Substation Resiliency Planning

The Predictive Revolution and Emerging Best Practices

DELTA STAR INCORPORATED

WHITEPAPER

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SECTION 1

INTRODUCTION

According to the U.S. Energy Information Administration, electricity customers averaged about four to six hours without power in 2016. In many industries, 99.95% uptime would be a major achievement. But in a business where 24/7/365 uptime is demanded, every hour of outages brought additional pressure to substations and their teams. A single incident can cost utilities tens of thousands in emergency equipment costs and manpower, with the added potential for stiff financial penalties from Federal regulators.

Yet, with stretched budgets and fierce competition in the energy sector, the temptation to put off the adoption of improved maintenance strategies is greater than it's ever been. In fact, most operators are doing precisely that. The Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) estimates that over 55 percent of electricity suppliers use reactive maintenance as their primary strategy.

In this whitepaper, Delta Star explores the present and future of substation maintenance and monitoring. We discuss what a well-executed planned maintenance program looks like and how it delivers value. We also look ahead to the world of remote monitoring and predictive maintenance – a world where suppliers will reap the benefits of light-touch inspection regimes and just-in-time repairs – provided they make the right decisions today. Finally, we explore resiliency planning options that help ensure continuous power delivery to customers.

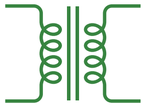
MAINTENANCE & MONITORING CHALLENGES

As competition between providers intensifies and customers demand lower rates, electricity suppliers are seeking new approaches to managing tight budgets.

As a result, many substations are under pressure to maximize the cost-effectiveness of their maintenance and monitoring strategies. Yet, with assets aging, these demands often mean doing more with less. The challenges substation operators and their teams face are many and include:

AGING ASSETS & SYSTEMS

Require a higher frequency of maintenance and scheduled outages, risking system availability. Transformers past the end of their normal operating life pose a particular risk.

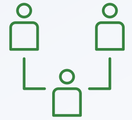


OVERUTILIZED ASSETS

Delivering more electricity without adding assets puts greater demand on transformers. When used beyond their normal operating limit, transformers are at high risk of failure and have potential to overload other transformers and equipment, causing them to fail as well.

LACK OF MONITORING TECHNOLOGY

Visual and manual inspections can be unreliable, leading to equipment overheating and leaking due to undiagnosed problems with the potential to cause critical substation failure.



SMALL TEAMS

Fewer people and resources often lead to such issues as missed maintenance cycles, less emergency support, and reduced oversight. In addition, as maintenance workers retire, their positions often prove difficult to fill, and they often take with them irreplaceable specialist knowledge.

SECTION 2

MAINTENANCE & MONITORING CHALLENGES

While the checklist of concerns for substation operators is growing, the real challenge is implementing new best practices for assessing and addressing issues to avoid failures. As any operator knows, when assets fail, the entire system is put at risk.

> *"The challenges substations face can either spur indecision or drive continuous innovation and efficiency improvements. As substations work smarter, reactive and preventive maintenance programs are being left behind in favor of predictive-based strategies and the deployment of smart grid technology built to help utilities automate and scale."*
>
> – Shane Smith, Delta Star Director of Quality, Customer Solutions Group

SECTION 3

SUBSTATION MAINTENANCE APPROACHES

Maintenance is key to profitability and reliability: it's critical for any substation to adopt maintenance strategies that minimize service disruptions and make power delivery more cost-effective. For most substations, inspection and maintenance – whether reactive, planned or, increasingly, predictive – remains the backbone of a strategy for keeping substations reliable and productive. Here we compare the three primary maintenance strategies to determine which is best for substations and their customers.

3.1 REACTIVE MAINTENANCE

According to the Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), over 55 percent of electricity suppliers use reactive maintenance as their primary strategy. Yet this "run it until it breaks" approach has few, if any, long-term advantages.

Day-to-day, maintenance costs are typically lower using reactive maintenance because equipment is only repaired or replaced once it fails. Plus, with less maintenance taking place, fewer team members are needed to keep a substation operational.

Over the long term, however, costs tend to be much higher than other maintenance approaches – and they can escalate suddenly and quickly.

Reactive Maintenance Challenges

Without proactive planned maintenance, substation assets experience shortened lifespans, bringing forward the cost of replacing assets by years or even decades. In addition, under-maintained assets create the ongoing threat of a "domino effect" that impacts secondary assets and systems. Finally, when equipment does fail, fixing it typically involves overtime and extra manpower to get backup systems online and fix the problem.

3.2 PREVENTIVE MAINTENANCE

Originally developed by the U.S. Navy to ensure fleet reliability, preventive maintenance uses a time-based or operation-based schedule to determine when an asset needs repair or replacement.

