operation

Mariella Epifani and Simone Talomo (TERNA) presented some cases from Italy and focused on the operational resilience of Italy's High Voltage grid and on managing the effects of climate change in real-time operations.

The main cases and the relevant mitigation strategies reported were:

- **Saline Pollution**: In recent years, prolonged periods of high temperatures and lack of precipitation have caused overheating and drying out of the soil, increasing the possibility of electric discharge in overhead power lines. Drought and wind lead to salt deposits on insulators in coastal areas. Humid and windy conditions cause conductive pollutants to dissolve in water on insulator surfaces, increasing leakage currents and affecting insulation performance. This results in erosion of the insulator shaft and the 'white corrosion phenomenon' in conductors, degrading their mechanical characteristics. Maintenance actions include replacing composite insulators with anti-salt painted glass insulators and periodic washing of insulators. Ongoing projects involve forecasting models to predict critical situations and failure probabilities.
- **Wildfires:** In 2022, Italy experienced numerous wildfires, requiring 1421 interventions by aircraft and resulting in multiple disconnections of power lines. Coordination with local authorities, civil protection, and other stakeholders was essential for emergency management. Measures included daily meetings to share critical issues, identification of synergic actions, and the use of mobile emergency generator sets. In 2023, wildfire incidents decreased by 54%, with fewer disconnections and interventions. Training for civil protection operators and firefighters, along with the development of tools for identifying HV power lines potentially affected by fires, were emphasized.
- **Storms:** Intense weather phenomena, including thunderstorms, whirlwinds, and hailstorms, hit Northern Italy in July and August 2023. Despite numerous outages, there were minimal impacts on the power supply to utilities. The anticipation phase involved monitoring weather forecasts and alert states, while the absorption and mitigation phase included activating emergency management procedures, coordinating with DSOs and producers, and inspecting and repairing faulted lines. Costs for power quality due to these storms amounted to 0.7 million euros.
- **Snowstorm:** In February 2023, Sicily experienced significant snowstorms, resulting in multiple disconnections and impacting over 120,000 end users. Countermeasures included increasing NTC above 225MW temporarily and coordinating with the Ragusa power plant to support Malta during concurrent adverse weather conditions. In November 2022, Calabria faced snowfall and strong winds, causing faults on several 150 kV lines. Early warnings and alarms for snow sleeves on conductors were issued, and anti-icing currents were forecasted to mitigate impacts.
- **Flooding:** In May 2023, Emilia-Romagna faced severe flooding, affecting several pylons and high voltage lines. Monitoring weather forecasts, activating emergency management procedures, and coordinating with local authorities were critical in managing the impacts.

Conclusion

The presentation highlighted the importance of resilient infrastructure and proactive measures to address climate-related threats to the power grid. The presentation underscored the significance of understanding and preparing for climate-related threats to ensure the resilience of the power infrastructure.

2.4. Climate related threats to electric power infrastructure in Greece

The fourth presentation of the first session focused on understanding the impacts of climate change on power grids in Greece. Charalampos Pitas from the Strategy and System Planning Department in IPTO, presented a comprehensive overview of extreme weather events, their effects on power systems, and the necessary measures to ensure resilience.

Extreme Weather Events and their Impacts

Pitas emphasized the increasing frequency and severity of extreme weather events due to climate change. These events include heatwaves, wildfires, hurricanes, cyclones, and flooding in Greece. Key highlights from the presentation included:

- **Heatwaves**: Many regions in Greece experienced record-breaking temperatures in 2023. Prolonged heatwaves not only threatened human health but also caused severe droughts, water shortages, and stressed agricultural systems as well as posing a significant strain on the electricity system, increasingly so over recent decades with the extensive use of air conditioners in homes and businesses.
- **Wildfires**: in 2023 Greece suffered its most intense burst of wildfires ever and the largest ever recorded in the EU, devastating sub-stations, utility poles and power lines and causing millions of damages and resulting in multiple disconnections of power lines.
- **Hurricanes and Cyclones:** Warmer sea temperatures intensified storms, leading to devastating impacts. Cyclone Daniel, the deadliest Mediterranean cyclone caused significant damage in Greece, starting also floodings and landslides that affected power lines. Mediterranean cyclones are becoming more frequent in a region that was historically unaffected by these extreme events

3. Session 2 & 3 – Increasing resilience of power grids through adaptation strategies put in place from the TSOs

The second and third sessions aimed to explore the adaptation strategies implemented by various TSOs to address the necessity of building a more resilient power system in response to climate-related threats. Future climate projections indicate an increase in the intensity and frequency of weather events, necessitating the adoption of new probabilistic risk-based approaches. These methodologies are essential for providing useful information to manage the impacts of climate change and enhance the resilience of the power system network.

