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POWER SYSTEMS TECHNOLOGY

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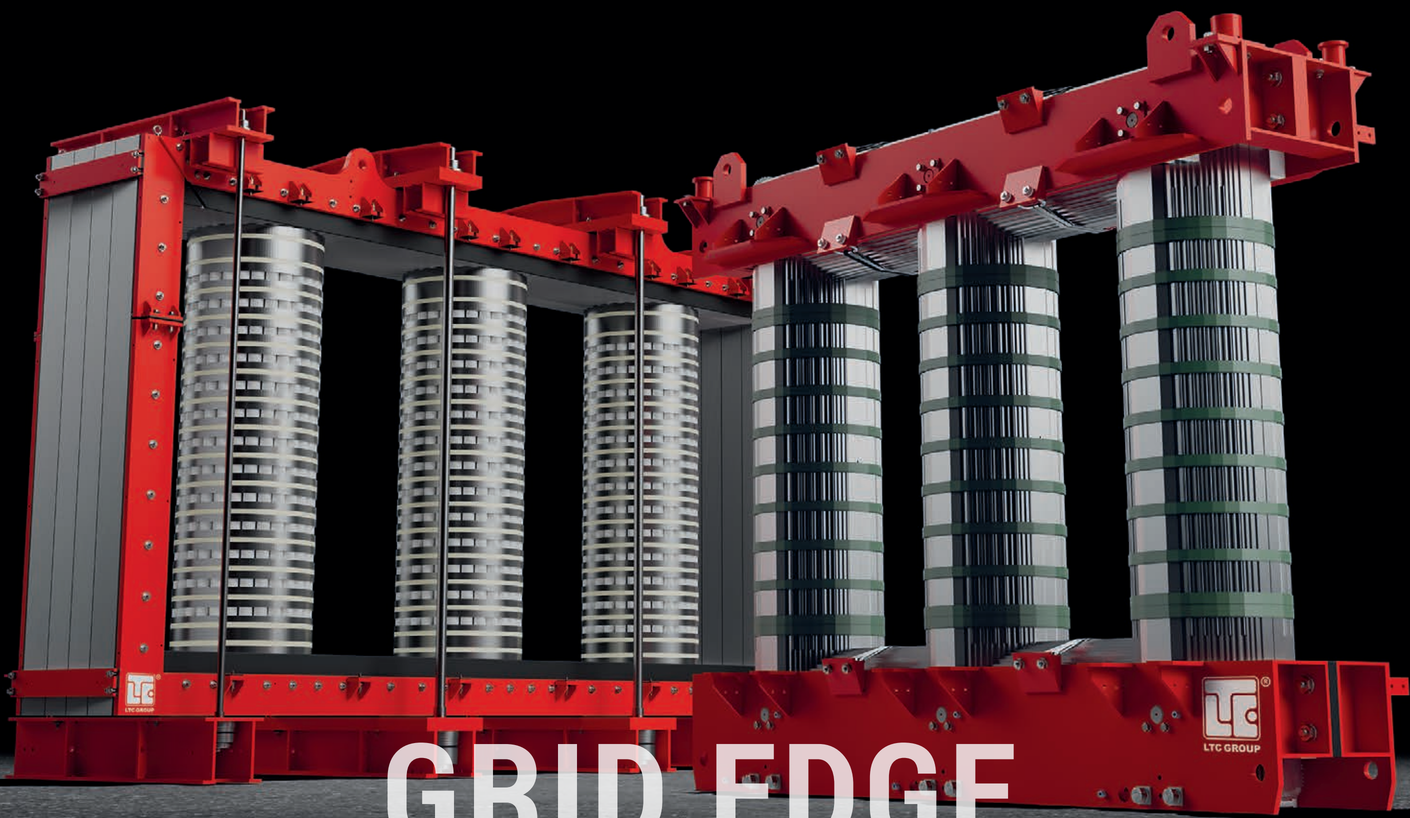

GRID EDGE

LTC: ENERGY AT WORK FOR AN ENDLESS EVOLUTION

TRANSFORMER TECHNOLOGY MAG

TRANSFORMER TECHNOLOGY MAG

The Battle for Supremacy at the Grid Edge in North America

Q&A with **Hamideh Bitaraf**, PhD, Advisory and Power System Simulations Manager, Hitachi

LTC Expands Presence in Asia with New Facility in Taiwan

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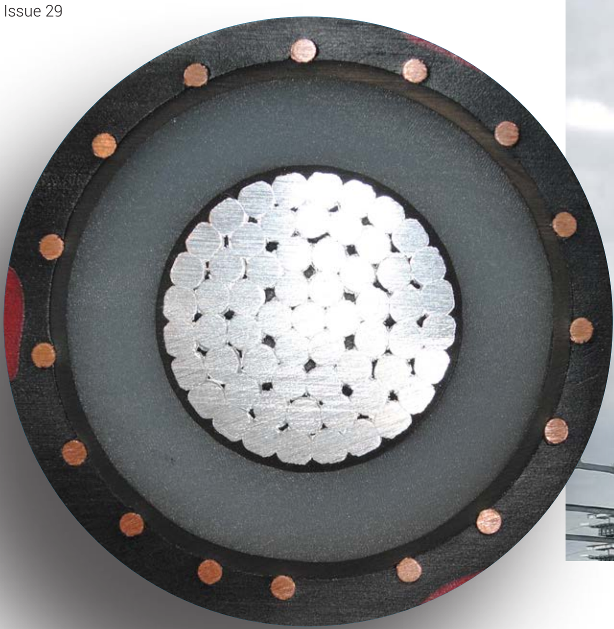

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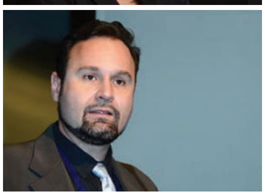

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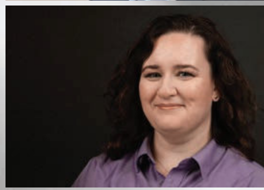

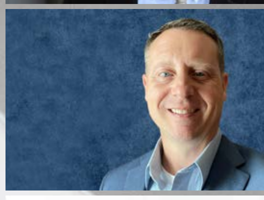

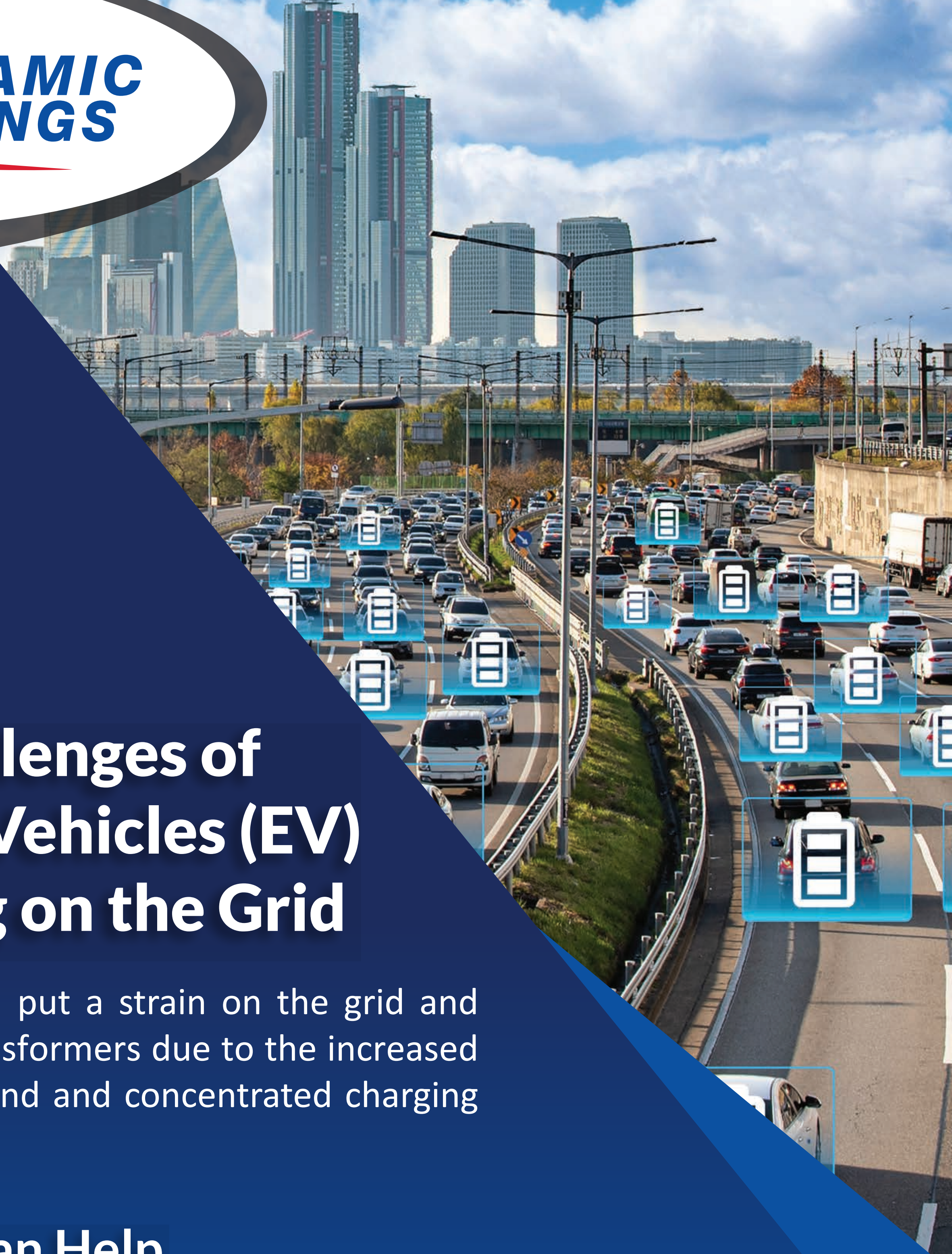

Dear Readers,

> **Bringing our growing communities' timely insights from technical articles and interviews is what makes our work so rewarding and for me personally, as the Managing Editor of our communities, it keeps me engaged in the most exciting times in the power industry in decades.**

I was honored to be on the IEEE PES Grid Edge Technologies Conference and Exposition steering committee. The event took place in April at the San Diego Convention Center. The conference served as a collaborative forum bringing together a variety of organizations essential to delivering enhanced productivity, efficiency, and interoperability to the grid. The conference, the first of its kind, exceeded our expectations and the plan is to have this as a bi-annual event in the years between IEEE PES T&D events.

As the inaugural event, we had some specific goals in mind which was to bring utilities, big tech, municipalities, design consultants and policy makers together. We also wanted to bring other stakeholders, like start-ups and other IEEE societies, together in a collaborative environment to work together to create the decentralized, distributed smart grid necessary for tomorrow's sustainable and reliable environments. I think we were able to do just that. Under the leadership of Ahad Esmaeilian and Wayne Bishop, we accomplished a

lot this year and laid a strong foundation for years to come. Thank you to every member of the steering committee who made this happen.

Some of the interviews in this issue are from that conference and also, I have provided a more detailed "Perspective" article that are my biggest takeaways from talking to so many gifted, experienced, and passionate people involved in some part of the grid edge. We will continue to publish interviews from both Grid Edge and DistribuTECH. Bringing our growing communities' timely insights from technical articles and interviews is what makes our work so rewarding and for me personally, as the Managing Editor of our communities, it keeps me engaged in the most exciting times in the power industry in decades.

Speaking of the power industry, you may have noticed more emphasis on Power System Technology lately with more content on things associated with but beyond transformers. We have also started a Green Energy Technology community for those focused more on decarbonization with wind, solar, storage and hydrogen playing an important role. Our commitment to Transformer Technology has not diminished but our interest in everything upstream and downstream from transformers is increasing, and for an interconnected grid, we want to bring you the best and brightest from around the world in all of these major areas. I think of them as swim lanes in the pool called power.

I hope you enjoy this issue and refer articles and interviews of interest to your colleagues. If there are any comments or suggestions, please let me know at alan.ross@apc.media. As always, let's be safe and reliable as we work to change our world for the better.

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

Harmonics in Renewable Systems

by **Corné Dames**

Corné Dames is the Managing Director of Independent Transformer Consultants, always striving to keep on top of new developments and research. She has expertise as Laboratory Manager in the analysis of transformer oils and as diagnostician identifying problem areas in transformers, as well as profiling of transformers according to available results thus empowering the customer to take preventative steps in maintenance. Corné has vast practical and theoretical knowledge on reliability maintenance programs. Coming from a strong chemical background she has insight in all the chemical processes that are part of the transformer system. Coupled with technical insight, her knowledge and experience help customers optimize their reliability maintenance and electrical asset lifetime.

Introduction

Harmonics are defined in physics as the component frequency of an oscillation or wave. The first time I heard the term I immediately thought about music and rhythm, in some bizarre way you might be able to see a similarity if you think in terms of harmony. In electrical terms harmonics are defined as the currents or voltages with frequencies that are integer multiples of the fundamental power frequency, in other words. If you are working at 50Hz fundamental frequency, you can expect harmonics at 100Hz, 150Hz, 200Hz and so on. These harmonics might have a detrimental effect on the power system and equipment linked to the network. The original sine wave is called the 1st harmonic. The 3rd, 5th and 7th harmonic are some of the typical harmonic content in electrical systems.

Photo: Megger

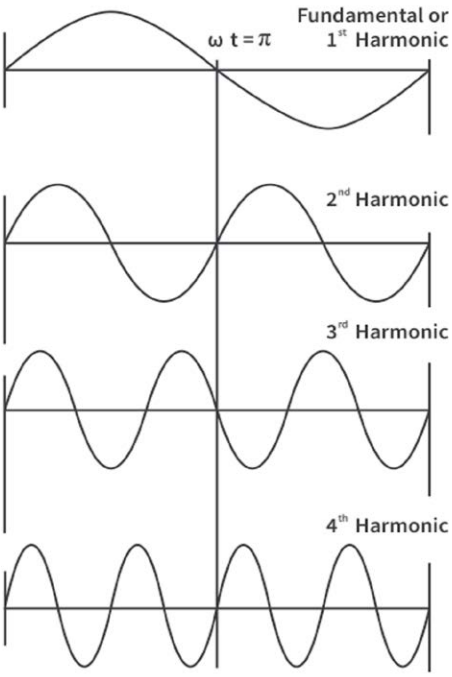

Figure 1: Sine wave frequency

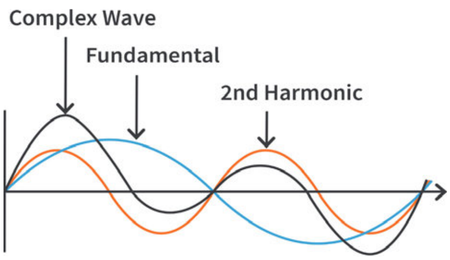

Figure 2: 2nd Harmonic illustration

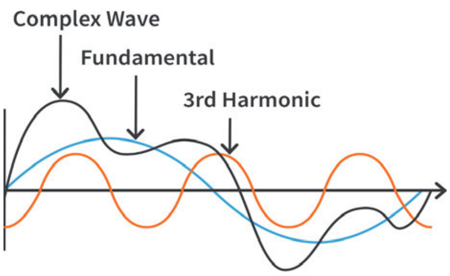

Figure 3: 3rd Harmonic illustration

Harmonics in collaboration with the fundamental wave might cause complex waveforms.

If you are working at 50Hz fundamental frequency, you can expect harmonics at 100Hz, 150Hz, 200Hz and so on. These harmonics might have a detrimental effect on the power system and equipment linked to the network.

What is causing the harmonics in electrical systems?[1]

All electrical loads are divided into two categories, one is linear loads which draw voltage and current in sinusoidal shape, but they may have a phase shift. The resistors, inductors, capacitors, and their combinations fall under this category. The other category is that of non-linear load which draws current in abrupt pulses rather than in a smooth sinusoid, indicating a distorted response. Modern power electronics consisting of inverting, rectifying, charging, and discharging circuits, etc. fall under this category. It is these non-linear loads that give rise to harmonics.

Some sources of harmonics that we see in our day to day lives are CFL/Fluorescent lights, electronic ballasts, fan regulators, UPS and invertors, ARC welders, transformers under no/light load and solar power systems.

Total harmonic distortion is the contribution of all the harmonic frequency currents to the fundamental. [1]

In transmission lines, the stray capacitance which are usually small at standard frequency increases drastically due to the higher frequency harmonics, this leads to poor power quality due to lower power factor.

Why are harmonics bad for the electrical network? [2,3]

Voltage distortions are detrimental to the electrical network, and it can result in the increase of the effective peak voltage value and can also change the RMS value of the current and result in increased losses.
In transmission lines, the stray capacitance which are usually small at standard frequency increases drastically due to the higher frequency harmonics, this leads to poor power quality due to lower power factor.

Conductor overheating - A function of the square rms current per unit volume of the conductor. Harmonic currents on undersized conductors or cables can cause a “skin effect”, which increases with frequency and is like a centrifugal force.

Capacitors - can be affected by heat rise increases due to power loss and reduced life on the capacitors. If a capacitor is tuned to one of the characteristic harmonics such as the 5^{th} or 7^{th}. The overvoltage and resonance can cause electric failure or rupture of the capacitor.

In **transformers**, the iron losses might vary in general with the square of the frequency. Due to the presence of higher frequency harmonics, the iron losses, copper losses or eddy currents in a transformer are increased due to stray flux losses. This might lead to excessive overheating of the transformer and consequent loss of the asset. It may also lead to resonance between the transformer inductance and capacitance which may lead to unwanted vibrations of the transformer core. The use of the appropriate K-factor rated units is recommended for non-linear loads.

In **circuit breakers and fuses** it can cause tripping and reduce the life of the connected equipment, damaging or blowing components for no apparent reason. [1,2,3,4]

The same is true for **motors and generators**. The flow of harmonics in the stator generates stray flux which may result in heating of the rotor, pulsating torques, noise generation which affects the overall lifespan of the equipment. Harmonics might also affect the operation of measuring equipment and relays and can also sometimes interfere with communication networks.

Utility meters - may record measurements incorrectly, resulting in higher billings for consumers.

Drives/Power supplies - can be affected by mis operation due to multiple zero crossings. Harmonics can cause failure of the commutation circuits, found in DC drives and AC drives with silicon-controlled rectifiers (SCR's)

Computers/Telephones – may experience interference or failures.

Evaluating system Harmonics [3]

Some important concepts and terms associated with a harmonic analysis involve PCC, TDD and THD. The Point of Common Coupling (PCC) is the location of the harmonic voltage and current distortion to be calculated or measured. PCC can be measured or calculated on the primary or secondary of a utility transformer or at the service entrance of the facility. In some cases, PCC can be measured or calculated between the non-linear loads and other loads of an industrial plant. Total Demand Distortion (TDD) is the percentage of total harmonic current distortion calculated or measured at PCC. Total Harmonic Distortion (THD) is the total harmonic voltage distortion calculated or measured at PCC.

A task force will be created to develop an application guide for IEEE 519 to help users and utilities in cooperate and understand how to solve potential problems related to power system harmonics.

It is important to evaluate the system harmonics if the facility conditions meet one or more of the criteria below, this is in order to prevent or correct harmonic problems that could occur.

It is important to evaluate the system harmonics if the facility conditions meet one or more of the criteria below, this is in order to prevent or correct harmonic problems that could occur.

Why are harmonics bad for the electrical network? [2,3]

- The application of capacitor banks in systems where 20% or more of the load includes other harmonics generating equipment.
- The facility has a history of harmonic related problems, including excessive capacitor fuse operation.
- During the design stage of a facility composed of capacitor banks and harmonic generating equipment.
- In facilities where restrictive power company requirements limit the harmonic injection back into their system to very small magnitudes.
- Plant expansions that add significant harmonic generating equipment operating in conjunction with capacitor banks.
- When coordinating and planning to add an emergency standby generator as an alternative power source in an industrial facility.

Reducing Harmonics [3]

Harmonics can be reduced in various ways, ranging from variable frequency drive designs to the addition of auxiliary equipment. The following are some of the primary methods used to reduce harmonics.

- Power system design – Harmonics can be effectively reduced by limiting the non-linear load to 30% of the maximum transformer capacity. If power factor correction capacitors are installed, resonating conditions can occur that could potentially limit the percentage of non-linear loads to 15% of the transformer's capacity. The following equation can be used to determine if a resonant condition on the distribution could occur.

$$h_r = \sqrt{\frac{kVA_{SC}}{kVAR_C}}$$

where:
h_r = resonant frequency as a multiple of the fundamental frequency
kVA_{SC} = short circuit current at the point of study
$kVAR_C$ = capacitor rating at the system voltage

If hr equals or is closed to a characteristic harmonic, such as the 5th or 7th, there is a possibility that a resonant condition could occur.

12 pulse converter front end:

In this type of configuration, the front end of the bridge rectifier circuit uses twelve diodes instead of six. The advantages are the elimination of the 5th and the 7th harmonics to a higher order where the 11th and the 13th become the predominate harmonics. Lower order harmonics have more detrimental effects than higher order harmonics. This will minimize the magnitude of the harmonics but will not eliminate them. The disadvantages are cost and construction, which also requires either a Delta-Delta or Delta-Wye transformer, "Zig-Zag" transformer or and autotransformer to accomplish the 30° phase shifting necessary for proper operation. This configuration also affects the overall drive system efficiency rating because of the voltage drop associated with the transformer configuration requirement. Figure 4 illustrates the typical elementary diagram for a 12-pulse converter front end.

- **Delta-Delta and Delta-Wye Transformers:** This uses two separate utility feed transformers with equal non-linear loads. This shifts the phase relationship to various six-pulse converters through cancellation techniques, like the twelve-pulse configuration.
- **Isolation Transformer** - An isolation transformer provides a good solution in many cases. The advantage is the potential to

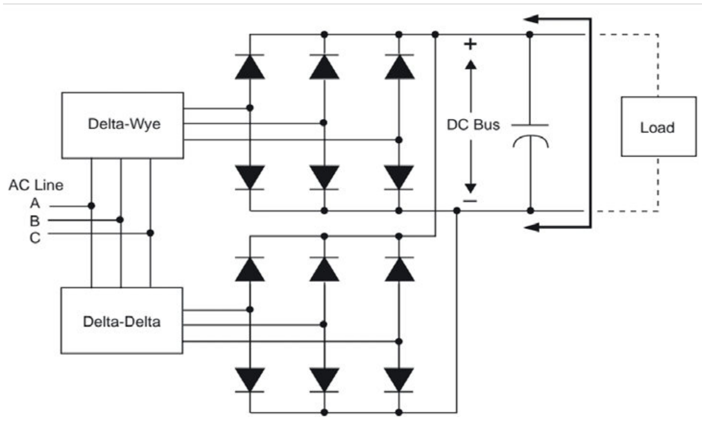

Figure 4: Typical Twelve-Pulse Front End Converter for AC Drive [3]

"voltage match" by stepping up or stepping down the system voltage, and by providing neutral ground reference for nuisance ground faults. This is the best solution when utilizing AC or DC drives that use SCRs as bridge rectifiers.

