WHITE PAPER:

MEET MERLIN™: HOW AI IS TRANSFORMING PQ ANALYSIS

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THE NEW FACE OF GRID RESILIENCE

For most of the twentieth century, "resilience" in electric power meant hardware: thicker conductors, tougher poles, more redundancy. Today, resilience is increasingly defined by awareness — how fast an operator can detect, understand, and respond to an event before customers notice. The modern distribution system is awash in information from recorders, smart meters, RTUs, and switching devices, yet human attention has not scaled to match it.

As grid and load complexity increases and distributed generation proliferates, utilities face a torrent of sensor data, ranging from simple RMS voltage and current to complex distortion, flicker, and stability metrics. In this environment, artificial intelligence is not replacing engineers; it is amplifying their interpretive capacity. Systems such as Merlin™ from Power Monitors, Inc. represent a quiet but powerful shift: instead of asking engineers to read every chart, they have "eyes on" every piece of data - classifying, ranking, spotting patterns, and summarizing what matters — so the human expert can act sooner and with greater confidence.

DATA NOISE VS. OPERATIONAL INSIGHT

Every utility engineer knows the paradox of abundance: more data often means less clarity. A single power-quality (PQ) recorder running for a month can generate gigabytes of stripcharts, waveform captures, and compliance reports. Sorting through that by hand once required hours of interpreting graphs, compiling statistics, and cross-referencing standards.

The human cost is real. Skilled PQ specialists are scarce; their time is consumed by triage rather than root-cause analysis. Different analysts interpret the same evidence differently, which complicates reporting and regulatory response. Meanwhile, the physical grid keeps changing — solar back-feed at noon, EV clusters at night, switching transients in between. Disturbances that once appeared rarely now appear daily, hiding among terabytes of benign variation. Permanent monitors provide valuable information on standards exceedances, PQ compatibility issues, and disruptive customers causing problems for others, but there isn't enough human bandwidth to interpret the flood of incoming data.

Resilience, in this context, is cognitive. The faster a utility can move from raw data to coherent diagnosis, the less exposure it has to prolonged or repeated voltage excursions, customer equipment damage, and liability for standards violations.

THE EMERGENCE OF "ANALYST-GRADE AI"

Early AI pilots in the power sector were powered on machine learning (ML), focused on prediction: outage forecasting, fault location, and load estimation. These models are useful, but too brittle and overfitted to be widely applicable in the "wild west" of the distribution network. Techniques successful in a transmission network, with far fewer nodes and static topology, do not scale well to the far more varied and ever-changing distribution system. A new generation of AI tools, like PMI's Merlin™, applies large-language-model reasoning to a different task — "eyes on" review and explanation. Instead of controlling or attempting to model the grid, these models interpret deterministic analytics already produced by utility software.

In the PQ domain, Merlin™ converts the numeric output of compliance engines and metrics, along with LLM-based graphical data interpretation into a structured narrative that an engineer or regulator can read in plain language (**Figure 1**). Merlin™ identifies which findings exceed IEEE or ANSI limits, groups them by cause, and ranks them by risk and potential utility and customer impact. LLM-based image analysis removes the brittleness that comes from ML algorithms trained on limited datasets. Every number still comes from standards-based deterministic algorithms, but the LLM-AI adds a layer of "human-like" graphical interpretation, then the AI organizes, explains, and highlights relationships that might otherwise take hours to see (**Figure 2**). Utility beta testing with Merlin™ shows that engineers spend more time solving problems rather than searching through data with AI-assisted analysis.

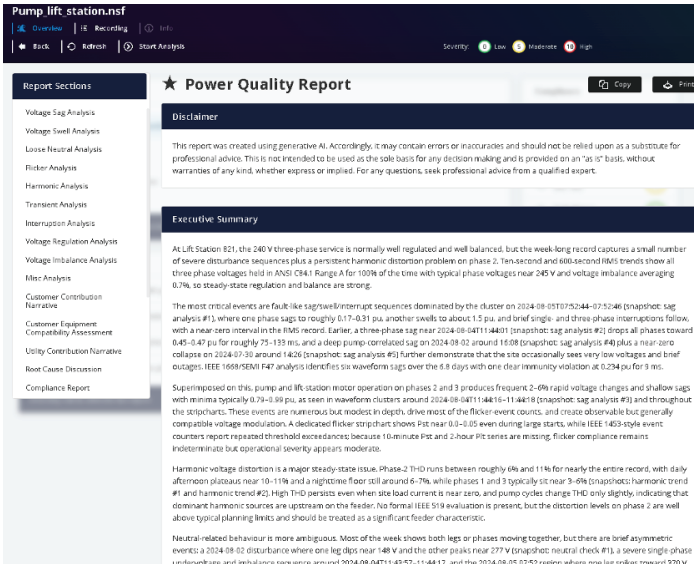

Figure 1.Top level PQ report generated by PMI's Merlin™.