Much like automobile manufacturers recommend having a vehicle's oil changed every six months or 3,000 miles, asset maintenance is performed according to a prearranged schedule.

DECREASES SUBSTATION DOWNTIME

IMPROVES LIFESPAN OF EQUIPMENT & ASSETS

SAVES 12-18% OVER REACTIVE MAINTENANCE

Preventive Maintenance Challenges & Advantages

only does this enable the inspection and replacement of lubricants and protectants – the first line of defense for any transformer – it enables teams to identify and correct an issue before it becomes a bigger problem, potentially saving on a larger or more expensive repair or replacement.

While this means more labor is involved on a regular basis, substation systems often run more efficiently, and asset lifecycles are improved substantially.

Compared to reactive maintenance, the EERE estimates that preventive maintenance generates cost savings for substations of 12-18 percent overall.

3.3 PREDICTIVE MAINTENANCE

Adapted and refined by NASA, which reported a 50 percent reduction in annual costs through the approach, predictive maintenance is gaining ground as a strategy for substations.

Where preventive maintenance uses time or hours of operation to determine a maintenance schedule, predictive maintenance relies on sophisticated technology, analytics, and expert insights to aid in maintenance decision-making.

ENHANCES SURVEILLANCE WITHOUT REQUIRING MORE PERSONNEL

IMPROVES TEAM RESPONSIVENESS & REQUIRES FEWER EMERGENCY REPAIRS

ENABLES A PHASED APPROACH AND INTEGRATES WITH MOST LEGACY SYSTEMS

SAVES 8-12% OVER PREVENTIVE MAINTENANCE & UP TO 30% OVER REACTIVE MAINTENANCE

Predictive Maintenance Advantages

Combining on-site and off-site monitoring, an electrical system undergoes real-time testing and measurements to detect issues that might go unnoticed through visual or manual inspection. As equipment is scanned using infrared, ultrasound, online temperature monitoring, fluid analysis, or other monitoring methods, data is captured that enables analytics to indicate the current status and project the future state of an asset or system.

With constant substation monitoring, issues can be identified in real time on such critical assets as:

- Power transformers
- Insulator bushings
- Lightning arrestors
- Mechanical disconnects
- Batteries
- Load tap changers
- Standoff insulators
- Circuit breakers
- Control cabinets

Predictive maintenance enables teams to respond before a component fails, resulting in less downtime and fewer emergency repairs. It also requires less system oversight, enabling operators to focus on other important tasks instead of scheduling unnecessary equipment inspections.

Plus, as retrofit or “wrap-and-extend” solutions become more available, the integration of advanced technologies with legacy equipment grows more seamless, making it easier to upgrade systems as budgets allow, without concerns about workability.

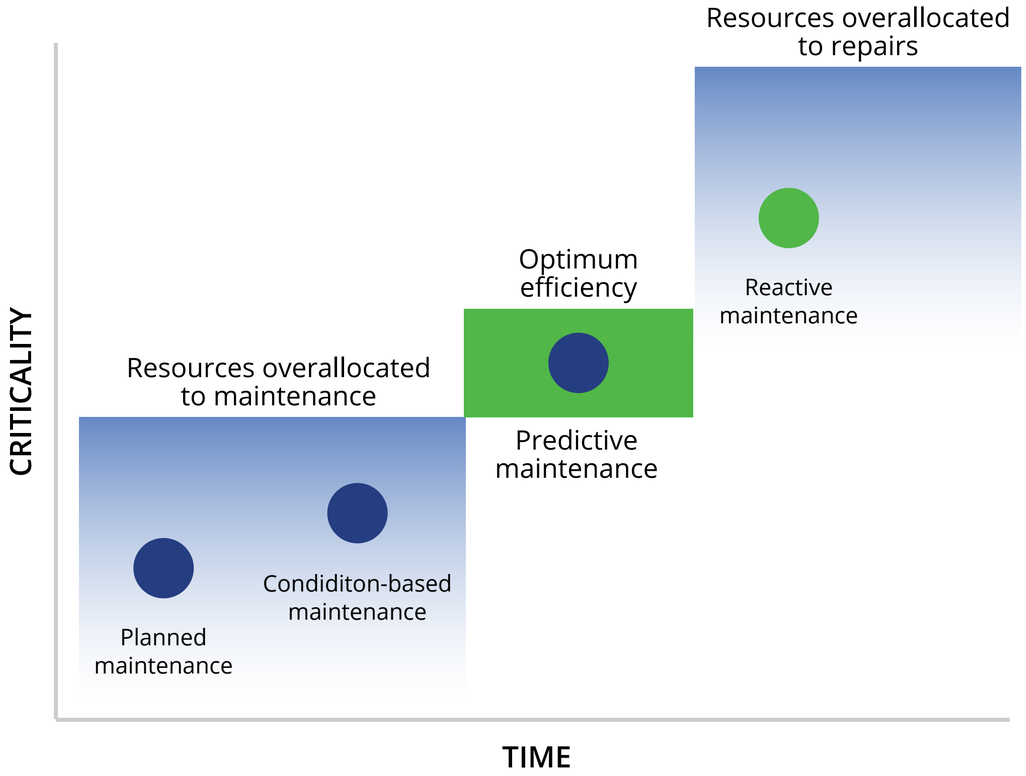
The EERE estimates that predictive maintenance programs generate 8-12 percent in cost savings over a preventive maintenance program, and up to 30 percent over the reactive approach, even for substations with older or legacy equipment.