- **Line reactors** – This is more commonly used for size and cost; the line reactor is the best solution for harmonic reduction when compared to an insolation transformer. AC drives that use diode bridge rectifier front ends are best suited for line reactors. Line reactors, commonly referred to as inductors, are available in standard impedance ranges from 1.5%, 3%,5% and 7.5%, respectively.
- **Harmonic trap filters** – Used in applications with a high non-linear ratio to system to eliminate harmonic currents. Filters are tuned to a specific harmonic such as the 5^{th}, 7^{th},11^{th} etc. In addition, harmonic trap filters provide true distortion power factor correction. Filters can be designed for several non-linear loads or for an individual load, as shown in Fig 5 [3]

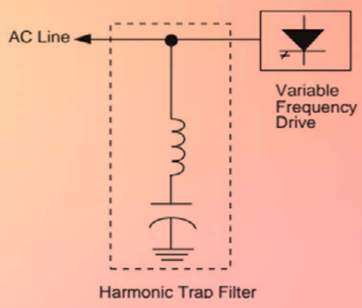

Figure 5: Typical Harmonic trap filter configuration

Conclusion

With the proliferation of non-linear loads, the issues of power harmonics are more apparent than ever. Controlling and monitoring industrial system designs and their effects on the utility distribution system are a potential problem for the industrial customer, who is responsible for complying with the IEEE 519, recommended practices, and procedures.

Industrial facilities should include a system evaluation, including a harmonic distortion analysis, while planning facility construction or expansion. Vendors of non-linear loads, such as variable frequency drives, can provide the relevant services and recommend equipment that will reduce the harmonics to comply with the revised IEEE 519 guideline.

Industrial facilities should include a system evaluation, including a harmonic distortion analysis, while planning facility construction or expansion.

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[2] "On the impact of Grid Harmonics on Transformers: A case study." B Thango, O Akumu, LS Sikhosana, A.F. Nnachi.

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Denis Phares

Photo: Dragonfly Energy

Interview with **Denis Phares**

CEO of
Dragonfly Energy

> If things are centralized, there's a risk that energy doesn't get delivered to where it needs to be. So as things become more distributed, especially storage, we're stabilizing the edge.

Alan Ross: Hi. I'm Alan Ross. I'm the managing editor of APC Technologies. My next guest is Denis Phares. He is the CEO of Dragonfly Energy.

I have a lot of questions about Dragonfly. Tell me a little bit about how you got involved with the company. When did it start, why did you start it?

Denis Phares: Well, I got involved with the company because I started the company. It really came out of technology that I was developing on the manufacture of lithium-ion electrodes. I was working on a way to do it in a more streamlined and inexpensive way, ultimately to reduce the cost of storage. And I had been a professor for twelve years, so I was sort of accustomed to development of technology, filing patents, gaining grant money. I started the company; I just went full speed and left tenure. It was scary. My colleagues thought I was crazy. My wife thought I was a little nuts. But I guess you have to be when you're entrepreneurial.

AR Excellent. We're going to get back to Dragonfly, but before we get there, what is the definition of grid edge in your mind?

DP In my mind, grid edge encompasses hardware, software, innovations associated with distributed power. We're talking grid-tied buildings, homes, what goes on there, and that interacts with basically the centralized power generation and distribution.

AR How about renewables changing what we define as the grid edge? Because now they're at the grid edge.

DP You define it now with renewables, particularly with solar, the energy generation occurs at the edge of the grid. Not exclusively, but it at least contributes a great deal.

AR I used to define the grid as step down. There was large scale generation, and then you step down, it's now step everywhere, because it can be coming from somebody's battery system in their home, the Tesla firewall they got there, but it is a uniquely changing thing. How is electrification of transportation going to change the grid edge in your mind?

DP I've spoken a lot about this. It is an issue, because basically, a third of our energy usage in general is transportation. We're used to having that generated in the internal combustion engine in the car. Now all of a sudden, it's going to be delivered to the car from the grid. If we don't move a lot of that generation and storage out to the edge, it's going to make things very difficult, because if it continues to be centralized, it's too much of a stress, too much transmission. I really think this is an exciting time. It's going to be a complete paradigm shift to how the grid behaves when all of transportation eventually becomes grid tied.

We're used to having that generated in the internal combustion engine in the car. Now all of a sudden, it's going to be delivered to the car from the grid. If we don't move a lot of that generation and storage out to the edge, it's going to make things very difficult, because if it continues to be centralized, it's too much of a stress, too much transmission.

AR In that statement you've just defined a lot of the challenges that we have. How do we bring about this paradigm shift? Because you also add to it the fact that labor forces are changing. We don't have as much of it. Technology has to change in order to make all of that happen and to make it make sense, right? What is the role of technology in creating this new grid edge across the board?

Change can't happen unless it actually is cost effective, it just won't. You can have so much subsidies to drive it, but ultimately, to be self sustaining, the technology has to make sense in terms of cost effectiveness for us to change the system in this way and make transportation grid-tied.

DP Technology is required to make things cost effective. Change can't happen unless it actually is cost effective, it just won't. You can have so much subsidies to drive it, but ultimately, to be self sustaining, the technology has to make sense in terms of cost effectiveness for us to change the system in this way and make transportation grid-tied. There's cost, there's efficiency. Because without efficiency you don't have stability of the grid. You have to create a system where, regardless of how much needs to be delivered to accommodate transportation, the grid doesn't go down. If we want more renewables and intermittency onto the grid to sustain such a large transition, we also need storage. Therefore, storage ultimately is going to be a big part of it.

DP I think when we talk about storage, we think about batteries, but it's not all batteries, there's all kinds of storage; mechanics, pumped hydro is a great example of that. But we've often focused on centralized storage, large storage facilities. When we start talking about distributed storage and storage at the grid edge, lithium becomes a big part of this. Not just batteries, but lithium, because now you do need the energy density of lithium. And I think the focus of lithium research historically has been propulsion and electric vehicles, transportation, right? But those metrics are different when you're

AR I agree with you, everything else is going to be a struggle if we don't have a better way of storing power than we have today. Because the intermittency of wind and solar, although it's great that we can produce renewable energy, and it's going to decarbonize, it can only make that gigantic leap if we can store it when we don't need it.

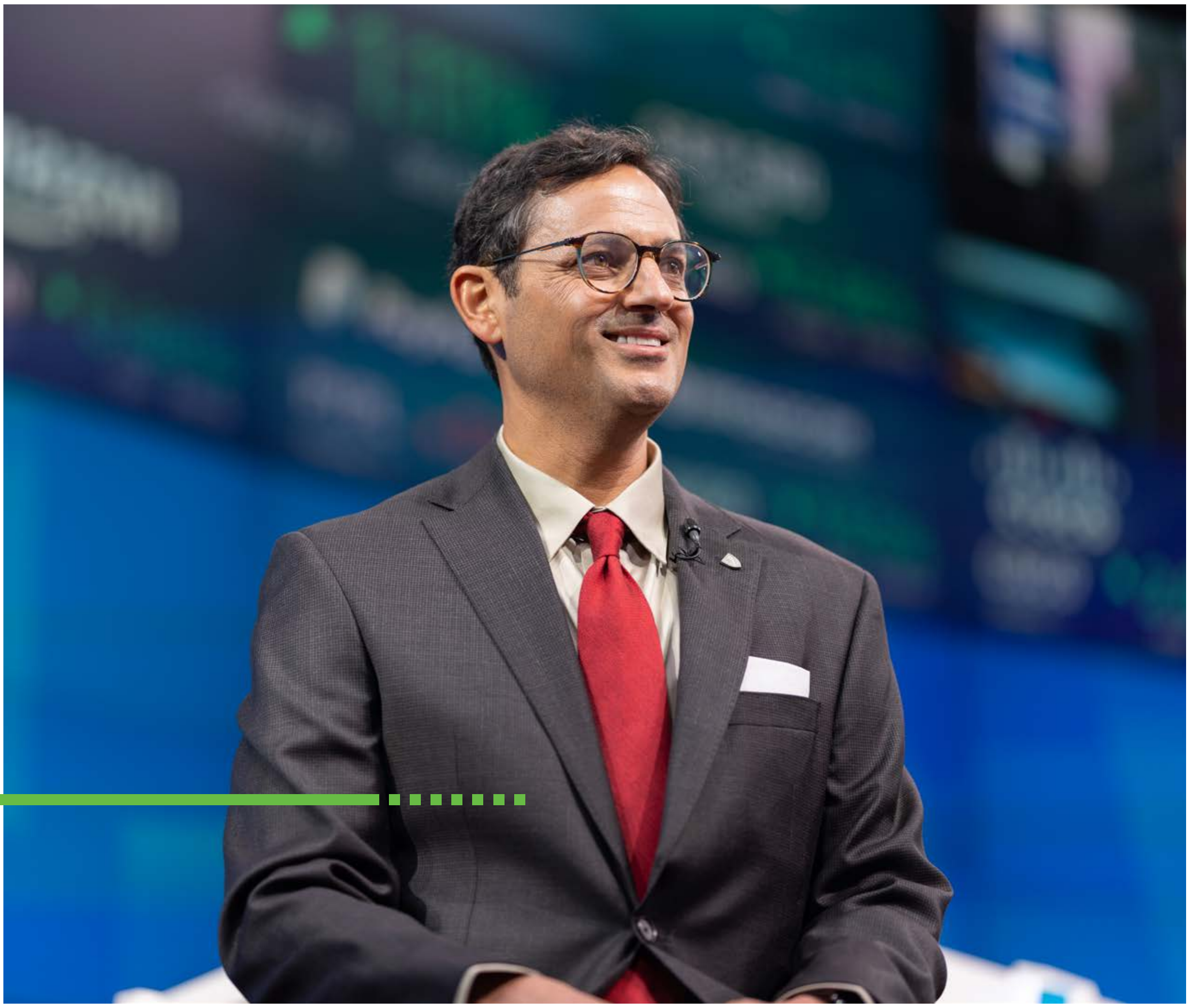
Talk about storage in general, because that's your background. You've already made the case for how important it is. But talk about where we are now and where you think we're going to be as it relates to storage in order to make the grid efficient, reliable, safer, more able to handle some of these extreme events.

talking about actual grid storage. Levelized cost of storage is important. Safety is huge, because now you're not talking about replacing gasoline tanks in a car with battery power. We know that works, we know that consumers are okay with that. Think about storage systems in your home. Safety and flammability become a big part of it. And that's where I think we need to focus.

When we start talking about distributed storage and storage at the grid edge, lithium becomes a big part of this.

Photo: Dragonfly Energy

AR I just read a report that allegedly, China has cornered a lot of the lithium market. When you think of countries and how they do it, there is this competition for a resource that is more and more scarce as we use more and more of it. Talk about that, the use of lithium and the growth of the use of lithium. You got life cycle planning. You've got this demand curve increasing rapidly. But at the same time the need for quality. It seems to me you're addressing a lot of issues. When is the plant officially going to have a grand opening?



DP Well, you talked about two different things here. There's the politics associated with the fact that China has basically subsidized the export of products that we historically haven't wanted to make here. And we facilitated a great rise in China, and China's done a great job. It makes me sad to think that we are in this political situation, because China has enabled us to even make this technology possible. But that's not sustainable. We need to bring that manufacturing here. That brings the second point, which is the resource. Where's the lithium? Certainly, there's lithium in China. There's lithium in South America, which China has access to, more than anyone else in the world. But there's lithium here in the United States, in Nevada. That's why Dragonfly Energy is there. We've got a number of mines that are going to be coming online over the next few years. There are more and more discoveries of lithium that occur that are going to propagate the increase of lithium mining, which is important.

Ultimately, the way I see it is, if you get lithium out of the ground, it's going to sell. We're going to make batteries; we're going to sell it. There's not a lot of downstream competition as much as upstream competition. Who gets access to the lithium? That's what I think companies in the US need to focus on - getting access to lithium. But ultimately, the US has to produce and mine lithium, so that we can be on the world stage and not just produce lithium here, but also export batteries to where they're needed globally.

AR Let's talk specifically about Dragonfly and what you're presenting here on the Grid Edge stage on the topic of distribution. Talk about your presentation and what it's about.

DP Well, I've spilled the beans already a little bit. I focus on those two metrics - cost and safety, why they are important, and

Photo: Dragonfly Energy

how Dragonfly is approaching it. I did mention that a lot of the focus of electrochemical research has been for propulsion. Our focus has been to sort of turn that around and look at the manufacturing of the cells in order to bring down the cost. We powder-coat electrodes. It's a very streamlined, inexpensive process to make cells. But what we've noticed is we're able to powder coat all solid-state cells, ceramic-heavy composite electrolyte, which means they're also non-flammable. So if you have something as energy dense as lithium, and yet it is non flammable and can be deployed in homes, that is a solution for the storage at the grid edge. That's what I'm talking about, and that's what we're excited about.

Our focus has been to sort of turn that around and look at the manufacturing of the cells in order to bring down the cost.

AR Okay, but doesn't that also positively impact lithium-ion batteries in transportation?

DP You're right, it does, because you're trying to stabilize the grid, and that's a great way to do it. You need distributed storage. You need centralized storage. You need everything that you can get in order to facilitate the electrification of transportation. It is going to be important that some of the lithium that comes out of the ground now goes to the grid. It doesn't all go to vehicles. I think that is sort of a challenge that we're addressing.

AR We have a cohort in the data center world. In a recent panel discussion that we had, we talked about how data centers are now installing battery storage systems. They're not just relying on generators anymore, which run for 3 hours, and then they stop running. They've had a lot of problems with generation, so in order to maintain reliability in a data center, now they're saying they got to have storage. It goes to the same thing. They're going to rely on lithium-ion or lead acid. They're going to rely on something in order to make sure their data centers keep running, and they are growing larger and more critical to society. I assume the same thing is happening in transportation, data center storage, telecom. It's a nice time to be in Dragonfly Energy, isn't it?

DP It's a nice time to be in storage, but specifically in distributed storage. The overarching point here is that, if things are centralized, there's a risk that energy doesn't get delivered to where it needs to be. So as things become more distributed, especially storage, we're stabilizing the edge. That's, of course, important for data centers. You want to have access if you need to charge your vehicles, you want to have access to the power and not have to rely exclusively on the centralized grid. In fact, we kind of look at

the distributed storage as oh, that's going to be our energy buffer for when there's a lot of renewables on the grid. I prefer to think about it as the grid itself. The centralized grid is the buffer for what's happening at the edge, and I think that paradigm shift is going to elucidate why it's important to reinforce what happens in the buildings, in the grid-tied houses and businesses.

AR That's a completely different way of looking at it and not necessarily the way the majority of the industry is looking at it. What role do utilities play in this when it comes to storage?

DP A number of things. First of all, you can't do anything without buying from the utilities, so you have to come up with a system that makes it financially favorable for utilities to select renewable and storage. You need to work with the utilities to ensure that the deployment is in their benefit. We don't want to make everyone off grid, we want to have a sustainable grid. I know that utilities are actively pursuing distributed storage now. One of the roadblocks they're running into is the liability associated with the flammability of lithium-ion batteries. And each time, even if you have a safe battery like lithium-ion phosphate, you still have a flammable electrolyte, where, even if you don't initiate thermal runaway in the battery, because it's a safe system, if there is a fire in the house, for whatever reason, the presence of the storage system could make it potentially more dangerous for firefighters. We want to help solve that liability issue for the utility companies to help mandate distribution of energy storage in buildings. They can't mandate something that is dangerous to the homeowner.

AR Last question for you, because you just brought it up. I've heard people say microgrids are the answer, and you say no, microgrids might be one of the answers, but they're not the answer. Storage and microgrids, how important are they and where do you see this going?

PJ Well, your step-down vision of the grid, I think it still continues to be accurate. There are still steps, and I think you've got the edge, you've got the community, you've got the microgrids, you've got the centralized grid. I just see it as energy coming from both sides, from the houses to the microgrid, from the communities to the central grid. Now we're talking software, and this is a little bit beyond my expertise, but now we're talking about the distribution of energy in terms of optimization of its efficiency, similar to how data is distributed on the Internet. I see software playing a very big role as to how the energy is transmitted from the different layers, from the centralized power generation to the microgrid to the individual homes, each one of which having their own storage nodes and energy generation nodes.

AR Energy management systems are trying to do that now, but they tend to still be based on the step-down grid. There's not a sophistication that says, we've got power coming from here and power stored here, and we got to take all of that into account to deliver efficient, reliable, safe power to all of our customers. What is the solution that Dragonfly Energy has got for the marketplace?

DP Dragonfly Energy evolved in a pretty unique way. We started off by producing lithium-ion battery packs for mobile consumers, RVs, boats, that sort of

Photo: Dragonfly Energy

thing. Now we are extending that to more stationary, grid edge, residential storage. What we focused on is communication and balancing, so communication among the battery cells and battery banks. That has culminated into a product we call the Dragonfly Wing, which is basically a home storage solution that self-balances the cells, but it can also communicate very effectively with each wing in the system and with the outside components, such as inverters and the like.

> We started off by producing lithium-ion battery packs for mobile consumers, RVs, boats, that sort of thing. Now we are extending that to more stationary, grid edge, residential storage.

AR It does make sense. Thank you. This has been insightful.

DP Thank you.

Legnano Teknoelectric Company (LTC) continues its global expansion by establishing a new branch, LTC APAC, in Taipei, Taiwan. With a dedicated team of industry experts and a state-of-the-art production plant, LTC aims to meet the growing demands of the Asia Pacific (APAC) market and provide efficient solutions to its customers. The new facility in Taiwan signifies LTC's commitment to delivering excellence and maintaining its position as the world market leader in the production of magnetic cores and laminations for a wide range of transformers and reactors.

LTC Expands Presence in Asia with New Facility in Taiwan

LTC GROUP

NEW PRODUCTION PLANT IN TAIWAN – TAOYUAN

The Board of Directors of LTC APAC comprises esteemed individuals with extensive experience in the industry. Christina Huang, a key member of the management team, ensures the seamless continuation of LTC's operations, fostering trust among customers, suppliers, and collaborators. Cristiano Michele Bertelli, the managing director of LTC Middle East and a member of the Bertelli family's third generation, brings his visionary leadership to drive the company's growth as President of LTC APAC. Mauro Mereghetti, already a manager of the factories in Dubai, and Gianluigi Bertelli, CEO and Managing Director of the entire LTC Group, further contribute their expertise to the success of the new company.

Spanning approximately 17,000 square meters, LTC APAC's new production facility in Taiwan boasts a manufacturing capacity of over 15,000 tons per year.

Legnano Teknoelectric Company (LTC) continues its global expansion by establishing a new branch, LTC APAC, in Taipei, Taiwan. With a dedicated team of industry experts and a state-of-the-art production plant, LTC aims to meet the growing demands of the Asia Pacific (APAC) market and provide efficient solutions to its customers.

Heading the management team is General Manager Bruno Carlo Giannotti, overseeing the operations and strategic direction of the Taiwan branch. Assisting Giannotti is Bennett Lo, Director of Operations, who plays a vital role in streamlining processes and optimizing efficiency. David Chang, as the Taiwan Sales Director, is responsible for establishing and maintaining strong relationships with customers in the region. Kris Lee, General Manager of Extra Taiwan Sales, leverages his expertise to drive sales growth beyond the local market. Sally Fang, as the Manufacturing Manager, ensures the smooth operation of the new production plant in Taoyuan.

Spanning approximately 17,000 square meters, LTC APAC's new production facility in Taiwan boasts a manufacturing capacity of over 15,000 tons per year. This significant expansion aims to meet the growing demands of the APAC market and reduce lead time, ensuring timely delivery to customers across the region. With a maximum cutting width of 1,250 mm at 45 degrees, LTC APAC is equipped to provide high-quality magnetic cores and laminations tailored to the specific needs of the local market.

Photo: Legnano Teknoelectric Company

In celebration of LTC's presence in Taiwan, the company has decided to participate in CWIEME Shanghai, a prestigious industry exhibition. From June 28 to 30, LTC invites everyone to visit their stand at 1F51 to explore their innovative offerings and engage with their team.

LTC Group, founded by the Bertelli family, started as a local manufacturer of electrical transformers and has now evolved into the world market leader in the production of magnetic cores and laminations for a wide range of transformers and reactors. With production sites in Italy, the United Arab Emirates, and Taiwan, LTC has cemented its position as a renowned industry leader. The company's relentless pursuit of excellence and meticulous attention to detail have driven its success.

LTC Group, founded by the Bertelli family, started as a local manufacturer of electrical transformers and has now evolved into the world market leader in the production of magnetic cores and laminations for a wide range of transformers and reactors.

Photo: Legnano Teknoelectric Company

The LTC Way, the company's production model, encompasses extensive experience, consolidated expertise, and ongoing research and development efforts. With a dedicated Technical Department and R&D team, LTC provides comprehensive support to its customers, offering tailored solutions based on 65 years of collected data and extensive testing. LTC Group employs over 850 professionals across eight different production units, including five in Italy, two in Dubai, and one in Taiwan. By utilizing cutting-edge equipment, machinery, and quality control systems, LTC ensures prompt responses to customer needs and delivers high-quality magnetic cores and laminations.

LTC's commitment to excellence extends beyond its production processes. The company prioritizes investments in human resources and raw materials, making it an integral part of the Industry 4.0 movement. By embracing innovation and anticipating future industry trends, LTC aims to overcome challenges and continue pushing boundaries.

LTC Group employs over 850 professionals across eight different production units, including five in Italy, two in Dubai, and one in Taiwan.

With the establishment of LTC APAC in Taiwan, LTC Group reaffirms its dedication to providing top-tier magnetic cores and laminations to the APAC market. By expanding its global footprint, LTC is well-positioned to meet the evolving needs of customers and solidify its position as the world market leader in the production of magnetic cores and laminations for transformers and reactors.

AI Powered VPP and DERM: Innovations to Resolve Grid Constraints

by **Asad Tariq**

Utilities all over the world, specifically in the advanced economies, are utilizing AI powered VPPs and DERM to optimize the use of renewable energy integrated with the electricity grid and achieve operational goals including economic efficiency, security, and reliability of supply.

After the Paris Agreement in 2016, the power sector across the globe began undergoing major changes which are focused on meeting the rising energy demand and curtailing carbon emissions. To meet the increasing energy demand and climate goals, industry is upgrading not only the grid infrastructure but also increasing the share of renewable energy resources. But there is a limit to how much additional grid infrastructure and generation resources (be it renewable or conventional) can be installed. This has forced us to look for other ways and completely rethink how we meet the electricity demand and climate goals, that too in an optimized manner.

Recently, Virtual Power Plants (VPPs) and Distributed Energy Resource Management (DERM) powered by artificial intelligence have emerged as potential solutions. Utilities all over the world, specifically in the advanced economies, are utilizing AI powered VPPs and DERM to optimize the use of renewable energy integrated with the electricity grid and achieve operational goals including economic efficiency, security, and reliability of supply.

AI-Powered Flexibility Services

Electric utilities in advanced economies are readily utilizing AI powered VPPs and DERM to achieve required grid flexibility. These technologies have become tools for the grid operators and utilities which are trying to optimize operations in developed economies.

Virtual Power Plants

VPP is a system of systems which relies on an advanced software platform-based AI-driven predictive models, which can optimally orchestrate the dispatch of distributed energy resources such as wind farms, solar parks, storage units, and flexible controllable loads to a distribution or wholesale market.

