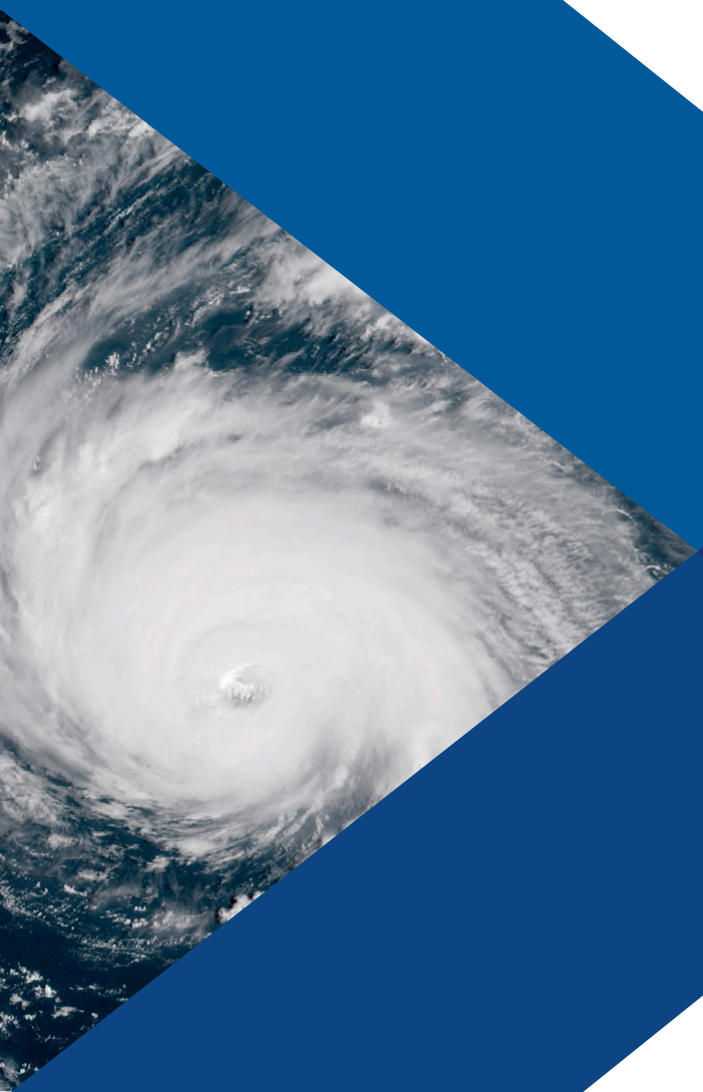
EnerNex
A CESI Company

WHITE PAPER

THE RESILIENCY CONTINUUM

N. Placer and A.F. Snyder



SYNOPSIS

Storm damage can wreak havoc on the electrical distribution system and instantaneously create a major impact on those who continuously depend on unfettered access to electrical energy. "Keeping the lights on" is a bedrock principle of utility operations, but is increasingly being challenged by more frequent and turbulent natural disasters. The quest for greater utility resiliency is therefore an ongoing pursuit that continuously takes shape over time—on a continuum.

This paper serves as a useful resource for grid practitioners who are seeking a strategic resiliency framework with actionable checklist items and one that concurrently aligns with evolving grid modernization efforts. The three resiliency categories presented progressively increase from foundational topics to more forward-leaning initiatives. This time-based progression enables utilities to assess where they fall on the resiliency continuum, their resiliency maturity level, and steps they can take to advance along this resiliency pathway.

What is Resiliency?

In its most basic form, infrastructure resilience is the ability to reduce the magnitude and/or duration of disruptive events.[1] However, it is important to note that resiliency measures themselves do not prevent damage. Rather, they enable electric facilities to continue operating despite damage and/or promote a rapid return to normal operations when damages and outages occur.[2]

A Resiliency Framework

Resiliency is an important topic that is growing in relevancy, both in a traditional sense (i.e., being prepared to mitigate the impacts of storm events) and also in terms of a utilities' capability to be prepared for the utility landscape of the future (i.e., grid modernization). The quest for greater utility resiliency is therefore an ongoing pursuit that continuously takes shape over time. To help synthesize various concepts within the context of an evolving utility marketplace, resiliency has been categorized into a three-part, time-based framework.

