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POWER SYSTEMS TECHNOLOGY

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TRANSFORMER TECHNOLOGY MAG

POWER PANELS

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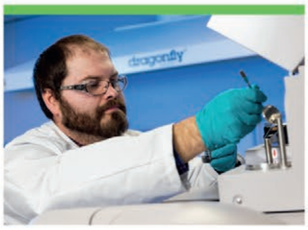

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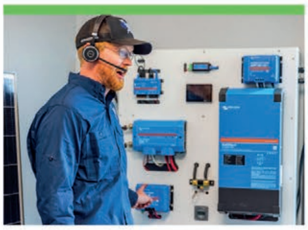

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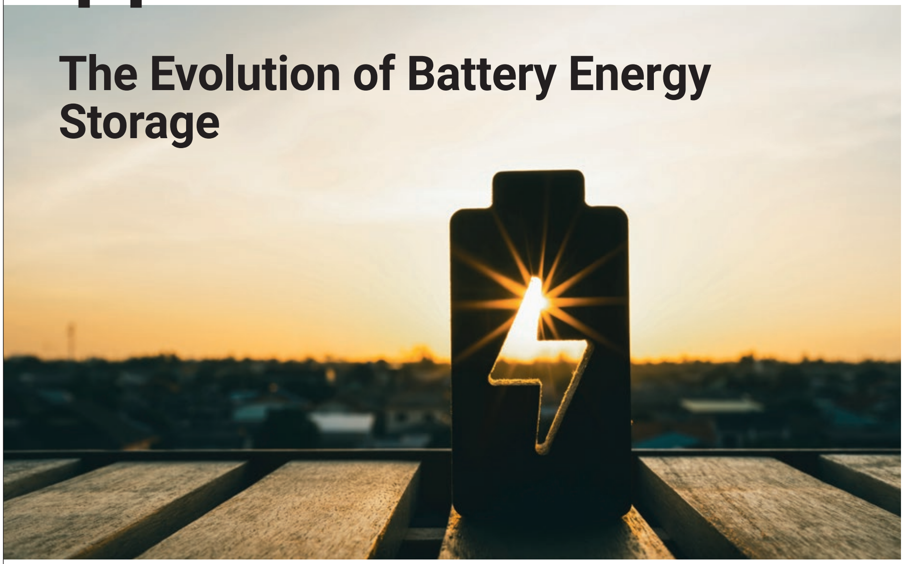
Index

Table of Contents

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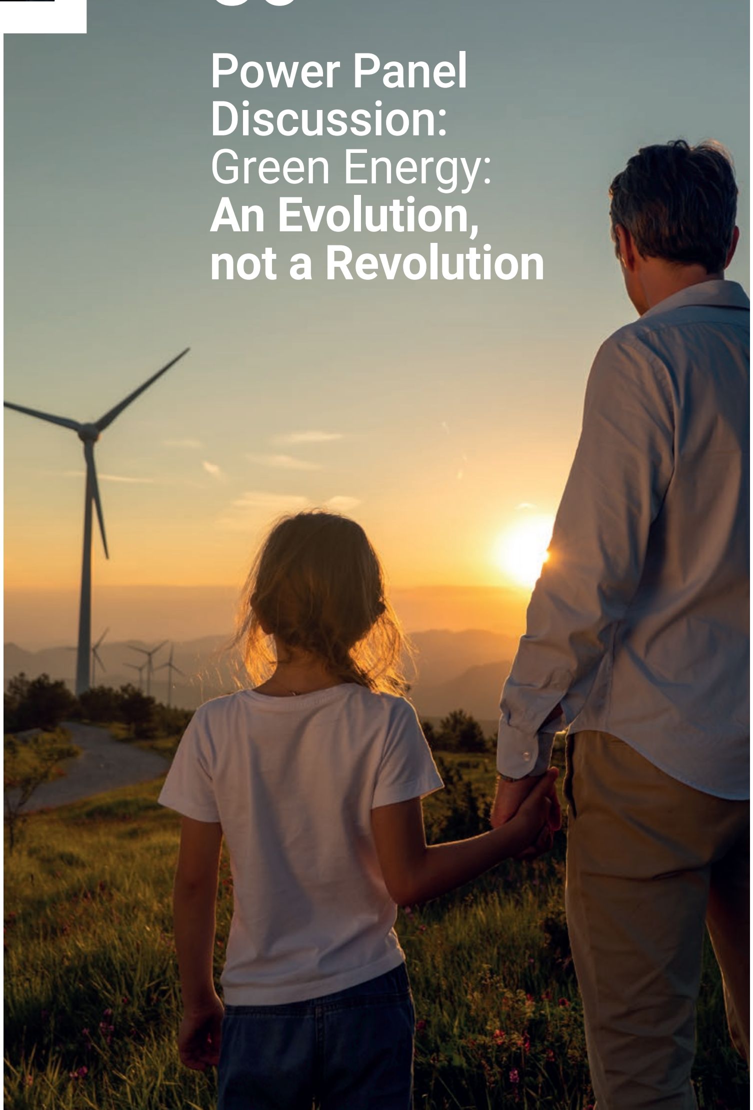
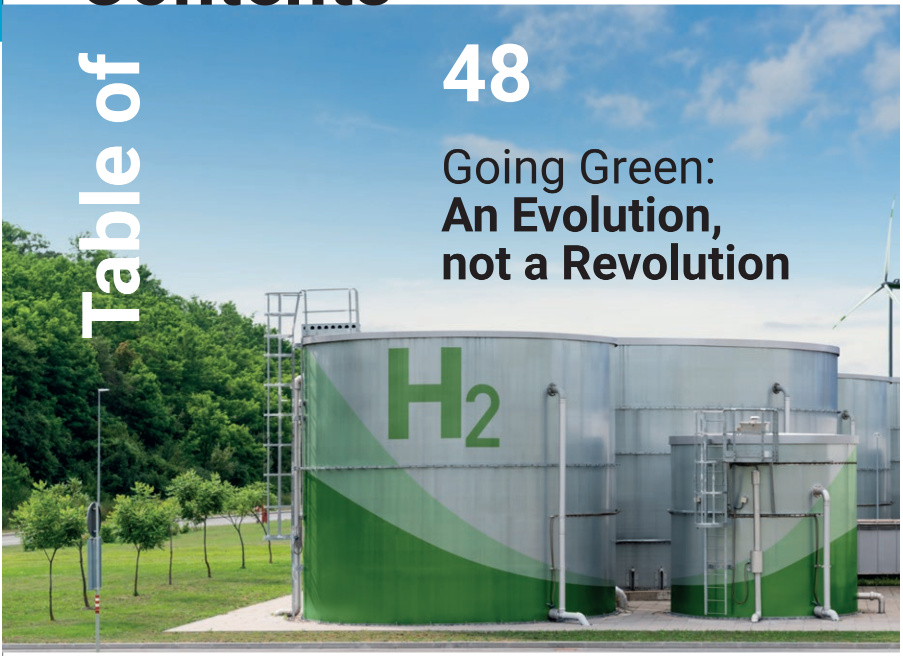
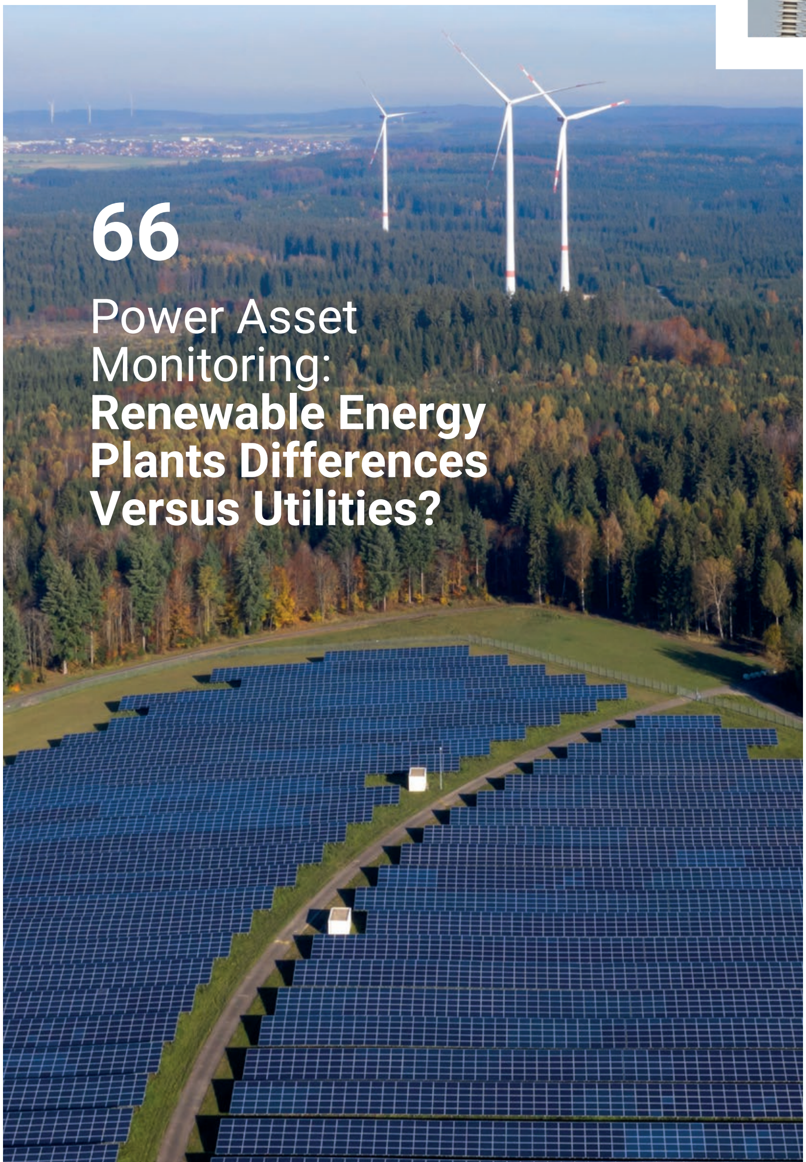
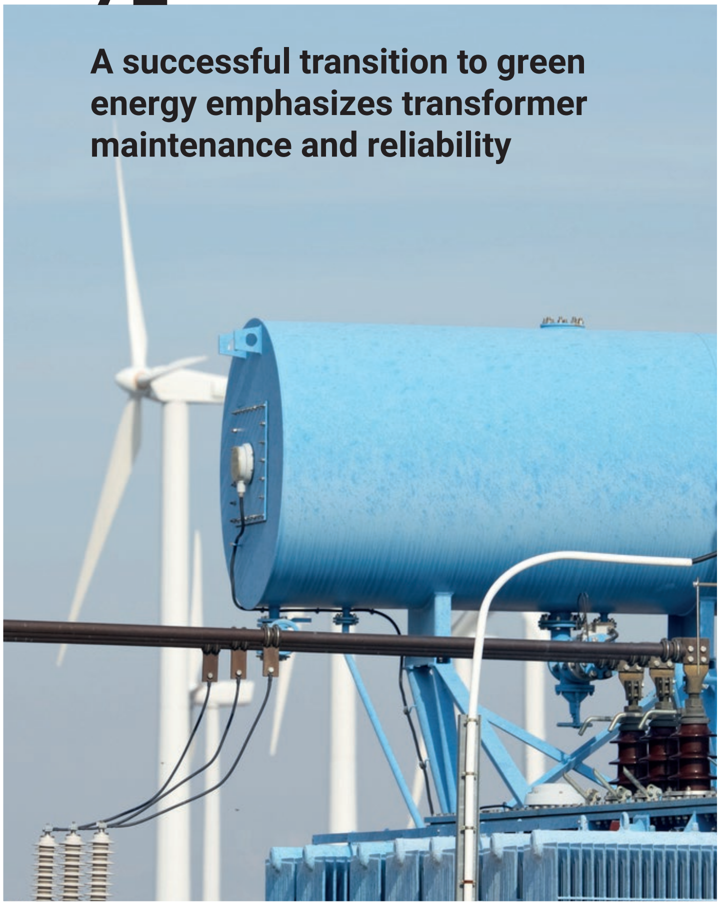


Index

Table of Contents







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Green Energy: Where Do We Stand?

We all should know by now what we mean by green energy as it refers to energy sources that can be naturally replenished and are not carbon based. This includes sunlight, wind, water, geothermal heat and more recently, white hydrogen. The growing focus on transitioning to green energy in order to combat climate change and reduce our reliance on fossil fuels has become a central component of energy policy in North America and much of Europe.

The Rise of Green Energy

The past few decades have seen significant progress in green energy technology. Solar and wind power costs have plummeted, making them increasingly competitive with fossil fuels.
In addition, there have been major advancements in energy storage, which is essential for making green energy more reliable.

At the most recent RE+ event, attended by over 40,000 people, it was clear that storage became a bigger part of the story. As a result of these developments, the use of green energy is growing rapidly. In 2022, renewable energy accounted for about 12% of global energy consumption, and this is expected to rise to 30% by 2030.

Challenges and Opportunities

Despite the progress that has been made, there are still some major challenges that need to be addressed in order to fully transition to green energy. One challenge is the intermittency of some renewable sources, such as solar and wind power. These sources cannot always produce electricity when it is needed. That is why the excitement about storage is front and center when it comes to decarbonizing the grid.
New technologies and/or approaches to utility scale storage has become more economical and if you want to find out about the feasibility of dynamic change, just follow the money. My money is on storage at present.

> **The past few decades have seen significant progress in green energy technology. Solar and wind power costs have plummeted, making them increasingly competitive with fossil fuels.**

Another challenge is the need to upgrade and expand the electrical grid in order to accommodate the increasing amount of green

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energy, with former rate payers now becoming prosumers. Interoperability is a major challenge when power flows in so many different directions, up and down the grid, which has been designed in a flow down to the end user. In the past, generation preceded transmission which preceded distribution. Now distribution has become generation through DER.

> **Despite the progress that has been made, there are still some major challenges that need to be addressed in order to fully transition to green energy.**

However, there are more opportunities for green energy as the continued development of technology makes green energy even cheaper and more reliable. In addition, there is growing public support for transitioning to clean energy, and governments around the world are starting to implement policies that support green energy development.

The Future of Green Energy
The future of green energy is bright. The technology is rapidly improving, the costs are falling, and public support is growing. While there are still challenges to overcome, it is clear that green energy is the future of our energy system.

Additional points for us to consider when it comes to green energy are;

- The role of green energy in job creation. Again, follow the money.
- The impact of green energy on air and water pollution.
- The potential for green energy to help developing countries. Let’s empower those without access to power through microgrids based on green energy.

We believe that green energy is one of the most important issues of our time. It is essential for our planet and our future. We encourage our industry to stay up to date with ever-changing technology and to support green energy generation, transmission, and distribution. Let’s move from hope and hype, to real world-changing application.

Alan M Ross
CRL, CMRP
Managing Editor
APC Media
Technical Director

Alan has decades of experience in the power systems industry and is one of the greatest reliability experts out there.

The Evolution of Battery Energy Storage

by **Jeff Donato**

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Jeff Donato is the Sales Director-Safety Products at H2scan. Jeff Donato has over 25 years of sales and management experience in the industrial battery industry, representing safety and compliance products in the datacenter, utility, and telecommunications applications. Jeff is an active member of the IEEE Power & Energy Society and is the current chair of working group 1578 in the Energy Storage and Stationary Battery Committee (ESSB). Jeff is also a member of several other IEEE working groups including alternative energy storage technologies and the nuclear working group. He has presented standby power system Environmental Health & Safety training to engineering, architect and OEM manufacturing firms and delivered solutions training to end users and specifying engineers.

Battery Energy Storage System (BESS), has undergone a remarkable evolution in recent years, driven by advancements in battery technology, policy changes, and the increasing need for grid flexibility with the rise of renewable energy. Battery energy is used in grid support, integration of renewable energy and commercial/industrial applications.

Advancements in battery technology have shrunk cell sizes, boosted capacities, and slashed costs, making BESS a viable and attractive option for diverse applications. Policy landscapes around the world are rapidly evolving, recognizing the crucial role BESS plays in grid resilience and decarbonization, with supportive regulations and incentives further fueling the BESS boom. Perhaps the most significant driver, however, is the focus on growth of renewable energy. As wind and solar power soar in popularity, their inherent variability challenges grid stability, demanding flexible solutions like BESS to bridge the gaps.

Advancements in battery technology have shrunk cell sizes, boosted capacities, and slashed costs, making BESS a viable and attractive option for diverse applications.

In grid support, BESS alleviates peak demand burdens stabilizing the system. They excel at integrating renewable energy, absorbing excess solar and wind generation power during periods of abundance, and releasing it when the sun dips below the horizon or the wind slows down, ensuring a reliable and uninterrupted energy supply.

In the commercial and industrial realm, BESS empower businesses with self-reliance, allowing them to store off-peak power and utilize it during peak hours, slashing energy costs and boosting operational efficiency.

Below are the application and advantages of having Battery Energy Storage.

Beyond the grid benefits, BESS contribute to climate change mitigation by enabling increased penetration of clean renewables and displacing polluting fossil fuel generation. They enhance energy security by providing backup power and mitigating the risks of blackouts. For businesses, BESS translate into cost savings, operational flexibility, and improved environmental stewardship.

Early Days in the 2000s:
BESS deployments were small-scale and mainly focused on niche applications like backup power for critical infrastructure. Lithium-ion batteries, the dominant technology based on its high energy density, were expensive, hindering widespread adoption. Batteries primarily provided basic grid support services such as frequency regulation.

Rise of Renewables in the 2010s:
The growth of solar and wind energy highlighted the need for energy storage to address their intermittency. Advancements in battery technology led to significant cost declines, making lithium batteries more commercially viable and started playing a broader role in the grid, including peak shaving, energy arbitrage, and transmission deferral.

Grid Support & Stabilization:

Objective	Description
Peak shaving	Batteries store excess energy during periods of low demand and release it during peak demand times, reducing strain on the grid and minimizing the need for expensive peak power plants and commercial buildings.
Frequency regulation	Batteries quickly respond to fluctuations in electricity supply and demand, helping to maintain grid frequency stability and prevent blackouts.
Voltage regulation	Batteries inject or absorb reactive power to stabilize voltage levels on the grid, particularly with the increasing integration of variable renewable energy sources.
Demand Power	Batteries provide backup power to critical infrastructure in case of grid outages, enabling faster restoration of power services.

Integration of renewable energy:

Objective	Description
Smoothing variability	Batteries store excess electricity generated by wind and solar power during periods of high production and release it when these sources are unavailable.
Enabling distributed generation	Batteries facilitate the connection of smaller, distributed renewable energy sources to the grid by managing their intermittent output and ensuring reliable power supply.
Improving grid access for renewables	Batteries help mitigate grid congestion issues and enable increased penetration of renewable energy into the energy mix.

BESS in the 2020s:

BESS deployments are no longer just utility-scale; residential and commercial systems are gaining traction. BESS are moving beyond traditional grid services, participating in wholesale markets, and providing flexibility for microgrids. New battery chemistries, promise even higher energy density and lower costs.

BESS will be pivotal in enabling a more distributed and resilient grid, facilitating the integration of distributed energy resources. BESS will become increasingly intelligent, utilizing AI and machine learning to optimize smart grid operations.

The Future of BESS:

BESS will be pivotal in enabling a more distributed and resilient grid, facilitating the integration of distributed energy resources. BESS will become increasingly intelligent, utilizing AI and machine learning to optimize smart grid operations. There is an increasing focus on developing more sustainable and ethical battery materials and recycling to minimize environmental impact. With continued innovation and policy support, BESS can play a key role in achieving a clean and sustainable energy future.

The modernization of the grid infrastructure is creating new opportunities for BESS to provide valuable services. Government policies promoting renewable energy integration and carbon emission reduction have incentivized BESS adoption. Growing awareness of climate change and the need for clean energy is also driving public support for BESS technologies.

As battery technology continues to evolve, costs will reduce, and applications grow, their impact will only broaden and deepen. This remarkable evolution, driven by the unwavering pursuit of a cleaner and more sustainable future, promises to reshape the very way we generate, store, and utilize energy.

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While lithium batteries are the primary choice of battery technology for BESS, there are many other technologies that are in place and emerging:

Battery Technology	Description	Strengths & Weaknesses
Lithium Batteries	Lithium-ion batteries in BESS store energy by moving Li+ ions between the anode and cathode. Charging pushes Li+ ions into the anode, while discharging pulls them back to the cathode. This movement of ions creates a potential difference that drives electrons through the external circuit, generating electricity.	Batteries store excess electricity generated by wind and solar power during periods of high production and release it when these sources are unavailable.
Pumped Hydroelectric Storage	Although not technically a battery, this technology utilizes water stored at different elevations to generate electricity through hydro turbines, offering large-scale energy storage with high efficiency and long lifespans.	Clean, sustainable, and capable of storing gigawatt-hours of electricity, ideal for balancing supply and demand on the grid, especially during peak hours. However, it has limitations based on geography, requires large scale civil engineering, and had long construction times.
Flow Batteries	These store energy in two liquid electrolytes that pump through a membrane, separating them when charged and allowing their interaction to generate electricity when discharged.	Batteries help mitigate grid congestion issues and enable increased penetration of renewable energy into the energy mix.
Metal-Air Batteries	Utilize atmospheric oxygen as their cathode material, potentially achieving high energy densities due to the oxygen not needing storage within the battery.	Made from abundant sustainable materials, lightweight with high energy density. However, there are efficiency concerns and has a slow discharge rate.
Sodium Ion	A potential alternative to lithium-ion batteries that use sodium ions instead of lithium.	They offer lower cost and abundance of sodium resources but suffer from lower energy density and faster cycle degradation compared to lithium-ion.