3.3 PREDICTIVE MAINTENANCE (CONTINUED)

Effective predictive maintenance depends on the ability to capture and interpret continuous streams of data, independently of the traditional inspection cycle. In turn, that approach requires investments in remote monitoring that operators have traditionally been hesitant to make, as well as in people who can quickly and accurately interpret that data and react appropriately. As technology advances, however, the value that can be derived from remote monitoring only continues to grow.

> *"Predictive maintenance is key to transformer life expectancy. Oil, DGA, and electrical testing helps identify problems early and is less time-intensive and costly than replacing assets, and can mean the difference between a transformer failing in months or lasting for decades more."*
>
> – Jon Langley, Delta Star Field Service Sales Manager

EFFICIENCY OF MAINTENANCE STRATEGIES



SECTION 4

THE VALUE OF SUBSTATION MONITORING

The ability to monitor facilities remotely has obvious advantages. However, substations that operate on tight budgets and with small teams typically prioritize inspection and maintenance over monitoring. This is understandable, but the approach also has limitations operators need to bear in mind.

3.1 REACTIVE MAINTENANCE

ADVANTAGES	DISADVANTAGES
✓ Equipment is physically inspected	✗ Inspection is often limited to what can be physically accessed
✓ Maintenance is only performed as needed	✗ Substation Resiliency Planning: The Predictive Revolution and Emerging Best Practices
✓ Day-to-day operational costs are reduced	✗ High risk of expensive repairs after asset/system failure
✓ Fewer team members to manage	✗ Less visibility into system reliability and asset performance
✓ Less technology to implement and learn	✗ Legacy systems and lack of technology can limit long-run competitiveness

4.2 THE RISE OF SUBSTATION MONITORING

Over the past decade, new technologies have changed how monitoring is performed at substations. The addition of microprocessor-based controllers that allow offsite monitoring capabilities has enabled substations to constantly monitor equipment status and improve repair responsiveness. What's more, they've lowered operational expenses by enabling substations to phase out unnecessary instrumentation and reduce maintenance visits.

Examples of real-time monitoring solutions include:

- Fiber optic probes
- Automated FLIR (thermal) imaging
- Switchyard sensors for temperature and pressure
- Oil and gas monitoring devices
- Current and voltage sensors
- Intelligent Electronic Devices (IEDs) for:
  - Metering and monitoring relays
  - Control house safety function relays
  - Transmission line protection relays
  - Transformer protection
  - Bus protection
  - Fault recorder

Historically, traditional systems have lacked the ability to react to failures quickly enough to prevent additional failures. By contrast, today's monitoring systems can regularly catch issues ahead of time, enabling teams to save connected assets from disaster. From monitoring individual pieces of equipment to an entire substation, new capabilities have changed how substations operate. This new strategy emphasizes the importance of identifying failures at the right time, to keep repair costs at a minimum and continue operating at peak efficiency.

Monitoring may not be a one-size-fits-all solution. But compared to twenty-five years ago, when most monitoring devices existed primarily to support immediate operations, today we see utilities capturing a richer data set to better serve functions like maintenance and asset management. Technology advancements and cybersecurity defense strategies have led some utilities to migrate this additional monitoring traffic off the operational network. At the same time, edge computing and smarter devices have enabled the fusion of all relevant data within the substation. This allows the owner to apply analytics, automate real-time decisions, and convert this data into actionable intelligence.

These increased capabilities come with implementation costs. However, those costs must be balanced against the expenses of existing maintenance – not to mention the harder-to-measure risk of unexpected equipment failures.