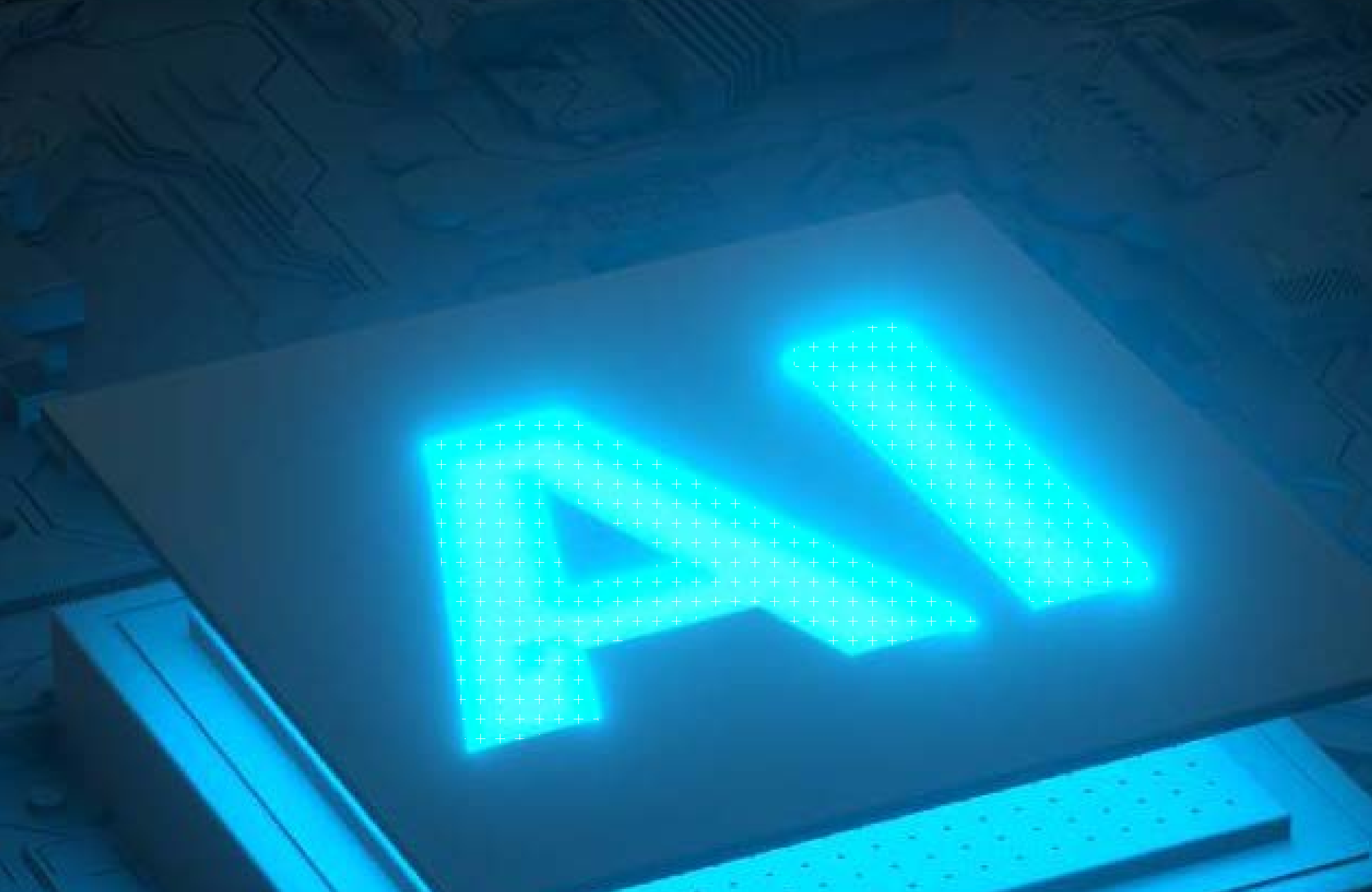
VPPs have enabled electricity consumers to participate in the electricity market and act as prosumers of electricity that provide services to the electricity grid while meeting their own needs which was otherwise not be possible. This has been made possible through aggregation of behind the meter DERs for instance solar PV systems, batteries, EVs and demand response potential.

It is interesting to note that VPPs provide control over the distributed energy resources which in turn provide services that are usually drawn from conventional power plants but with a much smaller environmental footprint and land use.

Distributed Energy Resource Management

DERM is essentially a software platform that allows real time control, coordination, and optimization of different types of distributed energy resources, for instance solar, wind and energy storage systems. As per the estimates of PTR, the cumulative annual power injecting capability of DERs for instance utility scale renewables, grid edge services such as rooftop PV solar, battery storage units, electric vehicles, combine heat and power units and controllable smart home appliances have for the very first time surpassed the electric power generation capacity from conventional power plants (thermal and nuclear) worldwide in 2021.

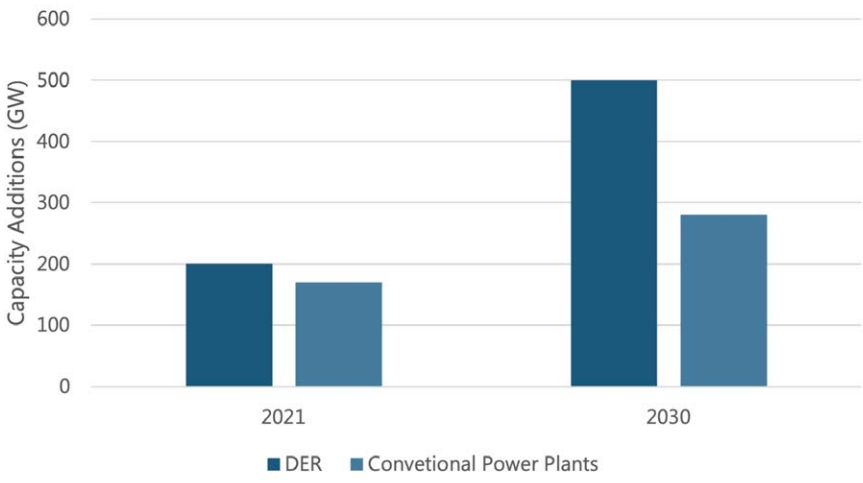
Photo: PTR Inc.



Asad Tariq is working as Market Analyst at PTR Inc., where he specializes in analyzing the impact of Artificial Intelligence (AI) on the power grid industry. With his deep understanding of the High Voltage Direct Current (HVDC) transmission sector, as well as Onshore Power Supply (OPS) and Flexible AC Transmission Systems (FACTS), Asad is able to provide valuable insights into the latest market developments in this rapidly evolving field. His extensive experience includes conducting specialized studies to better understand the applications and benefits of AI-powered solutions in the power sector. He has a strong research background, having previously worked as a research assistant at US PCASE, NUST, and published a research article in Elsevier. Asad holds an MSc and a BSc in Electrical Power Engineering from NUST Islamabad and UET Lahore, respectively.

VPPs have enabled electricity consumers to participate in the electricity market and act as prosumers of electricity that provide services to the electricity grid while meeting their own needs which was otherwise not be possible.

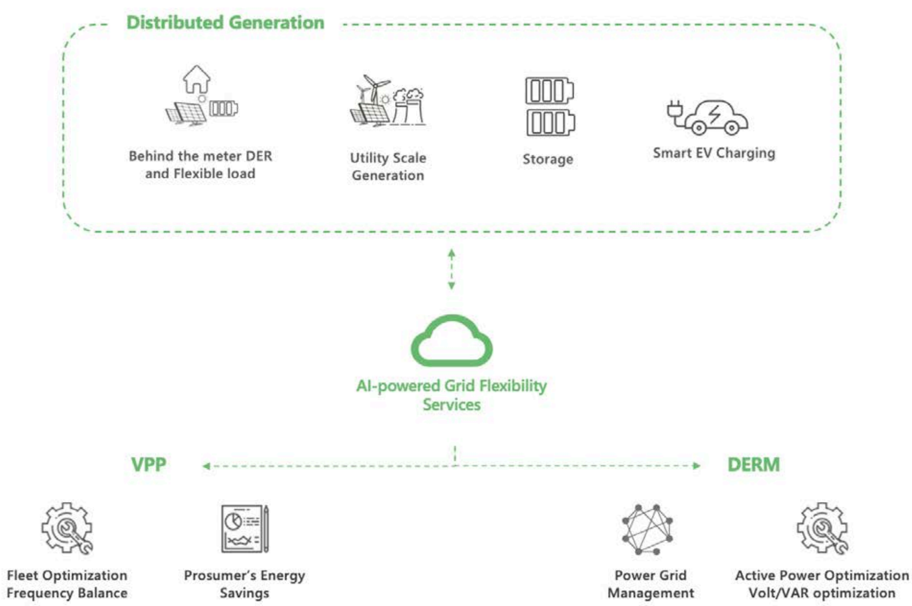
Figure 1: Generation Capacity of DERs versus Conventional Generation. Source: PTR Inc.



Decentralization of the generation assets at this scale, which is only going to increase in coming years, has created several challenges for the grid operators and utilities. Utilities and grid operators in order to cater to the surge in the distributed energy resources require an active power management system. As the majority of the distributed energy resources are not under the control of utilities or grid operators, utilities are under an obligation (under grid code) to supply the power to the consumers while maintaining a balanced DER portfolio.

In order to maintain reliability and stability of the grid, localized active power management of distribution feeders and circuits is required. These features are available in the latest DERMs through which utilities can effectively manage complex power systems and deliver reliable power to consumers.

Figure 2: AI-Powered Grid Flexibility Services Assisting Electric Utilities to Optimally Manage Decentralization. Source: PTR Inc.



Key Global Markets for Grid Flexibility Services

As per the estimates of PTR, Europe is the frontrunner in terms of AI powered grid flexibility services as both the VPP and DERM are gaining traction in the region due to rising share of renewable energy, and grid edge DERs. In this regard, Europe is followed by Australia which is a potential energy market for grid flexibility services mainly due to widespread deployment of grid edge distributed energy resources and high energy per capita consumption.

It is expected that the UK and Germany will remain the dominant market for both DERM and VPP in Europe till 2030. Grid flexibility capacity of the UK and Germany is anticipated to reach beyond 100 GW by 2030.

Photo: Shutterstock

Europe

Historically, the European VPP and DERM market is mainly driven by the requirement for integration of increasing share of supply-side renewable generation. The expansion in wind power from 94 GW to 197 GW and solar power from 18 GW to 120 GW in the last decade has paved way for grid flexibility services.

In 2021, the European DERM installed capacity accounted for around 50 GW. Within Europe, the UK is the leading market accounting for nearly 14 GW, followed by Germany with nearly 6.5 GW.

On the other hand, Germany is the leading market in terms of installed VPP capacity accounting for nearly 4 GW, followed by the UK with nearly 1 GW of VPP capacity. The majority of the VPP capacity is driven by utility scale solar and wind power deployments in these countries.

It is expected that the UK and Germany will remain the dominant market for both DERM and VPP in Europe till 2030. Grid flexibility capacity of the UK and Germany is anticipated to reach beyond 100 GW by 2030. The main reason behind the maturity of these markets is the increase in the deployment of grid-edge renewables. Furthermore, the regional and national regulations allowing the demand-side flexibility to be part of energy market for energy trading will also result in the increasing capacity of the grid flexibility.

Australia

Australia's energy per capita consumption is 25% higher than

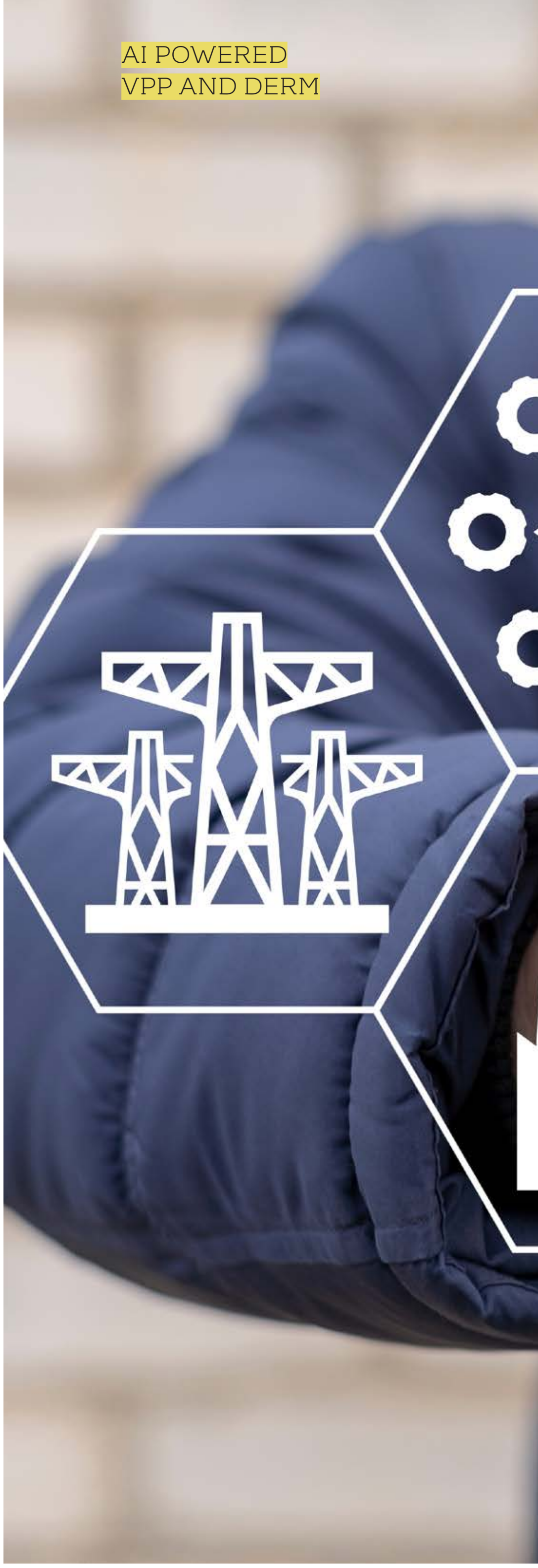
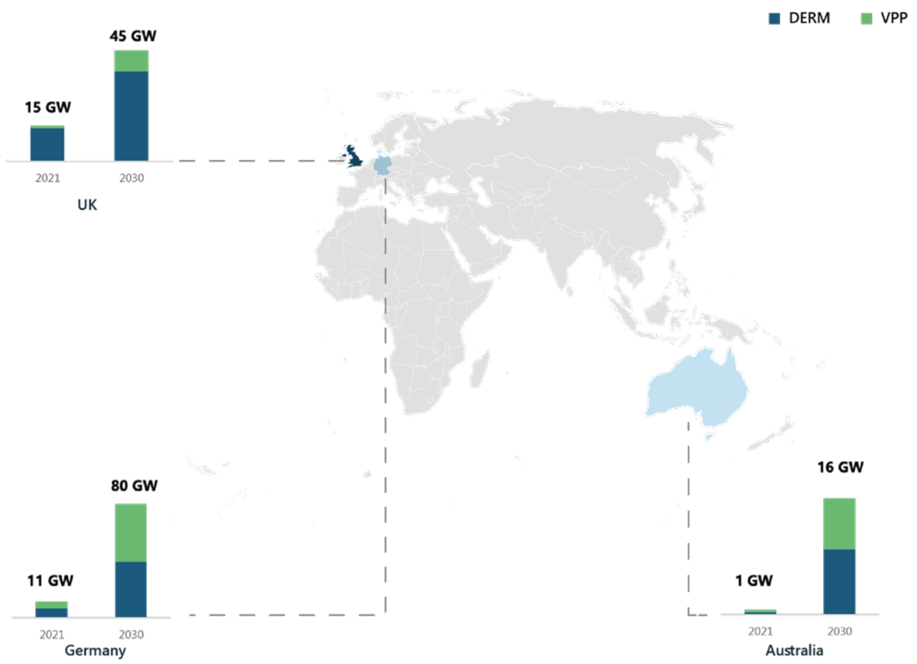


Figure 3: Grid Flexibility Capacity in Key European Markets and Australia (2021-2030)
Source: PTR Inc.



the average of OECD (Organization for Economic Cooperation and Development) member countries, accounting for nearly 8,930 kWh. Higher energy per capita consumption has created an opportunity for flexible loads to act as key grid flexibility assets via VPPs.

The Australian power sector is becoming more decentralized due to the growing share of renewable energy generation which is expected to be 45% of Australia's total electricity generation by 2050 up from 12% in 2021. A major portion of this renewable energy generation target is planned to be achieved by installing rooftop solar and residential energy storage battery units projected to account for 124 GW and 126 GWh by 2050. In line with the highest rooftop solar generation capacity and projected massive deployment of residential storage solutions, Australia stands out as a market for the VPP and DERM with significant potential.

With the ongoing expansion of solar rooftop and residential battery storage across all the states, Australia is right on its way to becoming one of the global leaders in terms of VPP deployment in the coming years. Australia is estimated to have nearly 9 GW of DERM and 7 GW of VPP capacity by 2030. The majority of the demand will be driven by the states including Victoria and Queensland.

The Vitoria's energy company, Origin, plans to achieve a VPP capacity of 2 GW in the coming four years, the major portion of the VPP will be coming from residential storage and solar rooftop. In addition, Transgrid and Ergon Energy Networks are also planning to build VPP aggregation platforms in Southern Australia and Queensland, respectively. The VPP programs will enable the utilities to optimally manage the dispatch of renewable energy resources.

Looking Ahead

PTR has observed that Europe and Australia are leading the way in terms of adoption of grid flexibility services focused on catering the evolving electricity grid challenges. Due to widespread adoption of utility scale renewable energy resources followed by national and regional regulations, significant growth in VPP and DERM is being observed in Europe particularly Germany and the UK. Furthermore, the UK and Germany are expected to remain the market leader in Europe with grid flexibility capacity projected to reach 45 GW in the UK and 80 GW in Germany in 2030.

On the other hand, PTR believes that owing to high energy consumption and solar generation per capita Australia is a prime location for VPPs. It is noteworthy that stakeholders in the country are showing strong affinity towards utilizing rooftop solar

With the ongoing expansion of solar rooftop and residential battery storage across all the states, Australia is right on its way to becoming one of the global leaders in terms of VPP deployment in the coming years.

DERMS

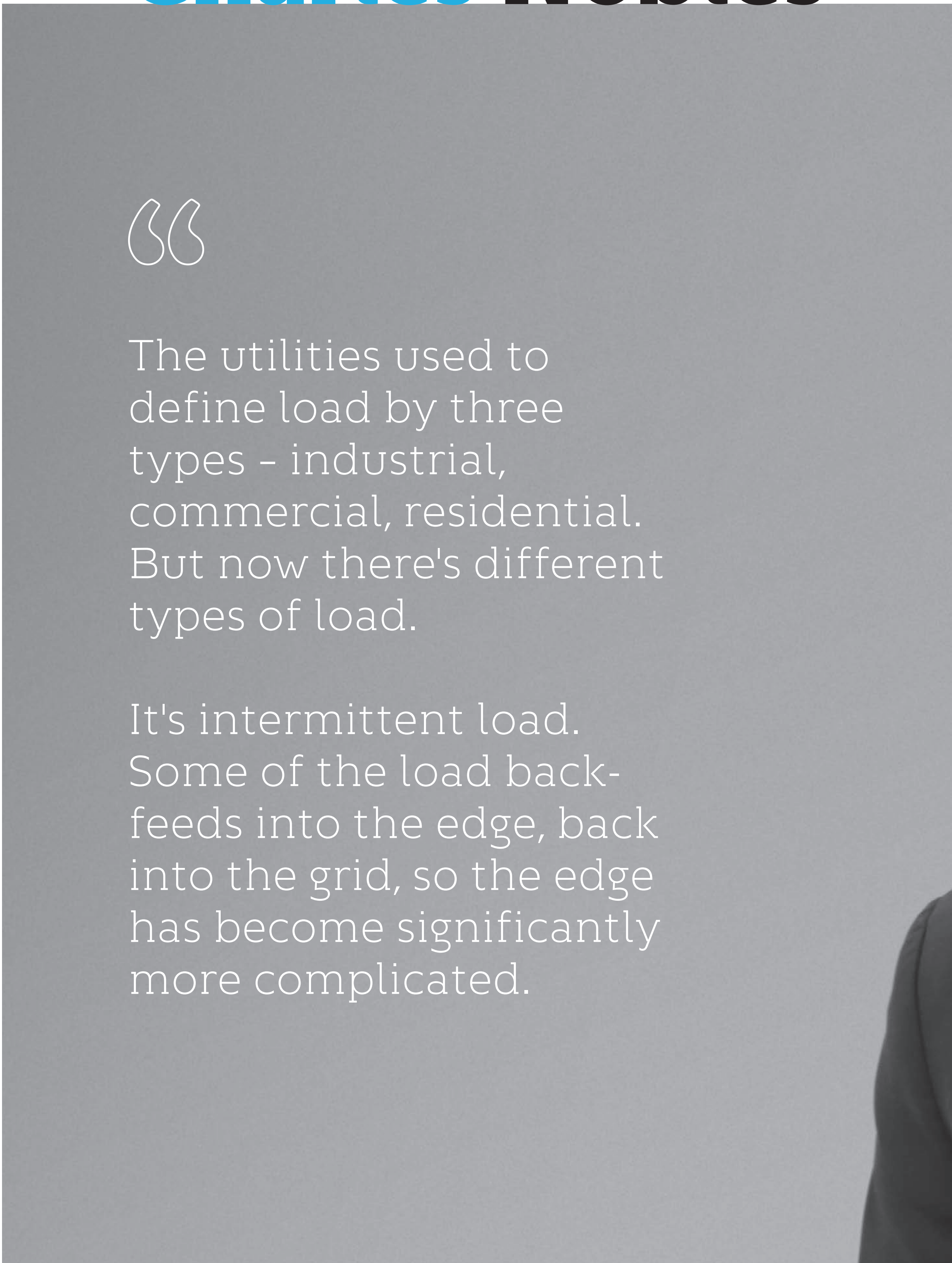
Photo: Shutterstock

and residential storage capacity for advanced VPP platforms that have the ability to predict and manage grid congestion. Grid flexibility capacity of Australia is estimated to stand at around 1 GW in 2021 and it is expected to reach 16 GW in 2030.

To conclude, the electricity market structure of countries paves way for the development of grid flexibility market. In the absence of a suitable electricity market structure such technological solutions cannot be deployed, and widespread market participation of consumers cannot be ensured.

Charles Nobles

Vice President of Utility Business Development at Ubicquia



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The utilities used to define load by three types - industrial, commercial, residential. But now there's different types of load.

It's intermittent load. Some of the load back-feeds into the edge, back into the grid, so the edge has become significantly more complicated.

Photo: Ubicquia

Alan Ross: My guest today is Charlie Nobles. Charlie, thank you for joining me. He's the vice president of utility business development with Ubicquia. I love that name. You made it up, didn't you?

Charles Nobles: Well, I didn't make it up, but it is made up. Ubicquia comes from the word "ubiquitous", which means everywhere. We use the carrier networks, LTE-based networks, which are everywhere. They're already built out.

AR What I want to ask you first is how did you get involved in the industry? Not just Ubicquia, but how did you get involved? It's always a strange story for most people.

CN Well, when I was in grad school, I worked for Carolina Power and Light. They funded my grad school in engineering. I worked for them part time at a power plant. That was my first exposure to the utility industry on the generation side. I came back to Carolina Power Light years later, and I worked on the metering side. At one point I ran all the metering for north and South Carolina for Progress Energy, which now is a part of Duke Energy.