Because Merlin™ never invents data or thresholds and backs up all conclusions with deterministic standards-based computations, LLM-flagged graphs, and cites to IEEE standards, this "analyst-grade" AI remains fully auditable — an essential feature for regulatory trust and cybersecurity. The result is not autonomy but augmented interpretation: an engineer receives a coherent story instead of a pile of plots or a sea of numbers.

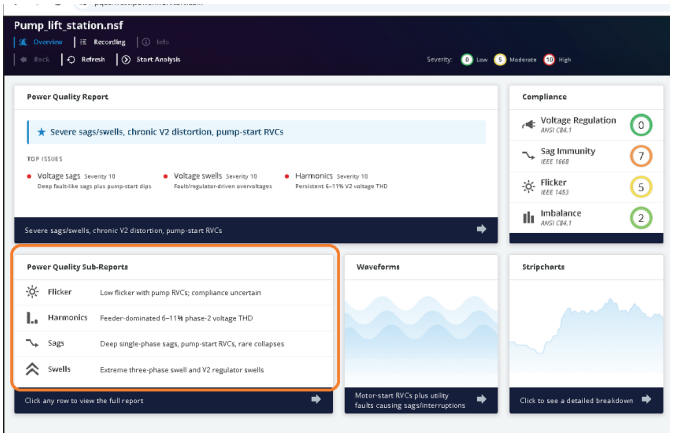

Figure 2. PMI's Merlin™ PQ Topic In-Depth Reports

FROM EVENT TO INSIGHT

Consider a common scenario. A feeder serving a mixed commercial district reports repeated voltage sags during weekday afternoons. Field crews install a PQ recorder at a key customer service transformer. Immediately, the PQ recorder begins streaming PQ data to the cloud platform. Behind the scenes, deterministic analytics calculate RMS profiles, sag metrics, and flicker indices. The AI layer then produces a concise report:

- Two sags around 80 % voltage for 0.15 s — classified per IEEE 1668 as Type B events that do not exceed SEMI-F47 limits
- Correlated current spikes suggest inrush from large motor starts around 13:20 local.
- Flicker within IEEE 1453 limits, voltage regulation within ANSI C84.1 Range A.
- Confidence high; further verification recommended if new loads were added that week.

THE HUMAN INTERFACE: TRUST, TRANSPARENCY, AND SECURITY

For utilities exploring AI, the first question is rarely "what can it do?" — it is "can we trust it?" The answer lies in design boundaries. PMI's Merlin™ exposes only human-verifiable information (**Figure 3**):

- Deterministic numbers stay fixed. Voltages, durations, and compliance flags are computed by established standards algorithms before the AI ever sees them.
- AI adds narrative and emphasis, not math. It clarifies findings, compares them to known standards, and explains likely mechanisms — for example, "motor inrush consistent with 0.78 pu sag."
- Everything is analyzed. The "eyes-on" concept ensures that every piece of data is thoroughly examined, every time.
- Confidence and uncertainty are explicit. Each section includes a confidence score derived from data completeness and sensor quality, so users can weigh statements appropriately.
- Cyber isolation is preserved. The AI works entirely within the utility's data domain; it has no control authority, network access, or ability to alter records.

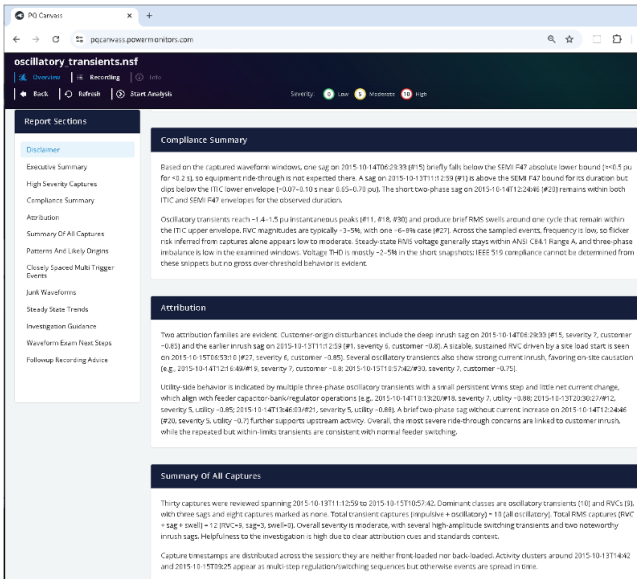

Figure 3. *Actual waveform report generated by PMI's Merlin™*

This architecture turns AI into a junior engineer and translator, not a controller. Engineers remain the final interpreters, regulators can audit every figure, and cybersecurity teams can certify that nothing autonomous touches operational systems. Transparency breeds confidence — and confidence is the foundation of resilient operations.

