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SUMMARY DSO BRIEF

THE RESILIENCE OF POWER DISTRIBUTION SYSTEMS

RECOMMENDATIONS FOR A NEW REGULATORY PARADIGM

AUTHORS AND COLLABORATORS

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Power distribution system resilience has become a critical topic in the current context of global warming and energy transition. As our planet faces the effects of climate change, the frequency and severity of impactful events—such as hurricanes, storms, floods, snowstorms, wildfires, and heatwaves—have significantly increased. These events pose substantial challenges to electrical distribution infrastructure, especially in Latin America—a region characterized by climate vulnerability and diverse geography—where electric infrastructures were built based on environmental parameters that are now rapidly and irreversibly changing.

Our energy systems are decarbonizing, leading to increased electrification of end-use energy demand. As this electrification trend grows, society becomes more reliant on the electrical grid to meet basic needs. Consequently, climate-related threats demand greater resilience from our electrical infrastructure, as service failures have amplified impacts on productivity and society at large.

Current regulations prioritize cost efficiency and stable coverage and access to distribution systems. However, these regulations lack flexibility to cope with increasing climate variability and environmental changes. However, an electric system resilient to high-impact events offers multiple benefits for electrical security. Recent studies suggest that the benefits of resilient electrical systems far outweigh the costs in most scenarios, considering the growing impacts of climate change. Investing one dollar in climate-resilient infrastructure can save six dollars. According to the World Bank, delaying resilience-building actions by ten years nearly doubles the cost (World Bank, 2019). For instance, in vulnerable countries, underground grids can significantly reduce potential damage from climate impacts and save recovery costs, even if their initial investment exceeds that of overhead grids. Resilience also facilitates the energy transition, enabling greater electrification solutions and accelerating the adoption of renewable energies, which are often sensitive to changing climates.

Significant events can have detrimental consequences for electric distribution infrastructure and service continuity. While some of these effects are well-known, others remain understudied and insufficiently documented. In general terms, distribution infrastructure exhibits varying levels of vulnerability to different categories of high-impact events.

Table 1. Vulnerability of Distribution Assets to High-Impact Events

Type	Earthquake	Storm	Flood	Tsunami	Fire	Drought	Heatwave
Power lines	Medium	High	Low	Medium	High	Medium	Medium
Substations	High	High	High	Medium	High	Low	Medium

Source: World Bank (2019).

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> In power distribution regulation, the treatment of high-impact events plays a crucial role.

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RESILIENCE OVERVIEW IN POWER DISTRIBUTION IN LATIN AMERICA

Latin American countries are just beginning to incorporate climate risk resilience as a regulatory objective. Resilience is currently only considered in some general policy and energy transition documents, but concrete regulatory measures are yet to be fully implemented.

In terms of monitoring and anticipation, only in some countries are climate risk analysis systems used to help utilities plan and deploy resources. In Brazil, there are climate analysis tools that allow for the identification of regions most prone to extreme events by comparing historical data and prediction models to create a climate threat map.

Contingency plans are essential to ensure a rapid and effective response to high-impact events. In Latin America, their use has been identified in countries such as Argentina, Brazil, Chile, and Peru. In Argentina, utilities must have control centers, workgroups, trained personnel, and resources to activate Emergency Operating Plans (POE). This is complemented by preventive maintenance plans and regular drills. In Brazil, the National Electric Energy Agency (ANEEL) requires contingency plans from utilities, including protocols for mobilizing equipment and resources, as well as coordination with local and national authorities. In Chile, in addition to the obligation to maintain contingency plans, annual plans are developed for the winter and summer periods, which must be reported to the Superintendency of Electricity and Fuels. Additionally, response protocols include regular drills and exercises for earthquake and other disaster preparedness.

Only after the occurrence of high-impact events have regional authorities developed initiatives aimed at improving the resilience of distribution systems. In Chile, the regulatory authority introduced the definition of Abnormal State and Aggravated Abnormal State, and the Technical Quality Service Standard included two concepts related to disaster response. The first is emergency disconnections to prevent forest fire incidents. The

second corresponds to an Operational Flexibility (FO) index that measures the percentage of customers who regain service within 30 minutes, whether through load transfers, meshing, island operations, or the work of company brigades and resources. This would be the first indicator measuring the resilience of distribution networks during supply interruptions.