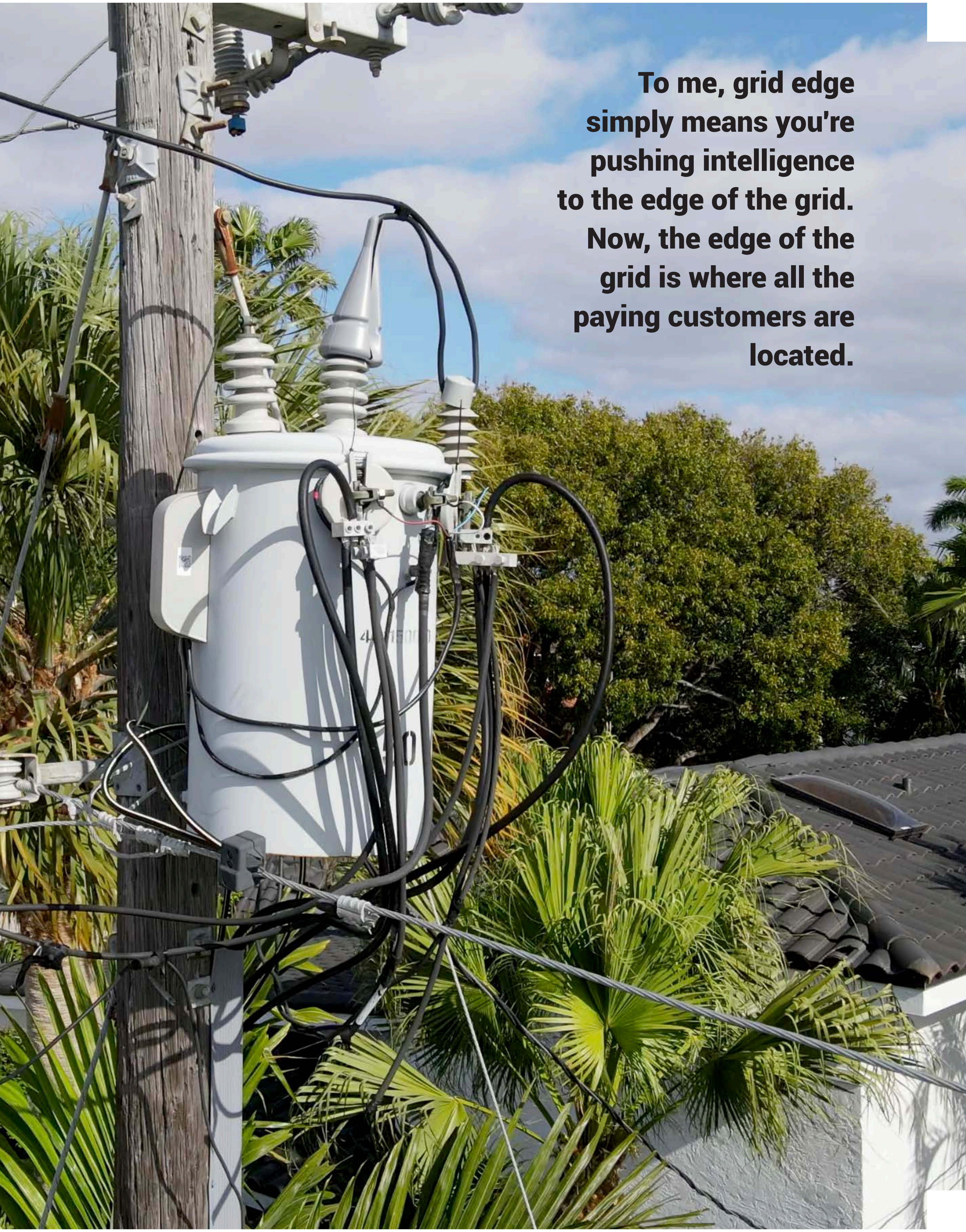
AR So now we know why you got in the industry, and you've been in it long enough now to be an expert. I have to ask you, as an expert - define the grid edge. What is it?

CN If you ask eight people that question, you'll get 15 answers. Historically, all the compute, all the analytics, all the intelligence is at the core. Years ago there was a move to digital signal processing technology in the client, where much of the intelligence is at the edge. It's faster that way, with less latency in moving the critical data up and down. You can make decisions more quickly. To me, grid edge simply means you're pushing intelligence to the edge of the grid. Now, the edge of the grid is where all the paying customers are located. All the money comes in from the edge of the grid, and all the rest of the grid is just to get power to the edge of the grid, so you're putting the intelligence where the customers consume the product.

AR And that's where smart meters started, so that we can get the customers to give us information. And when the power went out, we didn't have 50 people calling us saying, my power is out, right? The meter told them exactly.

CN The meter tells you. You're exactly right. There are two places today where all the intelligence seems to be located - at the meter, which is at the edge, but only at the meter, and then at the substation. And in between there's a vast arid landscape.

Photo: Ubicquia



To me, grid edge simply means you're pushing intelligence to the edge of the grid. Now, the edge of the grid is where all the paying customers are located.

AR When I think of grid edge, I used to think of it that way, the low-voltage side of the grid, right? Well, now you've got at the grid edge wind, solar storage, electrification of transportation. We changed the whole thing, so the definition of grid edge had to change. Now transmission is at the grid edge coming into the system. What does that mean?

CN Sure, especially when you have micro grids. The edge changed. The edge used to be just basic energy consumption, kilowatt hours. The nature of the kilowatt hour load didn't matter. The utilities used to define load by three types - industrial, commercial, residential. That's it. But now there's different types of load. It's intermittent load. Some of the load back-feeds into the edge, back into the grid, so the edge has become significantly more complicated. Now the meters alone are not enough to measure the total consumption for a bill. You need to know the type of loads. Is it intermittent? Is it steady state? Does it have harmonics? Is the energy flow bidirectional? There's so much more sophistication required at the edge, because the edge has become more complicated.

AR And with that you have more power quality issues introduced into the grid. It used to be substation and meter, forget about everything in between. Now we got to think about everything in between, right?

CN Yes. In fact, I like to call it *from feeder to meter*. The visibility gap is from the head of the feeder to the meter. But these other devices and loads connected to the meter, they're not electrically clean devices. Let me give you an example. Back in the day when I worked for the utility, we could always tell if there was a reactive power issue, if there was a log mill or some inductive load, because it

That's the core piece of information about Ubicquia – we leverage LTE networks that are already in place.

Photo: Ubicquia

caused imbalance and poor power factor on the grid. That was kind of a rare occurrence for just occasional industrial loads. Nowadays, every rooftop solar installation can produce harmonics back-feeding into the grid. Every electric vehicle plug in could have an AC to DC conversion that creates harmonics back-feeding. So now there are elements at the consumption side that back-feed. It's literally biting the hand that feeds you. The grid is feeding you and the hand is being bitten by these types of load.

AR I don't know if it's true in Carolinas, but in most states, they don't have a choice as to whether they take that dirty power. They have to take it.

CN Well, they have to take it. But also, if you think about it, historically in the utility business, if a large industrial customer or even a real estate developer was going to build a plant or install a development, they would come to the utility and say, hey, I'm getting ready to build out this load. Here's the profile of the load so that the utility could build infrastructure to support it. When you buy an electric vehicle, do you call the utility and register it? No, you just buy it. You just install it. The local utility doesn't know you did it. So they see this as unplanned load. It's not planned, and it's not insignificant, because there are often groups of EVs in certain neighborhoods or certain areas. So now they're seeing this unplanned load that has other harmful attributes and they have to not just supply power for it, but they have to withstand it, and so they're flying blind.

AR Now we're going to talk about solutions. You just introduced enough problems that I want to be out of the utility industry. There's too much going on, right? There's a lot of older people in the industry saying I'm done with all this, I'm retiring. And you got a lot of younger people coming in that have to manage all of this. They don't have legacy knowledge. I wrote an article one time and I said it's like the wild, wild west. And I got really attacked for it. They said no, it's all planned out. Talk about Ubicquia and what it is that you are bringing to solve some of the problems at the grid edge.

CN Let's go back to smart meters. Back in the day, all the smart meters communicated on bespoke networks; RF mesh networks, licensed spectrum networks. You had to build a network just to communicate with your devices. And the cost and the maintenance of these networks was expensive for utilities. Today we have the ubiquitous LTE networks. If you have a cell phone in your pocket, you use an LTE network connection today, you depend on it. They're robust, they have low latency. Why not use them? They're cost effective. I think utilities are realizing, *I still need the devices at the edge, but do I need to build a network to bring the data back?* Because every single point solution has its own point network. Now utilities are maintaining eight networks. Makes no sense. So even for smart meters, they're looking at maybe using LTE. Ubicquia leverages the existing LTE networks that the carriers support, e.g., ATT and T Mobile and Verizon, but also private LTE networks.

Many utilities are thinking, why don't I build a private LTE network? It's LTE-based, so it's standards based, but I own it. All my devices can operate and communicate on the one network. Ubicquia promotes the use of LTE, whether public or private. We tell utilities, don't build another bespoke network. Don't place these devices on your existing AMI networks because they're slow.

They're not built for it. They're built for meter reading. But there are other options. Use the existing LTE networks. They're fast, they're pervasive, they have low-latency. They can handle lots of data. They're cost effective. That's the core piece of information about Ubicquia – we leverage LTE networks that are already in place. And the second thing is, we wrap solutions around LTE networks for the grid operations, monitoring assets in the grid, at the edge, in between. But we use LTE to bring that data back.

AR A lot of it you mentioned earlier, substation to meter. You're talking about everything in between now, which we typically didn't monitor.

CN No, we don't. If you think about it, there is a finite number of devices that utilities can control and monitor. Capacitor banks, voltage taps, regulators, et cetera. But those are just a small portion of all the grid connections and devices between the substation and the meter. If you had to pick one spot to claim as 'king of the hill', that I will measure from this point, what would you choose? You would choose the transformer. Every single meter must be fed by a transformer, a distribution transformer.

AR I have to tell you, I'm a transformer guy, right? I believe the transformer is the heart of the system. And I'm a reliability guy, so the reliability of transformers okay, you're speaking my language.

CN You start at the transformer, whether it's a pole mount, pad mount, single phase, or a three phase. Because every meter, every customer is served by a transformer in some way or fashion. So you start there, because the transformer, I mentioned, it's 'king of the hill'. The transformer looks down into the load. It sees EV plug in loads. It sees rooftop solar loads. It sees the nature of the load. It sees harmonics. It also looks upstream. It's fed by the primary voltages. It sees issues on the primary side. Therefore, it's kind of uniquely positioned. And so, we focus on monitoring the grid at the transformer. It's a three-legged stool: What's the true condition of that transformer? What's the nature of the load it's serving? What's the nature of the primary voltages that feed it? It's looking upstream, downstream, and then at the asset itself.

AR That's brilliant. Most people in utilities would say, yeah, but those are run to failure. We just let them pop, and who cares? Make a case for why they should care. What is the value of me suddenly going from RTF - run to failure - to really monitoring all those assets?

CN Have you checked the lead time for transformers lately? We have this global issue called 'supply chain'. And it's getting worse. Can you really afford to wait till it fails to order a new one? Do you have one on hand or is it 15 months out? The second thing is, if you have important critical load customers, do you really want to put them in the dark? Do you really want to interrupt their processes, their commercial opportunities for a day or two while you roll trucks out there? Is that really good customer stewardship? The third thing is, you mentioned earlier that smart meters now tell the utility when there's an outage, it's not waiting for the call to

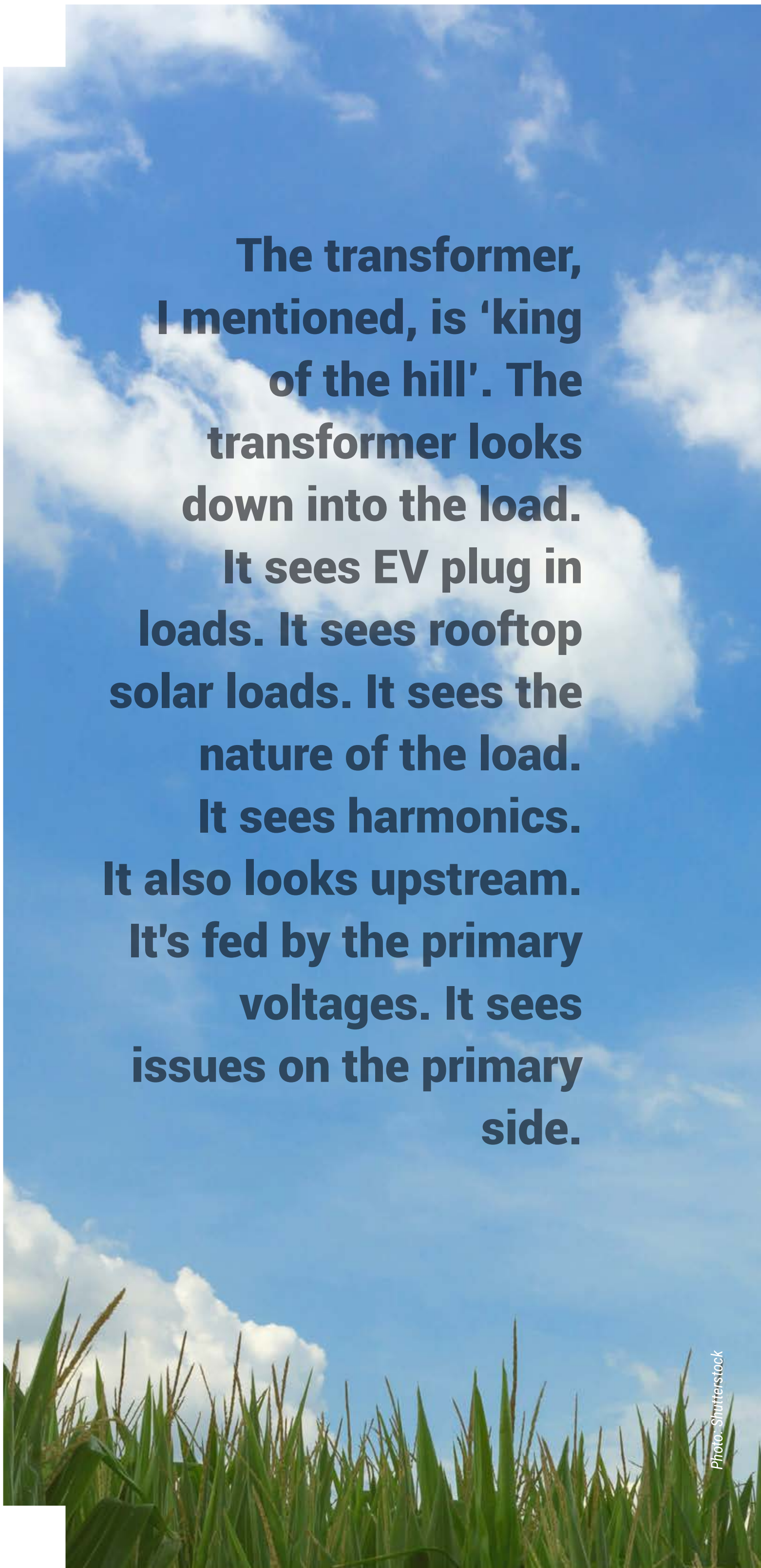
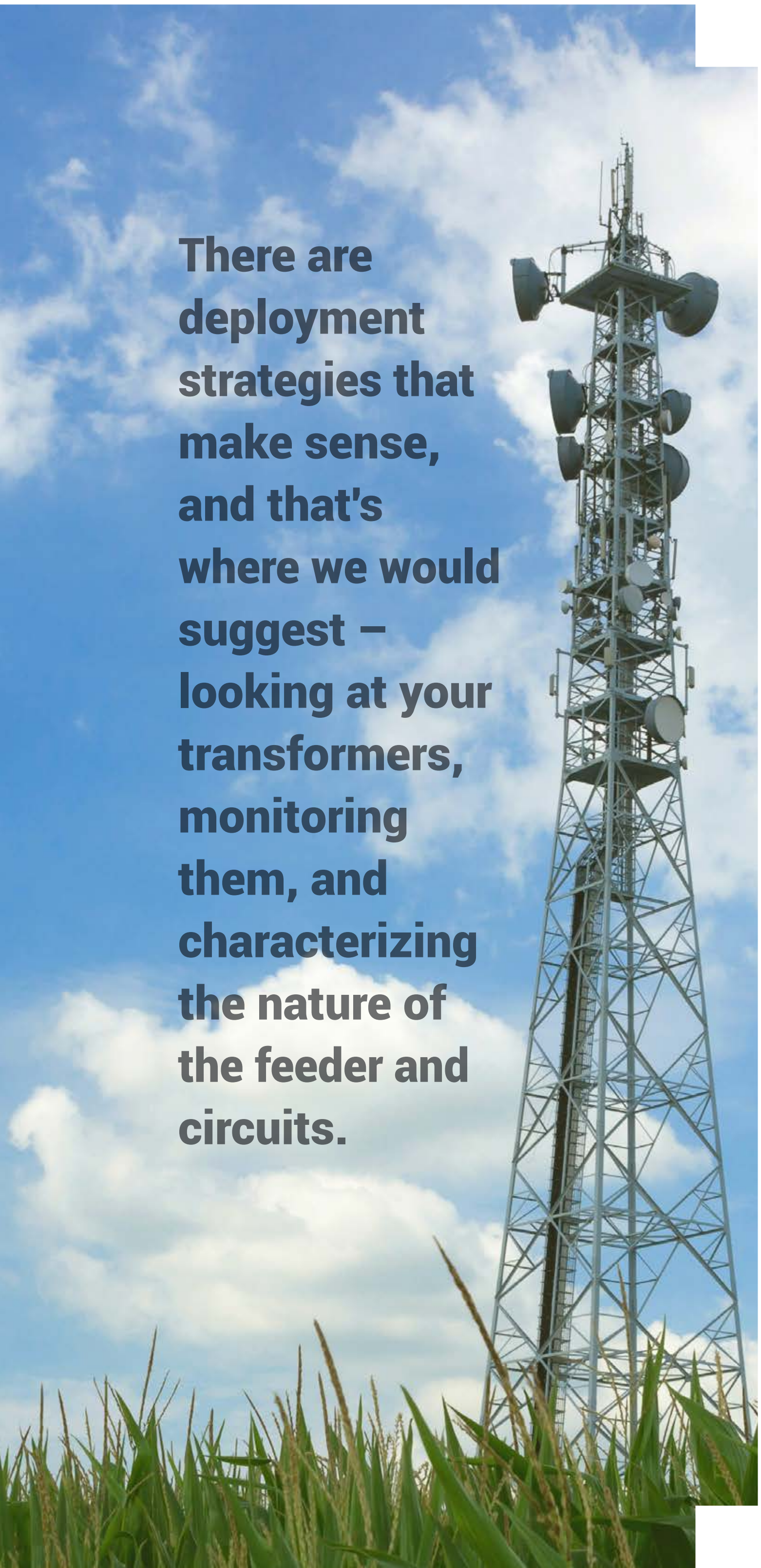


Photo: Shutterstock

come in. Do you really want a call to come in? Because a transformer issue is a meter issue. It is a customer issue. They will call in, or the meters will say, I'm out. But where is the failure point, is it further upstream? A lot of time is spent by utilities driving around trying to figure out where the fault is.

Do you want to spend a lot of time saying, *let's start at the meter, let's work way back to the transformer. Oh, it looks good from here. I can't tell anything wrong with it. Is the issue further upstream? Let's re-energize it (the transformer). It blows. Okay, now let's replace it.* How many truck rolls have you just spent? The bane of utilities is O&M expense. Wouldn't you rather know - "I've got a transformer that's in distress". It's going to fail. Let's get one ready to replace it. Let's take an outage on a blue-sky day when I can replace it. Or one just failed, I know exactly what happened with it. It can't be repaired in the field. It must be replaced. Here's the size it was. Maybe it was undersized. Just replace it in this one truck roll; one stop resolution. So it really impacts safety, customer satisfaction, and grid resiliency. Sometimes you need to change the failed transformer to a different transformer. If you remember, back to the EV load discussion, what if you found out that, because of unplanned EV load, the transformer is over utilized? You don't replace it with what was there originally. Replace it with the next size up.



There are deployment strategies that make sense, and that's where we would suggest – looking at your transformers, monitoring them, and characterizing the nature of the feeder and circuits.

AR Well, that's brilliant. I know you can do dissolved gas analysis (DGA) in an oil-filled transformer. Pretty expensive.

CN That's substation magic. You can't afford to do that *en masse*. The trick in the distribution grid is scalability and cost effectiveness. There are literally millions of transformers and you don't necessarily need to monitor them all, but maybe transformers at the head end of the feeder, maybe transformers at a midpoint, at the end of a circuit, where you go from overhead to underground service, etc. There are certain locations, certain deployment strategies that make a lot of sense. Take problematic feeders, for example, where you have voltage issues and want to know why, what's causing the issue. There are deployment strategies that make sense, and that's where we would suggest - looking at your transformers, monitoring them, and characterizing the nature of the feeder and circuits.

AR What data are you getting? What are you monitoring?

CN We're monitoring secondary voltages and currents, primary currents, oil pressure, oil temperature, and tilt/impact of the unit, which is important for pole mounted transformers. If you had to assess the true condition of a transformer, that's what you would measure. Electricals, mechanicals, oil pressure, oil temperature. You don't need to use dissolved gas analysis, but oil pressure and oil temperature, measured within the context of true delivered power tell you a lot about the condition of the transformer.

AR That's excellent. You know what? It ought to be ubiquitous.

CN I love that, you sold me.

In the last interview in Power System Technology 26 - "Green Energy" from February this year we mentioned that we know a lot about the FR3 Ester and its behavior in the field. We have shown some of the most important parameters and how they evolve over the years in a real everyday world of power transformers.

Let's dig a little deeper into the data we have and see how it compares to the known behavior of the mineral oil insulating fluids, which includes the GTL insulating fluids. In issue 24 of the Transformer Technology Magazine from December last year, we presented the dependencies of the mineral oil parameters in Figure 2. More on this topic can be found in IEEE Papers [1,2 and 3].

Taking a look at the FR3 data, first the data for the 'young' transformers, means less than 20 years of operation (<20). The best tool for this is the Multivariable Analysis [4], it is one of the main statistical methods used in studies with multiple inputs. We will try to provide a brief and comprehensive overview of multivariable analysis and present some of the core models that statisticians use to analyze experimental data.

One of the difficulties inherent in multivariate statistics is the problem of visualizing data that has many variables (in our environment here including age, acidity, temperature, water content, breakdown voltage, etc.) For example, a function chart showing a graph of the relationship between many of the FR3 variables is "Fig. 1".

Multivariable Analysis

Field behavior of Natural Esters

FR3 a Cargill brand

Passerro

The best tool for this is the Multivariable Analysis [4], it is one of the main statistical methods used in studies with multiple inputs.