AI AS A RESILIENCE MULTIPLIER

In distribution networks, resilience is measured in hours of service preserved and incidents avoided. AI contributes, not by replacing equipment but, by enhancing awareness at three crucial points: detection, diagnosis, and learning.

1. Detection — Surface the subtle.
   Continuous monitoring can reveal faint patterns: a slow rise in voltage imbalance, a repeating flicker

index that hints at evening load cycling, or harmonics creeping toward a limit. AI sifts through these variations automatically, flagging those worth human review

2. Diagnosis — Correlate cause and context. When a disturbance occurs, the system links PQ evidence to standards clauses and to correlated load behavior. The engineer sees both symptom and probable mechanism — without combing through hundreds of plots.

3. Learning — Build institutional memory. Because each analyzed recording is archived with its AI-authored summary, utilities accumulate a searchable library of PQ cases. Over time this becomes a knowledge base for training, benchmarking, and fleet-wide trend detection.

In practice, these capabilities translate into fewer repeated complaints, faster fault isolation, and better prioritization of field work — each a pillar of operational resilience.

INTEGRATING ENERGY STORAGE AND DISTRIBUTED GENERATION

Energy storage and inverter-based resources have become indispensable for grid flexibility — and new sources of PQ complexity. Rapid inverter transitions can cause flicker, harmonic resonance, or temporary voltage regulation challenges. Understanding these behaviors in context is critical for both customer satisfaction and grid security.

Tools like Merlin™ provides that context. When a storage system charges at full rate, the analytics may show a repeatable 2% voltage dip coinciding with current inrush. Merlin™ explains the event in plain language, relates it to IEEE 1547 limits, and distinguishes between utility-side and customer-side causation. For DER planners, this is invaluable: issues can be mitigated with control adjustments rather than costly infrastructure upgrades. By turning data into comprehension, AI tools become the connective tissue between distributed flexibility and system stability. They help ensure that resilience gains from storage do not come at the cost of local PQ degradation.

HUMAN-CENTERED AUTOMATION

A persistent misconception is that automation diminishes human expertise. In power quality work, the opposite is true. Automation liberates experts from routine synthesis so they can focus on judgment and communication — tasks still uniquely human. Engineers using AI-augmented tools report spending less time compiling reports and more time interpreting cause, impact, and remediation. The interface is conversational: they can ask for clarification ("show me the waveform behind this finding") or request a summary suitable for a customer letter or regulatory filing. The tone, technical depth, and emphasis can adapt to the intended audience — engineer, regulator, or non-technical stakeholder — without altering the underlying facts. This kind of human-AI partnership transforms PQ investigation from a reactive chore into a continuous learning process — one that directly supports grid-wide resilience.

SECURITY AND EXPLAINABILITY

Grid operators are understandably cautious about introducing AI. The key safeguard is explainability. Every conclusion in a Merlin™ report can be traced to deterministic evidence: a clause citation, a waveform capture, a measured voltage. Nothing is inferred without source data. Such traceability aligns with emerging NERC and DOE guidance that emphasize "human-in-command" AI for critical infrastructure. By keeping AI's role interpretive, not operational, utilities gain analytical speed without expanding their attack surface or losing accountability. In essence, explainable AI becomes another layer of defense — against both misinterpretation and misinformation.

TOWARD A MORE RESILIENT MINDSET

The industry's language around resilience is evolving. Hardening assets will always matter, but increasingly resilience means seeing trouble sooner, communicating it clearly, and learning faster from every disturbance. AI makes that possible at scale. Instead of waiting for a complaint or a violation report, followed by a human engineering review of the data, utilities can detect and understand PQ degradation proactively. Instead of losing time to data wrangling, they gain time for collaboration and planning. And because the underlying data and citations remain transparent, trust between utilities, regulators, and customers is strengthened rather than diluted.

RESILIENCE AS COMPREHENSION

In the end, resilience is not only about bouncing back from storms — it is about comprehending the grid's behavior under stress. The power system speaks in harmonics, sags, flicker, transients, and imbalance; AI tools like Merlin™ help translate that language into human understanding. When engineers can see the story behind the numbers, the grid becomes more predictable, safer, and more secure. AI is not a black-box replacement for expertise; it is an accelerant for insight. And insight, shared quickly and clearly, is what keeps the lights on in an increasingly complex electric world.