> *"Most of the challenges substations face can be overcome with today's technology. Simple monitors like pressure transducers and moisture-in-oil sensors enable early detection of conditions that might otherwise go unnoticed. Tremendous insight can also be obtained with thermal cameras, inspections, and online oil sampling while equipment is still in service. Finding the right blend of remote monitoring and physical inspection is key."*
>
> – Shane Smith, Delta Star Director of Quality, Customer Solutions Group

SECTION 5

THE IMPORTANCE OF RESILIENCY PLANNING

Ideally, the technologies used to monitor critical assets will reach a point where they can provide real-time intelligence, identify necessary maintenance, provide condition-based performance capabilities, and predict the end of life of critical assets.

However, each utility must still be prepared to ensure power delivery during outages and respond to the intelligence provided through smart grid initiatives.

For this reason, resiliency plans should include contingency assets, particularly for equipment with long lead times such as substations, power transformers, breakers, switchgear, and regulators.

5.1 SPARE TRANSFORMERS

Transformers are the most expensive and longest lead asset within the substation – often costing close to $1M to replace and anywhere from 12-17 months to quote, design, build, deliver, and install. However, transformers also play the biggest role in substation performance. As such, maintaining a spare transformer fleet should be considered a top priority for utilities.

As a best practice, many utilities purchase one spare transformer for every five to seven units of any specific design depending on the level of grid redundancy. When an asset needs replacement or a greenfield project is delayed, utilities pull from a spare program to replenish unit failures or fill in as a contingency asset. New units are ordered as soon as a spare is put into service.

For substations with storage limits or budget constraints, transformer resiliency options include:

- Onsite storage for transformers while pads are being completed
- Keeping materials and equipment such as load tap changers and bushings on hand
- Constructing a tank to reduce lead times

"Build and hold" programs can also help utilities by having transformers manufactured up to a year in advance, ensuring an emergency spare is on hand and can be delivered within a few days to a few weeks. This enables utilities keep assets off their property and away from such dangers as terrorist attacks and natural disasters.

5.2 MOBILE SUBSTATIONS

Spare transformers are essential to any resiliency initiative. However, monitoring spares and managing backup plans from resiliency partners can affect a team's responsiveness.

If the substation is compromised, it can take weeks or months to remove and replace damaged equipment and restore power flow. Meanwhile, mobile substations can be deployed and installed in less than a day and stay operational for a few years depending on the application.

Typically designed on a single trailer with low- and high-side protection, mobile substations are self-contained, ready-to-connect assets that are easily transportable, maneuverable, and designed for grid code compliance. And while mobile substations can cost utilities upwards of $2M, they spare utilities from the expenses associated with financial penalties, lost customers, and delayed projects.

5.3 SKID MOUNTED SUBSTATIONS

As a further alternative to mobile substations, many utilities find skid-mounted substations the ideal solution for supporting greenfield projects, unique industrial customers, and long-term reconstruction projects.

Made for quick and easy deployment, skid-mounted substations can be configured for longer deployments ranging from 1-30 years without requiring a traditional substation. Designed and constructed in as little as 38 weeks, and ranging in cost from $1.4-1.7M, skid-mounted substations are a more customizable, cost-effective approach for utilities seeking code-compliant options that ensure power delivery across a variety of applications. Additionally, skid-mounted substations often provide the versatility substations need as part of a resiliency strategy.