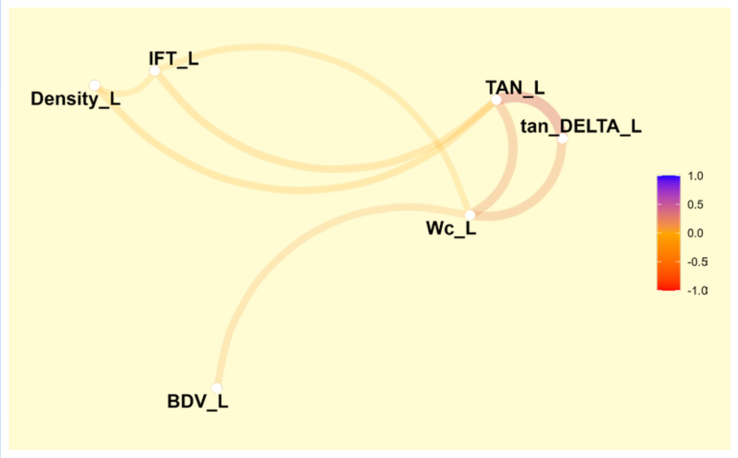


Figure 1. Function chart graph of the relationship between many of the oil's variables. The color bar shows the correlation coefficient between all the variables

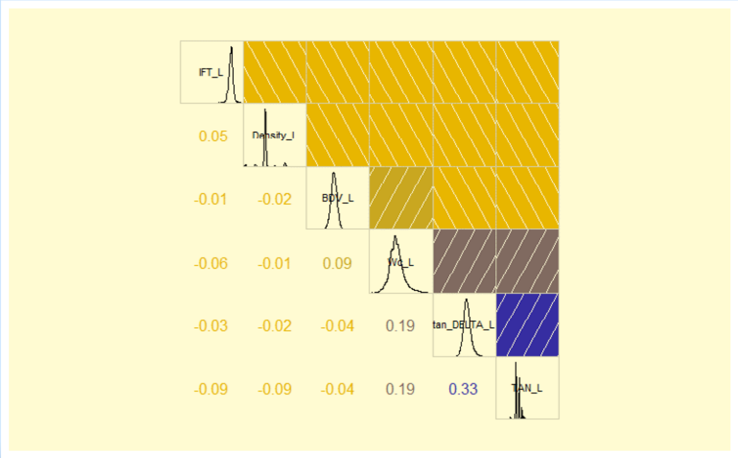


Figure 2. Partial correlation between all variables is displayed numerically and as a color filed. The distribution function of individual variables is also shown - it is a different view on the same variables shown in function chart Fig.1

When we apply the same analysis to 'older' transformers, that is older than 20 years, the parameters correlate as follows:

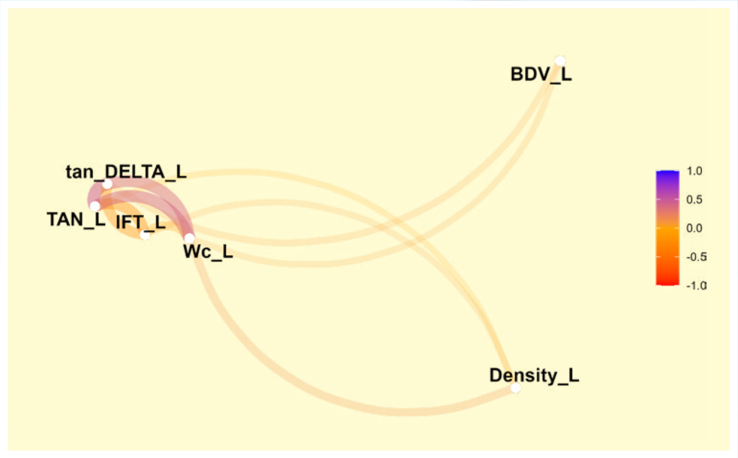


Figure 3.
Function chart graph of the relationship between many of the oil's variables in older than 20 years transformers.

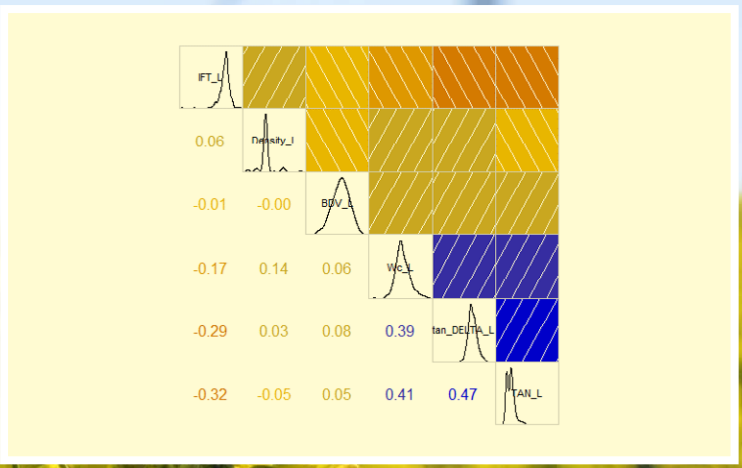


Figure 4.
Partial correlation between all variables for the >20 years old transformers – analog to Fig.2

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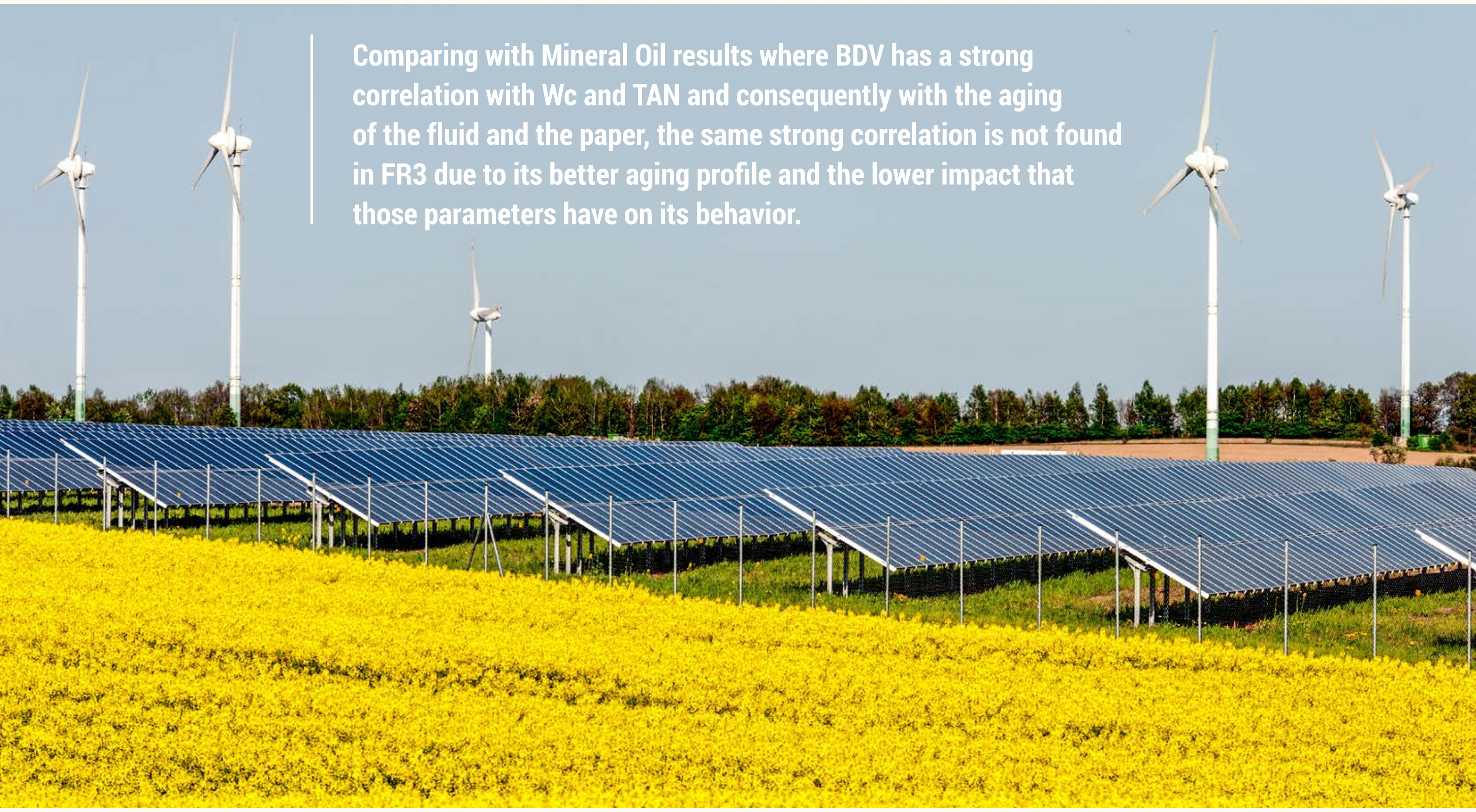
In datasets with many variables, groups of variables often move together, but as we can see the FR3 esters do not have a dominant variable. Comparing with Mineral Oil results where BDV has a strong correlation with Wc and TAN and consequently with the aging of the fluid and the paper, the same strong correlation is not found in FR3 due to its better aging profile and the lower impact that those parameters have on its behavior. This can be seen very clearly in the correlation matrix. It shows the well-known dependence of TAN, tan_Delta, IFT and Wc (water) in all types of oils. While in FR3, the BDV seems to be very independent of other parameters, which is an excellent performance.



Comparing with Mineral Oil results where BDV has a strong correlation with Wc and TAN and consequently with the aging of the fluid and the paper, the same strong correlation is not found in FR3 due to its better aging profile and the lower impact that those parameters have on its behavior.

As you will see in Figure 5 and especially in Figure 6, there we plot the behavior of BDV as a function of TAN vs. Wc. Even in cases where the maintenance limits of Wc and TAN have been reached, their impact on the BDV is not significant, even showing an increase under certain combinations.

Are conventional transformers basically "ester-compatible"?

Thanks to natural ester, it is possible to load transformers in a much more varied manner or to run them at higher operating temperatures without being exposed to the risk of a transformer fire and without jeopardizing the lifespan of the units. With a few exceptions, these are transformers with a mixed insulation made of a dielectric liquid and an impregnated solid material. The solid takes over the mechanical load-bearing properties and the liquid acts not only as an insulation in coordination with the previous but also as a cooling medium. The dielectric insulating liquid is used to cool the windings, insulate the individual winding packages from one another and thus achieve optimum heat transmission performance in the smallest of spaces. In the course of changing the insulating oil, not only the properties of the insulation change, but also those of the cooling.

Thanks to natural ester, it is possible to load transformers in a much more varied manner or to run them at higher operating temperatures without being exposed to the risk of a transformer fire and without jeopardizing the lifespan of the units.

In transformers with forced fluid cooling its flow is defined by the operating point of the pumps, so it can be adjusted to natural esters properties. But in natural flow, due to the higher viscosity of ester fluids compared to mineral oil, the flow of ester fluids through the windings, core and cooling equipment is lower than that of mineral oil. This may lead to a relative increase in the upper oil, winding and core temperature. Unlike mineral oil, heat capacity increases with temperature reducing the differences between both fluids at higher temperatures.

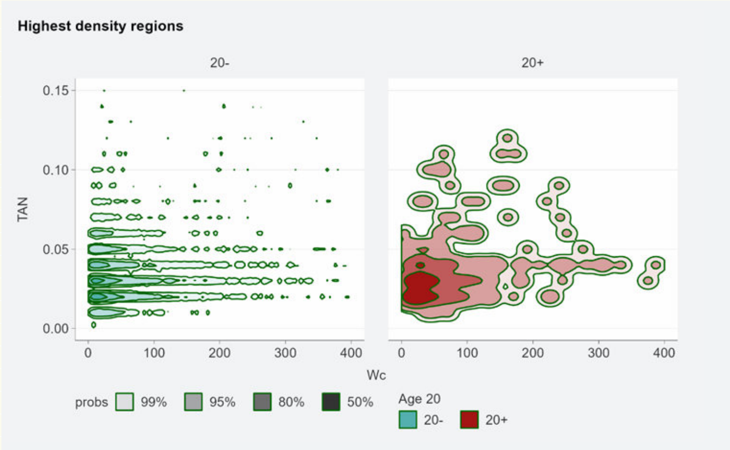


Figure 5.
Depicts the development of TAN vs. Wc dependency in transformers in two age groups <= 20 and older > 20 years

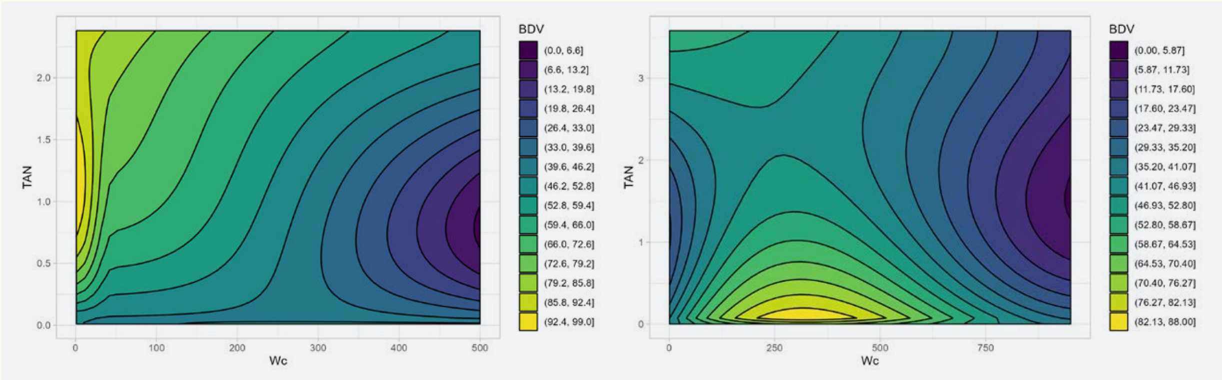


Figure 6.
shows the development of BDV as a function of TAN and Wc in young and old transformers. On the left the younger group <= 20 and on the right the older group > 20 years – The BDV values correspond to the IEC 60156 standard.

These better thermal properties can only compensate to some extent for the negative effects that occur due to the higher viscosity of ester. However, one additional benefit regarding cooling is the higher thermal class of the solid material immersed in natural ester compared with mineral oil, allowing the transformer to operate at higher temperatures [5]. This additional gap usually surpasses the negative viscosity effect as is has been shown on thousand "retrofilled" units.

When a transformer is designed and the enhanced properties of the insulation system formed by cellulosic material and natural ester are explored, allowing higher temperature rise limits, the cooling ducts may be reduced or some of them may be removed, saving resources and reducing the total weight.

The dielectric constants of ester fluids are typically higher than mineral oil and closer to the dielectric constant of pressboard and insulating paper. Changing the insulating liquid therefore leads to less inequality in the stress distribution between solid and liquid than with mineral oil and pressboard. Except for highly inhomogeneous field distribution, the results of breakdown voltage of natural ester and mineral oil, for AC, lightning impulse (negative and positive polarity), switching impulse (negative and positive polarity), chopped wave, both in oil gap and creep indicate a very high level of equivalency between the fluids [6]. Additionally, the test results clearly indicate a higher value of PD inception voltage for natural ester liquid [7]. A different dielectric optimization or an increased safety margin when design criteria from mineral oil are applied for a "partial discharge free" transformer can be obtained.

As previously mentioned, one of the most important and fascinating findings from this analysis was the BDV in FR3 fluid increases systematically over the years of use. The fact, that the water content is controlled by the hydrolysis reaction with ester molecules and the resulting acids are soluble, mild and non-corrosive results in a slight but significant, approx. 1.5 kV/year, increase in BDV over time. FR3 seems to age just as well as fine wine!

One of the most important and fascinating findings from this analysis was the BDV in FR3 fluid increases systematically over the years of use.

As mentioned in one of Mr. Sinatra's songs, "It Was a Very Good Year," FR3's DNA is undeniably found in Cargill's high quality food and beverage production. This high standard makes even an insulating oil - "as vintage wine, from fine old kegs, from the brim to the dregs".

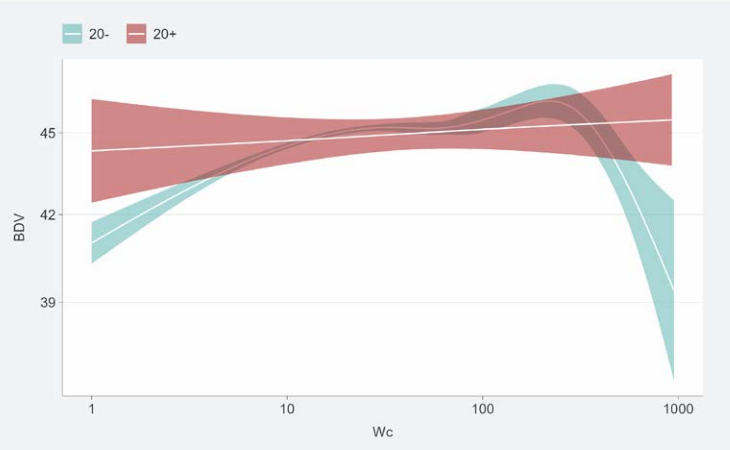


Figure 7.
shows the development of BDV as a function of Wc in young and old transformers.

These habits of the FR3 towards water are well illustrated in Figure 7, where excellent water behavior of the "older" oil can be observed. Taking a look to the rest of parameters analyzed, we see that no correlations are found, despite the weak connection between water content, dissipation factor and breakdown voltage. The interfacial tension can be used to detect soluble polar contaminants and products of degradation qualitatively but very sensitively. The level of interfacial tension influences the decision as to whether transformer oil should be regenerated or replaced.

The degradation byproducts were also measured (Fig 1,2,3 and 4) for natural esters. Results show that interfacial tension is generally lower than with conventional mineral oil due to the higher polarity and the associated interaction with water. It also makes it less relevant to address transformer degradation by itself. Next interesting issue is the pour point. The pour point, is the point at which the oil just barely flows. One also speaks of cold flowability (media flow at temperatures below -30°C; -22°F). This is important for the starting behavior at low temperatures. The main concern for mineral oil at low temperatures is its inability to handle dissolved water. Free water can appear and create a discharge path leading to a failure. This problem is solved with Cold Start Procedures that slowly heat the unit avoiding this issue. This is not a concern for natural esters due to their higher moisture tolerance. But same cold startup procedures that are used for power transformers filled with mineral oil can be used when they are filled with natural ester fluid to deal with its higher viscosity at lower temperatures [8].

As a summary, vegetable oils are highly biodegradable (> 98%), less toxic, less flammable and have an extraordinarily high fire points (> 350 °C) when compared with mineral oil. Furthermore, they not only can increase the lifespan of the units or increase the rating power with the same size but also show a very robust long-term behavior. The moisture and acid contents, typical weak spot for mineral oil, show a low impact on the breakdown voltage of FR3 and in the overall performance of the units.

As you can see from the data, in addition to the standard DGA of hydrogen and carbon monoxide, the parameters IFT, viscosity and tan_delta seem to be of great importance for monitoring natural ester transformers. Cargill and Passerro have been working together on such an ester sensor for a long time and are now looking for interested customers for a pilot project starting in autumn 2023. Please contact Roberto Fernandez (roberto_fernandez@cargill.com) or Miroslaw Wrobel (miroslaw.wrobel@passerro.de) in this regard.

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Miroslaw Ch. Wrobel received the M.Sc. degree in applied physics from Silesian University of Technology, Gliwice, Poland, in 1993. He received his Ph.D. degree from the Institute of Fundamental Technological Research, Polish Academy of Sciences Warsaw, Poland. He pursued his Ph.D. research in the area of medical physics focusing on molecular acoustics. He worked on non-invasive medical diagnostic and imaging techniques as a visiting fellow at the Defence R&D Canada, Toronto (previously known as DCIEM) of the Canadian National Defence. Since 2005, parallel to his medical research, he has been working on the application of acoustic and optical sensing method in high-voltage technology. He holds several patents in the field of medical diagnostics and monitoring of industrial plants.

Roberto Fernández the Technical Leader Cargill BioIndustrial-Power Systems. He is an experienced Electrical Engineer who has spent most of his career on the transformer design field and R&D activities focused on the magneto-electric and thermal design for a wide range of transformer applications. He is member of CIGRE and contributes to several IEC maintenance teams. Currently working as Technical Leader for European region at Cargill Bioindustrial.

As a summary, vegetable oils are highly biodegradable (> 98%), less toxic, less flammable and have an extraordinarily high fire points (> 350 °C) when compared with mineral oil. Furthermore, they not only can increase the lifespan of the units or increase the rating power with the same size but also show a very robust long-term behavior.

Mike Hoppe

> Our company offers solutions for distribution automation, protection and control. We're looking at new technologies, for example, centralized, or even better, virtualized substation protection and control.

U.S. Product Marketing Director at ABB

Interview with **Mike Hoppe**

Photo: ABB

Alan Ross: Hi. I'm Alan Ross. I'm the managing editor of APC Technologies. We are at the IEEE PES Grid Edge conference, and my next guest is Michael Hoppe. Mike, thank you for joining us.

You're with ABB. Tell me what your role is at ABB.

Mike Hoppe: I'm U.S. Product Marketing Director for our digital portfolio focused on our electrification products and solutions.

AR I've asked everybody to define grid edge. I've got nine different answers so far. Give me number ten.

MH Number ten, sure. What is the grid edge? The grid edge, to me and considering our focus with our electrification products portfolio, is really looking at where the grid meets consumers. That could be a commercial building, it could be a residential building, and the proximity of that commercial building or residence to the grid. What is happening now, with all the huge changes coming, is the need for electrification, either driven through government policy, or simply things like EV growth, EV charging growth, and the need for energy. Those things are driving a difference in how we approach that edge or what it means. It might be technology in terms of digital hardware, equipment, switchgear as an example, or the software that's making that change. Then, new technologies employing the cloud as an example, predictive analytics, artificial intelligence, and really looking at that as a way to automate our grid. The grid edge to me is really where that traditional grid interacts with consumers, whether it's residential, commercial or industrial.

Photo: AdobeStock

AR When you put in DER, wind and solar and storage, they're now the grid edge, but they're not consumers. They are delivered. Well, maybe battery storage is a consumer and a supplier. It's a much more complicated grid edge. I think it's like the wild west, right?

MH Yeah, I would agree. Those are some of the changes that ten years ago we couldn't predict, we were seeing growth. But now there's a step change. In terms of the microgrid itself, that's absolutely a part of it. Our job is to figure out how to distribute the energy from those new renewable sources. How do we create energy storage if it's battery or some other methods like we're seeing here at IEEE and then getting that to those consumers, and then how do we get it to them safely and reliably and whether this is a resilient microgrid or some other solution?

AR Electrification of transportation is going to change everything because when you talk about fast charging stations, they're going to need something different. Then when you talk about at-home charging and solar on roofs, that's another grid edge change. That is, as you said, step change.

MH There are many complexities. First of all, if we look at the commercial side of things, you have fleet EVs, to school buses, one of the areas that is being talked about here at the conference, trucks, Amazon fleet delivery. Just look at a utility itself. They have fleets, right, that's driving massive energy usage going back to the utility. The production of energy, how do we generate it, how do we distribute that and through to the grid edge? Then you look at the home and I think that's where the lines of grid

edge are being blurred, whether it's multifamily or private, separated, or detached homes, you're looking at new technologies, smart panels, load centers, and the reason is that we have to manage that energy distribution effectively with the growth in EVs. There might be more than one EV in a garage today. California is a good example. But as we see that across the country, not every home or house has a standard electrical panel that can handle the voltage or the standard service necessary for it. We're going to see a lot of changes that are going to drive changes in labor skills - how you install it and then effectively manage it.

AR When ABB looks at it, when you all look at the future, you look at challenges, because otherwise, you don't have a company if you don't have solutions. Talk a little bit about the challenges that the new grid edge, as you've just defined it, is going to create.

MH I think some of the challenges include the complexity of the new technologies. How do we simplify that for facility operators? Maybe it's the utility or perhaps it's an industrial manufacturing facility that is requiring a microgrid, as an example. Typically, that's been used for back-up power. Now we're seeing a new need, which is sustainable power. And part of that is caused by the challenges resulting from climate change – natural disasters that could create blackouts or brownouts. How do we maintain a sustainable, reliable energy flow? You look at microgrids as a potential, and then what do you put into that microgrid is, as you mentioned, the various renewables, such as solar, wind, and then that energy is stored for use when it's most needed in the example of a manufacturing plant. All of that requires systems control, and systems protection, if we can automate that. Our company offers solutions for distribution automation, protection and control. We're looking at new technologies, for example, centralized, or even better, virtualized substation protection and control. So, you take a typical relay and multiply by dozens of virtual relays in a server and now you use a software-based substation protection and control.

Cybersecurity of course is another challenge. We need to think about safety and security. I think the work force is absolutely a critical element. It's posing a challenge today as you have knowledge that may have previously existed around an aging infrastructure. That knowledge is still required. But then you have a need for

Then you look at the home and I think that's where the lines of grid edge are being blurred, whether it's multifamily or private, separated, or detached homes, you're looking at new technologies, smart panels, load centers, and the reason is that we have to manage that energy distribution effectively with the growth in EVs.