Members utilizing these approaches show that TSOs can be better supported in the planning and decision-making processes for new grid investments.

3.1. TERNA's new approach for increasing the resilience of power grid against climate change

At the beginning of the Session, TERNA presented a comprehensive overview of their newly developed risk-based resilience methodology aimed at enhancing the robustness of the power grid. Silverio Casulli, Head of Grid Resilience and Security Planning, and Federico Falorni, Senior Expert in Grid Resilience and Security Planning, led the presentation, detailing the methodology and its implementation.

Key Elements

TERNA's resilience methodology integrates prospective climate hazards, asset vulnerability assessments, and contingency analyses to create a robust framework for grid resilience.

- Prospective Climate Hazard: This element involves the use of specific climatological models to predict the likelihood of severe weather events with high spatial resolution. TERNA employs datasets such as ERA-5 and MERIDA:
    - ERA5 is the latest climate reanalysis produced by the European Centre for Medium-Range Weather Forecasts, providing hourly data on many atmospheric, land-surface and sea-state parameters together with estimates of uncertainty.
    - The Meteorological Reanalysis Italian Dataset (MERIDA) was developed to address the increasingly frequent extreme weather conditions of the past 20 years, which have caused various disruptions to the Italian electrical system. This work was carried out following the guidelines from the 'Resilience Working Group' established by the Regulatory Authority for Energy, Networks, and Environment (ARERA). MERIDA can respond to the needs of energy stakeholders, who require reliable meteorological data to implement effective adaptation strategies for safely operating the electrical system.

The datasets are employed in combination of climate models like CESM-LENS2 and Euro-CORDEX, to produce detailed climate projections up to the year 2050.

- Assets Vulnerability Assessment: the assessment focuses on evaluating the failure probability of overhead lines (OHLs) by developing vulnerability curves based on engineering approaches and technical standards. These curves take into account the orographic characteristics and other specific parameters of TERNA's grid, following standards such as EN 50341-1:2012 and CEI Standard 11-4.
- Contingency Analysis: TERNA's methodology employs a probabilistic N-k approach to simulate weather-induced multiple contingencies and evaluate system resilience. This analysis helps in quantifying the outage Return Periods (RP) and Expected Energy Not Served (EENS) for substations after simulating these contingencies.

Methodology Details

- Climate Hazard Modelling: TERNA uses high-resolution climate models to predict severe weather events, including wind speeds and wet snow load forecasts. The models provide detailed maps with 4x4 km spatial resolution to assess the exposure of the National Transmission Grid (NTG) to various threats.
- Vulnerability Curves: the curves estimate the probability of OHL failures as a function of threat intensity. They incorporate data on wind speed, snow load, vegetation, soil characteristics, and the structural integrity of different grid components.
- Contingency Analysis: this analysis calculates the probability of multiple and simultaneous outages due to severe weather events. It helps in understanding the impact of these outages on the grid, providing critical data for resilience planning.

Implementation of the model by TERNA

Since 2017, TERNA has been identifying and implementing various interventions to enhance the resilience of the power grid, as part of their Security Plan. The development of the risk-based resilience methodology began in collaboration with *Ricerca del Sistema Energetico* (RSE) in 2020 and was approved by ARERA with Resolution 9-2022, becoming Annex A76 of the National Grid Code.

TERNA’s Resilience Plan is a comprehensive, five-year plan outlining all initiatives aimed at increasing the grid's resilience. This plan includes preventive, mitigation, restoration, and monitoring measures, ensuring a balanced approach to investment and system robustness.

- Preventive Measures: include infrastructure upgrades such as reinforcing existing assets, converting overhead lines to underground cables, and building new lines to increase grid redundancy. Specific solutions like anti-torsional and interphase spacer devices are also implemented to mitigate the effects of severe weather.
- Mitigation Measures: capital-light interventions are employed to contain risks and reduce damage, such as using anti-icing paints and tools for de-icing currents.
- Restoration Measures: post-failure interventions include new emergency plans, fault locators, and the use of mobile generators and other rapid recovery tools.
- Monitoring Measures: advanced technologies such as LiDar mapping, drones, and IoT devices are used for real-time monitoring and predictive maintenance.