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ENERGY STORAGE

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Sources

LinkedIn article "2031 Battery Energy Storage Systems (BESS) Market Projections: Identifying Growth Opportunities and Emerging Trends"

Energy-Storage.News article "Global BESS deployments to exceed 400GWh annually by 2030, says Rystad Energy"

Energy-Storage.News article "Record growth for US BESS industry, but '2GW impacted by supply chain, interconnection challenges'

Global BESS market: 2031 Battery Energy Storage Systems (BESS) Market Projections: Identifying Growth Opportunities and Emerging Trends, LinkedIn article by Research and Markets (August 2022)

Global annual BESS installations: Global BESS deployments to exceed 400GWh annually by 2030, says Rystad Energy, Energy-Storage.News article (November 2023)

US BESS industry: Record growth for US BESS industry, but '2GW impacted by supply chain, interconnection challenges', Energy-Storage.News article (October 2023)

International Renewable Energy Agency (IRENA) report "Unlocking the Potential of Battery Energy Storage for Renewables Integration" (2023)

The Global Energy Storage Alliance (GESA) report "The State of Energy Storage 2023" World Energy Council's report "The Role of Energy Storage in Grid Modernization" (2022)

BloombergNEF's "2023 Battery Price Forecast" and BNEF's "Energy Storage Trends Report" (2023)

The International Energy Agency (IEA) report "Global EV Outlook 2023"

National Renewable Energy Laboratory (NREL), "Cost and Performance Analysis of Battery Energy Storage Systems" (2023)

International Renewable Energy Agency (IRENA), "Unlocking the Potential of Battery Energy Storage for Renewables Integration" (2023)

Electric Power Research Institute (EPRI), "Grid Integration Challenges for Large-Scale Battery Energy Storage Systems" (2022)

The Cost of Energy Storage: Understanding the Costs and Drivers of BESS Deployment" (2023)

International Energy Agency (IEA), "Global EV Outlook 2023"

World Energy Council, "The Role of Energy Storage in Grid Modernization" (2022)

The Energy Storage Association, "2023 BESS Deployment Guide"

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DRAGONFLY ENERGY is a leader in the green energy storage industry. Developing some of the most popular Lithium-ion Battery products in the RV and Marine industries today, through the Battle Born Batteries brand, while advancing the future of battery technology through unique patented manufacturing processes forged by a robust R&D department. Enabling high quality, effective domestic cell production and building towards the widespread deployment of proprietary non-flammable solid state battery cells built for safe, long term energy storage.

How is Dragonfly Energy helping create a greener planet?

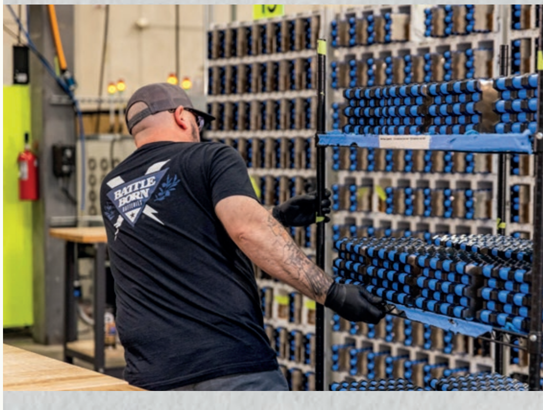
Dragonfly Energy Corp., head-quartered in Reno, Nevada, is a leading manufacturer of deep cycle lithium-ion batteries, which are sold direct-to-consumers under the Battle Born Batteries brand and to original equipment manufacturers, such as Keystone RV and Airstream. Dragonfly Energy's battery products are designed and assembled in the USA, and the company's research and development initiatives are revolutionizing the energy storage industry through innovating technologies and manufacturing processes. Today, Dragonfly Energy's non-toxic deep cycle LiFePO4 batteries are displacing lead-acid batteries across a wide range of end-markets, including RVs, marine vessels, residential off grid & backup storage, and industrial applications. Dragonfly Energy is also focused on delivering an energy storage solution to enable a more sustainable and reliable smart grid through the future deployment of the company's proprietary and patented non flammable solid state battery cell technology.

What is Dragonfly's most impactful product?

Our consumer brand of batteries, Battle Born Batteries. Traditionally, the RV industry relied on lead acid batteries, a product that, while widely deployed, remains dangerous to the customer and incredibly toxic to the environment. It was time for a change.

So, we created this popular line of deep cycle LiFePO4 batteries, coming to the market with a quality, reliable product that transformed the camping experience for RVers. Battle Born Batteries provide significant weight savings, up to three times the power, five times faster charging, and last over ten times longer. Our products took the industry by storm and propelled a widespread conversion to renewable energy throughout the RV industry, and now expanding into Marine, Residential, Trucking, and Industrial applications, as well. Battle Born Batteries are also integrated at the OEM level through popular brands such as Airstream, Tiffin, and Keystone RV.

Now, with hundreds of thousands of batteries that have been battle-tested in the field through consumer and OEM customers, we continue to innovate. New Dragonfly IntelLigence technology brings next-level communication and monitoring to power systems. This technology is designed to give users the utmost confidence in their power system by providing unparalleled access to monitoring, notification, performance and safety tools



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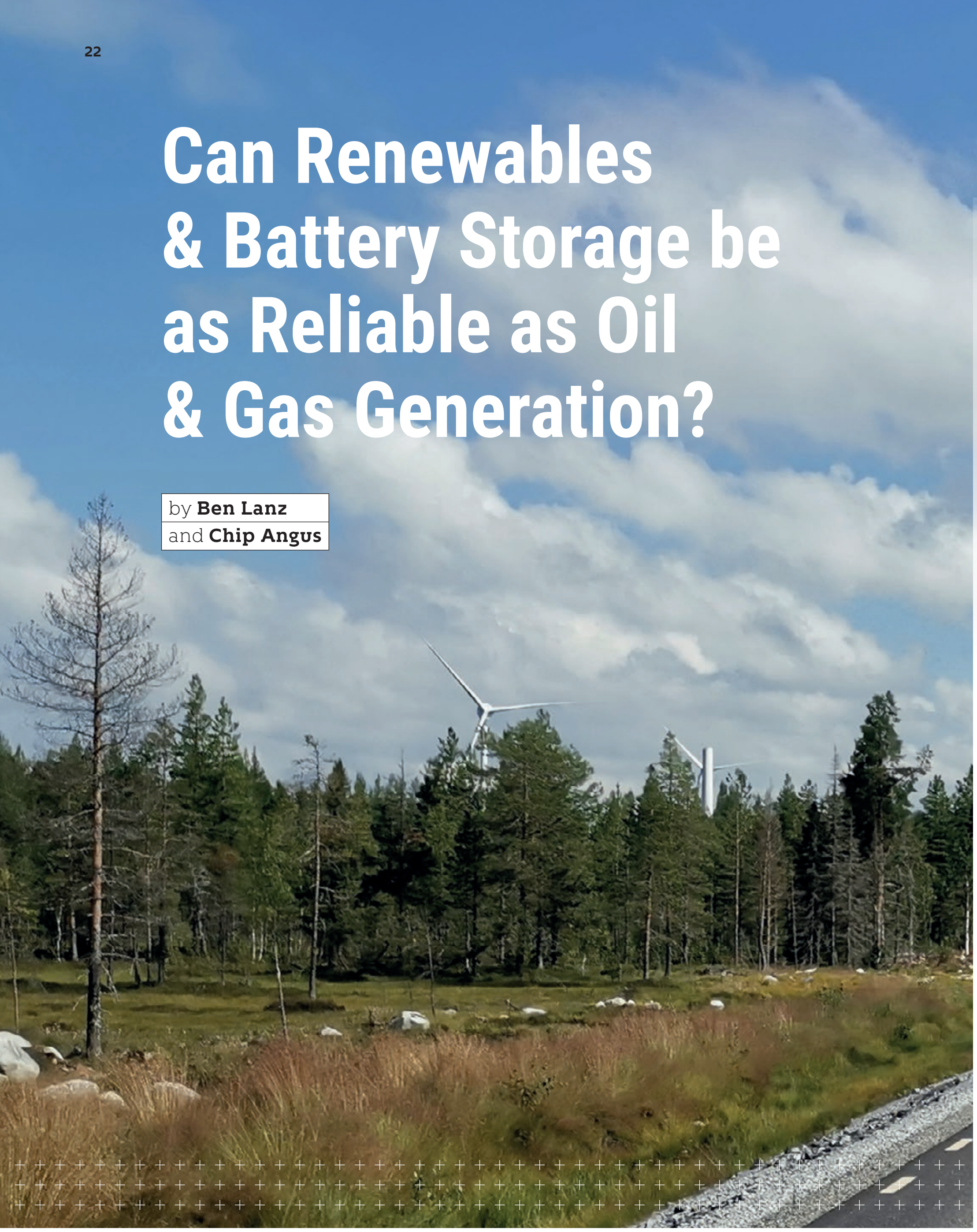
Can Renewables & Battery Storage be as Reliable as Oil & Gas Generation?

by **Ben Lanz**
and **Chip Angus**



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Yes! We can't control the energy source of wind and solar and connected battery storage systems, but we can ensure plant reliability by implementing best practices to maximize uptime when generation is available. Unlike oil and gas-powered generation facilities, power cables and transformers at utility scale renewable sites play a much bigger role connecting the distributed generation to the grid. Unplanned collector system outages can easily cost over one hundred thousand dollars per event including the impacts of repair cost, revenue loss and power purchase agreement penalties. In fact, simply based on typical cable system failures of cable systems not properly commissioned, the average utility scale site will experience more than 15 failures yielding over $1.5 million in losses over a 25-year plant life.

> ***Unlike oil and gas-powered generation facilities, power cables and transformers at utility scale renewable sites play a much bigger role connecting the distributed generation to the grid.***

When wind and solar energy are available, we need to ensure the medium voltage (MV) collector systems are reliable so revenues, operation and maintenance (O&M) budgets, and power purchase agreements are not negatively impacted. Scarcity in material supply chains and experienced resources are introducing additional risks. For example, the frequency of cable manufacturing defects, while only 5% of total defects found, have

Ben Lanz is Director of Strategy & Development at IMCORP. With over 30 years in the power and energy industry, Ben Lanz is currently responsible for IMCORP's technical outreach and education efforts and is the immediate past Chairman of the Board of the Power Delivery Intelligence Initiative (PDI2.org), a nonprofit dedicated to disseminating grid investment best practices. He is a senior member of IEEE PES and ICC, and a voting member of DEIS, IAS, ACP and CIGRE. He has chaired IEEE technical committees associated with power system reliability, protection, and testing, has published over 100 papers, articles and technical conference contributions on the subjects of power system reliability, asset management, design, work practices, longevity and diagnostics, and is a regular guest speaker at numerous conferences and seminars.

Chip Angus is Electric Reliability National Account Manager at SDMyers, LLC in Tallmadge, Ohio, where he specializes in helping industrial companies develop long-term transformer reliability solutions. Chip works primarily with manufacturing, steel, wind, solar, pulp and paper, and oil & gas customers by aligning their corporate reliability expectations with the realities at the plant operations level. Chip presents at conferences across the U.S. as a resource in the field of industrial electric power reliability. He has been published in a variety of leading trade publications in the electric power reliability space. Before specializing in transformer management and electric power reliability, Chip was the president of Ryco Metals, a structural and plate fabrication firm and service center.

doubled from what the industry experienced over a decade ago. Many veterans from the more mature utility-scale wind industry are making efforts to apply lessons learned to solar and battery applications.

In fact, simply based on typical cable system failures of cable systems not properly commissioned, the average utility scale site will experience more than 15 failures yielding over $1.5 million in losses over a 25-year plant life.

New industry recommended practices and guidance are available, but the knowledge is not evenly distributed. In addition to identifying how cable and transformers fail, this article provides insight into industry trends and specific case studies illustrating the benefit of implementing the latest in recommended proactive quality control (QC) commissioning, and maintenance practices.

Renewable Industry Learning Curve

According to American Clean Power (ACP), utility scale wind development ramped up in North America in the mid 2000s. The industry spent years developing solutions to many unforeseen reliability challenges including challenges with the collector systems. According to ACP, utility scale solar didn't reach the scale of wind until 2013. Data collected from about 65% of wind and solar collector systems built between 2014 and 2019 and commissioned using line scanning technology comparable to cable and accessory manufacturer factory QC tests (Table 1) shows a remarkable learning curve story. Wind systems meeting the cable and accessory manufacturers' standards maintained a consistent high level of performance whereas solar systems took 5 years to catch up. This strong correlation is also supported by onsite experience. We conclude that it took about 5 years for many solar developers to adopt training, construction, and commissioning best practices. In the last couple years, utility scale energy storage projects have ramped up, much like solar did in 2013, which brings us to the point. Our industry has a great opportunity to shortcut the learning curve with yet another round of new developers and contractors by implementing best practices including the ones in this article.

> ***Our industry has a great opportunity to shortcut the learning curve with yet another round of new developers and contractors by implementing best practices including the ones in this article.***

Implementing Best Practices to Prevent Transformer Failures

The fleet of transformers at utility-scale renewable sites plays a decisive role in connecting the distributed generation to the grid. Going beyond routine maintenance activities with best practices and reliability strategies for transformers is crucial to ensure the efficient and uninterrupted conversion and transmission of generation from wind and solar sources. Although transformers are designed to last for decades, a number of drivers can push them to premature failures, such as extreme heating, mechanical stress, contamination, extreme voltage stress, and corrosion of external components.

The insulating paper is the life of the transformer. The transformer paper is immersed in a dielectric liquid, which enhances the strength of the paper and serves as an inhibitor to heat, oxidation, and moisture, all of which contribute to a decline in performance and can lead to failure. If the paper is compromised, PD occurs and creates a destructive feedback loop that can eventually lead to failure. Additionally, a transformer leaking from its main valve or bushings can expose the paper, causing it to rapidly dry and initiate PD.

While there are extreme cases when a failure occurs without warning, proper commissioning, proactive maintenance, and regular monitoring of your transformers are key to fleet reliability, longevity, and avoiding premature failure. Implementing best practices and reliability strategies helps utility-scale renewable sites navigate the challenges of maintaining a robust transformer fleet in an ever-evolving energy landscape.

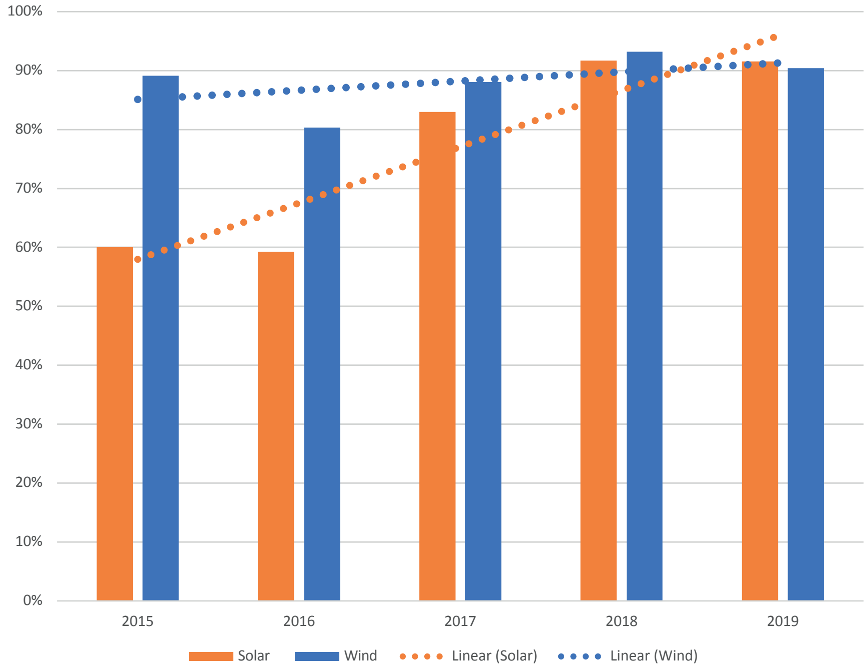


Figure 1
First pass performance of wind and solar MV cable systems portraying % of systems meeting manufacturers' standards as shown in Table 1

Commissioning Tests for Transformers

Main power, pad mount, and grounding transformers are typically tested over multiple stages during the commissioning process. Before a transformer leaves the factory, the buyer should ensure it has been properly tested. Ideally, key tests are repeated in the field after installation and during the initial energization process to ensure against transportation and installation damage. IEEE guides, ACP RP 601, and NETA ATS 2021 all recommend a battery of tests, including electrical, chemical, and infrared thermography. Electrical tests should include a turns ratio test, a winding resistance test, and an insulation resistance test. For the main power transformer, a sweep frequency response analysis is recommended. Chemical tests should comprise measurements such as the list in SDMyers' "CriticalPac," which includes interfacial tension, dielectric breakdown voltage, neutralization number, relative density, color, visual, Karl Fischer moisture, dissolved gas analysis, liquid power factor, oxidation inhibitor content, dissolved metals, and furanic compounds. After energization and the system is under load, infrared thermography of the transformer components, such as external bushings, connections, cooling fins, and the surfaces, is recommended as part of an ongoing electrical maintenance plan (EMP) that adheres to NFPA 70B standards.

Transformer Case Study

A site in the United States experienced a failure of their main power transformer. The owner was running a costly backup generator while awaiting delivery of a main power transformer. In the purchase agreement, the owner agreed to manufacturer warranty terms which outlined required acceptance testing, including a baseline electrical power factor test as well as weekly dissolved gas analysis for a period of three weeks following energization. Due to a limited budget and the steep and unexpected expense of rewiring a portion of the site for compatibility with the new transformer, management declined to provide the funds necessary to complete the commissioning tests on the new transformer. After nearly a year, the owner decided to conduct chemical testing to get a baseline on the health of the transformer and indicated that a power factor test could also be conducted during an upcoming planned outage. The chemical test indicated active arcing. To provide a comparative analysis, a chemical test was conducted 48 hours later, revealing concentrations of some key indicators had doubled. The owner was advised to immediately take the transformer offline but instead continued utilization. Within four days, the transformer exploded, caused damage to surrounding assets, and was a total loss. With no true baseline data or ability to perform a root cause analysis, the ultimate cause of the transformer failure remains undetermined. Additionally, the manufacturer was unable to honor the warranty because the acceptance testing outlined in the purchase agreement was never performed. Failure to properly commission and monitor the health of the new transformer turned into more than a million-dollar mistake.

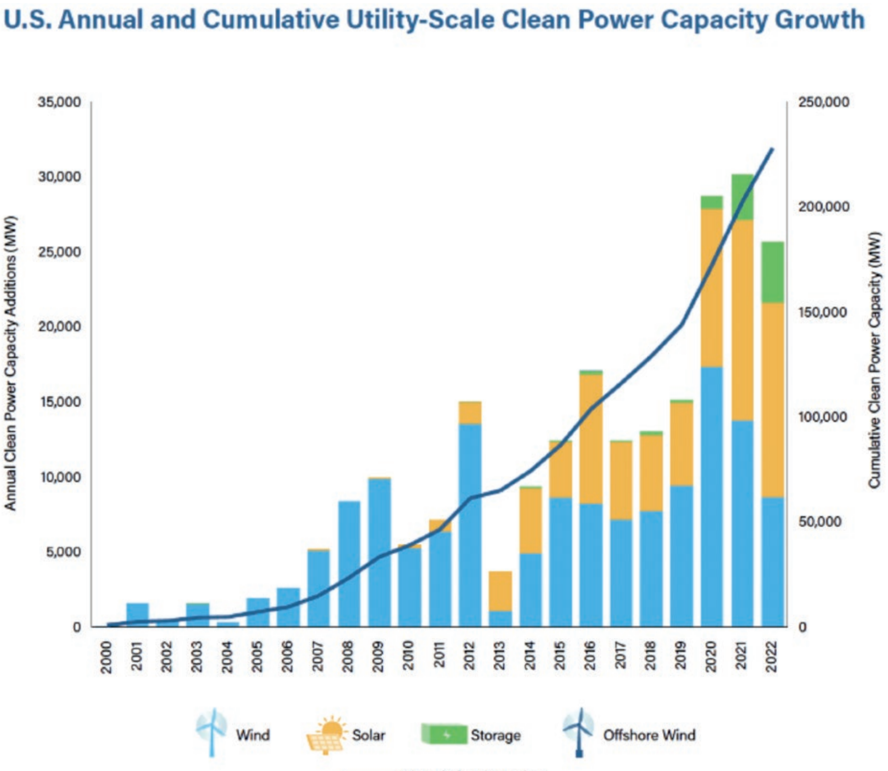


Figure 2

Implementing Best Practices to Prevent Cable System Failures

The primary cause of modern cable system failure is human induced damage exacerbated by extreme voltage conditions. Modern, medium and high voltage cable systems fail due to a voltage driven erosion process associated with a ‘micro arcing’ phenomenon called partial discharge (PD). PD can arise from an extreme focus of electric stress and a lack of the appropriate solid insulation. 93% of PD activity is not active at operating voltage but can be triggered by voltage transients which are common at renewable sites. Transients should be limited by surge arresters but unless properly tested and repaired, industry data shows about 40% of newly installed cable systems will have at least one substandard PD site active below protection levels, so effective commissioning to remove these risks is critical.

Commissioning Tests for Cable Systems

In their 2023, “Wind and Solar Underground AC Collection System Cable Testing," ACP recommends using offline 50/60 Hz partial discharge testing with 5pC sensitivity as a diagnostic method for both commissioning and aged cables. The IEEE 1185 “Recommended Practice for Cable Installation in Generation Stations and Industrial Facilities” states “PD testing is recommended for post-installation testing of medium voltage power cable systems. Experience has shown this test to be the most effective means of the detection and identification of issues associated with cable system accessories (improper cable preparation, interface contamination, improper alignment of stress control layers, improper shrinking, etc.)” and “when testing a complete cable system, each component should meet the partial discharge requirements” and provides the standards in Table 1 as a reference.