Photo: Shutterstock

Our company offers solutions for distribution automation, protection and control. We're looking at new technologies, for example, centralized, or even better, virtualized substation protection and control.

new skills, you have a need for people and certainly a workforce that not only can manage the number of incidents or prevent incidents in your infrastructure, but also has skills and ability to do that. And I think with the new technologies we're talking about, some of the new controls or systems that require different training, that's something we have to consider, but then there's also maintaining a workforce. In other words, keeping the labor on the team and thinking about the culture that we've instilled in the people, whether it's at the manufacturer or a utility or other parts of the industry. I think that's going to be a vital part of maintaining the infrastructure as we both have to grow to enable this massive energy growth and demand that's coming our way, but then also maintain it, so that if there's a fault, we're going to make sure that it can be fixed appropriately.

We understand there's a shortage of skilled people. How do you enable them to be more effective at their jobs with tools that are safe? Maybe that's installation and commissioning, using a new technology like a mobile app and augmented reality. These are all things that are being explored and or used today. But I do think that certainly people are the most important part of that solution and we have to focus on what we can do to enable them rather than displace them.

AR Especially given labor shortages, legacy knowledge leaving, that's a problem. New knowledge coming in, new technology, all of these things. If you look at it, it looks like a huge problem. If you look at it another way, you say what an opportunity, what a time to be alive. It has never been as exciting to be in the utility industry as it is now.

Most engineers don't want to be in utility. That's the old dirty thing, right? Not so anymore. And we're changing the world. The next generation likes to think they're doing something that matters.

ABB is a global company. Obviously, you're seeing things from a different perspective than maybe a North American or a European or somebody from the APAC region. Talk a little bit about your specific role because your responsibility is North America, right?

MH That's correct. The U.S., specifically.

AR U.S. Specifically. But you must interface with people around the world. Is anybody ahead of us or are we just like catching what have we learned from other people?

MH I think it's more of differences in different regions of the world. There are some areas, for example, Europe, I mentioned the augmented reality or what we call AR, perhaps using a mobile app that is being used in service industries at the utility or at industrials and manufacturing where the technicians are actually using that. Here in the U.S. we're testing it. But it’s a very new technology to bring to the traditional service organizations here. So again, it goes back to our workforce and we see differences in workforce amongst the different regions and acceptance of some of the new technologies that we roll out. I think one thing that's common around the globe is the huge increase in energy demand, the growth in EV, certainly climate change and what we're seeing in terms of some of the effects of climate change on the existing grid and where we need to continue to build resiliency in it. If we're offering new technologies, they have to be robust, they have to be resilient. And we really should consider redundancy, something that we talk about in the data center industry. We really need to be talking about that, I think, in our utility industry as well.

I think one thing that's common around the globe is the huge increase in energy demand, the growth in EV, certainly climate change and what we're seeing in terms of some of the effects of climate change on the existing grid and where we need to continue to build resiliency in it.

AR I'm a reliability person, okay? So power industry, but reliability. And one of the safest ways to work with especially younger, newer, non-legacy people is give them a tool that, when they're looking at the piece of equipment they are not allowed to touch, informs them not to touch that. There was a demo with a big red sign that says Danger. I thought that was absolutely brilliant, because it didn't show up on the machine, but on the augmented reality of the machine.

Let's switch gears a little bit, because obviously you're in charge of a division that has got a solution for some of, if not all. Give me the basics on what ABB in your division brings to the marketplace.

MH We do a lot of work in the distribution of energy through our equipment that could be switchgear, protection relays, and then, most recently, centralized or virtualized substation protection and control that fits squarely in the utility business.
If we talk about the grid edge and where we see some of those blurring lines both with commercial buildings or residences, we also play in those areas as well with our electrical equipment. Breaker panels, certainly circuit breakers and low-voltage building entrance switches. We have an e-mobility division focused squarely on EV charging - fleet charging, high-capacity chargers, and fast chargers. Last but not least, it's offering solutions in terms of controls and protection, including the software systems that we use to integrate all of that equipment.

AR Software, grid edge, substation, you're covering a lot here. But one of the things you said that really fascinates me - the virtual part of it. Help me understand how you create a virtual substation or a virtual relay.

Photo: AdobeStock

MH It involves taking the protection that a relay provides and other additional value that's in that device and moving from an analog to a digital device. Everybody's doing that in the industry today. But then we need to move beyond just that single relay. We look at how many relays might be needed in a single substation and we can put all of that in a server. Virtualization is the next step. Data centers have been doing this for decades. They basically take that box, the server or the computer, and they divide it up, similar to a partition on a hard drive. And you can imagine many or dozens of relays. They're software-based and that's in that single box. If you can imagine taking a step further and moving all of that data and information to the cloud, cloud being first of all protected through cybersecurity. We take that very seriously.

The benefit of predictive analytics then is, as you look at the equipment or the microgrid footprint, you can do several things. You could automate it; you could automate the monitoring alerts. But you can control that from the cloud, the algorithms or the AI, perhaps.

But what can you do in the cloud? What it really means is then you can add some level of prediction or predictive analytics. The cloud is where you're going to do all the calculations, the algorithms for creating the predictive analytics.

The benefit of predictive analytics then is, as you look at the equipment or the microgrid footprint, you can do several things. You could automate it; you could automate the monitoring alerts. But you can control that from the cloud, the algorithms or the AI, perhaps. This is a tool that should be used by humans, again, not completely displacing them. And the benefits are such that you can more effectively manage any of the physical devices that are there. In other words, if one of those devices might fail, you're going to have an idea of when that failure is going to occur, what the failure is going to be, and what to do to fix it. The benefits of not having to roll a truck, so diverting your workforce to be more efficient, there's a capital cost to that - how many trucks you have, the operating costs around oil, fuel, all of that. You can bring those costs down, as well as the cost of overall maintenance on the equipment, and do it when it's needed, even beyond just a typical scheduled maintenance.

AR So it is taking data that shows the condition of assets and what's happening to those assets, whether it's load, whether it's anything else, and using predictive analytics to say, look, you're going to have a problem here and that's where you need to address your truck rolls or your maintenance or whatever you do, that's your division.

MH It's part of what we do. We use predictive analytics today in some of our solutions and we're looking at that for the future of the grid edge.

AR There is not going to be a simple solution at the Grid Edge. And I really appreciate the fact that you're looking at a lot of different applications, whether that's EV charging, fleet, whatever it is. There's a lot of different applications because the same tool that you look at when you look at a substation is basically the same type of technology tool. You've got a great career ahead of you.
Mike, I appreciate it so much. Thank you for joining me.

MH My pleasure.

The Journey to Cable System

Remaining Useful Life and Predictive Maintenance

INTRODUCTION

The health of an underground cable system can often be traced back to its early life. In fact, over 90 percent of cable failures are associated with defects and anomalies that existed at the time of installation. Cable system components are highly engineered and are subject to significant quality control standards during manufacturing; however, after shipping and installation, about 40 percent of cable systems no longer meet those quality control standards. Properly commissioning a cable system in accordance with standardized partial discharge (PD) test specifications ensures that its components are free from significant factory defects and installation errors and will operate reliably for decades to come [1]. If defects and anomalies are addressed before a system is energized, grid operators realize increased system reliability, improved safety, and benefit financially; but not all cable systems have been properly commissioned, and proper commissioning does not guarantee that extreme transients, digging, or sabotage, for example, will not cause damage in the future.

Cable system components are highly engineered and are subject to significant quality control standards during manufacturing; however, after shipping and installation, about 40 percent of cable systems no longer meet those quality control standards.

Each year, millions of people and thousands of businesses are impacted by cable system failures, and the majority of these solid dielectric (SD) failures are associated with PD. All solid dielectric (i.e., plastic and rubber insulation) failures in underground cable systems are associated with PD, a phenomenon in which an electrical discharge does not completely bridge the insulating gap between two electrodes (conductors). But not every instance of PD poses an immediate threat to distribution systems, therefore the challenge to operators is to determine the severity of the PD, and to accurately estimate potential time to failure, or remaining useful life (RUL).

Detecting PD becomes more complicated once the cable is installed and then assembled with other cable system components. The only way to achieve a factory-comparable result in the field is to use a 50/60Hz excitation voltage, high-efficiency sensors, and advanced digital signal processing capable of achieving a measuring sensitivity of at least 5 picoCoulomb (pC) [1], as is the case with IMCORP's Factory-Grade® Technology. This allows identification of all potential PD signals for further determination regarding how far they deviate from the manufacturers' standards.

IMCORP™ Power Cable Reliability

AUTOMATION AND DEEP LEARNING

With approximately 20% of today's transmission and distribution cables defined as significantly aged underground assets, as well as the tremendous expansion of underground cabling in recent years, determining an accurate condition of these assets is vitally important. Accurate assessment of PD performance and the automation of signal interpretation has never been more necessary. For almost a decade, IMCORP has been developing machine learning algorithms and deep learning models to automate the detection and characterization of PD signals originating from defects in cable systems. Automated PD location and classification provide a time savings over human analysis by up to 500 percent in the analysis and interpretation of complex datasets. The automated process serves as a quality assurance tool that makes diagnostic procedures more consistent, allowing critical performance metrics to be reliably tracked.

With approximately 20% of today's transmission and distribution cables defined as significantly aged underground assets, as well as the tremendous expansion of underground cabling in recent years, determining an accurate condition of these assets is vitally important.

The key to deep learning is the size and quality of the database used to "train" the computer. The more meaningful information you have, the greater the accuracy with which the machine can learn to make predictions. The database IMCORP is using to train its computer to diagnose the condition of underground cable is massive: it comprises the "labels" (or answers) assigned by human analysts to characterize tens of millions of instances of PD defects in hundreds of thousands of shielded underground cable systems tested by IMCORP over our more than 20-year cable diagnostic history. This immense data warehouse, containing over 150 million digital signal waveforms and associated user determinations, is used for data exploration and data science work.

IMCORP utilizes this extensive database as sample data, enabling deep learning networks to identify and characterize signals by "partial discharge" or "nonpartial discharge," determine the approximate location of PD defect in the cable, and identify PD defect type with ever greater precision and accuracy. Already, the deep learning networks are providing results that rival the accuracy of the human analysts in finding and diagnosing defects in underground cable systems – to date, an accuracy rate of 97 percent. And reciprocally, the deep learning results have revealed that the human accuracy is also not at 100 percent; so, as the DL learns from the human data, the human process improves from the DL results.

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Photo: IMCORP

After applying the first AI tool to automate analysis, IMCORP set out to implement a proactive and predictive AI-based maintenance model for underground cable systems that provides visibility for future reliability and, ultimately, lower life cycle costs – a technology that costs less, takes less time, and is more accurate than training and using human analysts to analyze and interpret results from large data sets extracted from the field.

The new approach enables deep learning models to use the feature labels (features are numerical characteristics of PD signals) generated by analysts to autogenerate the best characteristics on which to base predictions. The model transforms PD signals originating from the same location within cable systems into images, called phase-resolved partial discharge (PRPD) plots. PRPD plots are composed of positively identified partial discharge events occurring from one specific defect location [2]. Figure 1 identifies a characteristic PRPD plot of the electrical-tree type. This second tool divides the PRPD plots into predetermined categories of risk ranging from higher-risk electrical tree types to very low risk, having no recognizable PRPD, and couples it with the defect's response to applied voltage level to create a condition-based triage for a cable system's health. Finally, operational environment data, such as loading, work history, overvoltage protection levels, and the statistical occurrence of transient overvoltage magnitudes, can be combined using a third AI tool into a risk factor that plays into the overall determination of RUL.

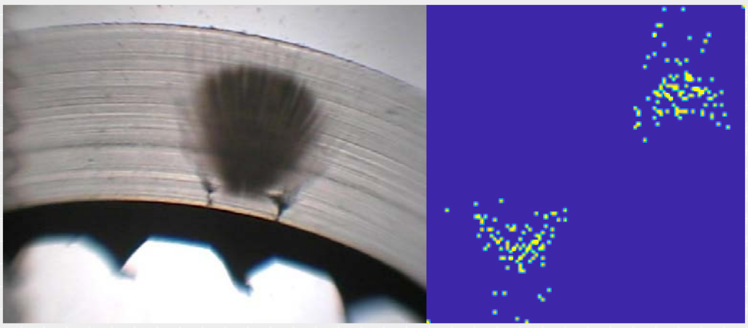

Figure 1.
Phase-Resolved Partial Discharge Pattern (PRPD) of electrical tree-type Defect.

REMAINING USEFUL LIFE (RUL) AND PREDICTIVE MAINTENANCE

To accommodate grid growth and modernization and the massive amount of asset and performance data while maintaining reliability, AI-based technology is necessary to effectively estimate RUL and drive optimized asset management and predictive maintenance decisions [2]. In the case of cable systems, RUL is the length of time a component is likely to operate reliably before it requires repair or replacement in order to avoid system failure. Knowing the RUL of cable system components provides the operator with the ability to accurately forecast when equipment will require repair or replacement, eliminating costly reactive O&M repairs, enabling the prioritization of critical repairs, and minimizing the probability of system failure and resulting impact to customers.

Multiple methods are used to calculate, or determine, RUL. The method used is determined by which types of data are available for input: lifetime data, run-to failure histories, or known threshold values. Lifetime data involves comparison to similar machines or components over the course of their operating life and evaluating the length of time it took for them to reach failure. Run-to-failure data is derived from similar components, or those with similar behavior, and can be used to estimate RUL using similarity methods. In the case of run-to-failure using similarity methods, covariates such as load or operating temperature, or other variables that may affect RUL, are also considered. Run-to-failure models estimate RUL by predicting when a condition indicator will cross the threshold. Last, threshold values are helpful when run-to-failure or lifetime data is not available. Threshold data evaluates component condition based on certain factors known to cause failure, such as temperature or pressure values which fall outside of recommend use ranges [3].

AI-based technology is necessary to effectively estimate RUL and drive optimized asset management and predictive maintenance decisions.

CASE STUDY

IMCORP employs similarity-based techniques in our predictive analytics, meaning a specific cable system defect with known severity will likely behave in a manner consistent with other, similar defects that have been historically detected and imaged [4]. In a recent utility case study, IMCORP was able to accurately reanalyze data from over 26,000 cable systems. The automated AI-based characterization and assignment of risk factors enabled the utility to reduce the number of repair actions by about 75% while maintaining a high level of reliability.

Predictive maintenance based on automated RUL calculations can decrease operating costs by reducing unnecessary maintenance, allowing maintenance to be scheduled when it is most needed, and minimizing the need for emergency repairs.

BENEFITS OF RUL CALCULATIONS AND PREDICTIVE MAINTENANCE

Predictive maintenance based on automated RUL calculations can decrease operating costs by reducing unnecessary maintenance, allowing maintenance to be scheduled when it is most needed, and minimizing the need for emergency repairs. This approach not only decimates capital expenditures (CAPEX), it also decimates future reactive operating expenses (OPEX) while improving reliability by over tenfold.

Additionally, minimizing unplanned downtime, or reactive work, by more than ten times, cable owners can greatly reduce accidents associated with site mobilizations, which often come with their own set of hazards, such as inclement weather, poor visibility, fatigue, rushing, and the potential of not having a proper Job Safety Assessment. As the OSHA Hierarchy of Hazard Control indicates, elimination of a hazard is the most effective method of risk reduction, and a planned outage is much safer than an emergency repair.

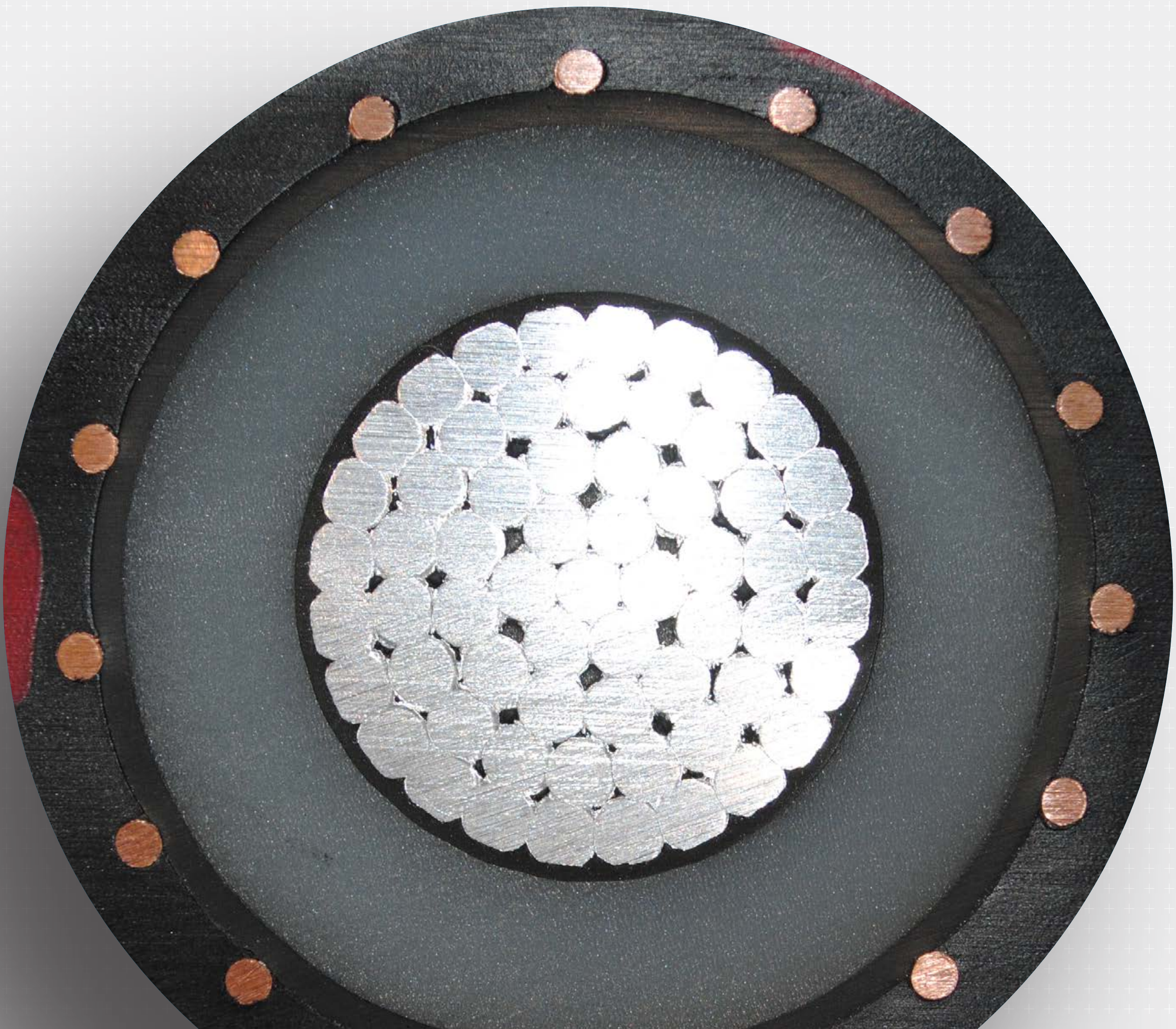

Photo: IMCORP

CONCLUSION

With only wholesale replacement or recurrent testing available to cable system operators, how are risks prioritized, budgets and financial forecasts established, and the safety and reliability of underground systems maintained? The answer is AI-based tools that make it possible to locate and rank system defects by severity, then predict faults before they occur through RUL estimation. Deep learning algorithms applied to IMCORP's immense Factory-Grade® PD test database, including hundreds of thousands of cable systems, has enabled the development of three new AI tools. These new tools simplify complex PD analysis and integrate both enhanced condition assessment and operational environment data. The results are up to a 500% increase in analysis efficiency and approximately 75% reduction in priority rehabilitation actions, while achieving ten times higher reliability, decimating O&M costs and operational safety events, and enabling a lean, just-in-time repair asset management approach.

Cited Items / Works

[1] Standards:

- IEEE 48 – Standard for Terminations rated 2.5 kV through 500 kV
- IEEE 404 – Standard for Cable Joints rated 2.5 kV to 500 kV
- IEEE 386 – Standard for Separable Insulated Connector rated 2.5 kV through 35 kV
- ICEA S-97/94-682/649 – Standard for MV Extruded Shielded Power Cables rated 5 through 46 kV
- ICEA S-108-720 – Standard for Extruded Insulation Power Cables rated above 46 through 500 KV AC
- IEC 60502-4 – Standard for cable accessories rated from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV)
- IEC 60502-2 – Standard for Power Cables rated from 6 kV (Um = 7,2 kV) up to 30 kV (Um = 36 kV)
- IEC 60840 – Standard for Power Cables with extruded insulation and their accessories for rated voltages above 30 kV (Um= 36 kV) up to 150 kV (Um = 170 kV)
- VDE 0278-629-1 – Standard for accessories on Power Cables with extruded insulation rated from 3,6/6(7,2) kV up to 20,8/36(42) kV
- VDE 0276-620 - Standard for MV Power Cables with extruded insulation rated from 3,6/6 (7,2) kV up to and including 20,8/36 (42) kV

[2] Ziegler, S., Shekhar, S. (2021). Using Machine Learning and Deep Learning for Characterizing Partial Discharge in Underground Utility Cables for Predictive Maintenance Application, CIGRE US National Committee 2021 Grid of the Future Symposium

[3] Baru, Aditya, Three Ways to Estimate Remaining Useful Life for Predictive Maintenance, Mathworks, 2018

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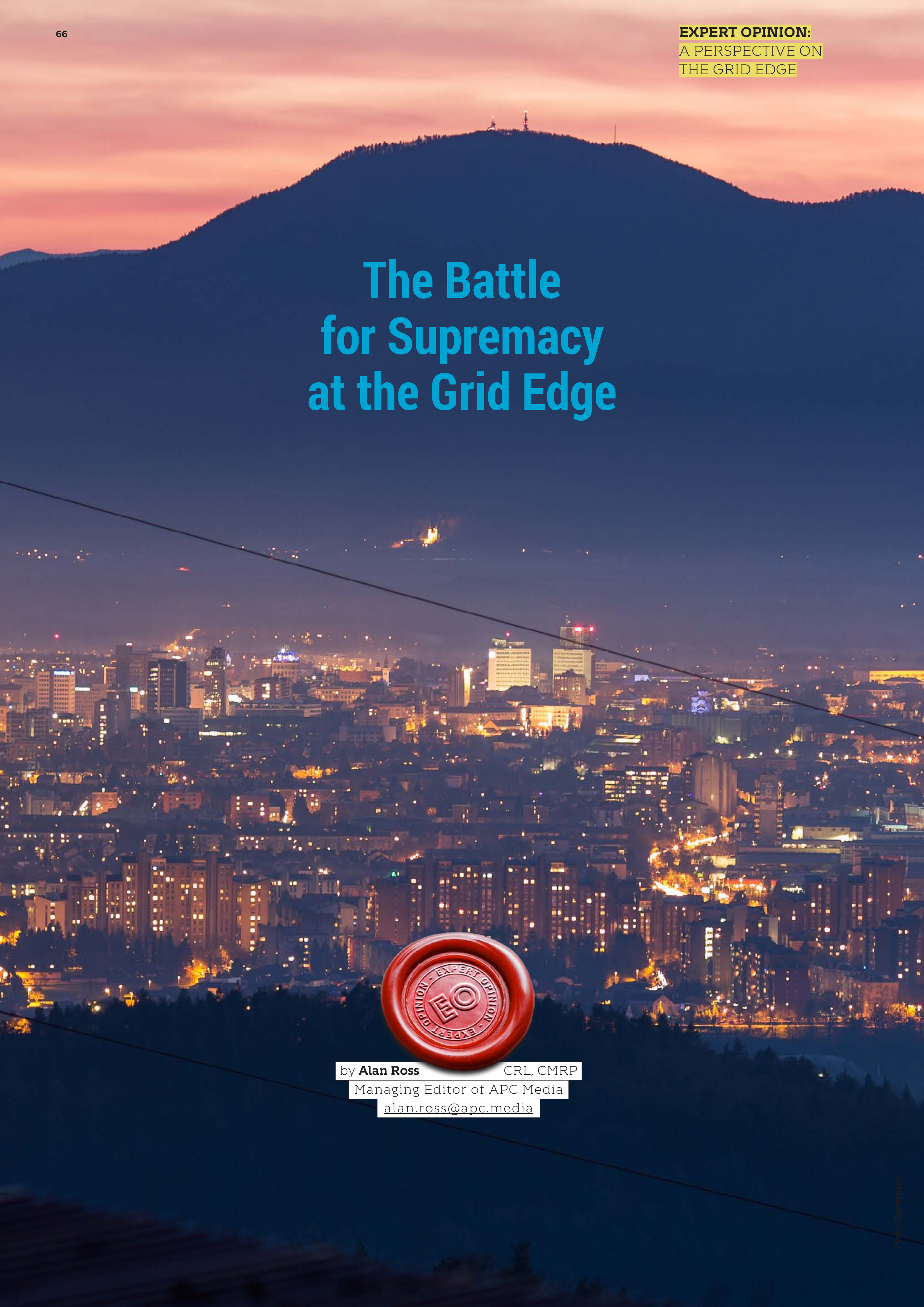
[6] Ziegler, Steffen, Morello, Tim, Ferraro Parmalee, Lisa, Deep Learning Characterization of PD Defects, An Important Step Toward Predictive Maintenance of Underground Cable Systems, Transformer Technology - Power Systems Technology, January 2023

Photo: IMCORP, Shutterstock

Steffen Ziegler holds a Master of Science degree in Electrical Engineering from the Karlsruhe Institute of Technology - Germany. Mr. Ziegler works for Eversource Energy as Lead Engineer in Advanced Forecasting and Modeling. His career began at IMCORP in 1999, where for over twenty years his positions included Director for Signal Analysis and Artificial Intelligence, and Manager for Research and Development. He has specialized in the field of digital signal processing applications and machine learning and deep learning applications for Underground Power Cable Systems.