Conclusion

TERNA's innovative resilience methodology, backed by advanced climate modelling and a structured approach to vulnerability and contingency analysis, positions it at the forefront of grid resilience. The integration of technological innovation and collaboration with research institutions ensures that TERNA continues to adapt and enhance its strategies to meet the challenges posed by climate change.

To ensure continuous improvement, TERNA prepares a yearly Resilience Plan outlining all initiatives planned for the next five years. This plan is crucial for systematically enhancing the resilience of the power grid against climate-related threats. The Resilience Plan not only aims to fortify the NTG but also serves as a blueprint for other regions facing similar threats.

3.2. ELES adaptation strategy to protect Slovenian power grid against climate change

Dt. Uroš Kerin of ELES presented a detailed overview of the various challenges and mitigation strategies employed by his company to enhance the resilience of the power grid in Slovenia against climate related threats. The main focus was on the following strategies:

- **High Design Standards and Manufacturing Norms:** The presentation emphasized the importance of high design standards and manufacturing norms, using high-quality materials, and proven equipment. Good engineering practices, lessons learned from field experiences, and operational flexibility were identified as crucial factors in maintaining grid resilience.
- **Dynamic Line Rating (DLR)**: Dt. Kerin discussed the implementation of Dynamic Line Rating, which has been in full operational mode since 2017. The system, which calculates dynamic thermal limits for 34 overhead lines, two phase-shift transformers, and 10 power transformers, helps mitigate N-1 and N overloading operational situations. The DLR system includes an inverse algorithm for icing prevention and provides alarms for extreme weather conditions along power lines.
- **Vegetation Management:** With 61.5% of Slovenia's land area covered in forests, vegetation management is critical. One-third of power lines run through densely forested areas. Effective vegetation management involves using advanced analytics and various data sources such as LIDAR,

drones, and satellite imagery to maintain clear corridors along overhead lines. This strategy helps prevent outages caused by tree falls during storms and improves overall grid reliability.

- **Regional Infrastructure Development:** Dt. Kerin highlighted the importance of regional infrastructure development at European Level, referencing the SINCRO.GRID project as a key initiative. This project enhances cross-border energy infrastructure and increases the transmission system's capacity. The integration of energy storage systems and power-flow control devices also plays a significant role in boosting grid resilience.

The presentation then focused on the significant challenges from ice and snowstorms that hit Slovenia in the past decade. The catastrophic icing event in February 2014 was particularly notable, with ice loads causing extreme stress on conductors and lattice steel towers. The damage was extensive, with 52 km of electric power transmission lines affected, resulting in the collapse of 58 steel towers and damage to 77 others. The response included the implementation of an anti-icing module and the development of dynamic line rating systems to mitigate similar future events.

Dr. Kerin then presented the future outlooks for Slovenia highlighting an expected increase in the intensity and frequency of strong winds, higher ambient temperatures, more frequent and severe floods, and wildfire incidents by 2030 and 2070. Dr. Kerin stressed the need for ongoing adaptation and mitigation strategies, including the adoption of grid-enhancing technologies and continuous improvements in maintenance practices as well as of the importance of being connected with other countries with the necessary coordination among the TSOs.

Conclusion:

The presentation underscored the critical need to understand and prepare for various climate-related threats to ensure the resilience of power infrastructures. The insights from Slovenia's experiences and strategies provide valuable lessons for other Mediterranean countries facing similar challenges. Dr. Kerin's comprehensive approach, combining high design standards, advanced technologies, and effective management practices, illustrates a robust model for enhancing grid resilience in the face of climate change.

3.3. RTE resilience to climate change strategy for network infrastructure

The third presentation of the Session was delivered by Erik Pharabod from RTE and focused on the resilience of electricity transmission network infrastructure to climate change in the French experience. The presentation focused the specific climate phenomena affecting the network and detailed the adaptive strategies employed by RTE to mitigate these risks.

Climate Phenomena Affecting the French Network: Pharabod’s presentation began by outlining the climate-related threats impacting the network, which include wind, thunderstorms, sticky snow, heat waves, drought, fires, and flooding. Each of these phenomena poses unique challenges to the integrity and functionality of the power grid.

Adapting to Extreme Heat: One of the critical issues discussed was the effect of extreme heat on the transmission network. Pharabod explained that high temperatures can cause overhead power lines to heat up and expand, potentially compromising safety distances. Historically, some older structures were designed for a maximum operating temperature of only 45°C, which is inadequate for current and future climate scenarios.