BEFORE

Managing Resiliency

Focuses on a utility's foundational plan to strengthen their distribution system infrastructure in advance of resiliency concerns

NOW

Maintaining Resiliency

Focuses on a utility's capability to keep the distribution system in an operational state

FUTURE

Modernizing Resiliency

Focuses on a utility's capability to be more flexible and adaptive to future grid technology integration and business markets

First, a utility must look back (BEFORE) to identify their existing resiliency plans. Next, they should evaluate their current resiliency capability (NOW) to consider their success in ongoing execution of resiliency. Lastly, they should look forward (FUTURE) to consider how they can continuously optimize resiliency as one component of a larger grid modernization strategy.

Resiliency Checklists & Maturity Level

High-level checklists have been developed for each of the three categories of the resiliency framework (managing, maintaining, and modernizing). These checklists have been provided for grid practitioners to initially assess their resiliency capability within each category. Additionally, a scoring system has been implemented which combines all framework category checklists together to assess a utilities' high-level resiliency maturity as described at the end of this white paper. The 5-point maturity scale presented is loosely connected to other industry maturity level models. The objective is for utilities to quickly assess where they stand within each resiliency category and their comprehensive resiliency maturity across all three categories.

BEFORE

Managing Resiliency

Focuses on a utility's foundational plan to strengthen their distribution system infrastructure in advance of resiliency concerns

- Distribution Infrastructure Processes & Standards
- Distribution Infrastructure Programs & Audits
- Distribution Infrastructure Future Modifications

Key Question: Are you PLANNING for resiliency?

Before a utility can effectively advance resiliency, they must first look back to identify the validity and effectiveness of their existing resiliency plans. There are several steps that can be proactively taken to strengthen a utility's base resiliency. Distribution system infrastructure planning and design should be focused on enhancing standards and processes, programs and audits, and future modification plans.

Distribution Infrastructure Processes & Standards

Finding appropriate design and construction standards should be based on the local conditions of the facilities. Studies from various regions of the country provide a myriad of hardening measures for overhead distribution reinforcement, including pole and line design processes and standards and the application of new technologies, all with the goal to mitigate widespread outages due to tear down situations from high winds, vegetation, or other natural disasters. Other reports, especially those in coastal areas, emphasize the importance of elevating substations and other vulnerable facilities that are susceptible to flooding.[2]

Applicable standards should be leveraged to develop processes which pertain to overhead distribution reinforcement and hardening. Some of the most effective resiliency management actions are relatively simple and straightforward. For example, adding structural reinforcement to existing distribution lines can be accomplished via adding guy wires, using steel poles, or reinforcing critical loads for high population density areas. Additionally, some best practices for distribution hardening processes can be followed.[3] Various processes can be established to account for different scenarios such as: distribution pole foundation failures, mechanical overloading, variances in pole material type, and treatment of foreign-owned poles.

Distribution Infrastructure Programs & Audits

While standard-driven processes ensure that overhead distribution is reinforced and hardened initially, regular programs and audits should also be put in place to ensure the long-term fidelity of the distribution system. For example, a hardening tool kit of approved hardening approaches and standards can be developed as a guide for field training, storm restoration preparation,



or for pilot implementation. This should cover items like test-and-treat programs for wooden poles, formal feeder inspection programs, and application of hydrophobic coatings to various components. When these programs are collectively aligned and coordinated they can function as a comprehensive plan for gradually hardening the distribution system through normal work practices. For example, like-for-unlike replacements can occur (e.g., different pole or conductor materials and types) or changes in pole line configurations (e.g., covered aerial medium-voltage systems) as a result of storm events or regular maintenance schedules.[4]

This also includes taking more targeted actions to identify, monitor performance, and strengthen critical poles that are highly undesirable to have fail during a major storm. Some examples of critical poles include those that may be difficult to restore (e.g., freeway crossing), have a high cost to restore (e.g., automation equipment), or are critical during restoration (e.g., communications repeater). This targeted action can include audits that occur on a regular frequency or as a result of a one-time event. Consideration should be given not only to utility-owned equipment but also for third-party equipment on the distribution system. For example, an audit of third-party attachments (e.g., telephone, cable) could be conducted on a pre-defined basis (e.g., every five years at a minimum). Additionally, a plan could be established for trained staff to collect statistically representative data of distribution damage immediately after a storm event.