Brenda Hite is a Strategic Communications Specialist for IMCORP. She is a technology evangelist who passionately supports industry electrification efforts through education about technical, financial, logistical, and societal benefits of using cutting edge diagnostics to increase power system resilience, reliability, and safety while lowering costs. Before joining IMCORP, Brenda was the Membership Engagement and Services Manager for EPRA (The Electric Power Reliability Alliance), where she supported a growing and collaborative community of commercial and industrial electric power safety and reliability practitioners. She began her career as a Project Manager in the environmental consulting industry.

Tim Morello is currently the Senior Vice President of Strategic Business Development at IMCORP where he is responsible for bringing IMCORP's Factory Grade technologies and services into various electric power generation and distribution markets. Specific focus is on services that support digital transformation initiatives that enable reduced operational costs, improved operating efficiency, underground power delivery reliability, and optimize revenue growth.



The Battle for Supremacy at the Grid Edge

by **Alan Ross** CRL, CMRP
Managing Editor of APC Media
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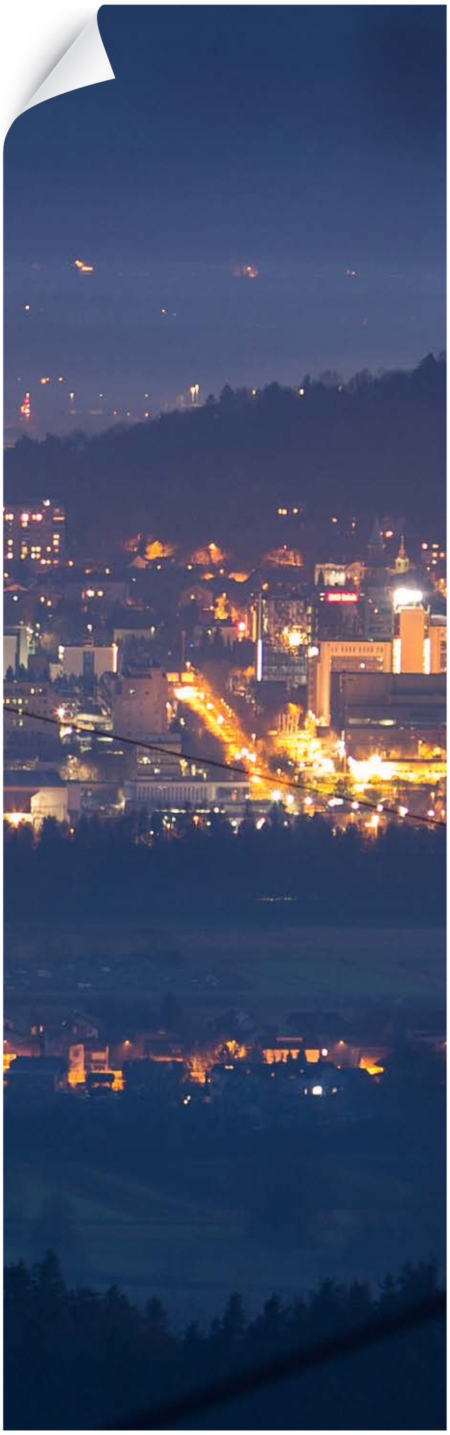
At steering committee meetings for the first IEEE PES Grid Edge Conference, recently held in San Diego, one of the first things that we had to agree on was the definition of the grid edge. As a representative of the IEEE Smart Grid Program, I was an advocate for referring to it mostly as grid modernization as we have been moving to a smarter grid through standards developed as long as 20 years ago. There are some who consider Grid Modernization and Smart Grid as synonymous terms. They are not. More simply, grid edge refers to the 'edge' of the electricity network, the point at which we connect to the network and electricity reaches our homes and businesses.

Grid edge refers to the 'edge' of the electricity network, the point at which we connect to the network and electricity reaches our homes and businesses.

It has also been called the 'low voltage' network, where the massive pylons, cables, and substations that make up the physical infrastructure of our energy system finally reach us. But in a grid that is rapidly moving from step-down to step-everywhere with solar, wind, electrification of transportation, microgrids, and new forms of battery systems; the definition must include all of these changes. So the grid edge now refers to sources of supply and demand, not just demand.

While the grid edge is undergoing a radical transformation, for purposes of this article we will focus on three main trends: electrification, decentralization, and digitalization. These major trends are creating new opportunities and challenges for various stakeholders in the electricity sector, such as utilities, regulators, customers, and technology providers. We will explore how these trends are shaping the battle for supremacy t the grid edge in North America and beyond.

Alan Ross CRL, CMRP, is the Managing Editor of APC Media. Alan has decades of experience in the power systems industry and is one of the greatest reliability experts out there.



Electrification

Electrification is the process of replacing fossil fuels with electricity as the primary energy source for various end uses, such as transportation, heating and cooling, and industrial processes. Electrification can reduce greenhouse gas emissions, improve energy efficiency, and enhance energy security. As much as it is a solution for decarbonization, it is also bringing tremendous challenges to the market.

Electrification can reduce greenhouse gas emissions, improve energy efficiency, and enhance energy security. As much as it is a solution for decarbonization, it is also bringing tremendous challenges to the market.

According to a report by McKinsey & Company, electrification could account for more than 20% of final energy demand in North America by 2050, up from 6% today. The main drivers of electrification are:

- The falling costs and increasing availability of renewable energy sources, such as solar and wind, which can provide clean and cheap electricity for various applications.
- The rising consumer demand for electric vehicles (EVs), which offer lower operating costs, better performance and environmental benefits compared to conventional vehicles. EVs also have the potential to provide grid services through vehicle-to-grid (V2G) technology, which allows them to store excess electricity or feed it back to the grid when needed.
- The development of new technologies and business models that enable electrification of hard-to-abate sectors, such as heavy-duty trucks, aviation, and industrial processes. For example, hydrogen fuel cells, synthetic fuels and power-to-x solutions can provide zero-emission alternatives to fossil fuels.

Electrification poses both opportunities and challenges for grid edge players. On one hand, it can create new sources of revenue and value for utilities, technology providers and customers. For example, utilities can offer new services such as EV charging infrastructure, smart home solutions and demand response programs. Technology providers can leverage their expertise in digital platforms, data analytics and distributed energy resources (DERs) to enable electrification. Customers can benefit from lower energy bills, improved comfort and convenience, and greater control over their energy consumption.

On the other hand, electrification can also increase the complexity and uncertainty of grid operations and planning. For example, utilities will have to cope with higher peak demand, greater variability and bidirectionality of power flows, and increased cybersecurity risks. Regulators will have to design new policies and incentives that balance the interests of different stakeholders and ensure reliability, affordability, and sustainability of electricity supply. Customers will have to adapt to new behaviors and expectations regarding their energy use.

Decentralization

Decentralization is the shift from ***centralized power generation***, which can best be described as step-down, from large generation, through transmission to distribution at the grid edge, to ***distributed power generation*** and delivery. Decentralization is enabled by the rapid deployment of DERs, such as rooftop solar panels, battery storage systems, microgrids and community energy projects. DERs can provide local power supply, reduce transmission losses, lower carbon emissions, enhance resilience and empower customers.

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According to a report by Wood Mackenzie, DER capacity in North America is expected to grow from 132 gigawatts (GW) in 2020 to 387 GW in 2025, representing a compound annual growth rate (CAGR) of 24%. The main drivers of decentralization are:

- The declining costs and improving performance of DER technologies, which make them more competitive with conventional power sources.
- The increasing customer demand for DERs, which offer greater choice, autonomy, and participation in the electricity market.
- The supportive policies and regulations that encourage DER adoption, such as net metering, feed-in tariffs, tax credits and clean energy mandates.

Decentralization also creates both opportunities and challenges for grid edge players. On one hand, it can unlock new value streams and business models for utilities, technology providers and customers. For example, utilities can leverage their existing assets and customer relationships to become DER aggregators, integrators, and orchestrators. Technology providers can offer innovative solutions that enable DER optimization, interoperability, and monetization. Customers can benefit from lower energy costs, higher reliability, and environmental stewardship.

On the other hand, decentralization can also disrupt the traditional roles and responsibilities of grid edge players. For example, utilities will have to deal with reduced revenues from conventional power sales, increased competition from new entrants and changing customer expectations. Regulators will have to balance the need for grid stability, fairness, and innovation in a more dynamic and decentralized environment. Customers will have to manage their own DER assets and participate in new markets and platforms.

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Digitalization

Digitalization is the process of applying digital technologies and data analytics to enhance the efficiency, flexibility and intelligence of grid edge operations and services.

Digitalization is enabled by the widespread adoption of smart meters, smart appliances, smart thermostats, smart inverters, and other internet-of-things (IoT) devices that generate massive amounts of data about grid conditions and customer behavior.

According to a report by Navigant Research, global spending on grid edge digital technologies is expected to grow from $14 billion in 2019 to $32 billion in 2028, representing a CAGR of 9%. The main drivers of digitalization are:

- The increasing availability and affordability of digital technologies, which offer improved functionality, scalability, and interoperability.
- The growing demand for digital services, which offer enhanced visibility, control, and optimization of grid edge resources.
- The evolving regulatory frameworks that support digital innovation, such as data privacy, cybersecurity, and interoperability standards.

According to a report by Navigant Research, global spending on grid edge digital technologies is expected to grow from $14 billion in 2019 to $32 billion in 2028, representing a CAGR of 9%.

Digitalization also offers both opportunities and challenges for grid edge players. On one hand, it can enable new capabilities and value propositions for utilities, technology providers and customers. For example, utilities can use digital technologies to improve grid management, customer engagement, and service differentiation. Technology providers can use digital platforms to provide end-to-end solutions that integrate hardware, software, and services.

Customers can use digital applications to access real-time information, personalized recommendations, and tailored incentives.

On the other hand, digitalization can also raise new issues and risks for grid edge players. For example, utilities will have to invest in upgrading their IT infrastructure, skills, and culture to cope with the increasing complexity and velocity of data. Regulators will have to ensure data security, privacy, and quality in a more connected and open ecosystem. Customers will have to trust their data providers, service providers and devices to deliver reliable and beneficial outcomes.

Conclusion

At the recent Grid Edge Conference and Expo and the DistribuTECH Conference and Expo, it was apparent that the grid edge is transforming rapidly due to electrification, decentralization, and digitalization. While there are many other factors at play, these three trends alone, are creating new opportunities and challenges for various stakeholders in the electricity sector. The battle for supremacy at the grid edge will depend on how well these stakeholders can adapt to these changes and collaborate with each other to create value for themselves and society.

To make this transformation process more reliable and sustainable we must apply the principal of collaboration, where different stakeholders work together to create the “new grid”, where society as a whole, wins. As a passionate IEEE member and member of the Grid Edge steering committee, that is exactly what we strove to provide, and based on the feedback, that is what those attending experienced.

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Q&A

AN EXPERT Q&A WITH:

ADVISORY AND POWER SYSTEM SIMULATIONS MANAGER

HAMIDEH BITARAF

Employers in the industry can show their support for gender equality by having family friendly work policies like providing the same opportunities to women as compared to men by boosting their corporate careers and closing the gender gap in terms of salary.

You are an Advisory and Power Systems Simulations Manager at Hitachi. Tell us about your professional journey. How did you come to this position? How does Hitachi as a company motivate you to build your career there?

Hamideh Bitaraf: I joined Hitachi Energy's predecessor in 2017 as a microgrid advisor after completing my PhD from Virginia Tech. This led to my interest in consulting and advisory services. I enjoy supporting customers on their path to achieve sustainability goals. I interact with a broad range of global customers from different sectors including utilities, commercial and industrial, remote communities, and universities. This was an exciting opportunity for me to get to know their challenges and their goals with different cultural maps.

Besides exposure to different customers and Hitachi grid edge technologies, I was chosen to attend the female talent development program to accelerate my career growth. Now, I am an Advisory and Power Systems Simulation Manager for Hitachi Energy in North America and Europe regions. I manage a team of consultants dedicated to providing advisory services to customers interested in Grid Edge Technologies with the goal of carbon emission reduction and a sustainable energy future.

Photo: Shutterstock

You have a PhD in Electrical Engineering. What inspired you to choose an engineering profession? What would you say to young women and men considering the engineering profession?

HB: I chose to take Electrical Engineering because I am passionate about math and renewable energy resources. I enjoy solving engineering problems by applying the science derived from both math and physics. For those who are considering going into the engineering profession, I would suggest to young men and women to follow their passion while also considering the market trends for that profession. Nowadays, a noticeable market trend across many engineering professions is the use and application of artificial intelligence and digital technologies. It is interesting to see how engineering professions are continuously evolving with new market trends and technologies.

I would suggest to young men and women to follow their passion while also considering the market trends for that profession. Nowadays, a noticeable market trend across many engineering professions is the use and application of artificial intelligence and digital technologies.

What are the specific challenges you have faced in your educational and professional journey? What can employers in the industry do to alleviate such challenges for current and new employees?

HB: The main challenge that I faced during my educational and professional journey was the unconscious bias towards minorities in the industry. The Power System industry is mainly dominated by men and women who often face unconscious biases which is an unintentional and automatic mental association, based on gender.

Employers in the industry can show their support for gender equality by having family friendly work policies like providing the same opportunities to women as compared to men by boosting their corporate careers and closing the gender gap in terms of salary.

As an engineer analyzing new market trends, regulations, and incentives – what would you list as the current challenges the Power Systems industry is facing? How can these challenges be addressed?

HB: Renewable power technologies are dominating the global market for new generation capacity, and key enabling technologies such as batteries are experiencing rapid reductions in costs. These grid edge technologies are growing fast and in need to get interconnection approval to be able to connect to the grid. Renewables and energy storage projects must secure an approval from electric transmission system operators before connecting to the grid. These projects submit requests for interconnection approval so that system operators can conduct a series of necessary grid impact studies. These studies establish the standard of interconnecting new assets to the grid exploring the need for any necessary transmission system upgrade. One challenge that these projects may face is the waiting time to get approvals, which often takes a couple of months to as long as a few years. This consequently delays the project executions for both the customer and the developers. There are fast tracks designed to accelerate the process which will hopefully resolve the issue in the near future.

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North American Transformer Production is Key to Reliable Electric Grid

VIRGINIA - GEORGIA TRANSFORMER
ONE SOURCE–ONE COMMITMENT

The federal government is reporting that our national security is at risk, and the vulnerability is one that most Americans wouldn't expect – the United States electrical grid.

While the grid has received increased attention in recent months due to the attacks on substations in places like North Carolina and Washington state, the Department of Commerce published an investigative report [1] that shows the country's power supply faces an even larger problem: the United States does not produce enough transformers to meet demand.

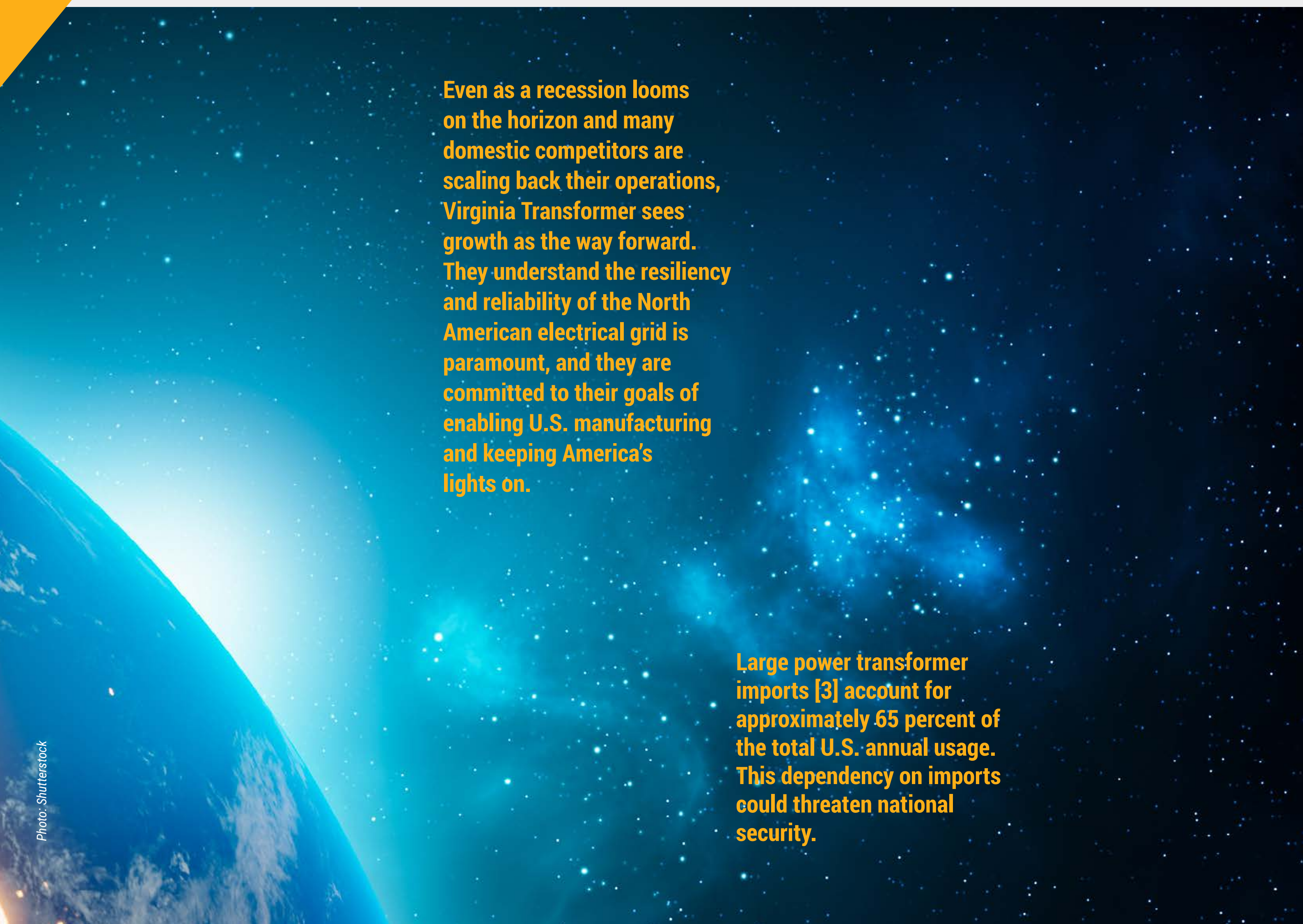
The 2021 investigation revealed the country's growing reliance on transformer imports has led to a significant decline in domestic transformer production. Large power transformer imports [2] account for approximately 65 percent of the total U.S. annual usage. This dependency on imports could threaten national security through bottlenecks, supply chain disruptions, and trade disputes. If exacerbated, these issues could result in outages across the grid.

The consequences of an excessive reliance on energy and infrastructure imports have been made especially clear to the European Union throughout the ongoing Russian invasion of Ukraine. According to the International Energy Agency, the EU imported 45 percent of its natural gas from Russia in 2021. The 2022 sanctions imposed against Russian oil and gas have left European parliaments scrambling to find alternatives to fill the Russian energy gap as their citizens grapple with soaring costs and government restrictions on energy use. Although maintaining close international relations through trade is necessary for success in an increasingly interconnected world, an overdependence on key imports can lead to trouble.

While there are domestic shortages of all sizes of transformers, the type most critical to the U.S. power supply is the large power transformer. The Department of Commerce reported that the U.S. imported more than 80 percent of its total large power transformers in 2020.

There are only six companies capable of manufacturing large power transformers in the United States. These companies face challenges competing on the global market and must account for rising labor costs, training and retaining skilled employees, and sourcing the necessary transformer materials in an increasingly uncertain geopolitical landscape.

According to a separate report [4] by the Department of Energy, North America needed 1,300 large power transformers in 2020, and demand will more than double by 2027. This sharp increase in demand is partly driven by the need to rebuild the electrical grid and other infrastructure. The Department of Commerce noted in 2021 that the average age of a transformer in the U.S. is 38 years old, and 70 percent of all transformers are older than 25. In 2023, the average transformer is approximately 40.



Even as a recession looms on the horizon and many domestic competitors are scaling back their operations, Virginia Transformer sees growth as the way forward. They understand the resiliency and reliability of the North American electrical grid is paramount, and they are committed to their goals of enabling U.S. manufacturing and keeping America's lights on.

Large power transformer imports [3] account for approximately 65 percent of the total U.S. annual usage. This dependency on imports could threaten national security.

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Investment in domestic production of transformers is vital to maintain the reliability and resiliency of the electrical grid. While many transformer manufacturers are turning to inexpensive overseas labor and materials, one company is stemming the tide and bringing transformer manufacturing jobs back to North America.

Virginia Transformer is the largest U.S.-owned and -operated producer of small to extra-large transformers in the United States. Based in Roanoke, Va., the company has expanded significantly over the past 50 years, with five manufacturing facilities located across the United States and Mexico. Due to its consistent growth and repeated investment in domestic manufacturing, Virginia Transformer has the shortest lead times in the industry.

Investment in domestic production of transformers is vital to maintain the reliability and resiliency of the electrical grid.

Per the Department of Commerce investigative report, some of the most common issues affecting the domestic transformer manufacturing industry are labor availability, lack of skilled labor, and employee retention. Virginia Transformer addresses these challenges by providing extensive training programs to both new hires and long-term employees. This continuous educational investment in their workforce ensures that all employees at Virginia Transformer are highly trained and prepared for their roles across the company.