To address this, RTE has implemented a "hot weather plan," which involves reducing the load flow capacity of around 1400 identified power lines during periods of high ambient temperatures. This measure ensures compliance with safety standards and prevents overheating. Additionally, RTE has increased the minimum operating temperature for new or refurbished structures, raising it to 85°C to account for future climate projections. This initiative will require significant investments, as structures designed for higher temperatures are more expensive due to the need for taller pylons, larger cable cross-sections, and more substantial foundations.

Adapting to Fire: Fires, particularly in the south of France, are becoming an increasing concern. RTE has extended its collaboration with firefighting services and is constructing a database to monitor power lines affected by fires. This database helps in analysing potential failures and ageing of conductors. Additionally, RTE is exploring the use of fire risk maps derived from the Copernicus database to anticipate future risks.

Adapting to Flooding: Flooding is another significant threat. RTE addresses this by adhering to town planning regulations based on historical flood data and implementing technical solutions such as watertight doors and water barriers for existing substations. New substations are designed with upgraded sensitive parts or entire structures to withstand flooding. RTE is also conducting a case-by-case analysis of existing substations and pylons to prioritize measures to be implemented when relevant built before the existence of Flood Risk Prevention Plans (PPRI).

To prioritize the security measures, RTE is now implementing a multi-criteria assessment based on results of future climate simulation, including frequency and intensity of floods, to be crossed with resilience characteristics and repair costs of the infrastructure. Future structures will be built outside flood-prone areas or with sufficient safety measures from the design stage

General Adaptation Strategy: Pharabod concluded the presentation by highlighting RTE's ongoing efforts to switch from designs based on historical data to those accounting for future climate exposure. This includes feedback from other TSOs in warmer climates and continuous research on the impact of climate change on infrastructure. The adaptation strategy will involve significant investments to ensure that the network can handle future climate conditions, thereby enhancing the resilience of the electricity transmission infrastructure.

This comprehensive strategy will be detailed in RTE’s Ten-Year Network Development Plan, focusing on resilience against heat waves, fire risks, and flooding.

The presentation highlights the importance of proactive adaptation measures and continuous research to safeguard the transmission network against the evolving threats posed by climate change. The insights provided by RTE's experience and strategies offer valuable lessons for other TSOs facing similar challenges.

3.4. IPTO strategies for adaptation of the Power Grids in Greece

The final presentation of the event focused on the resilience and adaptation strategies implemented by IPTO in Greece to combat the impacts of climate change on the electricity transmission network. Charalampos Pitas and Dimitrios Bechrakis (IPTO) detailed the comprehensive measures undertaken by the company to enhance the operational resilience of the power grid, particularly in response to the increasing frequency and severity of extreme weather events. The strategies are:

- **Preventive measures:** Pitas highlighted that IPTO has implemented several preventive measures to ensure the robustness of the power grid.

  The strategy involves using the N-k criteria for system planning to enhance system robustness, undergrounding overhead lines to protect against environmental damage, and reinforcing network topologies. This includes planning new alternative transmission lines, using high-temperature low-sag conductors, and constructing new substations. Special specifications are applied to materials, components, and sub-systems to withstand extreme conditions.

- **Operational Resilience:** the presentation highlighted the importance of ensuring adequacy and security of resources and robust system operations, including physical and cyber security. IPTO has developed processes for rapid recovery and quick restoration of services after an extreme weather event. Designing systems with redundancies to handle common cause failures and improve resilience is also a critical aspect of IPTO's strategy.

  To support this and guarantee the Operation and Control of the Power System IPTO has upgraded its SCADA systems to enhance energy control centres, thereby improving system security and resilience. By integrating data for efficient equipment management and maintenance and ensuring secure and reliable communication through robust telecommunication networks, IPTO has strengthened its operational control capabilities. These measures are crucial for maintaining system stability during extreme weather events and other emergencies.

- **Asset Management:** another important aspect is the management of the assets of the Grid, that is a key component of IPTO's resilience strategy. The installation of infrared cameras for temperature monitoring and smart early warning systems on critical overhead lines (OHLs) enables continuous health monitoring.

  Online monitoring systems (OLMS) for substations and critical equipment, such as auto-transformers, circuit breakers, reactors, and cables, provide real-time data that supports predictive maintenance. Utilizing artificial intelligence (AI) and machine learning (ML) tools to calculate asset health indices, probabilities of failure, and lifecycle costs further enhances the ability to predict and prevent potential issues.