Table 1
Manufacturing Standards PD Test Specification

Cable Component Standard	**Parameters (50/60 Hz only)**
IEEE 48 Terminations	No PD >5 pC up to 1.5 U_0
IEEE 404 Joints	
IEEE 386 Separable Connectors	No PD >5 pC up to 1.3 U_0
ICEA S-97-682/94-649 Cable 5 kV-46 kV	No PD >5 pC up to 4 U_0*
ICEA S-108-720 Cable 69 kV-500 kV	No PD >5 pC up to 2 U_0

** $4U_0$ is an estimate, actually 200V/mil or 7.9 kV/mm. Field tests are limited to the level of arrester protection, typically 2 to 2.5 U_0*

Cable System Case Study

In this case study involving over a dozen renewable energy projects with identical construction specifications and executed by the same pool of contractors, the efficacy of two distinct test approaches—IMCORP's AI-based line scanning technology and a conventional VLF (Very Low Frequency) commissioning test—was evaluated. The study encompassed a significant cumulative length of 1,616 miles over a four-year observation period. The circuits subjected to IMCORP's advanced technology demonstrated an outstanding performance, revealing an impressively low failure rate of 0.03 failures per 100 miles per year. In stark contrast, a subset of cables spanning 105 miles, undergoing VLF commissioning tests, exhibited a substantially higher failure rate of 2.53 failures per 100 miles per year over a three-year observation period.

Notably, the IMCORP-tested circuits demonstrated an 81-fold improvement in performance compared to their VLF-tested counterparts. The study also unveiled a disconcerting parallel between the failure rates of VLF-tested circuits and new cable systems not subjected to testing, both hovering around 3 failures per 100 miles per year. This implies that although the VLF test has the potential to identify weaknesses, it may also introduce new issues.

Consequently, it might be more beneficial for sites to forego

Figure 3
Electrical tree damage resulting from a passing VLF commissioning test.

Photo: IMCORP

commissioning tests altogether instead of a VLF test. These results emphasize the crucial role of IMCORP's AI-based line scanning technology and the importance of adhering to the cable and accessory manufacturer's standards (specifically, the "offline 50/60Hz PD test with 5pC sensitivity" outlined in Table 1). This approach ensures the reliability and performance of renewable energy projects, advocating for the widespread adoption of this superior alternative over traditional testing methods.

This implies that although the VLF test has the potential to identify weaknesses, it may also introduce new issues. Consequently, it might be more beneficial for sites to forego commissioning tests altogether instead of a VLF test.

Conclusion

Although renewable energy and battery storage sites have more complex collector systems, they have the potential to rival conventional oil and gas plant performance. Both wind and solar technologies have undergone painful learning curves in terms of commissioning practices. With the adoption of well-established commissioning and maintenance best practices, the renewable energy sector and battery storage facilities are positioned to perform reliably for the foreseeable future.

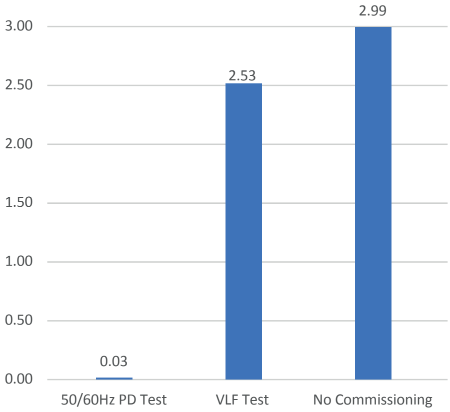


Figure 4
Post-commissioning failure rates per 100 miles per year.

Barriers to Green Technology Adoption: Implications for Power Grid Infrastructure Growth

For decades, the utilities sector was perceived as a slow-moving and stable industry. However, the advent of green technologies, with electrification at its core for decarbonization, has propelled the power grid and the utilities that manage it to the forefront of our climate goals.

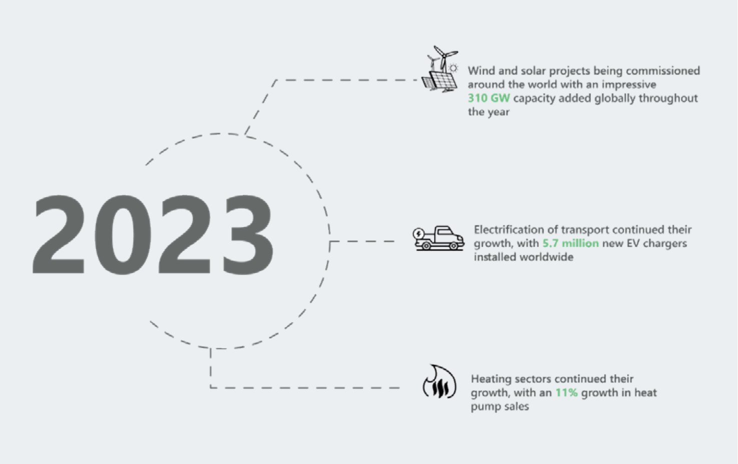
Recent progress in renewable adoption has been promising. 2023 witnessed a significant number of wind and solar projects being commissioned around the world with an impressive 310GW capacity added globally throughout the year, taking us to a cumulative installed capacity of 1.8 TW. [1] In addition to renewables, electrification of transport and heating sectors, continued their growth, with 5.7 million new EV chargers [2] installed worldwide and an 11% growth in heat pump sales [3] in 2023.

Projections by PTR Inc. indicate this growth trajectory will persist, with an estimated 670 GW of additional renewable capacity (wind and solar) expected to come online in the US and Europe by 2030. [1] The electric vehicle (EV) market is also poised for sustained growth, projected at a Compound Annual Growth Rate (CAGR) of 20% until the decade's end [2].

The rapid adoption of green technologies can be attributed in large part to significant cost reductions over the last decade. The cost of electricity from onshore wind and solar photovoltaic (PV) sources has become increasingly competitive, outpacing that of new and even existing fossil fuel plants in many countries. Similarly, the affordability of electric vehicles has surged, driven by decreasing battery costs and the economies of scale associated with mass production.

> **It is crucial to assess whether the anticipated high growth in grid infrastructure and equipment demand, driven by the adoption of clean technologies like renewables EV chargers, will materialize as initially predicted.**

Despite these positive trends, the green technology adoption faces challenges that may impede its growth. Economic uncertainties, pressure on public budgets, the financial health of the energy sector and financing challenges due to a high cost of capital today, add complexity to policy uncertainties for the adoption of clean technologies. Infrastructure hurdles, such as energy storage limitations, sluggish grid updates, delayed grid connections, and protracted permitting processes, further contribute to the deceleration of renewable and EV charging projects.



Wind and solar projects being commissioned around the world with an impressive 310 GW capacity added globally throughout the year

Electrification of transport continued their growth, with 5.7 million new EV chargers installed worldwide

Heating sectors continued their growth, with an 11% growth in heat pump sales

As the world grapples with geopolitical issues affecting public sentiment toward green technologies, a potential slowdown in the growth of renewables and EV charging infrastructure is becoming a reality. This raises critical questions for stakeholders in the electrical infrastructure space. From a planning perspective, it is crucial to

Photo: Shutterstock, PTR Inc.

assess whether the anticipated high growth in grid infrastructure and equipment demand, driven by the adoption of clean technologies like renewables EV chargers, will materialize as initially predicted.

> **Economic uncertainties, pressure on public budgets, the financial health of the energy sector and financing challenges due to a high cost of capital today, add complexity to policy uncertainties for the adoption of clean technologies.**

The answer comes with a caveat - the electrical infrastructure market is growing, but not as rapidly as initially envisaged. Predictions of a 13% annual growth in renewable capacity additions in the US and Europe until 2030 may be tempered, potentially dropping to as low as 9% if bottlenecks persist. [1] Similarly, a potential decrease of up to 15% in overall EV charger sales in the US and Europe compared to previous expectations is on the horizon. [2]

This slower growth trajectory in the electrical infrastructure market, which has thrived on the integration of green technologies into the grid, could result in a demand growth as low as 4% in Europe and 8% in the US. [1] Realistically, if this trend persists, achieving net-zero targets will become increasingly challenging. The industry must keep these challenges and the potential impact due to them in mind, so we can focus on fostering innovation to address these barriers and ensure a sustainable and expedited transition to a greener future.

> **This slower growth trajectory in the electrical infrastructure market, which has thrived on the integration of green technologies into the grid, could result in a demand as low as 4% in Europe and 8% in the US. [1]**

Bibliography:

[1] PTR Inc., "Power Grid Market Intelligence," PTR Inc., Sunnyvale, California, 2023.

[2] PTR Inc. , "EV Charging Infrastructure Market Research," PTR Inc. , Sunnyvale, California, 2024.

[3] IEA, "Global heat pump sales continue double-digit growth," 31 March 2023. [Online]. Available: https://www.iea.org/commentaries/global-heat-pump-sales-continue-double-digit-growth. [Accessed 19 January 2024].

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Hassan Zaheer is the Chief Operating Officer at PTR Inc. based in Abu Dhabi, UAE. With more than a decade of experience in the energy transition space, Hassan works for various Fortune-500 blue-chip clients on global market studies in the electrical infrastructure sector. In his current role at PTR, he works with clients to sustainably grow their businesses, both through custom consulting work and tailored research reports by PTR, helping their executive management and boards make data driven decisions. Hassan is also a Member of Advisory Board for CWIEME Berlin and an advisor to the educational non-profit Better Humans Academy. Hassan has a tech background with a Masters in Power Engineering from the Technical University of Munich (TUM) and a BS in Electrical Engineering from the Lahore University of Management Sciences (LUMS). Additionally, he is also an Alumni of Center for Digital Technology & Management (CDTM).

ETOS®

THE FUTURE OF POWER TRANSFORMER MANAGEMENT

ETOS® REPRESENTS A SYSTEMIC INNOVATION, SEAMLESSLY INTEGRATING EXISTING ACTUATORS, MODERN SENSORS, COMMUNICATION DEVICES, AND ALGORITHMS INTO A UNIFIED SYSTEM THAT ENCOMPASSES BOTH EDGE AND CLOUD COMPONENTS.

Photo: Maschinenfabrik Reinhausen

In the dynamic world of energy distribution, power transformers stand as the workhorses of the grid, silently converting electricity from one voltage level to another. While they play a crucial role in ensuring the smooth flow of power, these transformers face a myriad of challenges, including aging infrastructure, increasing demand, and the loss of skilled personnel. To address these challenges and maintain the reliability of power grids, energy network operators are increasingly turning to automation and artificial intelligence (AI) as powerful tools for optimizing transformer performance and reliability, as well as extending their lifespans.

> **TO ADDRESS THESE CHALLENGES AND MAINTAIN THE RELIABILITY OF POWER GRIDS, ENERGY NETWORK OPERATORS ARE INCREASINGLY TURNING TO AUTOMATION AND ARTIFICIAL INTELLIGENCE (AI) AS POWERFUL TOOLS FOR OPTIMIZING TRANSFORMER PERFORMANCE AND RELIABILITY, AS WELL AS EXTENDING THEIR LIFESPANS.**

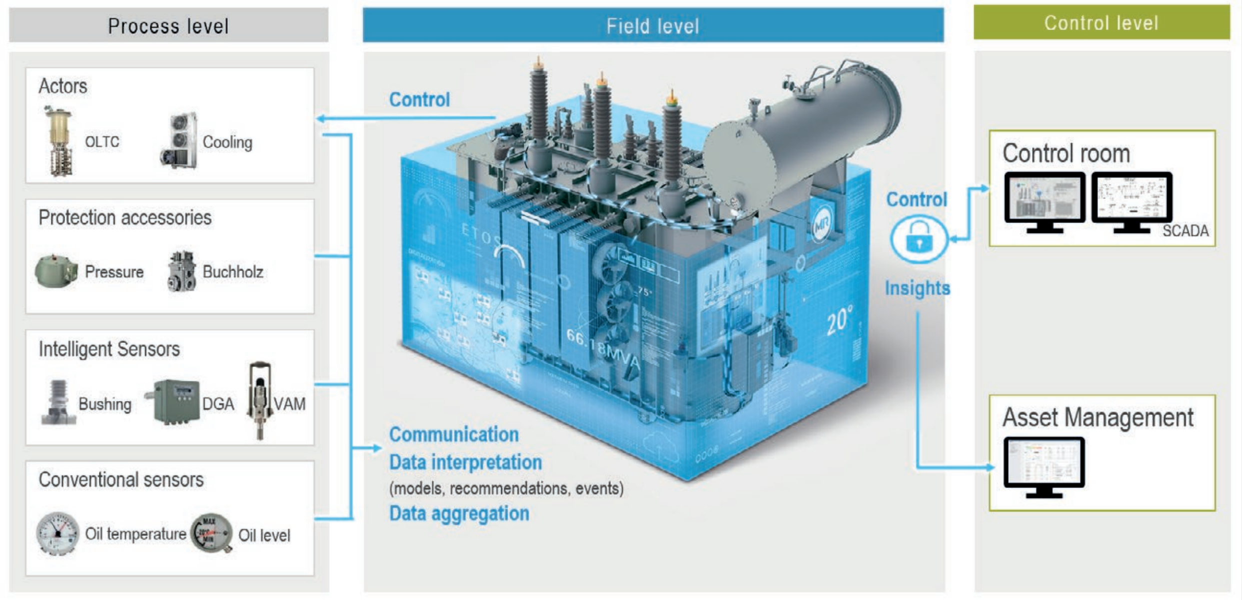


Figure 1: System overview

ETOS®: A Systemic Innovation for Power Transformer Management

At the forefront of this AI revolution is ETOS®, a pioneering solution developed by Maschinenfabrik Reinhausen (MR) that redefines the way power transformers are monitored, operated, and maintained. ETOS® represents a systemic innovation, seamlessly integrating existing actuators, modern sensors, communication devices, and algorithms into a unified system that encompasses both edge and cloud components. This intelligent infrastructure creates self-learning digital twins of network nodes, providing operators with unprecedented insights into the condition and performance of their transformers.

Figure 1 depicts a simplified representation of a power transformer's automation architecture, highlighting the three distinct levels: process, field, and control.

BY SEAMLESSLY INTEGRATING SENSORS, COMMUNICATION DEVICES, AND ADVANCED ALGORITHMS, ETOS® CREATES A DIGITAL TWIN OF THE TRANSFORMER. THIS DIGITAL TWIN SERVES AS A COMPREHENSIVE VIRTUAL REPRESENTATION OF THE TRANSFORMER'S CONDITION AND PERFORMANCE, PROVIDING OPERATORS WITH UNPRECEDENTED INSIGHTS INTO ITS HEALTH AND OPERATION.

Process Level:

At the heart of the power transformer lies the process level, encompassing the physical components that enable the conversion of electricity from one voltage level to another. On this level there are sensors (conventional and intelligent), protection accessories and actors (OLTC and cooling system). These are in physical contact with the transformer.

Field Level:

Acting as the bridge between the physical process and the control systems, the field level incorporates sensor information that monitor the transformer's condition and actuators that control its operation. ETOS® plays a vital role at this level, gathering data from various sensors and applying algorithms to analyze and interpret it as well as ensuring an efficient control of the temperature and the voltage. To suit different utility requirements, it supports the modular integration of functions in the areas of control, regulation, monitoring, and the tap-changer drive. By seamlessly integrating sensors, communication devices, and advanced algorithms, ETOS® creates a digital twin of the transformer. This digital twin serves as a comprehensive virtual representation of the transformer's condition and performance, providing operators with unprecedented insights into its health and operation. This holistic approach empowers operators to make informed decisions about maintenance schedules, optimization strategies, and overall asset management.

Control Level:

The control level forms the outermost layer of the power transformer's automation architecture, encompassing the software and hardware systems that manage the transformer's operation. It receives data from the field level, analyzes it, and sends commands to the actuators to ensure the transformer operates optimally. ETOS® acts as a bridge between the field level and control level, providing real-time insights and actionable recommendations to the control system (SCADA) and asset performance management systems.

Photo: Maschinenfabrik Reinhausen

Linking the dots with ETOS® Asset Intelligence

New technologies can help compensate for the loss of personnel knowledge and the increased demands on operating equipment.

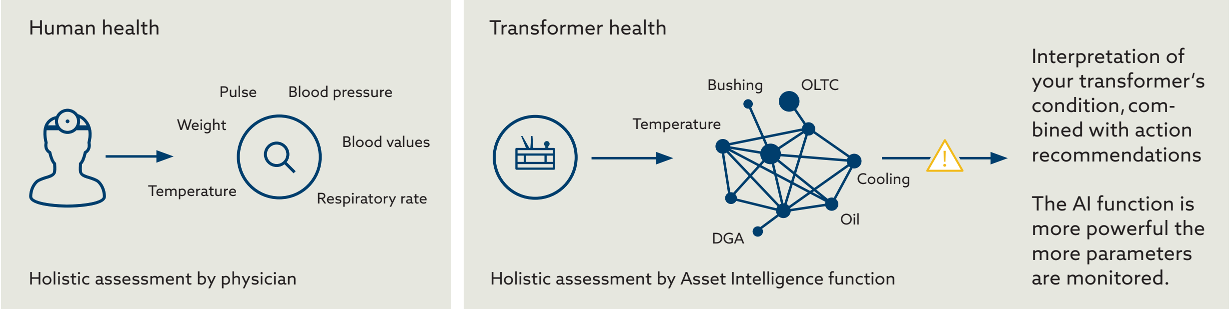
Monitoring and sensor systems on power transformers, such as DGA systems, are often installed on power transformers for early fault detection. These can detect operating states and send corresponding messages when limit values are exceeded. However, just adding more sensors to a transformer has limited benefit. If the information sources aren't consolidated, the frequency of false alarms increases with the number of sensors, and failure diagnosis requires human intervention.

For example, if temperature, partial discharge and DGA sensors are all capable of detecting winding faults, their statements are not compared with each other. Thus, contradictory statements can occur, and a simple diagnosis is not possible. With ETOS® Asset Intelligence, all sensors present on the power transformer are integrated and considered together. A probability-based network checks which error patterns best match the warning messages that have occurred as well as those which have not occurred. In addition, the occurrence rates of typical transformer faults, as well as the false positive rates of sensors are taken into account.

The result is a probability estimate for all known transformer problems, with the most likely problems being displayed to the customer, along with a list of reasons for the findings. This allows the specialist to interpret the diagnostic results in a simplified and efficient way.

This approach mimics the way a human doctor diagnoses an illness by considering various symptoms and medical tests, ensuring that operators receive accurate and actionable insights.

ETOS® innovative AI function merges individual data into actionable insights



Interpretation of your transformer's condition, combined with action recommendations

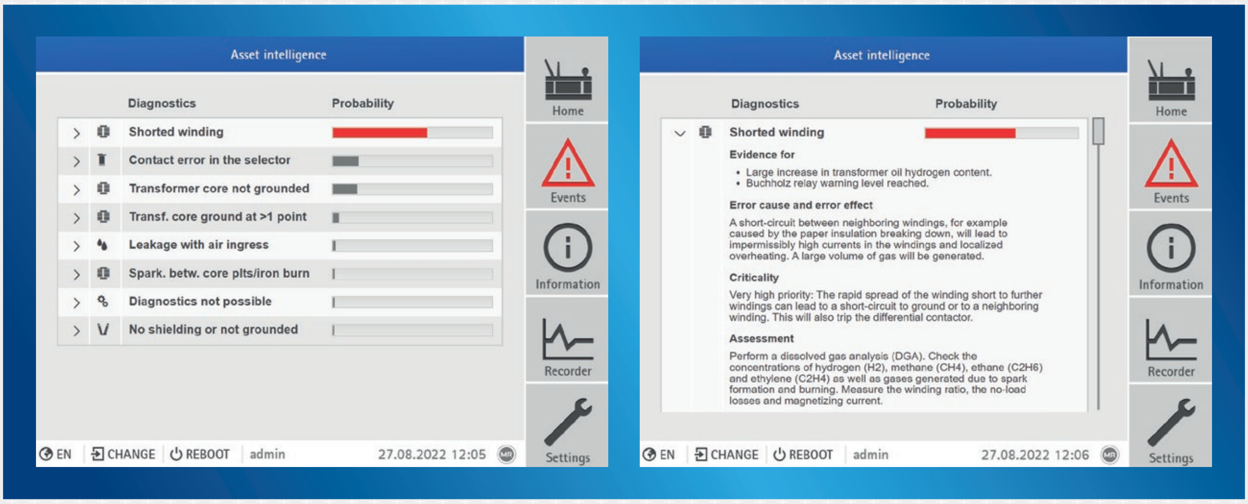
The AI function is more powerful the more parameters are monitored.

Single outliers say little. Only the integrated evaluation over time allows the reliable detection of potentially critical conditions.

> *Asset Intelligence for power transformers provides a guide to minimize risks and take corrective action quickly.*
> *Tobias Gruber | Product Manager ETOS®*

ETOS® Asset Intelligence in Action

The following example serves as an illustration: The Buchholz relay has tripped, and the hydrogen level is greatly increased. Otherwise, there are no further limit violations. The corresponding diagnosis by ETOS® Asset Intelligence is shown below.



Diagnostics	Probability
Shorted winding	
Contact error in the selector	
Transformer core not grounded	
Transf. core ground at >1 point	
Leakage with air ingress	
Spark. betw. core plts/iron burn	
Diagnostics not possible	
No shielding or not grounded	

Shorted winding

Evidence for

- Large increase in transformer oil hydrogen content.
- Buchholz relay warning level reached.

Error cause and error effect

A short-circuit between neighboring windings, for example caused by the paper insulation breaking down, will lead to impermissibly high currents in the windings and localized overheating. A large volume of gas will be generated.

Criticality

Very high priority: The rapid spread of the winding short to further windings can lead to a short-circuit to ground or to a neighboring winding. This will also trip the differential contactor.