Distribution Infrastructure Future Modifications

Once robust processes and programs are in place, distribution infrastructure modifications should be explored. Of all the system "hardening" techniques, undergrounding the distribution system can initially appear to be the most obvious solution to increase resiliency. Although undergrounding the distribution system may reduce outage frequency, when outages affecting the underground portions of a system occur, restoration times and associated restoration costs can often increase due to the complexity of the system and difficulty accessing equipment or cables (especially when flooding exists).[6] However, the primary reason that undergrounding is not a "silver bullet" is because it can be cost-prohibitive. The Congressional Research Service report[5] estimates that the cost of burying power lines is 10 to 20 times more expensive than overhead cables, with local conditions accounting for the variance. In fact, the Edison Electric Institute reported that there was not a single study that recommended a complete conversion of overhead distribution to underground facilities.[2] The costs associated with a complete distribution system conversion, typically in the billions of dollars, are not economically feasible, and would severely impact customer rates.

A distribution-level undergrounding assessment should be conducted to determine optimal undergrounding locations that most effectively balance system value and cost. A targeted or selective undergrounding approach is usually recommended rather than total system conversion. Some of the selective undergrounding recommendations include undergrounding the worst performing circuit sections and high population density circuits. Additionally, circuits that are difficult to access, especially in terms of restoration time, are also attractive candidates for selection. For example, single-phase tap lines that serve remote areas and "rear-lot-line" circuits that are installed along the back of residential properties. This type of selective undergrounding would address common tree damage scenarios that are difficult to reach and must be cleared before energizing feeder sections. This enables crews to concentrate on the "main-line" three-phase circuits along roadways (generally the first to be cleared), thus facilitating the restoration of large blocks of customers more quickly.[6]



Managing Resiliency Checklist

A high-level checklist has been provided to assess a utility's capability level to manage resiliency. The grid practitioner should consider the comprehensiveness of their management efforts before making a selection. We encourage you to use this checklist as a practical reference tool to diagnose your current state of preparedness.

MANAGING RESILIENCY CHECKLIST
○ Infrastructure Standards & Processes: Establishment of a comprehensive set of key standard-driven processes for distribution system infrastructure for reinforcement and hardening **(1 point)**
○ Infrastructure Programs & Audits: Establishment of a comprehensive set of programs and audits for distribution system infrastructure fidelity and progressive upgrading **(1 point)**
○ Infrastructure Modifications: Establishment of a comprehensive distribution system infrastructure modification plan, including a distribution-level undergrounding assessment **(1 point)**

NOW

Maintaining Resiliency

Focuses on a utility's capability to keep the distribution system in an operational state

- Corrective (Reactive) Maintenance
- Preventive Maintenance
- Condition-based (Predictive) Maintenance
- Reliability-centered Maintenance
- Performance-focused Maintenance

Key Question: Are you EXECUTING resiliency practices?

Maintenance has become a central utility activity, as it has a significant impact on customer reliability and the bottom line. In the 'Managing Resiliency' section, some elements of maintenance were addressed, especially as it pertains to program and audit functions. As we transition into maintaining resiliency, a more holistic approach to maintenance will be considered. Maintenance now must include a deep understanding of failure mechanisms, economic analysis, end-of-life prediction, risk analysis, process measurement, and stakeholder involvement, with a constant reminder to all involved that— while the current strategy is adaptive—it is built on solid engineering principles that stand the test of time.[7] The challenge for utilities is to find the optimal balance between expenditure levels and achieving reliability targets. Economic conditions, regulatory mandates, and reliability or safety events can trigger ongoing shifts towards one objective over another. Several maintenance optimization models will be presented that provide different approaches for balancing varying objectives and associated risks.