  IPTO has prioritized the replacement and upgrading of critical system components, including autotransformers, reactors, switchgears, and digital substation automation systems. Intensive inspection and management of vegetation around OHLs are conducted to prevent fire risks. These proactive maintenance and renovation efforts are essential for ensuring the long-term resilience of the power grid.

- **Research and Innovation:** IPTO is involved in European Union projects such as RAIN and FARCROSS focusing on developing advanced monitoring and early warning systems, and the implementation of cutting-edge technologies for real-time data analytics and system resilience. This continuous improvement approach ensures that IPTO remains at the forefront of resilience planning.

To reinforce these strategies IPTO is involved to support Greek governmental bodies and civil protection authorities for effective disaster response. IPTO has increased its readiness and technical staff intervention during extreme events and maintains close collaboration with local governments to ensure a coordinated response to disasters. This ecosystem coordination is vital for mitigating the impacts of climate-related threats and ensuring the resilience of the power grid.

A significant aspect of IPTO's actions listed above involves compliance with REGULATION (EU) 2019/941 of the European Parliament and of the Council of 5 June 2019 on risk-preparedness in the electricity sector, which repeals Directive 2005/89/EC. This regulation mandates Member States to develop national risk-preparedness plans that include measures for preventing, preparing for, and mitigating electricity crises. These plans must ensure transparency, cross-border cooperation, and solidarity in addressing electricity supply crises. IPTO has incorporated these regulatory requirements into its resilience and adaptation strategies, ensuring that the power system is prepared for potential disruptions and can maintain operational continuity during crises.

Finally, the presentation emphasized the crucial role of ENTSO-E in enhancing grid resilience across Europe. ENTSO-E facilitates cooperation and coordination among European TSOs, enabling the development and implementation of best practices and standards for resilience. By collaborating with ENTSO-E, IPTO benefits from shared knowledge and resources, contributing to the overall stability and reliability of the European electricity network. ENTSO-E's initiatives and frameworks support IPTO's efforts in improving operational resilience and adapting to climate change impacts.

4. Threats vs measures matrix

Climate-Related Threat	Adaptation Strategy	TSO
Wildfires	Use of mobile emergency generator sets, coordination with local authorities, development of tools for identifying HV power lines affected by fires, training for civil protection operators and firefighters	TERNA (Italy)
	Intensive inspection and management of vegetation around OHLs	IPTO (Greece), ELES (Slovenia)
	Use of fire risk maps derived from the Copernicus database	RTE (France) TERNA (Italy)
Storms	Monitoring weather forecasts, activating emergency management procedures, inspecting and repairing faulted lines	TERNA (Italy)
	Switching design approaches from historical data to future climate exposure, incorporating feedback from TSOs in warmer climates	RTE (France)
Snowstorms	Increasing NTC temporarily, coordinating with power plants for support during adverse weather conditions, issuing early warnings and alarms for snow sleeves on conductors	TERNA (Italy)
Flooding	Monitoring weather forecasts, activating emergency management procedures, coordinating with local authorities	TERNA (Italy)
	Adhering to town planning regulations based on historical flood data, implementing technical solutions like watertight doors and water barriers for existing substations, designing new substations to withstand flooding	RTE (France)
	Risk identification, emergency action plans, adherence to international standards, use of modular towers	ELES (Slovenia)

Heatwaves	Replacement and upgrading of critical system components, collaboration with local governments for coordinated disaster response	IPTO (Greece)
General Climate Adaptation	Integration of specific climatological models, asset vulnerability assessments, and contingency analyses	TERNA (Italy)
	Development and implementation of advanced monitoring and early warning systems through EU projects	IPTO (Greece)
	High design standards, use of proven equipment, operational flexibility, and dynamic line rating (DLR) system	ELES (Slovenia)
Lightning Strikes	Implementation of line surge arresters (LSA)	ELES (Slovenia)
Saline Pollution	Replacing composite insulators with anti-salt painted glass insulators, periodic washing of insulators, development of forecasting models to predict critical situations	TERNA (Italy)
Landslides	Risk identification, use of modular towers	ELES, (Slovenia) TERNA (Italy) IPTO (Greece) RTE (France)

Med-TSO

Legal Headquarters - Viale Egidio Galbani,70 – 00156 Rome – Italy

Info@med-tso.com • www.med-tso.com

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