Assessment

Perform a dissolved gas analysis (DGA). Check the concentrations of hydrogen (H2), methane (CH4), ethane (C2H6) and ethylene (C2H4) as well as gases generated due to spark formation and burning. Measure the winding ratio, the no-load losses and magnetizing current.

Figure 2: Example ETOS® Asset Intelligence

By using ETOS® Asset Intelligence, the operator gets not only data but qualified support which provides competent recommendations for actions.

Beyond Fault Diagnosis: A Holistic Approach to Asset Management

ETOS® Asset Intelligence goes beyond simply identifying faults; it provides a comprehensive assessment of the transformer's overall health. The system analyzes historical data and sensor readings to predict potential future faults, enabling proactive maintenance planning and preventing costly failures. This predictive capability allows operators to optimize maintenance schedules, extend transformer lifespans, and minimize downtime.

Compensating for Skilled Personnel Loss and Maximizing Efficiency

As the energy industry grapples with the retirement of experienced personnel, ETOS® Asset Intelligence steps in to bridge the skill gap. By automating fault diagnosis and providing actionable insights, the system empowers operators to make informed decisions independently, freeing up skilled personnel to focus on more complex and critical tasks. This automation not only enhances efficiency but also reduces the risk of human error.

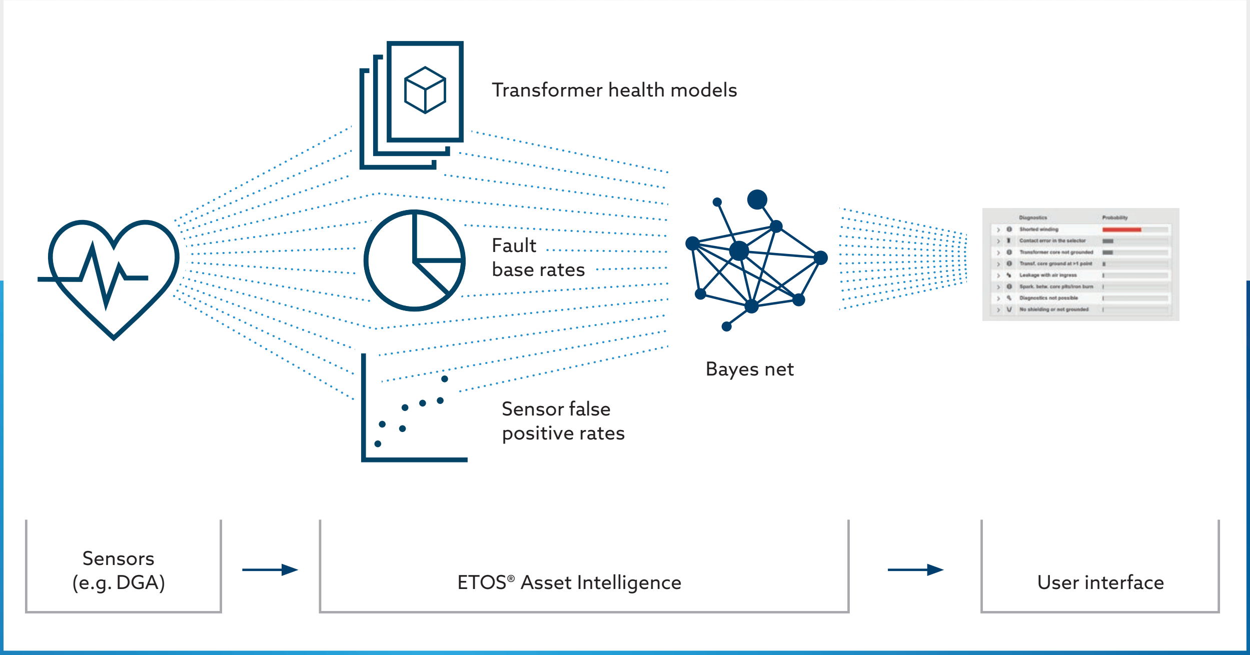


Figure 3: Function principle of ETOS® Asset Intelligence

ETOS®: A Catalyst for Sustainable Grid Operations

By harnessing the power of AI, ETOS® is revolutionizing the way power transformers are managed, leading to significant improvements in efficiency, reliability, and asset utilization. By extending transformer lifespans, reducing maintenance costs, and ensuring the smooth operation of power grids, ETOS® plays a crucial role in sustainable energy distribution. As AI continues to advance, ETOS® is poised to become an indispensable tool for maintaining the reliability and resilience of power grids worldwide.

Tobias Gruber is a transformer automation expert who holds a Master of Science degree in Electrical Engineering. He has spent over a decade at Maschinenfabrik Reinhausen GmbH (MR). As the Automation Portfolio MR Specialist, Tobias specializes in regulating and monitoring power transformers, leveraging his expertise to optimize performance, efficiency, and reliability.
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ETOS® ASSET INTELLIGENCE GOES BEYOND SIMPLY IDENTIFYING FAULTS; IT PROVIDES A COMPREHENSIVE ASSESSMENT OF THE TRANSFORMER'S OVERALL HEALTH. THE SYSTEM ANALYZES HISTORICAL DATA AND SENSOR READINGS TO PREDICT POTENTIAL FUTURE FAULTS, ENABLING PROACTIVE MAINTENANCE PLANNING AND PREVENTING COSTLY FAILURES.

Photo: Maschinenfabrik Reinhausen

POWER PANEL DISCUSSIONS

Green Energy:

An Evolution, not a Revolution

Denis Phares
CEO, Dragonfly Energy

Kevin Schneider
PNNL's Office of Electricity Program Manager,
Pacific Northwest National Loboratory

Pacific Northwest
NATIONAL LABORATORY

POWER PANEL SPONSOR: dragonfly® ENERGY

Bud Collins
CEO, American Energy Storage Innovation

Alan M Ross
Managing Editor, APC Media

Photo: Shutterstock

Alan Ross: Hi, I'm Alan Ross, I'm the managing editor of Power Systems Technology and Transformer Technology. I'd like to thank my guests. Denis Phares from Dragonfly Energy, Bud Collins from AESI, and Kevin Schneider from PNNL for joining me today for this Power Panel discussion.

ARE WE AT A TIPPING POINT?

At the RE+ Conference this past September, it felt very much like a "tipping point", the point at which an idea becomes so powerful that the speed of change becomes virtually unstoppable. It is when the momentum and the weight of change pushes through previous barriers. I believe we saw that at RE+ and our guests can address this tipping point since they are all experts in the field.

Denis, your thoughts please?

Denis Phares: Yes, I agree with you, Alan. I think that we are very much at a tipping point, or an inflection point that, I would say, was largely driven by the onset of the electrification of transportation.

There has been a focus on designing batteries for propulsion, for vehicles, as they become increasingly popular. But a by-product of that is we're transitioning a lot of that power from the internal combustion engine to the grid.

This creates more stress on the grid, so there are two things that happened with this transition in transportation. First, the development of better batteries. And second is the transition of a lot of this power onto the grid, so the combination of that creates the question, how do we stabilize the grid? How do we do so in a way that we're not producing more gas or coal plants, but how can we incorporate more renewable energy?

And, of course, the answer to that is you need a buffer, and that buffer is storage, and that storage is typically lithium batteries, because vehicle batteries have demonstrated that we can bring

> Now we're looking at batteries for how to lower the levelized cost rather than increase the yield, or decrease the charging time or increase the range.
>
> **Denis Phares**

down the cost. We can have more cost-effective solutions than we've ever had in the past when it comes to lithium battery storage.

In my view, now that we've hit this tipping point, we're looking at batteries differently than we have before, when it was strictly for propulsion. Now we're looking at batteries for how to lower the levelized cost rather than increase the yield, or decrease the charging time or increase the range. How do you lower the levelized cost of the storage such that when you combine it with whatever renewable source you want to use so that you have a stable renewable source of electricity that it is cost competitive or even cheaper?

And ultimately, the big change happens when it makes financial sense. So that's where we are right now: how do we make this cost-effective to deploy on a wide scale? This is related to the availability of the natural resources, particularly lithium. How do we make manufacturing more cost effective? And how do we improve the chemistry in order to have long cycle life? Because the levelized cost is basically the manufacturing cost amortized over the life of the battery.

AR Excellent insight, Denis. Bud, same question.

Bud Collins: First, I very much agree with what Denis said, about revolution, pushing the requirements for change, and how we generate electricity and how we distribute it. But I also think that there's some other factors at play when you look at the cost of storage as if it's a part of the grid.

You know, back in the early, the late 2000's, we saw many utilities that were forward-thinking allowing storage to play a role in frequency regulation, and, at that time, we were talking about a $1,000 a kilowatt hour for a system.

Today, we're talking about $165 a kilowatt hour for a system, so prices have come down tremendously.

As costs have come down, you can look at other opportunities. We passed the time of being able to replace a gas peaker plant cost effectively with storage years ago.

As we continue to develop new chemistries, we can make better systems that last longer to make it more reliable for deploying storage in a variety of other use cases; it becomes a viable business offering.

In the last three years we went from a very nascent industry into it being a real game now. It's a real business with a lot of new entrants. As you said at the show last year in 2023, we saw 2500 exhibitors.

There are a lot of people getting into storage, whether it be manufacturers, developers, IPPs, even some of the traditional fuel companies. The oil companies are getting into storage. So, we're excited about the industry. We're excited about the growth.

But I don't think that anybody has really figured out how much storage really will be needed, because I think the proliferation of electric vehicles is just starting.

Also, the change from fossil fuel, heating your homes, to pure electric, and those things are going to put a tremendous strain on the distribution networks, the transmission networks. Everything is going to change in the next 10, 15, 20 years.

AR Excellent Bud, thank you. Kevin, share with us what PNNL, and you specifically, are doing within this space.

Kevin Schneider: I would say that I think the key is how we take this from an academic exercise and transition it into something that will work. Not just in the laboratory, but at scale, because this goes back to your earlier comment of grid scale. People don't always understand the actual scale that we're dealing with when you talk about a full inter-connected power system.

> Prices have come down tremendously... We passed the time of being able to replace a gas peaker plant cost effectively with storage years ago.
>
> **Bud Collins**

When you look at this inflection point, in my mind, it's really due to three things that have been hit on a bit here.

The first is that the technology is advancing. There's more dedicated research going on where we are riding on the coattails of mobile phones, as lithium-ion batteries were being developed there.

A number of other areas such as electric vehicles where the technology, on its own, is advancing.

The other one is the regulatory and policy environment. It's slowly changing because we've always needed energy storage. The technology is starting to show that we can have more things we could do, but until the regulatory and policy catches up and says, *You can't do it*, that really doesn't manifest itself.

And then finally, the third one that brings it all together, is the business case.

If you have the technology, the regulatory and policy environment, then you can build the business case.

Then you have the tipping point because multiple stakeholders can take this new technology with ways to make money with it, solve problems, and that's what really differentiates it from a DOE funded field demonstration to a mature technology that spins off companies that stand on their own and have growing quarterly earnings.

WHAT ARE POSSIBLE DANGERS WE COULD FACE DURING THE GREEN TRANSITION?

AR Let's move on. When you're looking at the industry as a whole, you can see at how far we've come.

In the TV show *Lost in Space* there was a robot, and every time there was any danger the robot's arms would flap, and it would say: *Danger, Will*

Photo: Shutterstock

> I don't understand why the rest of the industry hasn't done what they should do to solve the problem [of battery safety].
>
> **Bud Collins**

Robinson, danger! And then you'd have to wait until the next episode to find out what that danger was about. Well, let me flap my arms at you all and say, *danger, gentleman, danger!*

What are the dangers that we face going forward? Some of the things that are the unintended consequences of our actions or just, hey, we did not see it coming?

Bud, let's start with you. Talk about the future and the dangers we face in our industry, specifically related to storage.

BC One of the things, and it was mentioned before, I think both by Kevin and Denis, is some level of sustainable domestic production. It is necessary for security, and in general, for our economy. We've got to make sure that we have the governmental tempo and guidance, and structure support. If we don't have that domestic production, then we'll be in danger, relying on maybe still be China, maybe it will be another country. That's one thing that poses a risk.

Every day, when I wake up, the first thing I do, I check the news feed and I say, did I have enough? Did somebody have another fire or an explosion in energy storage? To me, that is, A, unacceptable to have, and, B, I don't understand why the rest of the industry hasn't done what they should do to solve the problem.

We took a completely different approach with our system.

We're looking forward to not having the issues that other people have had, because it causes a problem with trying to get something permanent locally. The people with the pitchforks come out and say, *No, you're not going to put that in my backyard, because I saw that Tesla burning down the street, or, I heard about a fire in New York, and I don't want that in my street, in my town.*

I think it's really up to the industry to self police itself. It's not going to be standards or NSBA standards, it's going to be the industry itself that says, *Dammit, I don't want to have thermal runaway*. It's more than one cell in a system, because that's manageable and then we push the cell industry to not have thermal runaway period.

AR Excellent.
If you all remember, it was what about 20 years ago where the largest lithium-ion utility scale in Hawaii melted down to the ground.

BC That was lead acid.
I Had a conversation with the with the woman who chose that company, that supplier over lithium and sure, we were laughing about it, but it's not very funny that the people that owned it lost the money. But it wasn't the technology. It was absolutely application of the technology and how it was operated. Lead acid batteries are perfectly fine. You just have to treat them nice.

AR All right, it was a mess. I worked on behalf of an insurance company which insured that facility. The company that made it went out of business, I believe.

Denis, you mentioned solid state battery. Let me follow up on that, because you mentioned safety. One of the things that you all have been working on is the idea of using technology to create a safer system. Talk a little bit about that.

DP Batteries can be made very safe, especially with lithium-ion phosphate cathodes you can really reduce the possibility of a thermal runaway which of course it is each time it happens, it's awful for the industry as a whole.

We look at it from a different point of view – if you have a large installation in a home, then it's not just the potential for thermal runaway, but the flammability of the electrolyte itself. And so, we are looking at how we can remove the potential for even the contribution of the batteries to an existing fire. Because in homes you can get electrical fires and, if you've got a large battery there, then that fire is that much harder to put out. Therefore, we've been focusing our efforts on solid-state batteries.

The research on solid-state batteries is not focused on those metrics. You know, you put in a solid electrolyte to block dendrites and allow for lithium metal anode, or even an anode list battery, and all of a sudden, you got really fast charging and very high energy density. So it's a little bit of a different way that we look at it in terms of our approach, and it really is the reason we did that. Because of the manufacturing process, the powder coating process just lends itself perfectly to a ceramic-heavy composite electrolyte, but I also want to address your question about danger ahead.

I don't look at it like that, as much as the opportunity that awaits. It's historically huge, in terms of that we can change the economics of this country if we can keep things domestic.

This is the future, you know. If we go back to a fossil-fuel-based economy globally, then we're playing with fire. Literally.

But the fact that we could actually take the lithium-ion battery, or just storage in general, which is an American innovation anyway, and just lead the world again and drive the economy,

Photo: Shutterstock

> If we go back to a fossil-fuel-based economy globally, then we're playing with fire. Literally.
>
> **Denis Phares**

> You need to have enough trust between the manufacturers and society... We're moving fast, but we're making sure we take the due diligence regarding safety concerns.
>
> **Kevin Schneider**

> Microgrids – I love them, I think they're going to be a part of the future… the technology of microgrids with batteries is here today.
>
> **Kevin Schneider**

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I think will put this country back on a path of innovation and profitability as a country that I think we are, we desperately need right now.

AR Excellent, excellent. So, Kevin, last to comment on the danger.

KS I think it goes back to what Bud said about building trust, because you're dealing with something inherently has a lot of energy. It's never going to be 100% safe. There's always going to be an instance or two of a risky situation, or there'll be a certain challenge.

But you need to have enough trust between the manufacturers and society that they say, *OK, it happened, but we know that these folks are doing their due diligence, doing the proper engineering so that we can move forward.* Because what we're looking at as an industry, it's going to have to move very fast to get to all those things that Denis was talking about, building local capacity. All the new technologies are going to have to move fast. And then these devices are going to reside there. This is going to be happening on utility scale for 15, possibly 20 plus years. Over that timeframe, there will be events that are going to have negative press, so how do we make sure that we build that trust between the developers that say *no*?

Yes, we're moving fast, but we're making sure we take the due diligence regarding safety concerns. We're looking at new chemistries, and how do we build that together? That's going to be tough, and I think it's going to be one of the things that we really have to focus on, in order for it to be successful.

AUDIENCE QUESTIONS

AR We've got a lot more questions than we have time to answer. I'll go through the ones I've got really quickly.

Is there documentation showing that BESS implementation is a lower cost solution compared to a gas gen solution? Let's start with you, Bud, what does that mean?

BC Like I was saying earlier, you when we crossed that thousand-dollar-per-kilowatt-hour threshold, which was years ago, that's really the threshold where you don't put in a gas peaker. The battery can provide that. We're not talking about gas generation for baseload, we're talking about a peaker plant. I know you're talking about 2-4 hours worth of storage. We're already there.

AR Fortunately, we already have a lot of gas peaker plants and shale oil pumping, we're trying to get gas to became so cheap that you saw a lot of utilities get those peaker plants. When we started closing down coal plants, you had to now use some of them. They weren't just peaker plants anymore, some of them. You had to get your normal generation from them.

But good point. Anybody else, comment on that?

KS I guess I would add one thing. Bud is absolutely right. There are economic cases where it pencils out right now. But I would also look at extreme events, resiliency type events.

People are used to situations where a big storm comes through, and they are blacked out, maybe, and you've got enough backup fuel on hand for a little bit of time. But if you have these hybrid systems that have some solar and batteries, they can operate not necessarily indefinitely, but they can go a lot longer.

I'm up here in Seattle, one of the big concerns we have is a Cascadia earthquake event. We're 100 years past due, if that ever hits, you will not be able to get fuel in, probably for weeks. Not that solar is necessarily the perfect resource in Seattle, but in summertime you could possibly run 24/7 because you've got storage and some renewables.

It is, as I say, not an either-or, but right now there are some cases where the batteries went out, hands down.

AR You just hit on one of the other questions, I want to stay on it.

The question is, and the question was posed more in a negative way, how does the advancement of large-scale, utility-scale storage impact the resiliency, reliability, and stability of the grid?

So, you might have just answered it, but it's talked about more than just resiliency.

KS I'd break that into two parts. One is your local resiliency. If you have a big storm that comes by, energy storage could power up a house, or a small community.

We saw this down in Florida during one of the big storms, where they had a whole plan developed that rode through on batteries and solar the whole time.

That's one example, but if you start talking about very large scale, gigawatt-scale energy storage on the bulk system, I would say it has the technical potential to significantly improve the system. When you've got technologies like grid-forming inverters, there are very fast controls. They can stabilize instabilities in the system, and they can be a real benefit.

The real challenge with that, though, is that once you have a single utility, we've got multiple utilities operating the system. There are different power plants in different locations, so co-ordination becomes an issue. So where I'm going with this is that they have the technical potential. They can absolutely stabilize the system, if we don't learn how to do it in the context of the larger system that could actually cause instabilities in the system, which is true of any large-scale resource. So that's an opportunity, but also a caution.

AR Thank you, Bud, Denis, comment on that.

DP I would agree that the resiliency is really optimized when you have distributed generation and distributed storage.

We've talked about the grid edge before, Alan, and the fact that you can generate and store at the edge means that locally you have more resiliency.

AR What is the role of storage in micro grids? How important is it and what have we done, and what are you seeing out there, because there are more and more opportunities?

I know there's a bakery in California, they have six plants. Bakeries usually emit heat, right? And they are off the grid. One of the big reasons they're off is because of storage. They use primarily solar, some wind, but storage is the most significant. They're not using Southern Cal Edison or PG&E anymore, and I know that's bad for those utilities, but it is good for us, and good for us who eat bread.

Let's talk about the future of these microgrids and why storage will play a role in it, and how storage is already playing a role on it. Let's start with you, Bud.

BC When we talk about microgrids, you can go from having a small cluster of homes or a cluster of businesses, or a microgrid could be a 10-megawatt type generating system.

One of the biggest things about distributed energy storage are really the regulations. California continues to lead in setting markets and allowing for storage to participate in grid-scale activities. So, now you have things that are behind the meter; a lot of businesses, large buildings, they've got storage deployed for their systems to give them resiliency. But that's an asset sitting there that could earn some money, and now they can participate in grid activities. That's a unique opportunity in California. We want to see that all across the whole country.

All utilities that allow that participation do so because that will give us that resiliency. If you look at the amount of money that it's going to take to strengthen the distribution network and change the distribution network to bring double the power to the homes, because they're going to have EVs, and they're going to be all electric, that's not going to happen very quickly. There’s a lot of capital. It has to be deployed. So, storage plays a big role in fitting in there, and cutting down on the need to do those big upgrades, where storage can handle those peaks, those long periods of time when the grid is just overstressed, or there's no power grid.

AR Same question, Denis, and we're coming to an end here, so you're going to be our last, Kevin, on this one.

DP I apologize for pre-empting that question, because that was my point in terms of the distributed nature of it.

But just to expand on that, I think the exciting part of it is the ability of these distributed and micro networks to contribute to a very smart grid, a software-driven grid, where we can optimize and minimize transmission and optimize efficiency. I think that's the world where we're headed. That's the grid that we're heading towards when we start to talk about distributed generation and storage.

AR Excellent. So, Kevin, we're at the end here. The last word.

KS Microgrids - I love them, I think they're going to be a part of the future. It's not an either-or. I think we're going to have a bulk system that provides us a lot of economic benefit. Microgrids can help us during local events, as well as be collaborative partners in that.

I would say that the technology of microgrids with batteries is here today. I've toured Duke Energy's Mount Hollie microgrid, all inverter-based, transition is seamless, you can't tell it. I toured a ship yard in Hawaii that 95% of the time ran off batteries and solar. That's a shipyard, a heavy industrial environment, and they were able to do it.