Corrective (Reactive) Maintenance

Corrective maintenance is essentially the "run until it breaks" approach and is sometimes referred to as reactive maintenance. No maintenance actions are taken to ensure the design life is reached and repair or replacement only occurs when obvious problems or abnormal operations are detected. Typically, there are no expenditures of manpower or capital costs until something breaks, leading to the perception that money is being saved. In reality, this approach can often lead to less prudent capital expenditures associated with having to react to situations that demand a more urgent response (e.g., larger than needed material inventory, expedited shipping for specialty parts, overtime labor rates, additional contract labor, extended downtime costs). Additionally, waiting for equipment to fail typically shortens equipment life, leading to more frequent replacement and most likely more extensive repairs than would have been required as part of a more planned and controllable maintenance approach (e.g., costs associated with the failure of secondary devices).

Preventive Maintenance

Preventive maintenance is carried out at predetermined intervals, or according to prescribed criteria, aimed at reducing the failure risk or performance degradation of equipment. This type of maintenance approach seeks to sustain or extend equipment life by performing actions on a time or component-run-based schedule that detects, precludes, or mitigates degradation.

Preventive maintenance will not completely prevent catastrophic failures; however, the number and frequency of failures will be reduced. Equipment is also more likely to reach its design life and function at optimal levels which can result in energy and cost savings, especially for capital intensive processes. Although preventive maintenance may save or reduce labor costs, it can also be labor-intensive, involve unneeded maintenance, and can result in incidental damage to periphery components due to increased maintenance cycles. Preventive maintenance periodicity can be flexibly adjusted to optimize various equipment maintenance cycles.

Condition-based (Predictive) Maintenance

Condition-based Maintenance (CBM), sometimes referred to as predictive maintenance, involves the measurement and detection of degradation onset, thereby allowing causal stressors to be eliminated or controlled prior to any significant deterioration in the physical state of equipment. Similar to preventive maintenance, equipment is more likely to function at optimal levels which can result in energy and cost savings. CBM varies from preventive maintenance in that maintenance is based on the actual measured condition of the equipment rather than on a pre-set, time-based schedule (e.g., lubricant replacement based on properties rather than run time). CBM can extend equipment life, decreased equipment and process downtime, and reduced labor costs. Additionally, having quantifiable metrics for equipment degradation enables preemptive corrective actions, improved worker safety, reduced overtime, and even improved worker morale due to employee-driven corrections. Lean inventory levels can also be kept as parts can be ordered as required to support downstream maintenance needs.

CBM also comes with certain disadvantages. An increased upfront investment in diagnostic equipment is required along with ongoing staff training. More equipment means more parts that can potentially fail, regular hardware or software upgrades, and a firm commitment to make the program work by all pertinent staff. All of these added cost components can sometimes result in a savings potential that is difficult to quantify or justify to management. However, studies have estimated that properly functioning CBM programs can provide a savings of 8% to 12% over a program utilizing preventive maintenance alone.[8] Depending on a facility's reliance on reactive maintenance and material condition, it could easily recognize savings opportunities exceeding 30% to 40%.[8]

Reliability-centered Maintenance

Reliability-centered maintenance (RCM) is a systematic engineering framework that prioritizes and optimizes equipment and resources to increase equipment reliability and cost-effectiveness. RCM recognizes that not all equipment in a system are of equal importance from a process or safety perspective and that equipment has varying degradation mechanisms

and failure probabilities. It combines predictive and preventive maintenance techniques along with root cause failure analysis to precisely pinpoint and eliminate potential problems. SAE JA1011[9] establishes a minimum process criteria standard for RCM that is based upon a specific operating context.

RCM is highly reliant on predictive maintenance but also recognizes that maintenance activities on equipment that is inexpensive and less important to facility reliability may best be left to a reactive maintenance approach. Therefore, many of the benefits and disadvantages of predictive maintenance are realized but in a more efficient and cost effective manner by prioritizing reactive maintenance on less critical components. Additionally, the incorporation of root cause analysis techniques can increase equipment reliability by reducing repeated failure mechanisms, but typically involves greater upfront commitment and training of staff to apply a more rigorous analysis method and process.