In Brazil, the concept of Interruption in Emergency Situations (ISE) has been established, which filters out service quality indicators associated with Emergency or Public Calamity Situations. Additionally, ANEEL has opened a public consultation with the aim of improving regulations related to the resilience of distribution and transmission systems.

In Puerto Rico, a resilience working group was formed with public authorities, electric companies, and research institutes to identify actions for future storms. This group recommended a three-level approach, including building perimeter barriers at substations to prevent flooding, installing high-capacity pumps and backup generators, improving the roofs and walls of substations to withstand strong winds, increasing the use of galvanized steel poles, and burying lines in particularly susceptible areas.

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REGULATION REGARDING HIGH-IMPACT EVENTS

In power distribution regulation, the treatment of high-impact events plays a crucial role in determining responsibilities and compensations by Distribution System Operators (DSOs). These events, due to their unpredictable and often destructive nature, require special development within regulatory frameworks to protect companies from unfair penalties while incentivizing necessary investments to enhance the resilience of electrical networks.

For many years, operators of transmission and distribution networks facing with highly significant impact events, have invoked the exemption from liability compensations owed to consumers by resorting to the legal concept of "force majeure," which is not specific to the power sector and applies broadly to all activities subject to impacts. Additionally, regulators adjust service quality indicators to exclude periods affected by force majeure events or fortuitous events, ensuring that companies are not penalized for circumstances beyond their control.

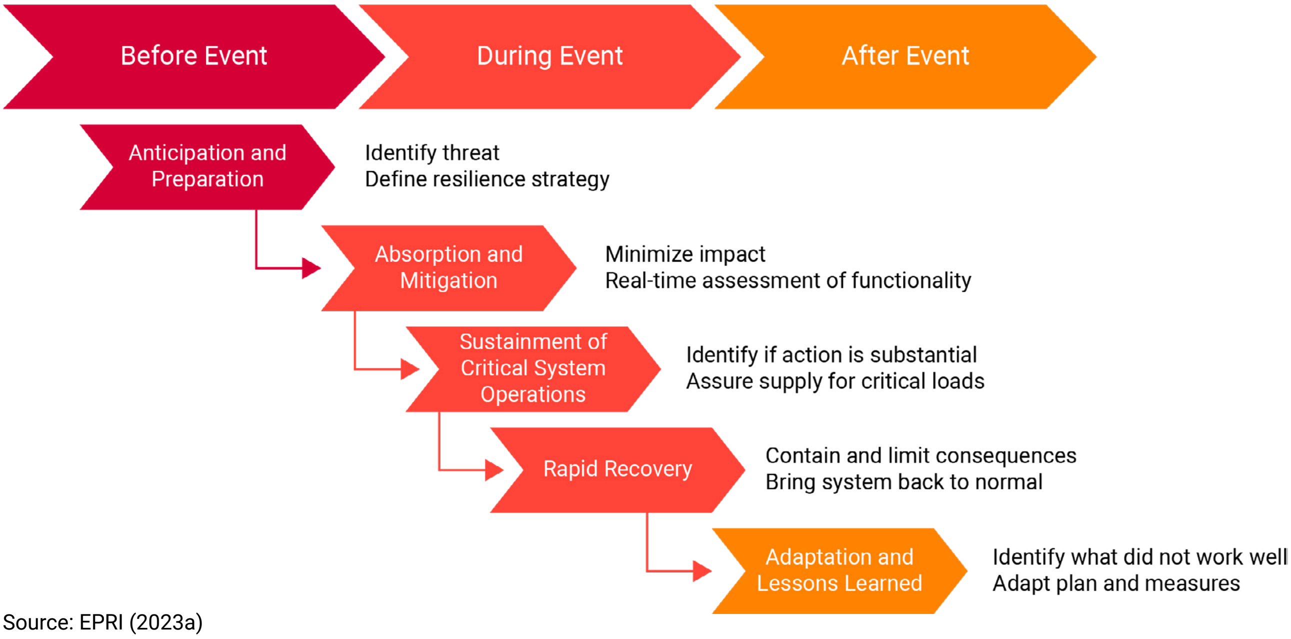
In Portugal, to minimize the misuse of force majeure, the ERSE (Portuguese energy regulator) established that its invocation was only applicable in the case of events "that simultaneously meet the conditions of externality, unpredictability, and irresistibility vis-à-vis good practices or applicable and mandatory technical rules." Furthermore, the concept of an "exceptional event" has been adopted by all European regulators, albeit with variations among different countries. When evaluating exceptional events, statistical methods or other criteria, such as the number of consumers affected by supply interruptions or the duration of those interruptions, can be used. Additionally, ERSE introduced the concept of a "High-Impact Incident," defining it as any incident that, regardless of its cause, results in one or more interruptions leading to the non-supply or distribution of more than 50 megawatt-hours (MWh).