I'm not going to say it's turnkey off the shelf, but it's something that can be bought today, and the technology is quite advanced.

AR We’ve come to an end. You mentioned this whole concept of inter-operability, which is using software, making grid smarter, and being able to level throughout the grid. This requires a lot of collaboration between a lot of organizations from the federal government to the municipals and the co-ops and the IOUs. I think it's going to be driven by economics, and, as you said, Denis, we've got to have a secure nation that we can supply.

This, to me, is Henry Ford, when he created the assembly line. If he didn't have a national program to build gas stations across the country, no matter how many Model T or Model A Fords he built, they wouldn't have been able to get anywhere because Stanley Steamer had everything he needed - water and wood. It was all around. You didn't have gas stations in Peoria, and they had to make sure that they're there, and it was a national project. Of course, Standard Oil had a lot to do with it, the Rockefellers, and so on. That became a national mandate in order to create what we now live with, which is a modern transportation system powered by gas. That's where we are. That's my last word.

Kevin Schneider from PNNL, thank you so much, brilliant. Denis Phares from Dragonfly Energy. Once again, I appreciate you, brother. You always bring great perspective and insight. Bud Collins from AESI, thank you for joining us. You guys have been brilliant, and we appreciate it very much. This has been a Power Panel discussion from APC media. Thank you all for joining us.

POWER
PANELS

Watch the full Power Panel Discussion on our website.

Samantha Deeney

SAMANTHA DEENEY *joined Mitsubishi Electric Power Products, Inc. (MEPPI) Power Systems Engineering Division in February 2018. Prior to joining MEPPI, she graduated from the University of Pittsburgh at Johnstown with her Bachelor of Science degree in Electrical Engineering Technology. She then continued her education at the University of Pittsburgh as a graduate student researcher and earned her Master of Science degree in Electrical Engineering with a focus on power. During her time researching at the University of Pittsburgh, Samantha focused on grid-tied microgrid protection schemes for upstream faults researching ways to safely disconnect and island microgrids in the event a fault would occur upstream on the bulk electric system.*

Samantha is a Senior Engineer at MEPPI in the Power Systems Engineering Division (PSED). She has continuously developed her skills at MEPPI in various niche areas. Throughout her career, Samantha has performed load flow and dynamic stability analysis for system impact and generation interconnection/retirement, as well as large scale resiliency analysis, such as CIP-014. She has executed and managed multiple Flexible AC Transmission System (FACTS) studies for STATCOM devices, involving PSCAD and PSS/E studies such as control tuning, dynamic performance, short-circuit, interaction analysis, harmonic stability screening, and electromagnetic transient analysis. Samantha has also performed various steady-state feasibility analyses for potential HVDC placements and planning evaluations, specifically within dense load pocket areas, such as data center concentrated load. She has executed harmonic analysis and is experienced in filter design. She has modeling and software experience in platforms such as EMTP-RV, PSCAD, PSS Sincal, PSS/E, and TARA PowerGEM. Her responsibilities at MEPPI include leading, managing, and executing projects for the reliable integration of power electronic and FACTS devices and other resources.

Samantha has authored several publications and has received a patent for the creation of a power oscillation damping controller with dynamic gain control, such that the control adaptively detects and adjusts gain whilst damping sustain power oscillation utilizing reactive power, which is integrated into devices such as STATCOMS.

Samantha looks to stay on the cusp of technology given the ever-changing industry and continues to pursue advancement in education and industry activity. She continues to be involved in groups such as CIGRE and continues to actively publish papers on developments within her group in PSED, as well as participating in internal organizations within MEPPI such as the company's Professional Women's Network (PWN).

MEPPI's culture has continuously proven as a supportive environment from our leaders to grow and develop skills within the organization with equal opportunity amongst women and men. Innovative ideas and advancement are encouraged at MEPPI, which fosters technical solutions for the challenging problems that are faced presently by the overall power industry and in the years to come.

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Going Green:

An Evolution, not a Revolution

The quest for sustainable energy and alternative low-carbon fuel sources persists as the global community pushes towards decarbonization, recognizing the pivotal role of energy consumption in greenhouse gas (GHG) emissions worldwide. Nations worldwide are committing to carbon neutrality and achieving net zero emissions, necessitating substantial shifts in our energy consumption patterns. One of the most impactful strategies in this endeavor involves electrifying various sectors while simultaneously reducing carbon emissions from the power generation process. However, certain industries present unique challenges, making electrification alone insufficient for decarbonization. These hard-to-abate sectors include long-haul transportation (such as trucking, shipping, and aviation) as well as heavy industries like steel and cement production. Additionally, the transition to electrification demands a parallel effort to decarbonize the power sector itself. In this landscape, hydrogen emerges as a promising solution for decarbonizing these challenging sectors and those resistant to electrification. Renewable energy-driven green hydrogen stands out as a sustainable and eco-friendly alternative. Unlike gray hydrogen derived from fossil fuels, the production of green hydrogen involves water decomposition using renewable electricity, resulting in zero carbon dioxide emissions and negligible pollutants. Embracing green hydrogen technology is imperative for advancing environmental sustainability and curbing carbon emissions, signaling a significant stride towards a cleaner, more sustainable future.

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Dr. **Ahad Esmaeilian** is Vice President of Clean Energy at Audubon Engineering Company. He holds bachelor and master's degrees in Electrical Engineering from The University of Tehran, a master's degree in Business Administration from the Clarkson University, and a PhD in Electrical Engineering from the Texas A&M University, and has a rich experience in both electrical engineering and business. He is also a Senior Member of the IEEE and currently serves as the Chairman of the IEEE PES Grid Edge Technologies Conference & Expo.

> *ONE OF THE MOST IMPACTFUL STRATEGIES IN THIS ENDEAVOR INVOLVES ELECTRIFYING VARIOUS SECTORS WHILE SIMULTANEOUSLY REDUCING CARBON EMISSIONS FROM THE POWER GENERATION PROCESS.*

While green hydrogen presents a plethora of benefits, its optimization requires concerted efforts in enhancing production, storage, transportation, and utilization technologies. Additionally, factors such as production costs and infrastructure development warrant careful consideration to fully exploit its potential. Nonetheless, the widespread recognition of green hydrogen as a sustainable and clean energy solution underscores the current emphasis on advancing related technologies.

> *HYDROGEN EMERGES AS A PROMISING SOLUTION FOR DECARBONIZING THESE CHALLENGING SECTORS AND THOSE RESISTANT TO ELECTRIFICATION.*

Green Hydrogen Production by 2050:

Despite its complexity, various organizations and research institutions have developed models to estimate the production of green hydrogen in major countries worldwide from 2020 to 2050. These models incorporate factors such as policy support, technological advancements, market dynamics, and the accessibility of renewable energy. [1].

- **Europe:** The European Union aims to achieve 40 GW of green hydrogen production by 2030, alongside generating 10 million tonnes of renewable hydrogen within the same timeframe. Projections from the Hydrogen Council suggest Europe could annually produce up to 800 TWh of hydrogen by 2050, potentially constituting a market worth EUR 630 billion annually.
- **China:** With a focus on green hydrogen derived from renewable sources, China targets an annual production of 5 million tonnes by 2025. The International Energy Agency (IEA) forecasts that China could produce up to 60 million tonnes of hydrogen yearly by 2050, translating to a market size of USD 150 billion per year.
- **United States:** By 2030, the United States aims to achieve 5 GW of hydrogen production, prioritizing green hydrogen from renewable sources. The Hydrogen Council anticipates that by 2050, the U.S. could cater to a quarter of the global hydrogen demand, potentially amounting to a market size of USD 140 billion annually.
- **Japan:** Japan's target for 2030 includes producing 300,000 tonnes of hydrogen annually, with a preference for green hydrogen sourced from renewables. As per the Hydrogen Council, Japan might contribute up to 20% of the world's hydrogen demand by 2050, with a prospective market size of USD 80 billion per year.
- **Australia:** By 2030, Australia aims to produce hydrogen at a cost below AUD 2 per kilogram, primarily focusing on green hydrogen from renewable sources. Projections from the Australian Renewable Energy Agency (ARENA) indicate Australia could account for up to 10% of global hydrogen demand by 2050, potentially comprising an AUD 11 billion per year market.

These estimations and forecasts collectively suggest a significant surge in green hydrogen production across key countries from 2020 to 2050, driven by supportive policies, technological advancements, market dynamics, and the availability of renewable energy sources.

Industries and Applications:

Green hydrogen is poised to revolutionize diverse industries by offering a clean, efficient, and versatile energy solution.

- **Transportation:** The transportation sector is increasingly embracing green hydrogen as a zero-emission fuel option. Automakers like Toyota, Hyundai, and BMW are developing and deploying fuel cell electric vehicles (FCEVs) powered by hydrogen. Additionally, initiatives are underway to utilize hydrogen for heavy-duty vehicles, buses, and trains.
- **Industrial Applications:** Industries such as steel, chemicals, and refineries are exploring green hydrogen to reduce their carbon footprint. Hydrogen can serve as a feedstock, reducing agent, or source of heat in various industrial processes.
- **Refining and Petrochemicals:** The refining and petrochemical sectors are investigating green hydrogen to lower carbon emissions. Hydrogen can replace fossil fuels in refining processes like desulfurization and hydrocracking, thereby supporting the decarbonization of operations in these industries.
- **Aviation:** The aviation industry is actively researching the use of green hydrogen as a sustainable aviation fuel. Hydrogen-powered aircraft, whether through combustion or fuel cells, have the potential to significantly reduce greenhouse gas emissions compared to traditional jet fuels.
- **Energy Storage and Grid Balancing:** Green hydrogen plays a vital role in energy storage and grid balancing. During periods of low demand, excess renewable energy can be utilized for hydrogen production through electrolysis. The stored hydrogen can then be converted back to electricity through fuel cells or combustion during periods of high demand, thereby stabilizing the grid and ensuring a reliable energy supply.
- **Residential Heating:** Green hydrogen offers a viable alternative for residential heating, displacing natural gas and other carbon-intensive fuels. Hydrogen boilers and fuel cells can provide heat and hot water without emitting carbon.
- **Energy Export:** Countries abundant in renewable energy resources, such as Australia and Canada, are exploring green hydrogen export opportunities. Liquefied hydrogen

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GREEN HYDROGEN IS POISED TO REVOLUTIONIZE DIVERSE INDUSTRIES BY OFFERING A CLEAN, EFFICIENT, AND VERSATILE ENERGY SOLUTION.

or other derivative green fuels such as ammonia and methanol can be transported as a commodity, enabling nations to share their renewable energy potential with regions lacking such resources.

These examples underscore the global momentum toward green hydrogen adoption, driven by its potential to decarbonize various sectors and foster a sustainable, cleaner energy future.

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Innovative Methods of Producing Clean Hydrogen:

Researchers and scientists worldwide are actively investigating and developing new technologies, materials, and processes to enhance the efficiency, scalability, and cost effectiveness of renewable hydrogen production, storage, and usage. By continuously advancing these methods, the aim is to facilitate the widespread adoption of clean hydrogen as a sustainable energy solution [51].

- **Plasma Arc Decomposition:** Plasma arc decomposition, also known as plasma reforming, utilizes high temperatures generated by an electric arc to break down natural gas (methane) into hydrogen and carbon monoxide. This occurs within a plasma reactor, where the intense heat dissociates methane molecules, liberating hydrogen gas. When electricity for the plasma arc decomposition is sourced from renewables, this method qualifies as a green hydrogen production technique.

- **Thermolysis:** Thermolysis involves the decomposition of a chemical compound, such as water or hydrocarbons, by applying heat. Subjecting the compound to high temperatures breaks molecular bonds, releasing hydrogen gas. By using heat from renewable energy sources, thermolysis ensures an environmentally friendly production process.

- **Photo Electrochemical (PEC) Water Splitting:** PEC water splitting utilizes specialized semiconductor materials to directly convert solar energy into hydrogen. These materials can absorb sunlight and initiate the water-splitting reaction within the cell, generating hydrogen and oxygen. PEC technology offers the potential for efficient and direct solar-driven hydrogen production, eliminating the need for external electricity sources.

- **Artificial Photosynthesis:** Artificial photosynthesis is an emerging field that seeks to replicate the process of natural photosynthesis in plants to produce hydrogen. It involves using specialized materials and catalysts to capture sunlight and initiate chemical reactions that produce hydrogen from water. Artificial photosynthesis holds promise for renewable and sustainable hydrogen production, but it is still an area of ongoing research and development.

Green Hydrogen Challenges and Observations:

It is crucial to recognize the transformative potential that green hydrogen holds in the transition to sustainable energy is not without its obstacles. Below, we explore the array of challenges that must be addressed to realize the full promise of green hydrogen as a clean energy solution.

- **Energy Loss:** Around 30% of green hydrogen's energy content is lost during hydrogen liquefaction, meaning each unit produced only retains 70% of its available energy.
- **Liquid Hydrogen Storage:** Storing liquid hydrogen presents challenges due to the extremely low storage temperature required (-253°C) and the necessity for effective isolation systems.
- **Safety Concerns:** Hydrogen's flammability and potential for oxygen dilution pose safety risks.
- **High Energy Density:** Hydrogen's wide combustible range, low boiling point, and high energy density require careful handling to prevent accidents.
- **Technical Hurdles:** Technical challenges, like high temperature and pressure requirements, complicate hydrogen storage.
- **Cost:** Competitiveness requires reducing hydrogen gas costs to around USD 2 per kilogram or lowrer.
- **Electricity Demand:** Green hydrogen demands significant electricity, necessitating increased renewable energy production.
- **Offshore Wind Capacity:** Developing offshore wind energy is crucial to meet green hydrogen demand.
- **Infrastructure:** Establishing comprehensive infrastructure for production, storage, and distribution is challenging.
- **Scaling Up:** Meeting demand across sectors requires significant production scale-up.
- **Electrolysis Technology:** Enhancing electrolysis efficiency and cost-effectiveness is key.
- **Renewable Energy Availability:** Reliance on intermittent renewables poses supply challenges.
- **International Collaboration:** Global cooperation is necessary for successful green hydrogen implementation.
- **Regulatory Framework:** Supportive regulations are vital for green hydrogen deployment.
- **Public Awareness:** Raising public awareness and acceptance is essential.

Currently, the clean hydrogen market struggles to match the economic competitiveness of fossil fuels, largely due to the absence of environmental costs in fossil fuel prices. Nevertheless, as technology advances and production costs for clean hydrogen decrease over time, this disparity is anticipated to diminish. Meeting the rising demand for clean hydrogen necessitates robust infrastructure, efficient production and storage methods, and cost reductions.

Governments and enterprises are poised to invest in research, development, and innovation to bolster the clean hydrogen market's competitiveness [68].

It is through careful consideration and collaboration that the full potential of green hydrogen can be realized, leading to a cleaner and more sustainable energy future.

> *CURRENTLY, THE CLEAN HYDROGEN MARKET STRUGGLES TO MATCH THE ECONOMIC COMPETITIVENESS OF FOSSIL FUELS, LARGELY DUE TO THE ABSENCE OF ENVIRONMENTAL COSTS IN FOSSIL FUEL PRICES.*

References

[1] EIA. Renewable Energy Explained. Available online: https://www.eia.gov/energyexplained/renewable-sources/

[2] Di, L.G.; Olufemi, O.A.; Kumar, A. Blending blue hydrogen with natural gas for direct consumption: Examining the effect of hydrogen concentration on transportation and well-to-combustion greenhouse gas emissions. *Int. J. Hydrogen Energy* 2021, 46, 19202–19216.

Solid State Batteries: Current Status and Future in the BEVs Market

by **Abdullah Bin Kamran**

Photo: PTR Inc.

- ***Recent years have seen a surge in demand for sustainable transportation driven by environmental awareness, with electric vehicles (EVs) leading the way in reshaping the automotive industry.***
- ***Battery technology, particularly Lithium-ion batteries, has significantly improved, enabling longer driving ranges and faster charging times for EVs. However, challenges linked with energy density, safety, and cost persist.***
- ***Solid-state batteries hold promise in addressing these challenges and revolutionizing the EV landscape.***

Abdullah Bin Kamran serves as an Analyst at PTR Inc. He focuses on the topic of energy storage and battery energy storage systems. He specializes in research on the global energy storage market, covering areas such as market sizing of different markets, policy landscapes, market developments, project pipelines, project installations, and the advancement of new battery technologies. He also covers the battery value chain and tracks the supply chain advancements in the industry, such as the installation of raw material plants and battery gigafactories. He holds a BS in Electrical Engineering from LUMS, which gives him the required technical knowledge on his topic.

In recent years, the demand for sustainable transportation has surged, driven by awareness of fossil fuels' environmental impact. Electric Vehicles (EVs) are reshaping the global automotive industry and pushing towards a greener future. Batteries are crucial for electric vehicles, their performance, and the safety of the driver. Currently, lithium-ion batteries are dominating the global electric vehicles market, but it is expected that solid-state batteries will revolutionize the EV landscape due to their superior characteristics, including improved lifespan, energy density, and safety.

> Unlike oil and gas-powered generation facilities, power cables and transformers at utility scale renewable sites play a much bigger role connecting the distributed generation to the grid.

Overview of the EV Global Growth Landscape

The worldwide rise in EV adoption can be attributed to government-driven clean energy goals. Governments globally promote EV adoption with incentives, subsidies, and green policies to cut emissions, boost energy security, and generate eco-friendly employment opportunities. Substantial investment by automotive OEMs in EV R&D and diverse electric models have also sped up consumer adoption, making EVs more accessible. The global EV market forecast reflects the anticipated significant expansion in the industry.

- ***Current lithium-ion batteries suffer from limitations in energy density, which can constrain the driving range of electric vehicles, presenting a challenge to EV manufacturers striving to meet consumer expectations for extended range capabilities.***

- ***Lithium-ion batteries are vulnerable to thermal runaway, a situation in which overheating can result in rapid and uncontrollable battery failure, raising safety concerns and necessitating the implementation of robust thermal management systems in EVs.***

- ***The persistently high cost of lithium-ion batteries continues to be a major impediment to widespread EV adoption. While prices have decreased over time, affordability remains a pivotal factor in expanding the electric vehicle market.***

- ***The substantial weight of lithium-ion batteries can have a significant impact on the overall weight and handling characteristics of electric vehicles.***

> Solid-state batteries hold promise in addressing these challenges and revolutionizing the EV landscape.

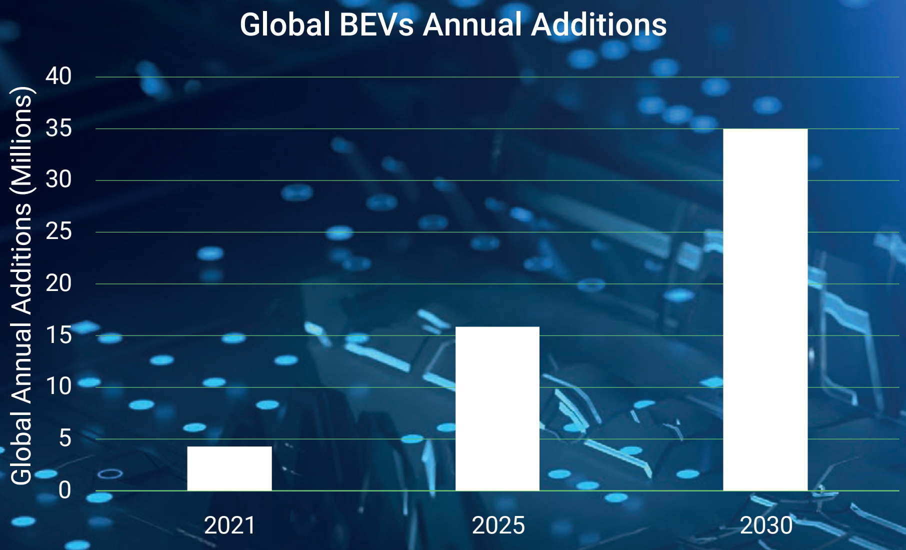


Figure 1: Global BEVs Annual Additions.
Source: PTR Inc.

Photo: Shutterstock

Existing Battery Technologies

One of the primary catalysts behind the growth of the EV market is the rapid progression in battery technology. Lithium-ion batteries, which power most EVs, have seen significant enhancements in energy density, charging speed, and overall performance. This has led to extended driving ranges and reduced charging times, addressing key concerns that previously hindered EV adoption. Furthermore, ongoing research and development into next-generation batteries like solid-state and lithium-sulfur batteries hold the potential for even greater energy densities, further boosting the EV market's expansion.