Performance-focused Maintenance

Performance-focused Maintenance (PFM) is a full-spectrum maintenance philosophy that broadly covers various facets of maintenance including technical, financial, business, customer, and regulatory aspects. PFM does not require the replacement of an existing maintenance strategy (e.g., RCM, CBM) and can be comprehensively applied (e.g., in-depth maintenance approach analysis) or implemented in a specialized manner (e.g., correction of a specific maintenance issue). While traditional maintenance approaches focus on asset preservation and reliability, PFM seeks to establish maintenance targets that match strategic service-level requirements (e.g., comprehensive equipment performance and maintenance contributions) towards reaching an organization's business goals. This holistic approach is taken to overcome some of the existing shortcomings of maintenance approaches, such as: cost without considering value, short-term equipment issues vs. long-term corporate planning, inconsistent maintenance business cases and disparate asset data, reliance on historical asset data, and insufficient attention to risk and vulnerabilities.

Maintaining Resiliency Checklist

A high-level checklist has been provided to assess a utility's capability level to maintain resiliency. The grid practitioner should consider the comprehensiveness of their maintenance efforts before making a selection. We encourage you to use this checklist as a practical reference tool to diagnose your current state of preparedness.

MAINTAINING RESILIENCY CHECKLIST
○ Comprehensive Maintenance Plan Development: Establishment of a comprehensive maintenance plan that leverages one or several of the maintenance optimization models that most effectively match functional needs to budget constraints **(1 point)**
○ Comprehensive Maintenance Plan Performance: Regularly execute actions associated with a comprehensive maintenance plan that is broadly accepted and implemented across the utility at an enterprise level **(1 point)**
○ Comprehensive Maintenance Plan Review: Regularly review comprehensive maintenance plan to refine and update maintenance practices and actions, at least annually **(1 point)**

FUTURE

Modernizing Resiliency

Focuses on a utility's capability to be more flexible and adaptive to future grid technology integration and business markets

- Operational Technology (OT)
- Information Technology (IT) and OT convergence
- Energy market convergence

Key Question: Are you OPTIMIZING resiliency?

Once robust distribution infrastructure plans and comprehensive maintenance approaches are in place, the final step is to look into the future to continuously improve and optimize resiliency practices. In reality, resiliency is just one component of a larger grid modernization strategy, which involves a multi-dimensional optimization of the utility grid system. Grid modernization can be an expensive and complex endeavor affecting a multitude of stakeholders many of whom have conflicting interests and goals. To realize a future state of grid modernization, multiple value streams will need to be leveraged to justify the investment cost. Evolving grid technologies provide an opportunity for resiliency to grow from its traditional roots, as covered to this point, to a future state that is marked by progressive layers of enhanced grid system management. This progression toward a more comprehensive and holistic future and view of resiliency will be presented in three stages of evolution.

Operational Technology (OT)

Improved situational awareness and control of grid equipment significantly enhance a utility's ability to reduce the impacts of major events and speed up restoration efforts. In the context of infrastructure hardening, among the most cited benefits is the ability of the system to detect outages and remotely reroute electricity to undamaged (un-faulted) circuits. Through automated distribution technologies utilizing reclosers and automated feeder switches, faults can be isolated for greater system reliability with fewer customers affected. This involves the redesign of the distribution grid as a looping system that provides channels for rerouting power and several key technologies can be deployed:[10]

- Fault location, isolation, and service restoration (FLISR) systems (centralized or distributed)
- Intelligent Electronic Devices (IEDs) (e.g., line sensors and smart relays)
- Energy Management Systems (EMS)
- Distribution Management Systems (DMS)
- Advanced Meter Infrastructure (AMI)
- Supervisory Control And Data Acquisition (SCADA) systems for transmission & distribution
- Meter Data Management Systems (MDMS)
- Outage Management Systems (OMS)
- Geographical Information Systems (GIS)
- Mobile Workforce Management Systems (WFM)
- Communications Networks

Information Technology (IT) and OT Convergence

Although OT-focused deployment increases distribution system monitoring, control, and automation to potentially improve resiliency in a traditional operational sense, grid modernization efforts also provide new categories of resiliency and optimization on a more holistic level. This progression begins with the desire to aggregate various OT technologies, communications, and Information Technology (IT) networking together to enable more direct and comprehensive monitoring and control capability. This move towards enhanced aggregation not only creates more redundant and integrated systems but these operational technologies typically require a more robust IT backbone. Hence an IT/OT convergence begins to take form that simultaneously helps to strengthen vulnerabilities from both an operational and data management perspective to create a more robust and integrated grid.