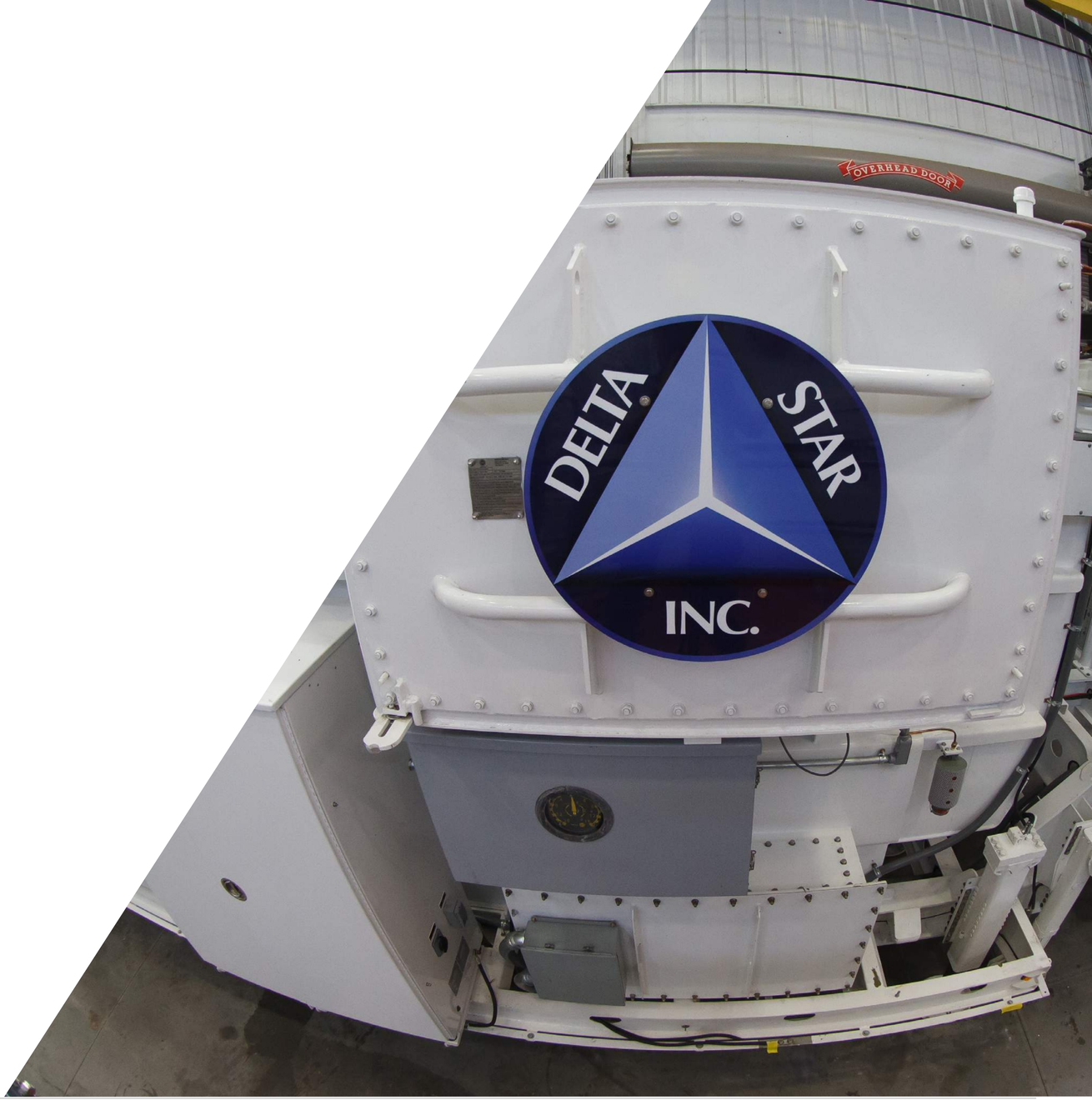
SECTION 6

CONCLUSION

With over 4 trillion kilowatt hours used in the U.S. annually and industry growth picking up, always-available and always-reliable electricity is, and will continue to be, the ultimate goal of substation operations.

For that to happen, teams must adopt a well-planned maintenance strategy to ensure substation reliability, along with a smart monitoring strategy. This monitoring strategy should include the use of physical/visual inspections, real-time monitoring, or a combination of both efforts to keep systems and assets running optimally.

For even better preparedness, substation strategies should also include a resiliency plan that may include deploying a mobile substation or skid substation to ensure power can be restored within a few hours. With these strategies working together, utilities have the tools and assets needed to maintain power with little to no interruption.



ABOUT DELTA STAR

Founded in Chicago in 1908, Delta Star launched as a manufacturer of electrical devices in the generation, transmission, and distribution sectors. As the company grew, it became nationally recognized for its substation development and improvement expertise, leading to a special request for 15-ton, 286,000-volt air-break switches for the Hoover Dam.

Today, Delta Star owns more than 100 electrical industry-related patents and delivers power transformers, mobile transformers, mobile substations, and parts to U.S. customers and globally. As part of its ongoing commitment to customer service, Delta Star also offers field service to assist customers with installation, processing, standard maintenance, and asset optimization.

Delta Star is an ESOP (employee-owned company) that owns and operates three manufacturing facilities and a North American service division. Our range of products and services include:

Products

- Power Transformers (up to 345 kV & 200 MVA)
- Auto Transformers (up to 345 kV & 300 MVA)
- Single Phase transformers
- Single- and three-phase regulators
- Skid-mounted substations or portable substations
- Mobile substations
- Mobile transformers
- Mobile regulators
- Auxiliary cable reel trailers (enclosed options available)
- Auxiliary breaker trailers
- Auxiliary barrier trailers (various quick deploy fence options)

Services

- Substation security
- Asset assessment
- Asset monitoring
- Transformer services
- Relocations services
- Mobile substation services
- Mobile transformer/substation retrofit & repair (field & factory options)
- Control retrofits & monitoring upgrades
- Oil processing services
- LTC repair/retrofit services