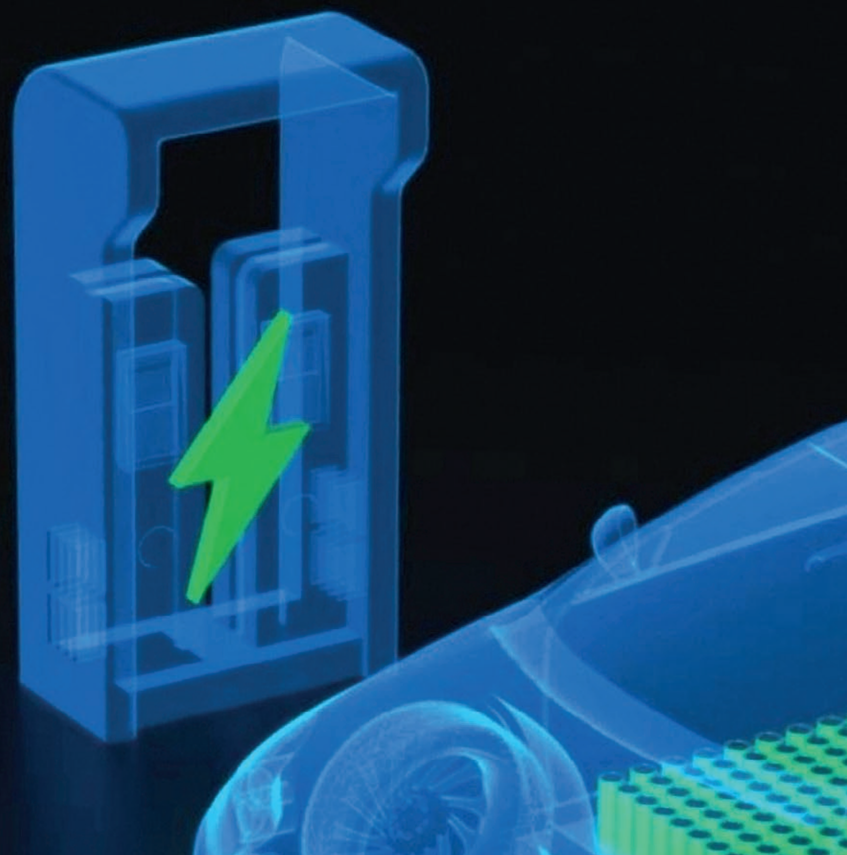
The distinctions among currently used batteries stem from differences in safety, lifespan, and energy density. Battery chemistry plays a pivotal role in determining the performance, safety, and cost of various battery types utilized in EVs. Within the realm of widely used lithium-ion batteries, some common types include lithium cobalt oxide (LCO), lithium iron phosphate (LFP), and lithium nickel cobalt manganese oxide (NCM/NMC), each offering specific trade-offs in terms of energy density, safety, and cost.

LFP batteries are renowned for their intrinsic safety and thermal stability, making them a favored choice for certain EV applications. Conversely, NCM/NMC batteries strike a balance between energy density and cost, making them a widely adopted option by many automakers for their electric vehicles. LCO batteries, while offering high energy density, are more frequently employed in smaller EVs, such as electric scooters and e-bikes, due to their lower cost.

Solid State Batteries: The Promising Solution to EV Batteries

Solid-state batteries signify a groundbreaking advancement in battery technology. In contrast to conventional lithium-ion batteries that use liquid electrolytes to facilitate ion movement between the cathode and anode, solid-state batteries employ solid-state electrolytes, eliminating the need for flammable and volatile components. This critical design change enhances safety by reducing the risk of thermal runaway and fire hazards while also enabling higher energy density, longer cycle life, and faster charging.

The potential benefits of solid-state batteries aim to address critical challenges associated with traditional lithium-ion batteries. Enhanced safety instills greater consumer confidence, addressing a primary concern hindering widespread EV adoption. Additionally, solid-state electrolytes allow for the use of lithium metal anodes, which offer higher energy density compared to the graphite anodes typically used in lithium-ion batteries. This translates to increased electric vehicle driving range, alleviating range anxiety and making them more suitable for long-distance travel. The improved energy density also allows for reduced battery weight, addressing a current issue with existing batteries.



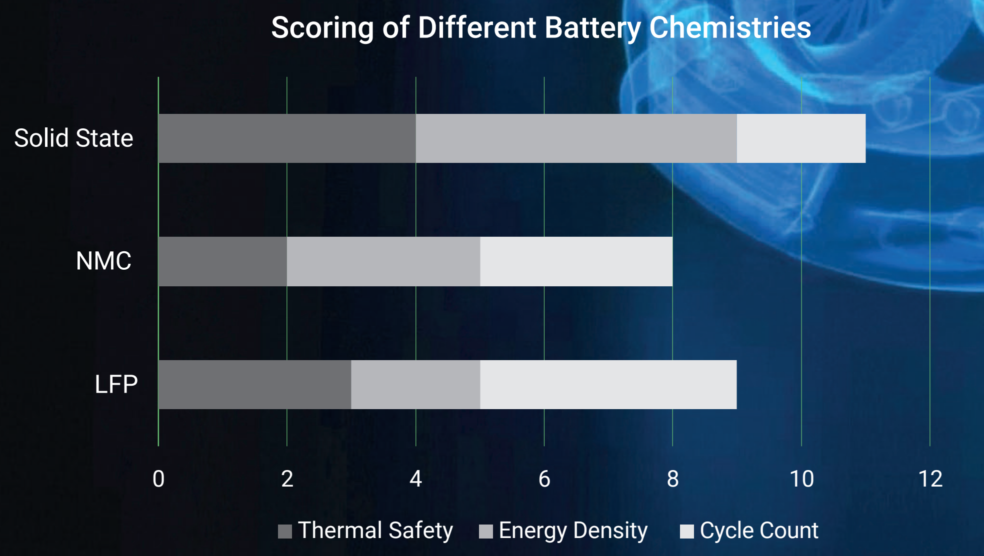


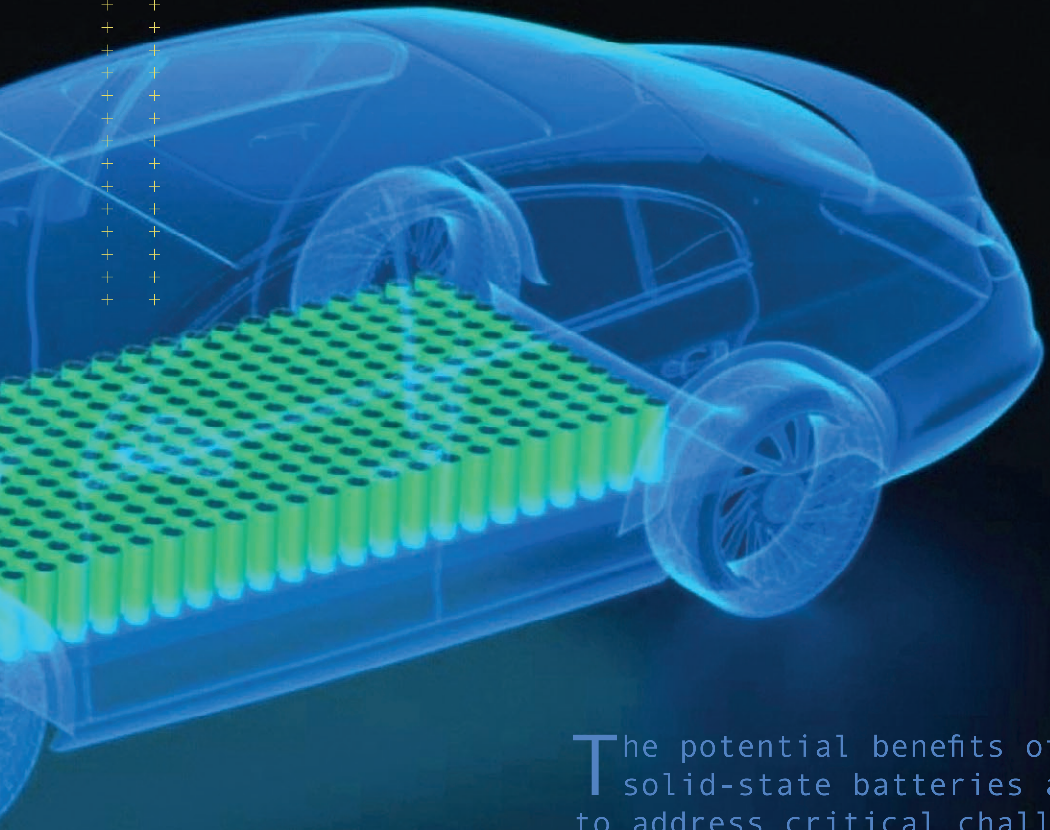
Figure 2: Scoring of Different Battery Chemistries
Source: PTR Inc.

Photo: Shutterstock

The accompanying graphic illustrates the anticipated decline in the average price per kWh for solid-state batteries in comparison to existing technologies. Ongoing research and development by major industry players suggest that this price could potentially drop significantly lower as the product is mass-produced and the supply chain and material sourcing are optimized for solid-state batteries. Battery costs constitute a significant portion of the overall cost for consumer-market EVs. With higher energy density and improved cost efficiency, solid-state batteries have the potential to become the dominant battery technology for EVs, resulting in lower prices for consumers.

Players Working on Solid-State Batteries

The emergence of solid-state batteries has attracted significant attention from prominent stakeholders in the automotive, technology, and energy industries. Leading car manufacturers like Toyota, BMW, and Volkswagen are actively dedicating resources to research and develop solid-state battery technology for use in electric vehicles. The attached graphic provides a timeline illustrating ongoing and forthcoming collaborations and advancements within the solid-state battery sector.



> The potential benefits of solid-state batteries aim to address critical challenges associated with traditional lithium-ion batteries. Enhanced safety instills greater consumer confidence, addressing a primary concern hindering widespread EV adoption.

Inhibitors

Nonetheless, the commercialization of solid-state batteries encounters hurdles associated with production expenses and enduring reliability. An issue within solid-state technology is the formation of dendritic growth on lithium anodes, a phenomenon occurring during rapid charging that can result in battery failure, diminishing battery health, and its overall number of charge cycles. Since this technology is still in the developmental phase, ongoing research and testing are being conducted to address and mitigate this drawback. Once successfully managed, electric vehicles equipped with solid-state batteries could achieve a significant charge in a considerably short timeframe, greatly reducing charging durations and enhancing user convenience.

Solid-State Batteries Beyond EVs

Beyond their use in electric vehicles, solid-state batteries find applications in various other domains, including stationary energy storage. The unique attributes of solid-state battery technology render them well-suited for energy storage applications requiring heightened energy density and enhanced safety compared to conventional battery technologies.

In the realm of stationary energy storage, solid-state batteries prove invaluable for storing surplus renewable energy generated by sources like solar or wind power, especially in space-restricted projects. These batteries accumulate energy during periods of low demand and discharge it during peak demand, thereby enhancing grid stability and reducing dependence on fossil fuels. Moreover, solid-state batteries can elevate the performance and efficiency of off-grid systems, such as remote power stations or telecommunications infrastructure. Their capacity to provide a dependable and long-

> As the world progressively embraces a sustainable, emissions-free future, solid-state batteries are positioned to play an indispensable role in reshaping the landscape of electric transportation and stationary energy storage.

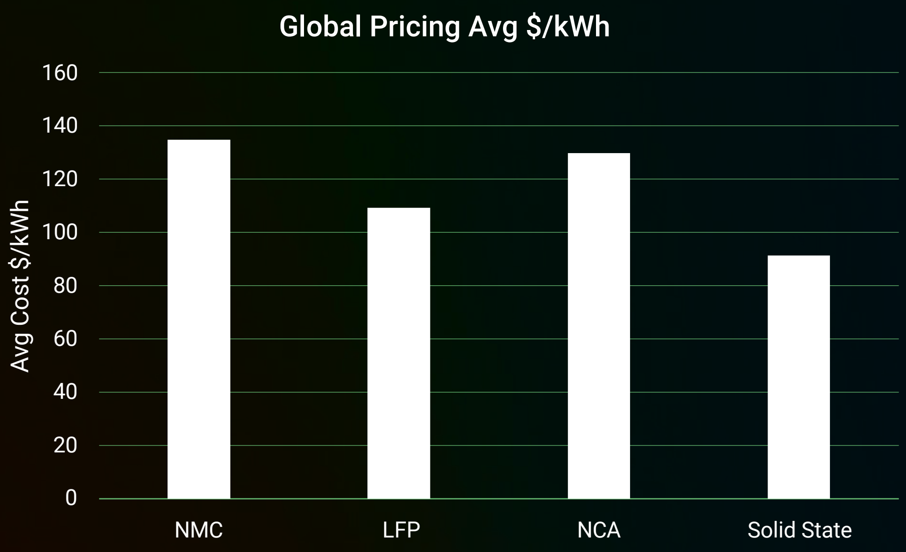


Figure 3: Global Pricing Average USD/kWh.
Source: PTR Inc.

lasting power source makes them invaluable in scenarios where grid access is limited, or supply is intermittent. As solid-state battery technology advances and becomes more prevalent, we can anticipate further developments and innovative applications that offer more dependable, sustainable, and efficient energy solutions.

Looking Ahead

The automotive sector, battery manufacturers, and research institutions have all discerned the profound potential inherent in solid-state batteries. They are currently engaged in collaborative endeavors aimed at surmounting the challenges that this technology confronts in terms of expanding production and seamlessly integrating solid-state batteries into the mass production of electric vehicles. This concerted effort is expected to lead to reduced electric vehicle costs and enhanced reliability, thereby facilitating the widespread adoption of electric vehicles.

Furthermore, the application of solid-state batteries in stationary energy storage is poised to benefit from these advancements. As the world progressively embraces a sustainable, emissions-free future, solid-state batteries are positioned to play an indispensable role in reshaping the landscape of electric transportation and stationary energy storage. It will also contribute significantly to the energy industry's progression towards a cleaner and more environmentally friendly energy ecosystem.

Advancements in the Solid-State Battery Sector

2020

Toyota // Panasonic

Toyota, in 2020, announced a collaboration with **Panasonic** to establish a joint venture focused on solid-state.

QuantumScape // Volkswagen

QuantumScape gained attention for their innovative solid-state battery designs, attracting investments from industry giants like **Volkswagen**, which materialized in the form of a $200 million investment from.

2021

Ford // Solid Power

In 2021, **Ford** invested $130 million in **Solid Power**, a solid-state battery development company.

BMW // QuantumScape // Solid Power

BMW collaborated with various partners, including **Solid Power** and **QuantumScape**, for solid-state battery development.

2024

Swiss Clean Battery (SCB)n

An industry-first solid-state Gigafactory is set to be active by 2024 in Switzerland by battery research start-up **Swiss Clean Battery (SCB)** AG.

Figure 4: Ongoing and Forthcoming Advancements in the Solid-State Battery Sector. Source: PTR Inc.

The Pacing of Solar Power Integration in Industrial America: Unraveling the Deliberate Stride

In an era marked by an increasing global consciousness regarding environmental sustainability, the slow adoption of solar power in the industrial sector of the United States raises questions about the underlying factors contributing to this gradual transition. While the residential sector has witnessed a surge in solar installations, the industrial landscape seems to lag behind. A nuanced exploration of this phenomenon unveils a confluence of economic, regulatory, and technological considerations that have influenced the measured pace of solar power integration in Industrial America.

> **One significant factor contributing to the slow adoption of solar power in the industrial sector is the substantial upfront cost associated with installing solar panels, often deterring businesses due to a misalignment with immediate financial priorities and ROI capital goals.**

One significant factor contributing to the slow adoption of solar power in the industrial sector is the substantial upfront cost associated with installing solar panels. Industrial-scale operations often require extensive energy, and the initial investment required for solar infrastructure can be a deterrent. Without extensive government incentives, most find this investment not aligning with many ROI capital goals. Despite the long-term cost savings and potential return on investment over a longer time period than most are willing to accept, businesses may find it challenging to allocate significant capital for solar projects, particularly when weighed against more immediate financial priorities.

Regulatory hurdles also play a role in the cautious approach toward solar power adoption. The complex nature of regulations governing energy production and distribution varies across states, creating a patchwork of compliance standards. This inconsistency adds an extra layer of complexity for industrial entities seeking to implement solar solutions, as they must navigate a labyrinth of bureaucratic processes and compliance requirements, which can stifle enthusiasm for adopting renewable energy sources.

Moreover, the existing energy infrastructure heavily relies on traditional fossil fuels, and

Photo: SDMyers

transitioning to solar power necessitates a restructuring of the energy grid. Integrating solar energy at an industrial scale requires extensive planning, technological upgrades, and coordination among various stakeholders. This process can be time-consuming, and businesses may be hesitant to undertake such endeavors without clear incentives or mandates compelling them to do so.

> **Regulatory hurdles also play a role in the cautious approach toward solar power adoption, with varying compliance standards across states creating a complex landscape that industrial entities must navigate, potentially stifling enthusiasm for renewable energy sources.**

Furthermore, some industrial entities may be skeptical about the reliability of solar power, especially in regions with inconsistent sunlight patterns or severe weather conditions. Concerns about the intermittency of solar energy production and the need for supplementary energy sources during periods of low sunlight can create reservations among industrial decision-makers.

Despite these challenges, it is crucial to acknowledge the positive strides being made. Many industrial players are gradually recognizing the long-term benefits of transitioning to solar power, not only in terms of cost savings but also in reducing their carbon footprint. Government incentives and an increasing societal emphasis on sustainability are gradually tilting the scales in favor of solar adoption.

> **Moreover, the existing energy infrastructure heavily reliant on traditional fossil fuels presents a barrier to solar adoption in the industrial sector, requiring extensive planning, technological upgrades, and coordination among stakeholders, which can be time-consuming and may lack clear incentives or mandates compelling businesses to transition.**

The slow integration of solar power into the industrial landscape in America is a multifaceted issue, with economic, regulatory, and technological dimensions. As awareness of the environmental impact grows and as technology advances, it is anticipated that the industrial sector will increasingly embrace solar power solutions, paving the way for a more sustainable and resilient energy future.

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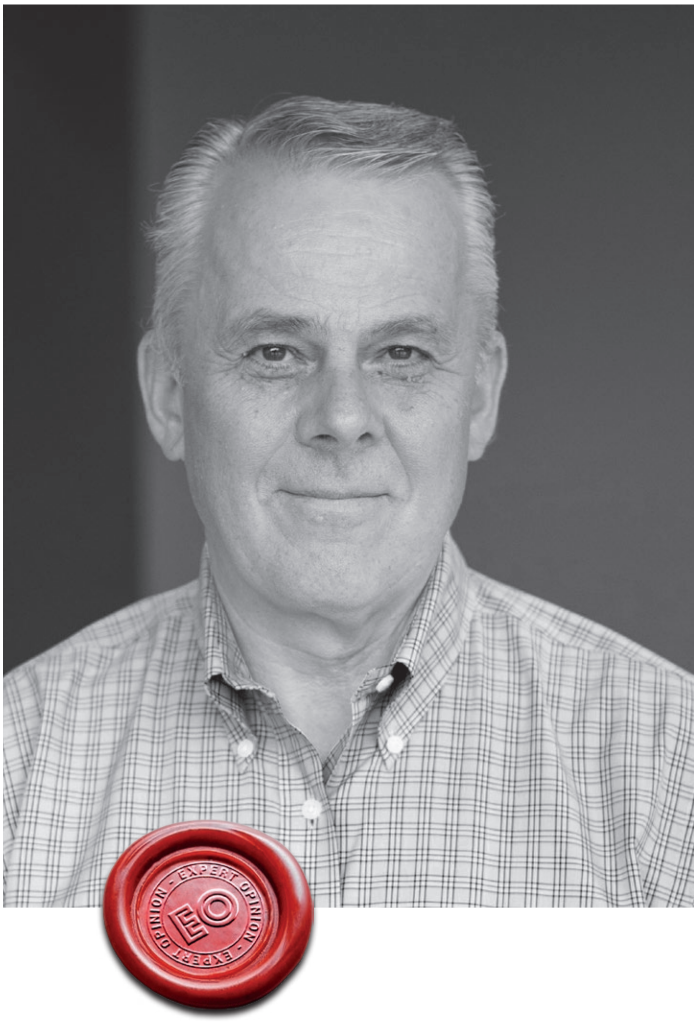


Dale Bissonette is the CEO of Good Place Holdings and SDMyers (a Good Place Holdings company). Dale has led local, national, and international organizations in the for-profit and non-profit sectors based on Biblical principles and values for over thirty years as Owner, CEO, President, Board Chair and Member, and CFO. He is also a board member and audit chairman of the Timothy Plan Trust, a $2 billion mutual fund with 80,000 investors. Under Dale's leadership, Good Place Holdings manages and operates nine businesses, including B2B, B2C, industrial, and community-based organizations. He has also served as a board of trustee member at the Chapel in Akron and the Chapel Hill Christian School. Dale holds a Bachelor of Science in Accounting from The University of Akron. He has been married for 40 years with four children and 11 grandchildren.

Power Asset Monitoring:
Renewable Energy Plants Differences Versus Utilities?

by **Dan Roth**

Photo: Dynamic Ratings

It is no secret that energy policy in North America is focused on increasing the availability of renewable energy resources to meet environmental objectives. This policy extends from tax subsidies to encourage construction of utility scale wind and solar sites to federal grants to support transmission infrastructure to deliver this energy from generation to load centers. Policy is also in place to accelerate the deactivation of fossil fuel generation sites. Wind, solar PV, and hybrid generation are projected to be the primary additions to the resource mix over the next 10 years; this leads the continued energy transition as older thermal generators retire [1].

What is surprising is that there are several areas of the country that are projected at High or Elevated risk levels of inadequate electricity supply driven in many ways by this energy transition. Generator retirements and increasing demand are outpacing planned projects to maintain necessary energy reserves [1]. This puts an ever-increasing concern over the availability and reliability of existing installed renewable energy sources.

Dan Roth is currently the Sales and Marketing Director for Dynamic Ratings based in Sussex, Wi. He received his Bachelor of Science degree in electrical engineering from the University of Illinois at Urbana-Champaign. He possesses more than 20 years of industry experience having previously been employed at Eaton (Cooper Power Systems) and Schweitzer Engineering Labs. His career has allowed for a wide range of experiences from relay system protection, feeder automation, communicating smart sensors to distribution line installation and protective equipment. Mr. Roth has contributed several papers and patents to the industry in that time.