A natural result of this convergence is the deployment of grid systems which function to control or aggregate other existing grid systems. Some examples of aggregating grid systems include Advanced Distribution Management Systems (ADMS) and Distributed Energy Resource Management Systems (DERMS). An ADMS provides real-time situational awareness of the electric grid and customer outages, using primarily the SCADA network, and is accessible by system operators and field personnel during the restoration process. Extending ADMS integration to include AMI meter data (power outage flag, power restore flag, voltage, communications ping) provides control room operators with real-time outage information at the individual service point level that enables them to check for service restoration and notify customers via various communication platforms, in addition to ensuring that field personnel are aware of the extent of the outage or restoration as it evolves. DERMS has an operational impact through direct monitoring and control of the DER equipment, but can also include AMI meter data and weather data to better monitor, control, and predict the operation of that equipment. Unless the IT components of an AMI and MDMS are included, the full potential of the OT components of an ADMS and DERMS will go unrealized.

Energy Market Convergence

The OT/IT convergence will occur over the course of several years and the pace of transition across the utility industry will be driven by varying utility drivers, both internal and external. There are common grid modernization themes but no single formula; therefore, each utility will need to determine a preferred grid modernization approach. Utilities must also consider factors that span beyond technology to geographic, political, regulatory, and customer concerns. The integration of hardware, software, and communications infrastructure provides

a more broadly capable platform for technology to more effectively interact and engage utility customers. This convergence between technology and people results in increased business channel potential and the evolution of enhanced energy services. As these energy services evolve, they will likely span across multiple types of energy sources (e.g. electric, water, gas), involve new types of solutions providers, and attract new types of customers. The result is a future state of advanced market convergence of people and technology. The definition of resiliency therefore continues to evolve into a more holistic concept. A utility's competence related to resiliency will not only be based on technical aptitude of operational and information technology, but also in terms of business acumen as it relates to people and markets.

One example of how OT/IT advancements could help advance technology into a future state of market convergence are microgrids. Microgrids are essentially miniature versions of the electric grid that include localized generation (e.g., different combinations of diesel generators, gas turbines, fuel cells, solar photovoltaic and other small-scale renewable generators), storage, and controllable load management devices. A microgrid can isolate itself from the utility grid or an undamaged branch of a utility circuit can be isolated to support customers while damaged sections are being restored. The microgrid senses loads and fault conditions and can reroute power to as many critical areas as possible given any situation, which is sometimes referred to as "self-healing".

As microgrid generators are connected to the utility grid, connected facilities may be able to purchase energy from the utility or wholesale market (Independent System Operator (ISO) or Regional Transmission Organization (RTO)) and sell locally-generated electricity back to the utility or wholesale market grid during times of peak demand. Additionally, several types of organizations that have a high demand for energy or a critical need for energy resiliency to avoid significant financial, safety, or security issues have an increasing interest in microgrids. Some examples are government facilities (federal, local, military bases), hospitals, data centers, research institutions/universities, commercial campuses, or densely populated urban centers. This combination of isolated two-way energy networks along with a growing involvement of different types of business entities begins to form the basis for transactive energy exchange.



Although there is increasing industry interest in the microgrid concept, deployment has been limited largely due to unattractive financial returns. The evolution of transactive energy markets and new energy services could help to address current financial microgrid roadblocks. In this way, microgrids could become a primary enabling technology to facilitate market convergence.

Modernizing Resiliency Checklist

A high-level checklist has been provided to assess a utility's capability level to modernize resiliency. The grid practitioner should consider the comprehensiveness of their modernization efforts before making a selection. We encourage you to use this checklist as a practical reference tool to diagnose your current state of preparedness.