In other European countries, distributors need only provide documentary evidence based on predefined meteorological parameters. Waiting for an external body to declare an event as high impact is not necessary. However, the European Network of Transmission System

Operators for Electricity (ENTSO-E) establishes guidelines for qualifying high-impact events, categorizing them based on severity and frequency.

High-impact events impose critical responsibilities on energy distribution companies to ensure service continuity, minimize damages, and protect consumers. These obligations span from pre-event preparation and planning to immediate response once the event occurs, post-event recovery and rehabilitation, and regulatory compliance.

Responsibilities of DSOs during a High-Impact Event



Source: EPRI (2023a)

> Investments in resilience face certain barriers stemming from market failures, which can be mitigated through public policy and regulation.

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REGULATION FOR DISTRIBUTION SYSTEM RESILIENCE

Policy makers and regulators play a crucial role in promoting resilient electrical systems by assessing climate-related risks and impacts, making resilience a central element in energy plans, identifying cost-effective measures, creating appropriate incentives for distribution companies, and evaluating their effectiveness. To achieve this, regulatory authorities must implement best practices that holistically promote resilience. These practices include action plans, resilience index calculation methodologies, regulatory signals for investment remuneration, and adoption of new technologies and emerging solutions.

The parameters of network resilience should not remain embedded solely in service quality indicators, given the extreme and atypical nature of high-impact events. It is essential to define a methodology for calculating resilience indicators to guide actions toward the desired level. These indicators can be categorized into three types: recovery, robustness and adaptability indicators. According to a study conducted by EPRI, metrics for resilience evaluation should exhibit the following attributes: verifiability, ease of interpretation, objectivity, accessibility, comparability, clear definitions, and linkage to performance areas.

Actions related to improving network resilience can be incorporated into detailed investment plans with investments associated with technologies and solutions. These efforts may aim to reduce the magnitude of event impact (physical infrastructure resilience) or minimize system recovery time (operational resilience).

Table 2. Types of Resilience Investments

Infrastructure Resilience	Operational Resilience
Vegetation management Selective undergrounding of lines Replacement of components with superior design and construction standards	Mobile equipment for provisional supply restoration Repair team management Monitoring and communication systems Microgrids and distributed energy resources (DER) Protection and control schemes Forecasting systems Mutual assistance agreements

Source: Own elaboration based on IDB (2021).

These plans should be submitted by the DSOs to the Regulator and incorporated into their tariff review processes. To do so, it is necessary to define explicit signals for ex ante remuneration to the DSO for investments in projects and solutions to enhance system resilience. These signals can be accompanied by bonuses for companies that exceed certain resilience thresholds based on previously defined indicators.

On the other hand, it is essential that contingency plans be integrated through Mutual Assistance Groups that coordinate actions among nearby DSOs for equipment exchange. This includes establishing indicators for companies that provide and receive resources, as well as the repercussions for respective consumers.