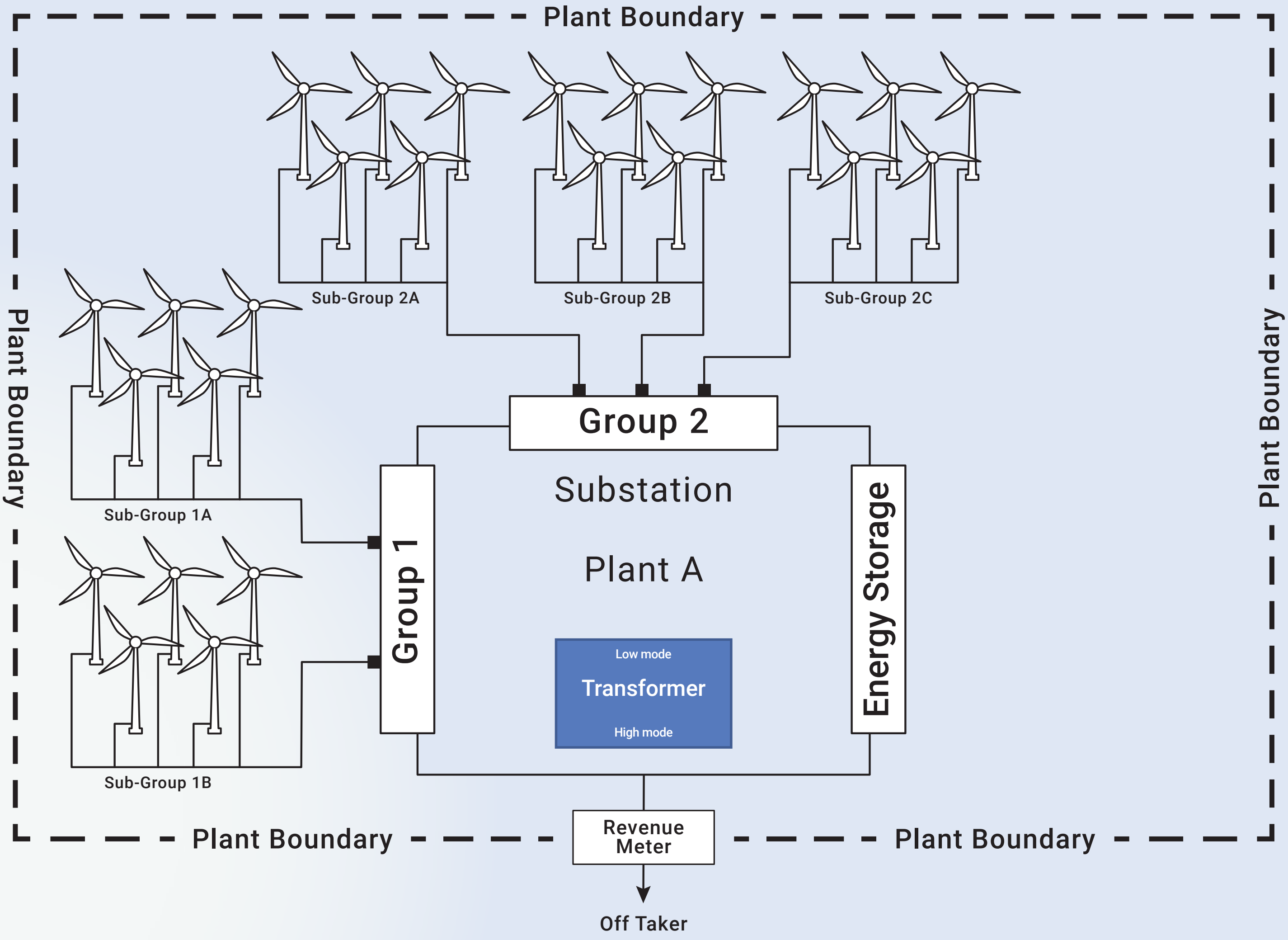
When adverse conditions occur from extreme heat and cold temperatures it is critical to the reliability of the bulk energy systems that these generating resources are available. From a plant owner perspective, these times of adverse conditions are also the most profitable to produce energy creating an additional incentive to keep plant online.

These key points above have many owners and operators of renewable energy sites hyper focused on maintaining uptime and providing highly reliable energy to the grid. These sites are also starting to be deemed as more critical to the overall infrastructure to the grid which is bringing more and more reporting requirements. These reporting requirements can be arduous and costly given the remote nature of many renewable energy sites. There are many elements required in a successful asset management strategy, but online condition monitoring is starting to become the gold standard. Online condition monitoring provides the information needed meeting reporting requirements as well as proactively address asset health conditions before they impact site reliability.

Many wind farms today already have sophisticated monitoring for the mechanical systems in the wind turbines themselves. The problem is this philosophy has not commonly been extended to the balance of the plant and electrical infrastructure needed to deliver generated energy to the grid and more specifically net metering interconnect where revenue is realized. Typically, the plant boundary is where the revenue meter installed on the high voltage bushings

Photo: Dynamic Ratings

Figure 1: Typical Wind Plant Layout [2]



of plant Generator Step Up (GSU) transformer [2] as shown in Figure 1. If the feeder circuit breakers or GSU transformers fail unexpectantly, the result can be millions of dollars of loss revenue from a single outage.

Today's online monitors are capable of monitoring the condition of circuit breakers, switchgear and GSU transformers from a common platform. This includes the monitoring of electrical, mechanical and insulation systems [3]. This capability allows for needed standardization within a single plant and a common look and feel for plant operations. The benefits of condition monitoring extend beyond just detecting degraded performance and risk mitigation. The monitors themselves can simplify PRC reporting for battery systems and circuit breakers alike by automating the process and eliminating routine inspection requirements. This helps owners reduce their operation and maintenance (O&M) budgets to further

support the deployment of monitoring technology system wide.

Another challenge that extends beyond immediate financial returns of improved reliability and reduced O&M budgets is the availability of replacement assets in the event a problem arises, or when failure does occur. Extending the life of an asset and getting early warning of developing issues is crucial in navigating transformer supply chain environments. Large power transformers are commonly available at five (5) year lead times with very limited availability of spares [4]. Much has been written about transformer supply chains in the last few years, but this is very large and complex issue to resolve. It is important that all renewable plant owners and operators have a resiliency plan in place for these long lead time items.

Many utilities will carry their own inventory of spare transformers, but this practice is not common among renewable energy owners except on the lower MVA distribution class transformers. Another approach is implementing substation design principles to have full redundancy to eliminate single points of failure. This has not commonly been done in the industry because often the original owner during construction and development phase is different than long term owner/operator and there was no total cost of ownership considerations during construction. This makes continuous online condition monitoring a far easier first step to provide a level of risk mitigation while still providing long term benefits.

Once a renewable owner/operator decides to move forward with a balance of plant asset management strategy, the same driving forces creating the need to implement a monitoring system become challenges to overcome in the implementation. Large wind farms can only incur short outage windows and associated loss revenue to install monitoring equipment. The reason for this is the loss revenue can destroy the return on investment of monitoring if outage is extended too long. This creates certain challenges in project management, and commissioning that must not be overlooked. Even short outages can cause significant delays in restarting an entire feeder of connected turbines because of various mechanical and electrical issues associated with restarting turbines.

The best solution is to have a substation design with high redundancy. Substations utilizing a breaker and a half scheme are ideal for installing HV circuit breaker monitoring. This bus configuration allows all breakers to be fully commissioned with monitoring equipment without taking an outage.

Since it is impossible to switch all feeders to adjacent bus because of available fault current, it is more to take outage in original bus configuration. Often the delays in restarting turbines and complications that arise from trying to switch feeders individually undermine efforts to maximize revenue output by segmenting buses. Since the entire bus is being taken down, the breaker

Photo: Dynamic Ratings

monitor commissioning should be coordinated with installation of transformer bushing monitoring that also requires an unavoidable outage as part of installation process.

In order to minimize outage windows and the impacts to revenue it is important to have an effective project management team. Project teams need to work closely together to make sure all the appropriate approvals and risks are understood when performing pre-outage work. This includes completing as much work as possible during pre-outage work dates. Cabinets should be hung and conduit run with care in hopes that monitoring will soon be there. To further expedite the time it takes to install sensors, such as bushing & temperature sensors, many sites are preferring armored cable in leu of traditional conduit runs. Miscommunication at this stage can be very costly if the commissioning team is intending to complete work that the site manager denies because of previously uncommunicated concerns. Before outage work begins, proper grounding and safety work practices must all be cleared defined so that work can begin immediately after outage is taken because time truly is money in this case.

Renewable Energy is becoming a more prevalent part of the energy resources for the bulk energy system. This is driving the need to maximize uptime to deliver reliable power, maintain grid stability and maximize generation revenue.

Renewable Energy is becoming a more prevalent part of the energy resources for the bulk energy system. This is driving the need to maximize uptime to deliver reliable power, maintain grid stability and maximize generation revenue. Asset monitoring of electrical equipment is a critical part of that strategy and working with an experienced partner to deliver on that solution can have a far greater impact on the bottom line than the initial first cost than the monitor itself.

Asset monitoring of electrical equipment is a critical part of that strategy, and working with an experienced partner to deliver on that solution can have a far greater impact on the bottom line than the initial first cost than the monitor itself.

References

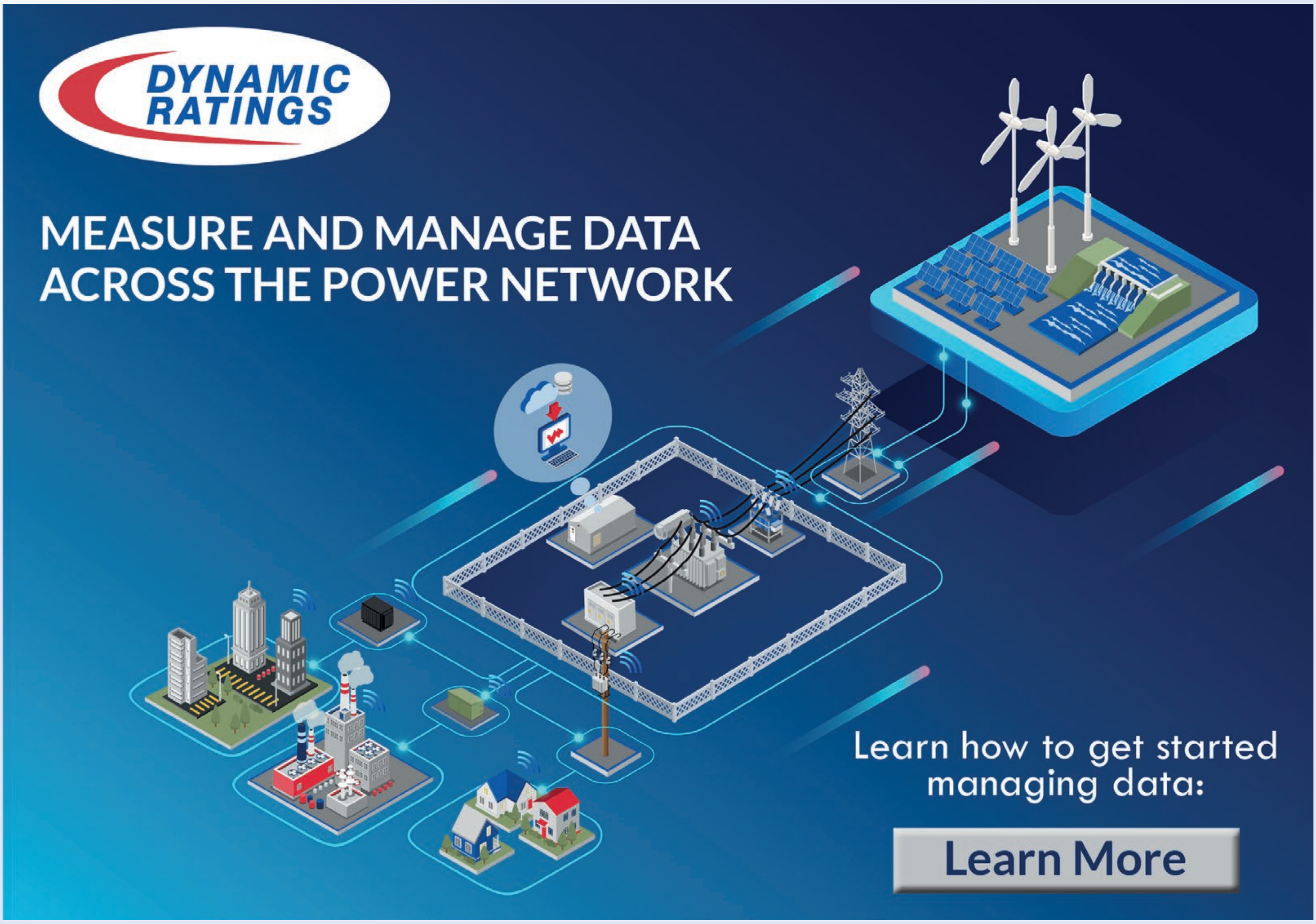
[1] https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2023.pdf

[2] https://www.nerc.com/pa/RAPA/gads/GADS_Wind_DRI_DL/2023_GADS_Wind_DRI.pdf

[3] https://info.dynamicratings.com/improving-reliability-of-circuit-breakers-white-paper

[4] https://www.gao.gov/products/gao-23-106180

[5] https://www.pjm.com/-/media/planning/plan-standards/private-peco/peco-transmission-bus-configuration-design-philosophy.ashx?la=en



A successful transition to green energy emphasizes transformer maintenance and reliability

Transformer maintenance and reliability play a critical role in the shift toward green energy for several reasons. First green energy sources like solar and wind can be intermittent, and their output can fluctuate due to weather conditions. To ensure grid stability, transformers must be highly reliable and capable of withstanding varying loads and voltage levels. Regular maintenance checks and preventative measures are essential to ensure transformers remain dependable. Energy storage integration is another consideration. Battery energy storage systems (BESS) are becoming essential components of green energy systems. They play a critical role in smoothing out intermittent renewable generation. Well maintained transformers are needed to connect these energy storage systems to the grid safely and efficiently.

In the context of Distributed Energy Resources (DER), distribution transformers at the local level must be reliable to handle power flows from small-scale renewable sources like rooftop solar panels. Regular maintenance ensures that these transformers continue to function efficiently and safely.

> **To ensure grid stability, transformers must be highly reliable and capable of withstanding varying loads and voltage levels.**

Aging infrastructure is a well-known issue in the power sector, and transformers are a part of this aging infrastructure. As the demand for green energy grows, these older transformers may need refurbishment or replacement to ensure they can handle the increased demands and integration of renewable sources.

The push for energy efficiency and grid resilience is driving innovation in transformer technology. Smart transformers equipped with monitoring and control capabilities are being developed to optimize power flow, reduce losses, and respond to changes in grid conditions.

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Battery energy storage systems (BESS) are becoming essential components of green energy systems, and well-maintained transformers are needed to connect these energy storage systems to the grid safely and efficiently.

With a focus on green energy, there's also a growing emphasis on the environmental impact of transformers. For example, addressing oil leaks or upgrading to eco-friendly insulating fluids like natural esters can reduce the risk of environmental contamination. In some cases, transformer life can be extended through refurbishment and retrofitting, reducing the need for new manufacturing, which can have environmental benefits. Proper maintenance practices can help maximize the lifespan of transformers.

Transformer maintenance can include measures to extend the reliable life of the transformer or improve efficiency, such as cleaning cooling systems, oil reclamation, moisture reduction, leak repairs, and upgrading insulation. Higher transformer efficiency means less energy loss during power transmission, which is especially important when transmitting renewable energy over long distances.

Reliable transformers are crucial for the safety of the grid and its operators. Proper maintenance practices ensure that transformers operate safely, reducing the risk of accidents or outages that could disrupt green energy generation and distribution.

Smart transformers equipped with monitoring and control capabilities are being developed to optimize power flow, reduce losses, and respond to changes in grid conditions, driven by the push for energy efficiency and grid resilience.

Remember, transformer maintenance and reliability are integral to the safety and success of the shift toward green energy. They ensure grid stability, facilitate the integration of renewable sources and energy storage, and contribute to the overall efficiency and sustainability of the energy infrastructure. As the energy landscape continues to evolve, maintaining and enhancing the reliability of transformers will remain a key priority for utilities and grid operators.

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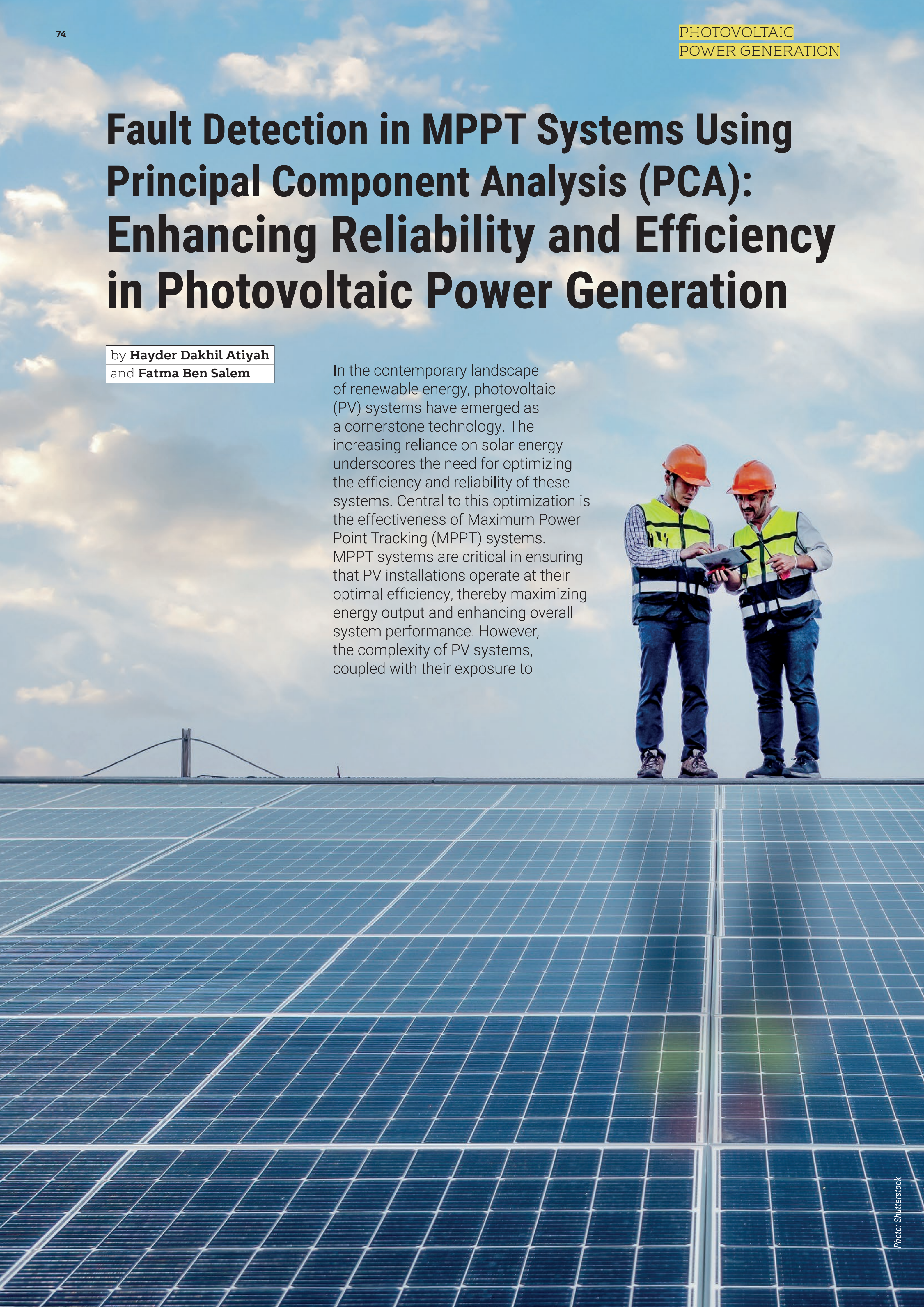
Before joining SDMyers, Jon spent 11 years at General Motors Corporation, holding a variety of leadership positions. He eventually led the Industrial Engineer group and was a New Car Launch Manager before completing his time at GM as the Director of Engineering at the Parma Metal Center.
Jon focused on his passions for engineering and education by creating a School of Engineering at Cuyahoga Valley Christian Academy (CVCA). He then took on a startup operation as the VP of Operations that used algae as a plastic extrusion supplement. He was responsible for setting up the extrusion facility and manufacturing harvesters to procure algae from catfish farms in America and lakes in China.
Jon holds a BS in Mechanical Engineering from The University of Akron and an MS in Operations Management from Kettering University.

Fault Detection in MPPT Systems Using Principal Component Analysis (PCA): Enhancing Reliability and Efficiency in Photovoltaic Power Generation

by **Hayder Dakhil Atiyah**
and **Fatma Ben Salem**

In the contemporary landscape of renewable energy, photovoltaic (PV) systems have emerged as a cornerstone technology. The increasing reliance on solar energy underscores the need for optimizing the efficiency and reliability of these systems. Central to this optimization is the effectiveness of Maximum Power Point Tracking (MPPT) systems. MPPT systems are critical in ensuring that PV installations operate at their optimal efficiency, thereby maximizing energy output and enhancing overall system performance. However, the complexity of PV systems, coupled with their exposure to



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variable environmental conditions, makes them susceptible to a range of operational faults. These faults can significantly impede the performance and longevity of solar installations, posing a challenge for sustainable energy solutions. The traditional approaches to fault detection in PV systems often hinge on monitoring specific parameters, such as current and voltage outputs. However, these methods can fall short in the face of complex, multi-dimensional faults, especially under fluctuating environmental conditions. Consequently, there is a growing impetus for developing more sophisticated, data-driven fault detection techniques capable of navigating the intricate dynamics of PV systems. It is in this context that Principal Component Analysis (PCA) emerges as a promising solution. PCA, a statistical technique renowned for its efficacy in reducing data dimensionality and extracting meaningful patterns, offers a robust framework for analyzing the multi-faceted data generated by PV systems. By transforming the high-dimensional operational data into a set of linearly uncorrelated variables known as principal components, PCA facilitates a more nuanced understanding of system behavior. This capability is particularly advantageous in identifying subtle, yet critical, deviations that signify potential faults. The application of PCA in this domain is not just about enhancing fault detection; it is about redefining it. By harnessing the power of PCA, it becomes possible to preemptively identify faults, paving the way for proactive maintenance and intervention strategies.