MODERNZING RESILIENCY CHECKLIST
◯ Operational Technology (OT) Optimization: Establishment, prioritization, and deployment of a functional list of operational technology (OT) solutions that enhance and reduce impacts of major events and speed up restoration efforts **(1 point)**
◯ Information Technology (IT) & OT Optimization: Establishment, prioritization, and deployment of a functional list of technology solutions that enable the convergence of OT, communications, and IT solutions to enhance operational and data management resiliency **(1 point)**
◯ Energy Market Preparedness: Establishment of a functional list of technology solutions that enable the future convergence of energy markets and more effectively align business solutions with existing and new customer types to enhance operational, data, and business resiliency **(1 point)**

High-Level Maturity Assessment

Maturity is presented in terms of relative maturity within each framework area and according to total maturity. The relative maturity is determined by identifying how many points were earned within each of the three framework category checklists (a maximum of 3 points possible within each category). The points from each of the three areas are then added together to determine an overall resiliency maturity (a maximum of 9 points possible). To account for the importance of proper organizational alignment, an additional point is added, resulting in a 10-point scale. This final point is awarded to utilities that have clearly defined roles, accountabilities, and cross-functional organizational alignment (vertically and horizontally) across all three categories of resiliency presented (managing, maintaining, and modernizing).

Resiliency Maturity Scorecard

YOUR SCORE	EXPLANATION
0-2	>> **LEVEL 1—INITIAL:** Initial resiliency efforts exist, but additional planning and capability growth is needed. This level of maturity should focus on developing preparedness plans under the 'Managing Resiliency' section.
3-4	>> **LEVEL 2—BASIC:** Basic resiliency efforts and plans have been established. This level of maturity likely requires additional focus in developing 'Managing or Maintaining Resiliency' areas further.
5-6	>> **LEVEL 3—INTERMEDIATE:** Intermediate resiliency efforts and plans have been established. This level of maturity only requires slight optimization within the 'Managing or Maintaining Resiliency' areas and should begin to focus efforts in the 'Modernizing Resiliency' area.
7-8	>> **LEVEL 4—ADVANCED:** Advanced resiliency efforts and plans have been established. This level of maturity is almost exclusively focused in developing the 'Modernizing Resiliency' area and are robustly prepared within the 'Managing or Maintaining Resiliency' areas.
9-10	>> **LEVEL 5—OPTIMIZING:** Optimal resiliency efforts and plans have been established and are consistently being refined. This level of maturity is on the leading edge of grid modernization and is well positioned to manage all levels of concern along the resiliency continuum.

Conclusions

This white paper presents and makes the case for a resiliency framework targeted at strategic and tactical efforts to ensure safe, reliable electric power delivery. The time-based framework is equally applicable before, during, and after any type of grid contingency that impacts the delivery, and provides guidance for the gamut of utility and vendor personnel empowered to ensure this delivery.

Similar to the resiliency framework, maturity is on a progressive continuum that can never fully be attained and necessitates continual effort. When low maturity levels are indicated, corrective action should be put in place as soon as possible to increase preparedness, responsiveness, and to minimize long-term costs. However, once higher levels of maturity are attained, the focus shifts towards continuous improvement of established business practices with an eye towards integrating anticipated changes occurring within the energy landscape.

As a utility grows in resiliency maturity, the scope of work and strategic planning required becomes broader and more complex. Resiliency is one component of a larger grid modernization strategy that empowers utilities to take part in shaping the electric industry evolution. This is both an exciting and daunting proposition for many grid practitioners who are uncertain where to begin or what steps to take next. Although a grid practitioner's work never ceases, those that seek continuous improvement, new ways of thinking, and embrace industry shifts will end up being the most successful. Resources like these help to provide some practical guidance for defining and taking steps along a grid modernization pathway. We hope you find this white paper to be a practical guide in assessing your resiliency maturity, identifying immediate areas for improvement, and that it leads you to take incremental steps forward.

ABOUT ENERNEX

EnerNex, a CESI company, is a leader in providing research, engineering and consulting services to the electric power industry worldwide. Founded in 2003, the company is focused on helping our clients understand, adopt and leverage new and emerging electric power technologies to advance a cleaner, smarter energy system of the future.