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INTERNATIONAL BEST PRACTICES FOR RESILIENCE REGULATION

RISK ASSESSMENT AND MITIGATION

The resilience of power distribution systems is an increasingly prioritized goal in the regulation of some developed countries to address the challenges posed by high-impact events. Several countries have introduced guidelines for climate risk and impact assessments. For example, the United States government has developed a guide for vulnerability assessments related to climate change as the initial step in climate resilience planning for the electricity sector. The US Climate Resilience Toolkit provides tools to explore climate hazards and evaluate vulnerability and risks.

These initiatives can be complemented by the creation of specific disaster response funds, improved governance in emergency declarations, broad societal discussions on defining high-impact events and the best ways to prevent and combat them, mutual aid protocols among distributors for mobilizing additional teams and resources during extreme events, and integrated climate change plans with joint governance involving distributors, regulators, and national, state, and municipal governments.

Additionally, comprehensive risk assessments must be accompanied by mitigation measures, such as preventive tree pruning near power distribution lines, considering resilience criteria for electrical infrastructure in urban planning, and community awareness to avoid behaviors that increase risk.

Effective risk management requires coordination among government authorities, electric distribution companies, and emergency response agencies (firefighters and civil defense). Given recent cases and evidence that extreme weather events will become more frequent, improving processes and governance in the collaboration between these entities is essential.

FORECASTING AND ANTICIPATION MECHANISMS

The European Early Warning System, used in several European countries, combines meteorological, geological, and technical data to anticipate high-impact events and coordinate rapid responses. In Italy, companies use tools like Weather Alerting to make forecasts and calculate the impact of weather conditions on network infrastructure. The output provides a risk level indicating the probability of an emergency occurring on the network within the next 72 hours. This application also allows monitoring of specific wind, rain, and temperature information on an hourly basis for a specific area. The Resilience Index (IRI) incorporates the probability of event occurrence before and after measurement (in this case, by multiplying the projection by the number of affected customers).

In the United States, the National Energy Forecasting and Analysis Center uses big data and predictive analytics to anticipate high-impact events on the power grid. Tools like Geographic Information Systems (GIS) help map risks and plan responses. Additionally, the Department of Energy (DOE) funds research to develop advanced predictive models that anticipate infrastructure failures due to natural or cyber events.

CONTINGENCY PLANS AND CRISIS MANAGEMENT

The United Kingdom, France and Italy have developed detailed contingency plans that include specific protocols for different types of events, from storms to cyberattacks. These plans are regularly reviewed and updated.

In the United States, the Federal Emergency Management Agency (FEMA) collaborates with electric companies to develop robust contingency plans. These plans focus on interagency coordination and rapid resource mobilization. Specifically, California, prone to wildfires and earthquakes, has developed an advanced crisis management system that includes controlled deactivation of the power grid to prevent fires and rapid service restoration.

In the southeastern United States and the Gulf of Mexico, annual training is conducted in preparation for hurricane season (DOE, 2010). For example, Florida Power & Light tests its contingency plan through simulations related to locating outages, damage assessment, communication with customers and employees, and initiating service restoration.

RESPONSE MECHANISMS AND COORDINATION

In the United States, there is a long tradition of electric utility companies providing assistance in response to severe weather events. This practice has been standardized through seven Regional Mutual Assistance Groups (RMAGs). When a company requires assistance, it submits a request through the regional group, which assesses personnel and equipment needs. Additionally, there is a Resource Allocation Management Program (RAMP UP) that allows RMAG leaders to activate an online event, granting the requesting company access to neighboring resources. The National Response Event (NRE) framework has also been established to expand assistance nationwide.

In Japan, the Disaster Cooperation Plan aims for rapid and flexible recovery during high-impact events. It leverages cooperation examples between energy and gas transmission and distribution companies. The plan covers mutual support among transmission and distribution operators, coordination during normal times for extreme event preparedness based on lessons from previous natural disasters, country division into areas, mutual support manual development for distribution restoration, creation of a list of essential facilities, collaboration with telecommunications companies, self-defense forces, and local governments, communication planning between companies, governments, and business associations, and joint training for transmission and distribution teams.