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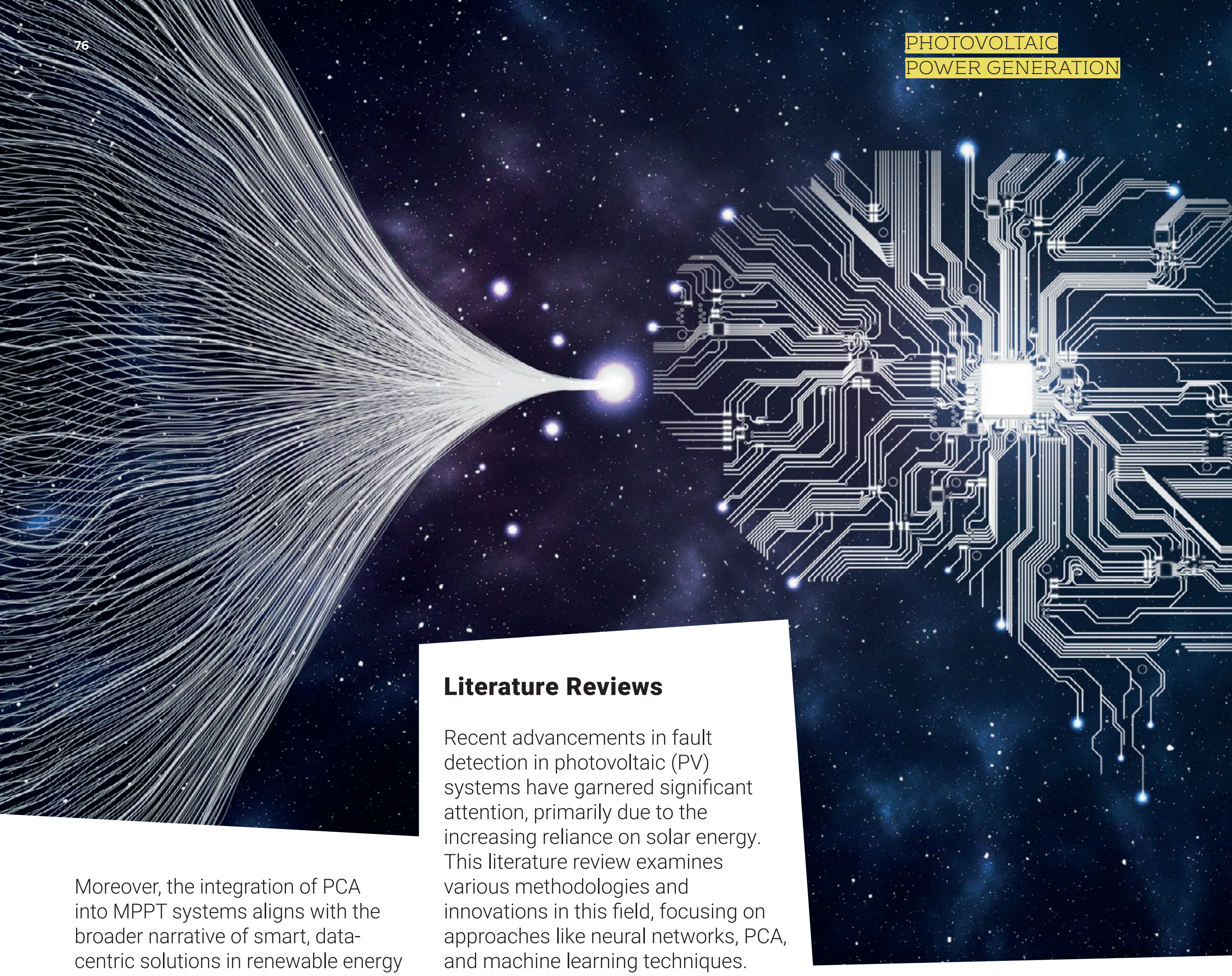

Moreover, the integration of PCA into MPPT systems aligns with the broader narrative of smart, data-centric solutions in renewable energy technologies. The push towards smarter energy systems is not merely a technological aspiration; it is a requisite for the sustainable and efficient harnessing of renewable resources. In solar power generation, where the stakes are as much about environmental stewardship as they are about energy efficiency, the role of intelligent fault detection mechanisms cannot be overstated. This paper delves into the application of PCA for fault detection in MPPT systems within PV installations. It explores the theoretical underpinnings of PCA and its compatibility with the operational dynamics of MPPT systems. Through a blend of simulated scenarios and empirical data analysis, this study demonstrates how PCA can effectively identify and isolate faults in MPPT systems. The findings of this research not only contribute to the enhancement of PV system reliability but also underscore the potential of advanced data analysis techniques in revolutionizing renewable energy technologies.

Literature Reviews

Recent advancements in fault detection in photovoltaic (PV) systems have garnered significant attention, primarily due to the increasing reliance on solar energy. This literature review examines various methodologies and innovations in this field, focusing on approaches like neural networks, PCA, and machine learning techniques.

1. Enhanced Neural Network and PCA Methods:

Rujittika Mungmunpuntipantip (2023) in "Enhanced Neural Network Method-Based Multiscale PCA for Fault Diagnosis" proposes an innovative approach combining neural networks with multiscale PCA for fault diagnosis in grid-connected PV systems. This study is pivotal in showcasing the integration of advanced data analysis techniques with neural network methodologies to enhance diagnostic accuracy and efficiency in PV systems.

2. Switched Model-Based Fault Detection:

Ayyoub et al. (2022) in their work on simultaneous switched model-based fault detection and MPPT for PV systems offer a unique perspective. They emphasize the simultaneous implementation of fault detection and MPPT, suggesting that integrating these processes can improve overall system reliability and performance.

3. Real-Time Fault Detection Using Multi-Sensor Data:

Bakdi et al. (2021) explore real-time fault detection under MPPT using PMU and high-frequency multi-sensor data through an online PCA-KDE-based method. This approach, utilizing multivariate KL divergence, underscores the importance of real-time data processing and the potential of using multiple sensors to enhance fault detection accuracy in PV systems.

4. Machine Learning Techniques:

Attouri et al. (2020) delve into machine learning techniques for fault detection in PV systems. Their research contributes to the growing body of literature that leverages

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By harnessing the power of PCA, it becomes possible to preemptively identify faults, paving the way for proactive maintenance and intervention strategies.

The push towards smarter energy systems is not merely a technological aspiration; it is a requisite for the sustainable and efficient harnessing of renewable resources.

machine learning algorithms, demonstrating the effectiveness of these techniques in identifying anomalies within PV systems.

5. Quality-Related Fault Detection:

Wenxiao Gao et al. (2020) introduce a modified principal component regression method for quality-related fault detection. Although not directly focused on PV systems, this work contributes to the understanding of PCA applications in fault detection, offering insights that could be translatable to PV system diagnostics.

6. Circuit Breaker Fault Diagnosis:

The work by Hao Feng et al. (2020) on PCA-BPNN-based circuit breaker fault diagnosis method, while not directly related to PV systems, provides valuable insights into the application of PCA in conjunction with neural networks for fault detection in electrical systems.

7. Statistical Process Monitoring Techniques:

Mohammed Ziyan Sheriff et al. (2019) investigate fault detection using statistical process monitoring techniques. Their approach, focusing on single and interval-valued data, can offer a statistical perspective relevant to fault detection in PV systems.

8. Fault Detection Apparatus and Methodologies:

Park Ki Ju and Park Sae Hee (2020) contribute to the field with their development of an apparatus and method for detecting faults in PV systems. Such innovations highlight the ongoing efforts to create practical solutions for PV system monitoring and maintenance.

9. Automatic Observation and Detection Technologies:

Sachin Thakur et al. (2023) in "Automatic Observation and Detection of Faults for Solar Photovoltaic Systems" explore multilevel inverter topology in PV systems. Their focus on automation and fault detection technologies aligns with the growing trend towards more intelligent and autonomous PV system management.

10. Automatic Observation and Detection of Faults for Solar Photovoltaic Systems with Multilevel Inverter Topology

These studies collectively signify a shift towards more sophisticated, data-driven approaches in fault detection within PV systems. The integration of neural networks, PCA, and machine learning methods demonstrates a notable trend towards harnessing advanced computational techniques to enhance the reliability and efficiency of solar power generation. This body of work provides a foundation for future research aimed at developing more resilient, efficient, and intelligent PV systems in the realm of renewable energy.

Methodology

This research adopts a systematic approach to improve fault detection in photovoltaic (PV) systems by leveraging Principal Component Analysis (PCA). The methodology is meticulously designed to encompass data acquisition, preprocessing, feature extraction, PCA implementation, and validation stages to ensure the reliability and applicability of the findings.

To create an equation that would be relevant for a paper on "Fault Detection in MPPT (Maximum Power Point Tracking) Systems Using Principal Component Analysis (PCA)," we can focus on the application of PCA in the context of identifying faults in PV systems. The core of PCA is the transformation of the original data into a set of linearly uncorrelated variables called principal components. Here's a fundamental equation representing the PCA transformation:

Let XX be the original data matrix with dimensions n×mn×m, where nn is the number of observations and mm is the number of variables (such as voltage, current, temperature). The standardized data matrix is given by XstdXstd.

The PCA transformation can be expressed as:
Y=Xstd×PY=Xstd×P

Where:

- YY is the matrix of principal components.
- PP is the matrix of principal component coefficients, also known as the loading matrix, which is derived from the eigenvectors of the covariance matrix of XstdXstd.

In the context of fault detection:

- The rows of YY represent the observations in the new principal component space.
- By examining the distances of these observations from the origin in the PCA space, anomalies (potential faults) can be identified.

This equation encapsulates the essence of PCA in transforming multidimensional operational data to facilitate the identification of deviations indicative of faults in MPPT systems. In your paper, you can elaborate on how the principal components derived from YY are used to detect faults in MPPT systems, emphasizing the reduction of dimensionality and the enhancement of pattern recognition capability.be free of particulates, sediment, or observable water droplets.

Data Acquisition

A comprehensive dataset comprising operational parameters from diverse PV systems was compiled. This dataset shown in table 1 includes voltage, current, temperature, and irradiance data sampled at high-resolution intervals across various environmental conditions and system configurations. Special attention was paid to capturing data from instances with known faults to enrich the dataset's potential for revealing fault-related patterns.

Parameter	Description	Measurement Tool	Data Points
Voltage Output (V)	Electrical voltage output of the PV modules.	Multimeter	Every 1 minute
Current Output (I)	Electrical current output of the PV modules.	Multimeter	Every 1 minute
Solar Irradiance (W/m²)	The power per unit area received from the Sun.	Pyranometer	Every 1 minute
Ambient Temperature (°C)	Temperature of the surrounding environment.	Thermocouple	Every 5 minutes
Module Temperature (°C)	Surface temperature of the PV modules.	Infrared Sensor	Every 5 minutes
Efficiency (%)	Conversion efficiency of the PV system.	Computed from V and I	Hourly
Capacity Factor (%)	Ratio of actual output over a period to the maximum possible.	Computed from V and I	Daily
Performance Ratio (%)	Performance compared to the ideal conditions.	Computed from V and I	Daily
Fault Events	Record of any operational faults and maintenance.	Maintenance Logs	As events occur
System Downtime (hrs)	Duration when the system is not operational.	System Logs	As events occur

Table 1: Summary of Photovoltaic System Data Acquisition Parameters

Voltage (V)		Current (A)	Temperature (°C)	Irradiance (W/m^2)
0	5.1	1.2	25	1000
1	5.3	1.1	26	950
2	5.0	1.3	27	1100
3	5.2	1.2	28	1050
4	4.9	1.0	29	1000

Table 2

Data Preprocessing

The raw data underwent a rigorous preprocessing routine, including normalization to standardize the scale of different measurements, outlier detection and removal to ensure data quality, and smoothing to mitigate transient noise. This phase was critical in preparing the data for effective PCA application and ensuring the subsequent analysis's fidelity.

Photo: Shutterstock

These studies collectively signify a shift towards more sophisticated, data-driven approaches in fault detection within PV systems.

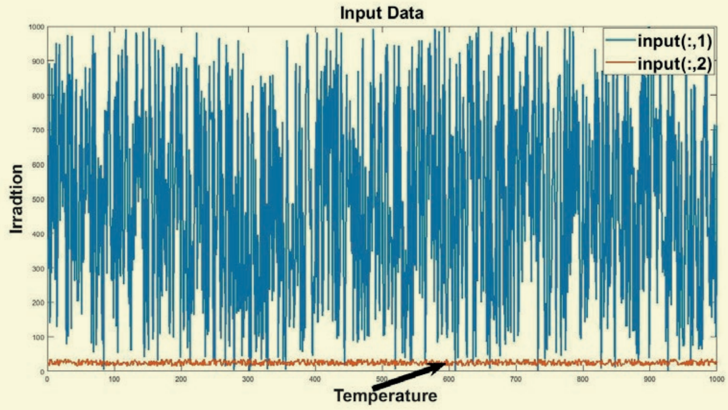

Figure 1

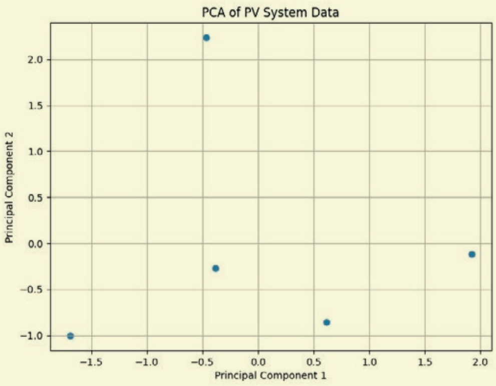

Figure 3

Feature Extraction

Key operational features were extracted based on their relevance to system performance and historical fault records. These features included, but were not limited to, derivatives of power output, fluctuation indices, and statistical descriptors, all of which were computed to provide a comprehensive feature set for PCA.

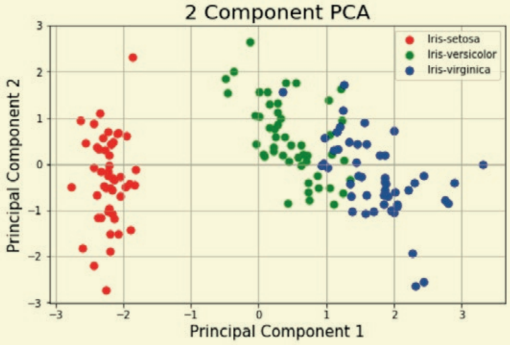

Figure 2

PCA Implementation

PCA was employed to reduce the dimensionality of the feature space, facilitating the identification of the most informative features - the principal components. These components served as a condensed representation of the data, capturing the most significant variance and patterns associated with fault conditions.

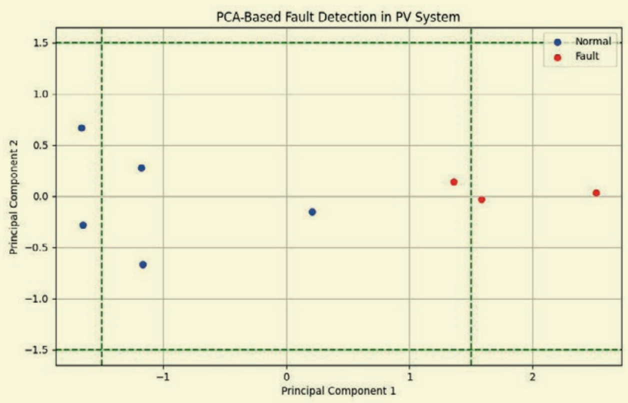

Figure 4

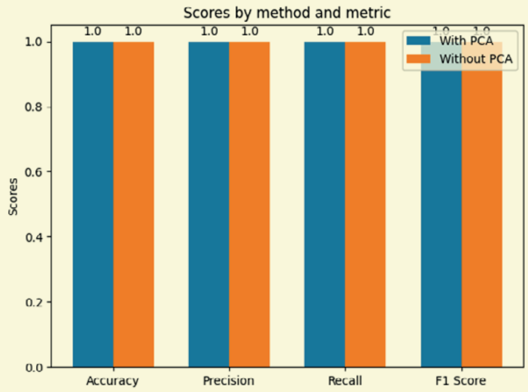

Figure 5

Fault Detection Algorithm

A fault detection algorithm was developed, utilizing the principal components as inputs. This algorithm was designed to distinguish between normal operation and fault states, employing a threshold-based mechanism to flag potential faults. The thresholds were iteratively refined to balance sensitivity and specificity, thereby reducing the incidence of false positives.

This study presents a groundbreaking PCA-based fault detection framework for MPPT systems in PV installations, demonstrating enhanced efficiency and reliability.

```
import numpy as np
import matplotlib.pyplot as plt
from sklearn.decomposition import PCA
# Example data (including normal and fault states)
data = {
'Voltage': [5.1, 5.3, 5.0, 5.2, 4.9, 4.7, 4.8, 4.6],  # Last 3 are fault states
'Current': [1.2, 1.1, 1.3, 1.2, 1.0, 0.7, 0.8, 0.6],  # Last 3 are fault states
'Temperature': [25, 26, 27, 28, 29, 30, 31, 32]        # Last 3 are fault states
}
labels = ['Normal', 'Normal', 'Normal', 'Normal', 'Normal', 'Fault', 'Fault', 'Fault']
# Convert to DataFrame
df = pd.DataFrame(data)
# Standardize the data
df_standardized = (df - df.mean()) / df.std()
# Apply PCA
pca = PCA(n_components=2)
principalComponents = pca.fit_transform(df_standardized
# Fault Detection Algorithm
# Setting a threshold for fault detection (this is a simplified example)
threshold = 1.5
faults = np.linalg.norm(principalComponents, axis=1) > threshold
# Plotting
plt.figure(figsize=(10, 6))
for i, (pc1, pc2) in enumerate(principalComponents):
if labels[i] == 'Normal':
plt.scatter(pc1, pc2, color='blue', label='Normal' if i == 0 else "")
else:
plt.scatter(pc1, pc2, color='red', label='Fault' if i == 5 else "")
plt.title('PCA-Based Fault Detection in PV System')
plt.xlabel('Principal Component 1')
plt.ylabel('Principal Component 2')
plt.axhline(y=threshold, color='green', linestyle='--')
plt.axhline(y=-threshold, color='green', linestyle='--')
plt.axvline(x=threshold, color='green', linestyle='--')
plt.axvline(x=-threshold, color='green', linestyle='--')
plt.legend()
plt.grid(True)
plt.show()
```

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Validation

The PCA-based fault detection framework was validated using a twofold strategy: first, through simulated data reflecting a range of fault scenarios, and second, via real-time data from operational PV systems. The validation process involved assessing the framework's accuracy, precision, recall, and F1 score, comparing it against existing fault detection methods to establish its superiority shown in fig 5.

Conclusion

In conclusion, this study presents a groundbreaking PCA-based fault detection framework for MPPT systems in PV installations, demonstrating enhanced efficiency and reliability. Validated through comprehensive simulations and real-world data, the approach effectively identifies operational anomalies, reducing false positives and optimizing maintenance. This research significantly contributes to advancing sustainable solar energy technologies.

References

[1] Rujittika, Mungmunpuntipantip. "Enhanced Neural Network Method-Based Multiscale PCA for Fault Diagnosis: Application to Grid-Connected PV Systems." Signals, undefined (2023). doi: 10.3390/signals4020020

[2] Ayyoub, Ait, Ladel., Rachid, Outbib., Abdellah, Benzaouia., Mustapha, Ouladsine. "Simultaneous switched model-based fault detection and MPPT for photovoltaic systems." undefined (2022). doi: 10.1109/ICSC57768.2022.9993833

[3] Azzeddine, Bakdi., Wahiba, Bounoua., Amar, Guichi., Saad, Mekhilef., Saad, Mekhilef. "Real-time fault detection in PV systems under MPPT using PMU and high-frequency multi-sensor data through online PCA-KDE-based multivariate KL divergence." International Journal of Electrical Power & Energy Systems, undefined (2021). doi: 10.1016/J.IJEPES.2020.106457

[4] Simultaneous switched model-based fault detection and MPPT for photovoltaic systems." undefined (2022). doi: 10.1109/icsc57768.2022.9993833

[5] Khadija, Attouri., Mansour, Hajji., Majdi, Mansouri., Mohamed-Faouzi, Harkat., Abdelmalek, Kouadri., Hazem, Nounou., Mohamed, Nounou. "Fault detection in photovoltaic systems using machine learning technique." undefined (2020). doi: 10.1109/SSD49366.2020.9364094

[6] Wenxiao, Gao., Aihua, Zhang., Zhongdang, Yu. "A Modified Principal Component Regression Method for Quality-related Fault Detection." undefined (2020). doi: 10.1109/DDCLS49620.2020.9275140

[7] Hao, Feng., Wen, Zhigang., Guo, Shuxiang., Bai, Yongxiang., Ji, Hong., Hai, Wei., Wang, Fuhe., Wang, Xiaoguang., Wu, Riheng., Gao, Bo., Zou, Dayun., Yuan, Feifei. "PCA-BPNN-based circuit breaker fault diagnosis method." undefined (2020).

[8] Mohammed, Ziyan, Sheriff., Nour, Basha., Muhammad, Nazmul, Karim., Hazem, Nounou., Mohamed, Nounou. "Fault Detection of Single and Interval Valued Data Using Statistical Process Monitoring Techniques." undefined (2019). doi: 10.5772/INTECHOPEN.88217

[9] Park, Ki, Ju., Park, Sae, Hee. "Apparatus and method for detecting fault of photovoltaic system." undefined (2020).

[10] Sachin, Thakur., Kamal, Sharma., Akhilesh, Gupta. "Automatic Observation and Detection of Faults for Solar Photovoltaic Systems with Multilevel Inverter Topology." undefined (2023). doi: 10.1109/DELCON57910.2023.10127357

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