Visit **enernex.com** *to schedule a conversation and learn more about how we can help.*

@enernex enernex

REFERENCES

1. National Infrastructure Advisory Council, "A Framework for Establishing Critical Infrastructure Resilience Goals," www.dhs.gov/xlibrary/assets/niac/niac-a-framework-for-establishing-critical-infrastructure-resilience-goals-2010-10-19.pdf, October 19, 2010.

2. Edison Electric Institute, "Before and After the Storm—A compilation of recent studies, programs, and policies related to storm hardening and resiliency," www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/BeforeandAftertheStorm.pdf, March 2014 updated.

3. R.E. Brown, T&D World, "Storm Hardening the Distribution System," www.quanta-technology.com/sites/default/files/doc-files/TDW-Storm-hardening-paper.pdf, June 2010.

4. Southwire, "Covered Aerial MV Systems (formerly Spacer Cable) now available," www.southwire.com/distribution/CAMVavailable.htm.

5. R.J. Campbell, Congressional Research Service, "Weather-Related Power Outages and Electric System Resiliency," www.fas.org/sgp/crs/misc/R42696.pdf, August 28, 2012.

6. Electric Power Research Institute, "Enhancing Distribution Resiliency: Opportunities for Applying Innovative Technologies," www.epri.com/#/pages/product/1026889/, January 11, 2013.

7. J.E. Skog, *Electric Light and Power*, "Alphabet Soup: Making Sense of Maintenance Strategies," https://www.elp.com/articles/powergrid_international/print/volume-13/issue-8/features/alphabet-soup-making-sense-of-maintenance-strategies.html, August 1, 2008.

8. Department of Energy, DOE: Federal Energy Management Program (FEMP), "Operations & Maintenance Best Practices: A Guide to Achieving Operational Efficiency," Release 3.0, section 5.3, https://www.energy.gov/sites/prod/files/2013/10/f3/omguide_complete.pdf, August 2010.

9. SAE International, "Evaluation Criteria for Reliability-Centered Maintenance (Rcm) Processes," *SAE JA1011*, www.sae.org/standards/content/ja1011_199908/, September 26, 2009.

10. The GridWise Alliance, "Improving Electric Grid Reliability and Resilience: Lessons learned from Superstorm Sandy and Other Extreme Events," Workshop Summary and Key Recommendations, https://www.energy.gov/sites/prod/files/2015/03/f20/GridWise%20Improving%20Electric%20Grid%20Reliability%20and%20Resilience%20Report%20June%202013.pdf, June 2013.

ABOUT THE AUTHORS



Neil Placer

Neil Placer is the Director of Utility Services Consulting at EnerNex. Placer has an in-depth understanding of the energy sector based upon his 20 years of cross-cutting professional experience. He has been a policy strategist for a major electric utility, a design engineer for a renewable energy manufacturer, and an engineering officer for the federal government. His current role as a strategic energy consultant is to assist utilities with solving complex grid modernization challenges. Placer's overarching focus is to combine his strategic, technical, and communications capabilities to translate multifaceted challenges into holistic, "no regrets" solutions for clients. Placer has a B.S. in Mechanical Engineering from Virginia Tech. You can reach Neil at nplacer@enernex.com.



Aaron F. Snyder

Aaron F. Snyder obtained his BSEE (1993) and MSEE (1997) from Virginia Polytechnic Institute and State University, and his *Diplôme d'Études Approfondies* (1996) and *Diplôme de Docteur* (1999) from the *Institut National Polytechnique de Grenoble* in Grenoble, France. As the Director of Grid Technology Consulting at EnerNex, Aaron works with utility and vendor clients on metering, AMI, Smart Grid, and Grid Modernization projects. In recent years he has been supporting AMI, DA, Microgrid, and ADMS projects in the USA and Middle East, including enterprise architecture, strategy development, requirements, equipment specifications, procurement support, and pre-deployment activities. He is a Board member of the UCA International Users Group, and participates in standards development activities at national and international levels. He is a Senior Member of IEEE. You can reach Aaron at aaron@enernex.com.