In Brazil, due to the floods in the state of Rio Grande do Sul between late April and early May 2024, there was unprecedented mobilization of DSOs beyond those directly affected by the tragedy. Companies like Enel and Light sent teams and materials to assist Equatorial and CPFL in crisis management.

REGULATORY INCENTIVES FOR RESILIENCE INVESTMENTS

In Italy, the regulatory authority defined initial provisions for bonus mechanisms as incentives for distribution network developments in anticipation of extreme events. These provisions offer incentives for investments with higher benefit-cost ratios, such as expanding underground grids (or converting overhead to underground).

Similar incentives exist in the United Kingdom, where the Office of Gas and Electricity Markets (OFGEM) implemented the RIIO model (Revenues = Incentives + Innovation + Outcomes) starting in 2010. Under this new model, tariff revenues are determined through incentives to provide innovation and products to consumers. Regarding system resilience, companies can obtain resources as part of the tariff agreement. These resources can be used to cover flood protections, black start activation, physical security of critical infrastructure, and protection of overhead lines through tree trimming.

In the United States, the Department of Energy provides funding and grants for projects aimed at improving the resilience of the electric grid, incentivizing the adoption of advanced technologies. Additionally, the Federal Energy Regulatory Commission (FERC) implements regulations that allow companies to recover costs associated with resilience investments through tariffs.

INDICATORS FOR MEASURING RESILIENCE

In Italy, network resilience is measured by the benefit in terms of fewer disconnected users (delta IRI). Bonuses for investments in anticipation of extreme events are defined based on performance in categories such as reduced outages, avoided costs, decreased renewable generation loss due to interruptions, expected reduction in severe voltage drops, avoided operation and maintenance costs, expected reduction in electricity generation costs through energy vector substitution, and reduced CO_2 emissions due to expected variations in grid losses.

France and Spain are also advancing evaluation systems that combine technical performance metrics, responsiveness, and grid redundancy to assess the resilience of distribution systems. In the United States, the DOE has developed tools that allow companies to evaluate their resilience using a combination of historical data, simulations, and predictive analysis.

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CONCLUSÕES E APRIMORAMENTOS REGULATÓRIOS

It is essential to incorporate resilience concepts into distribution networks at the level of public policy and subsequent regulatory development. This can encourage investment in infrastructure, promote the adoption of advanced forecasting and crisis management technologies, and establish effective coordination and response mechanisms. The process could consider the following elements:

Develop guidelines for quantifying the social impact of power outages attributable to High-Impact Events, including economic, safety, and health effects.

Develop guidelines for assessing risks and vulnerabilities in electrical systems to prioritize mitigation investments, such as preventive tree pruning and incorporating network resilience criteria into urban planning. This collaboration should involve authorities, utility companies, and emergency response agencies.

Establish guidelines for rating High-Impact Events based on severity and frequency, defining the responsibilities of Distribution System Operators (DSOs) in risk management and contingency planning.

Contingency plans should include protocols for various events, from storms to cyberattacks. These plans should be regularly updated, include drills and training, have clear and efficient communication actions, and appoint a coordinator to harmonize efforts.

Regulatory signals should promote the implementation of forecasting and early warning mechanisms. These systems should combine meteorological, geological, and technical data to anticipate infrastructure failures related to high-impact events and coordinate rapid responses.

Mutual assistance mechanisms should coordinate nearby DSOs, authorities, firefighters, police, and medical units. These mechanisms should have predefined responsibilities, equipment availability, cost determination processes, and tariff recognition guarantees.

Develop indicators and methodologies for evaluating distribution system resilience, separate from service quality indicators. Given the extreme and atypical nature of high-impact events, these criteria should include recovery, robustness, and adaptability.

Present resilience improvement plans to regulators, incorporating investments in network reinforcement, increased system flexibility, and intensified restoration. These plans should be part of tariff review processes.

Provide ex ante compensation for investments in system recovery from high-impact events. Examples include fault diagnosis systems, immediate response infrastructure, protection management centers, mobile generators, mobile storage systems, communication systems, auxiliary services, critical spare parts, and accessories. These incentives can take the form of tariff bonuses based on resilience indicators.

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