To help meet North America's rising energy demands, Virginia Transformer recently constructed an additional manufacturing facility in Chihuahua, Mexico. The plant began production in October 2022 and features four production lines for pad-mounted transformers, along with additional lines for dry-type transformers and integrated power modules. It can currently manufacture transformers up to 100 MVA, with the capacity to produce larger units in the future. Virginia Transformer's other facilities have been substantially upgraded with new equipment such as robotic carts, advanced testing labs, winding mushrooms, and other technology to increase production and further shorten lead times.

Even as a recession looms on the horizon and many domestic competitors are scaling back their operations, Virginia Transformer sees growth as the way forward. They understand the resiliency and reliability of the North American electrical grid is paramount, and they are committed to their goals of enabling U.S. manufacturing and keeping America's lights on.

Photo: Virginia Transformer

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[2] A large power transformer is generally considered to be greater than 60 MVA
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The Integration of the EV Into the Home/Grid and What Does it Mean

by **Gregory Smith**

Gregory Smith has 24 years of experience in development of advance automotive power electronics and traction motors at General Motors starting with the EV1 up to the Chevrolet Bolt. He left General Motors in 2014 and became a founder of Flex Power Control, a developer of distributed energy resource management systems that integrate electric vehicles, stationary energy storage, and solar into a unified energy management system. He has over 20 patents in electric propulsion and energy management systems.

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When we talk about integrating electric vehicles (EVs) into the home and grid, people typically think about the process of connecting EV charging systems with the electrical infrastructure of the home, and by extension, to the power grid. This integration can include installing charging equipment in the home, connecting the charging system to the grid, and using smart technology to manage the charging process.

Implications of the EV

Our first consideration is, "what does an EV mean to the home and the grid?" The average U.S. home used 29 kilowatt-hours (kWh) daily in 2021 according to the Energy Information Administration (EIA). [1] The average U.S. daily commute was reported to be 41 miles per day by Zippia in February of 2023. [2] EVs typically get between 2 to 4 miles of range per kWh consumed. This means that for the average U.S. daily commute, we would expect to see a charge requirement of between 10 to 21 kWh per day. Where does charging occur? The U.S. Department of Energy says over 80% of all EV charging occurs at the residence. [3] What this means is that we are going to see residential power consumption grow by 28% - 58%. Certainly, public charging could potentially help relieve some of this by making it more accessible, but it will never be as convenient as residential charging. This will result in a significant burden on the residential power distribution system.

The U.S. Department of Energy says over 80% of all EV charging occurs at the residence. [4] What this means is that we are going to see residential power consumption grow by 28% - 58%.

When EVs are integrated into the home and grid, several benefits can be realized. For example, it can make charging more efficient and cost-effective, by optimizing charging times and avoiding peak demand periods. It can also help reduce the strain on the grid, by enabling EV owners to charge their vehicles during off-peak hours.

There are additional benefits, though, that could be extracted, including:

- Integration of EVs as an essential element of home energy management
- Increased reliability and resilience of the home/grid by providing backup power during outages
- Balancing the grid by storing and releasing excess renewable energy
- Reducing the cost of energy

This integration would redefine how power is managed at the home and in the grid. The cost of doing this can be more than offset by the resulting benefits that consumers, utilities, and vehicle OEMs would gain.

Challenges of Integration of EVs

However, there are also challenges that must be addressed when integrating EVs into the home and grid. Homeowners may need to invest in new infrastructure to efficiently utilize and manage not only the EV, but the other Distributed Energy Resources (DERs) they have, such as Stationary Energy Storage and Solar. These DERs, along with the home's existing energy loads, need to be treated as a system. The complexity of today's solutions, and the likely need to upgrade the home electrical systems to handle the increased demand for electricity from these new sources and loads, is daunting. This, along with the need to manage power flow in order to maximize benefits and efficiency to a household, is essential. All of this must be done while maintaining data privacy and security.

Homeowners may need to invest in new infrastructure to efficiently utilize and manage not only the EV, but the other Distributed Energy Resources (DERs) they have, such as Stationary Energy Storage and Solar.

Overall, the integration of these DERs into the home and grid has the potential to revolutionize the way we think about transportation assets, home assets, and energy, but it requires careful planning and coordination to ensure that it is implemented in a way that is effective, efficient, and secure.

On-Board (AC Charging) vs. Off Board (DC Charging) Systems

The integration of the vehicle into the home/grid has been thought of in two different ways:

1. Using On-Board vehicle power electronics to provide AC power to the home/grid.
2. Off-Board power electronics taking DC power from the vehicle and then converting it to AC.

The figure 1 below provides context of the two different bi-directional implementations.

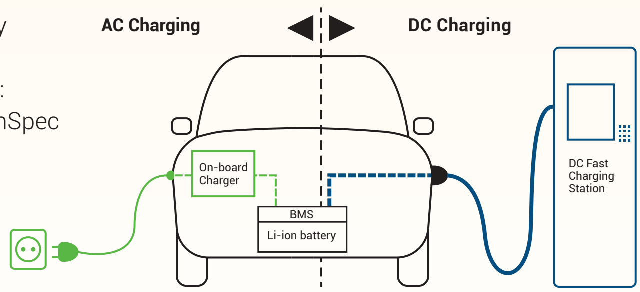
Each of these implementations has their pros and cons, which have been captured in Table 1.

The AC system (On-Board) would inherently seem to have a cost advantage over DC systems (Off-Board). AC systems incrementally add functionality to the vehicle existing charging system that is liquid cooled (i.e. providing higher power density) allowing it to convert DC power from the vehicle battery to AC. A DC system is a stand-alone power conversion system that is not tied to the vehicle, but is stationary. The function of converting the DC vehicle battery power to AC is the same in either case.

- Solar, storage or other DERs that could potentially export to the grid require anti-islanding safety certification (UL 1741) to prevent backfeeding.
    - California has also added smart inverter requirements (UL 1741-SA, SB).
- For North America, only DC-V2G interconnection is allowed today
    - AC-V2G is so early, timeline is unknown.

AC-V2G is being worked on by OEMs for interconnection

- Standards in development: UL1741SC, SAEJ0372, SunSpec 13072-2030.5 Profile
- 6 Pilots for California approved by CPUC



DC-V2G is approved for interconnection with UL 1741

- Most of US: UL1741
- California: UL1741-SA, SB (Rule 21)
- IEEE 1547 (aligned to Rule 21) is anticipated to spread across the US

Figure 1. AC vs. DC Interconnection

Configuration	Pros	Cons
On-Board (Typically referred to as AC systems)	Power processing On-Board the vehicle required for AC Charging the vehicle. Adding bi-directionality is incremental.	Vehicles are not UL and U.S. Utilities require UL for interconnection to the grid. Not a fixed location asset
Off-Board (DC Systems)	UL Certified and interconnected to the grid and designed to work with location circumstances. Enable higher power vehicle charging than AC Integration with the building and other DER components	Not mobile

Table 1. AC vs. DC Bi-Directional Charging

The question that needs to be asked, though, is what we are trying to achieve. When we consider discharging the vehicle battery to support a load, the home, or the grid, they are very different in their requirements. The following will help to better understand what we need for each of these applications and their requirements.

Types of Bi-Directional Functionality

Vehicle to Load or V2L (Power Convenience) is a system where an electric vehicle can provide power to external electrical devices or loads. This means that the EV can be used as a mobile power supply to power devices like appliances, power tools, or even other electric vehicles. V2L systems typically use the vehicle's on-board charger and DC-to-AC inverter to convert the DC battery power to AC power suitable for use by external loads.

These types of systems have been introduced by several vehicle OEMs as a convenience for consumers for tail-gate parties and to help out during power outages. The ability to have power at a location that is remote is enticing. There are, though, limits to these systems, as they can only support a few specific loads (i.e. appliances) and nothing more.

Vehicle to Grid or V2G (Grid Services) is "grid-following," that can export power to the grid. This can be accomplished by either an On-Board or Off-Board bi-directional charging system. The technology enables electric vehicles (EVs) to interact with the electrical grid, allowing them to serve as mobile energy storage devices and contribute to the stability and efficiency of the grid. It establishes a two-way flow of electricity between the EVs and the power grid.

Vehicle to Home or V2H (Microgrid) is a "grid forming" system where an electric vehicle can provide power to a home during a power outage or when electricity demand is high. In this case, the EV battery is used to supply power to the home's electrical system through a bi-directional charger (Off-Board). The bi-directional charger can also charge the EV battery from the home's electrical system when electricity prices are low or when renewable energy sources like solar power are available.

The requirements of each of the above modes of operation vary significantly. In terms of relative complexity, V2L is the least complex, then V2G, and then V2H. The essential difference is the number of factors that need to be controlled, the precision needed, how quickly, and how many of those factors need to be managed simultaneously.

Benefits & Costs

We need to recognize that there are three different stakeholders involved in the integration of the vehicle into the home/grid. We have the vehicle OEM who delivers a product for the purpose of transportation. Then we have the consumer, who must obtain the vehicle and integrate it into the home. Finally, there is the utility, who is responsible for the grid. Each of these parties have their own unique perspective and needs, see figure 2.

The successful adoption of fully integrating the vehicle with other DER resources at the home will depend on a "win-win" scenario occurring. The extent that this integration will occur will depend on finding increased alignment of benefits from the different stakeholders.

The successful adoption of fully integrating the vehicle with other DER resources at the home will depend on a "win-win" scenario occurring.

How Do We Create a Cost-Effective Solution to Integrate the Vehicle into the Home/Grid?

BENEFITS: Each of these solutions (V2L, V2G, and V2H) has their own benefits. However, we can combine V2G and V2H (often referred to as V2X) to realize additional benefits. We can also look at combining these functions with other DER elements present at the home, to see if even greater benefits could be obtained. EPRI (Electric Power Research Institute) has calculated the potential benefits of integrating the vehicle into the home:

Vehicle to Grid (Grid Services)

- Distribution Peak Savings of $1,100 per year. Grid services, also known as ancillary services, are a set of essential functions and capabilities provided by electricity grids to ensure the reliable and efficient operation of the power system. [4]

- Resource Adequacy of $1,200 per year. Resource adequacy refers to the ability of an electricity system to reliably meet the expected demand for electricity at all times, while maintaining an acceptable level of reliability. [4]
- Renewable Curtailment of $454 per year. Renewable curtailment mitigation refers to the strategies and measures implemented to minimize or eliminate the curtailment of renewable energy generation. [4]

Vehicle to Home (Microgrid)

- Resiliency Savings of between $15,000 to $20,000 by not needing a stationary battery. Home resiliency refers to the ability to withstand and recover from power disruptions, disturbances, or adverse events while minimizing the impact on electricity supply and maintaining reliable service to customers. [4]

Above we have laid out the savings of utilizing the vehicle energy storage for other purposes beyond transportation. But we must look at the cost of power outages to have a true appreciation of the benefits to be gained. According to Energysage, power outages cost homeowners between $25 to $25,000 per event. [5] These costs are made up of replacing spoiled food, emergency supplies, lost productivity, property damage, and alternative housing. Briggs & Stratton has calculated the average cost of power outage-related property damage to be $1,916. [6]

We should also consider the savings from lowering a home's energy cost. This is done by taking advantage of the ability to avoid buying power from the grid during high peak demands by consuming energy from DERs at the home. A University of Kentucky report calculated a yearly savings of $2,477. [7] This was for a 2,500 square foot house in Southern California. DERs included solar, stationary energy storage, and an EV.

We should also consider the savings from lowering a home's energy cost. This is done by taking advantage of the ability to avoid buying power from the grid during high peak demands by consuming energy from DERs at the home.

Finally, let's talk about efficiency. Integrating EVs into the home and grid can make charging more efficient. For example, homes can use solar panels to generate electricity for charging EVs, which can be more cost-effective and environmentally friendly than using grid electricity. In addition, by taking the energy locally from other DERs we can avoid peak demand periods, which can help reduce the strain on the grid.

Figure 2 – Vehicle Integration Benefits by Constituent

All of these benefits are not cumulative, but some can be. The potential of substantial benefits exists and is worthy of consideration by homeowners.

COSTS: Vehicle to Load runs approximately $500. This will enable you to pull up to any location and provide power to an appliance. No installation cost as this is completely self-contained within the vehicle. This use has a negligible impact on the vehicle battery.

Vehicle to Grid cost is estimated to be approximately $7,000 (Off-Board System is the only one approved at this time). This will enable power to be exported to the grid. Installation cost, depending on home service, can range from $1,000 to $4,000. This application has the greatest impact on the vehicle battery because of the potential duty cycles required.

Vehicle to Home cost can range from $8,000 to $12,000. This will enable backup power to the home. Backup power is typically limited to critical loads only, as sizing a system for whole home would be cost prohibitive to the average consumer. Installation cost again will depend on existing home service but should range from $2,000 to $5,000. This will result in an overall cost of $10,000 to $17,000.

Future - Integration of the Vehicle into the Home Ecosystem

There are opportunities for improving the benefits and lowering the costs when we look at combining V2G/V2H and other DERs. Based on the earlier assessment, an On-Board system would seem to have a distinct cost advantage over Off-Board systems once they get approved, but this may not be true.

Homes have additional power electronics present that have to manage and process power for other DERs, such as solar and stationary batteries. If these could be combined, it may lead to a more cost-effective energy management system that can be more efficient, and highly integrated. A highly integrated system would be capable of providing a level of awareness, seamless communications, and dynamic controllability beyond anything that exists today. This system would enable the home to become an interactive participant in the management of power, not only at the home, but also of the grid. Homes could become their own microgrid or could be aggregated into virtual power plants for the grid.

A highly integrated system would be capable of providing a level of awareness, seamless communications, and dynamic controllability beyond anything that exists today.

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Carl Imhoff

Manager, Electricity Market Sector
at Pacific Northwest National Laboratory

Interview with **Carl Imhoff**

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Collaboration is increasingly fundamental to everything that we do. One thing I found is that the utility industry is not the most agile one in terms of picking up new technology, and one of the key success factors is to work closely with the vendors.

Photo: PNNL

Alan Ross: My guest is Carl Imhoff. He is the manager I would consider the future of the power grid right at the Pacific Northwest National Laboratories up in the northwest of the United States. Carl, thank you for joining me.

Carl Imhoff: My pleasure.

AR Tell me a little bit about your background and how you ended up at PNNL. How did you end up there and why the power industry?

CI I got my master's degree at Purdue University in industrial engineering with an emphasis on operations research. I did my research on some Department of Energy work looking at electric vehicles. That was back in 1980. As I was presenting my work in Washington, DC, the Department of Energy, afterwards it was my birthday, they took me to an Irish bar just across the street. There happened to be a gentleman there who worked at PNNL. He slipped his business card across the table and said, well, if you're interviewing, come visit us. I'd never heard of a national laboratory. I came to the Pacific Northwest and fell in love with the ability to work on both technical issues around the energy system, but also sort of policy challenges; at that time, it focused more on energy efficiency and solving the oil crisis, that kind of thing. So that sort of got me into a place at the nexus of technology and energy policy. I've been here ever since.

AR Excellent. I'm glad you did because we are now at, I think some of the most exciting times as it relates to the power industry as a whole. There's more change now than I've seen in my lifetime. It was the old step-down grid. Just make sure rates are low and customers are happy and don't let the generating stop. You've seen a lot of change, even though I think we've been pretty static within the utility industry. Within the power industry and your time there, what are the most important changes that you see taking place today?

CI I believe the journey started in the late 90s, when the inexpensive natural gas began to flood the market. That transition to natural gas really transformed the power industry. We saw a big drop in coal generation, a lot of very high-performance, agile gas turbine fleets sprang up, and that really changed the price structure and everything else. Big shift in the power system followed very quickly caused by digitization in the early two-thousands in terms of protection, control, and situational awareness. The emergence of the phaser measurement technologies that let operators see the system like never before was an incredible transformative activity in terms of running the system as we have come to know it, and led to smart grid activities. And then, all that has just been dwarfed by the challenge we faced with the climate extremes we've experienced in terms of hurricanes and other issues, big push in terms of decarbonization. What we see today is a complete transformation driven by decarbonization that's at the center of state policy and individual corporate policies, as well as the federal agenda.

++ **What we see today is a complete transformation driven by decarbonization that's at the center of state policy and individual corporate policies, as well as the federal agenda.**

AR I believe PNNL is a leading laboratory in the US. Could it be said that you are coordinating between some of the other labs as well?

CI Well, we're a leader, we're one of the leading laboratories and we do co-lead Grid Modernization Laboratory Consortium for DOE.

AR I'm on the IEE PES steering committee for Grid Edge and their recent conference that they had in San Diego. When we first got there, we were trying to define grid edge. These are the three main terms: grid edge, grid modernization, and smart grid. What R&D efforts are going on at PNNL right now that we need to know about?

CI A couple of things jump out. Alan. I think one is that the journey towards decarbonization is going to require the capture of system flexibility at levels never before seen. That's the ability to increment and decrement both generation and load, to handle sort of the real time needs of the system. We used to all do it on the generation side, we're going to have to capture anywhere we can get it. You're going to have to find ways to coordinate and orchestrate generation and demand in ways that we've never had to do before. We're working on some advanced concepts, transactive energy concepts, such that you can engage demand at scale, at the interconnection scale, hundreds of thousands of devices, et cetera. That's a really big push for ourselves. The other issue is, as we look ahead to some increased levels of renewable generation in the future, whether it's 80 or 60% or whatever, we're going to have

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substantial growth in the use of inverter-based resources and power electronics and incredibly fast agile devices. But we're a little uncoordinated in terms of the standards and how we want to move in that direction.

++ **The journey towards decarbonization is going to require the capture of system flexibility at levels never before seen.**

We are going to have to come up with new approaches for controlling those devices and ensuring protection of the system as we move towards a high inverter-based resource fraction in the industry. That's an area where we're trying to do some analytics around what needs to change, how we adjust the standards and the ability to protect and control those future systems. Another area is the challenges of threats. Cybersecurity has become really big in the last decade. That's sort of a human-posed threat I mentioned earlier, the weather extremes and the big heat domes we've had on the West Coast the last several years are really transforming demand. Peak demands in California and the Pacific Northwest and all hurricane damages are much more intense than they had been previously. We need to have a way to better reflect the increasingly complex threat profiles that not only today's system has to face, but tomorrow's system as well. If we electrify and become more dependent on electricity, less dependent on natural gas, then that's going to change the dynamics and we need to assure that we not only decarbonize, but also keep it resilient and keep it robust.

++ **If we electrify and become more dependent on electricity, less dependent on natural gas, then that's going to change the dynamics and we need to assure that we not only decarbonize, but also keep it resilient and keep it robust.**

AR Resilient, robust, reliable, those are the three R's that I like to talk about.

One of our community members wrote an article saying that, because of this inverter-based system that's being installed, there's an increased degradation of distribution transformers already hooked up to the grid. Have you heard anything about that? The inverter-based system ages existing assets more rapidly than they have in the past.

CI I've heard that discussed. I've not seen a broad base of evidence yet. I think it's worth examining, and I think that points to where industry and probably the Federal Government need to work a little bit in terms of what are the right test beds for validating the controllability of these fleets of devices, some of the degradation and wear issues, how vulnerable might they be to various cyber or digital attacks, those sorts of things. What improvements do we need to make in secure design of these new digital devices? From a supply chain standpoint, I think there's just a lot of kind of question marks there that we don't quite understand yet that give us some rich topics to investigate in the near term.

AR I hope PNNL does some investigating on it, because here's the problem. If the existing assets are degrading faster than planned, and the lead time on transformers, distribution transformers, it used to be three to six months, is now two years, up to three years, you have a double whammy.

You mentioned cybersecurity. We all talk about it. You hear it over and over again. The issue of cybersecurity, it's not really one issue, right? There's multitude of issues. What are you all working on? What threats are we really trying to mitigate?

++ **The large utilities with substantial engineering staffs put a lot of emphasis on this and doing a great job. The challenges are much greater for the small and mid-sized utilities who might have two or three engineers on their staff. We're working to give them tools for them to self assess the level of maturity for their cyber readiness.**

CI There are two main domains. We're looking both at the interface between the electric system of the utilities and the outer internet world, sort of the business side of those activities. And they're the challenge. It's the same threats we face on our home computers and everything else, just increasingly complex threat profiles from external entities. And I think the industry has done a phenomenal job of responding and adapting. But we have three and a half thousand utilities in this country. The large utilities with substantial engineering staffs put a lot of emphasis on this and doing a great job. The challenges are much greater for the small and mid-sized utilities who might have two or three engineers on their staff. We're working to give them tools for them to self assess the level of maturity for their cyber readiness, identify where there are some gaps. We're also working with workforce development, with the colleges and community colleges and universities around the country to increase the flow of knowledgeable cybersecurity analysts as well as double leap power engineers who have some exposure to cybersecurity tools to help infuse in that supply chain, the workforce of the future to help better mitigate those issues.

The other side of that equation is on the control side, sort of inside the utility, the control systems or the OT systems, a very different environment, but still very important. We're developing new techniques to help monitor and control some of the really fast streams of SCADA and Phasor measurement data and other things, using some automated analytics to improve our ability to detect threats, position, and help resist those threats going into the future. It's sort of in those two domains, the IT side and the OT side. New tools, new workforce giving smaller and mid sized utilities the tools they need to keep up with the race.

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AR I think I feel better about the future of the power grid with organizations like you and some of our other national labs working on it, because it is a daunting task to come up with something that works at scale for the larger utilities who can afford it, and down to the small, because most of the problems will affect all of them. If I were attacking the grid, I would attack at the weakest point, which is many times going to be the lower level of the grid, because then you can get into it. You create all kinds of problems from there. The last question that is really more of a philosophical one: collaboration is critical in every major endeavor. It can't be done in a silo. Collaboration is absolutely critical to what happens with the future of the grid. We have a very disconnected grid in the US. Talk a little bit about how PNNL handles collaboration.

CI Collaboration is increasingly fundamental to everything that we do. The majority of our programs for Department of Energy all have industry participants or partners. We have industry advisory groups so that even if they aren't participating in a funding way, they can come in and have full transparency in terms of the progress of research projects. We have annual peer reviews and headquarters when we work with EPRI and EEI and the large public power council and others to bring them in to make sure they're infused with what the possibilities are, as well as the vendor community. I think one thing I found is that the utility industry is not the most agile one in terms of picking up new technology, and one of the key success factors is to work closely with the vendors. As they are seeing the emergence of new high-performance techniques, or new situational awareness techniques, and so on, I have them in the room with the utility participants, so they all hear together about what the possibilities might be. One of the most successful moments in a control room demonstration of a new advanced technique is when an operator turns around and says to the vice president, it'd be great if this were to be part of our next upgrade on our EMS system or our DMS system.

++ **If you look at lithium-ion batteries and Teslas or other electric vehicles today, that was a 40-year journey from new academic discoveries to where we are today. We can't afford another 40 years to come up with the equally successful grid-scale energy storage device, or some of the next generation inverter-based resource controls. We have to move faster.**

That's always been, I think, one of the most effective ways of getting new innovations brought forward, when the vendor community and the industry are working together on things that's very powerful. Almost every one of our projects, we have two or three laboratory partners, and the DOE has this grid modernization initiative and strategy, and they basically have assembled sort of all star teams and topics around operations or planning or devices and other things. We're doing the best we can to bring the best the DOE has to the table. The challenge we face, Alan, is we got to move fast. If you look at lithium-ion batteries and Teslas or other electric vehicles today, that was a 40-year journey from new academic discoveries to where we are today. We can't afford another 40 years to come up with the equally successful grid-scale energy storage device, or some of the next generation inverter-based resource controls. We have to move faster. This collaboration of the past has given us the 50 states and three and a half thousand utilities and everything else. Business-as-usual

Photo: PNNL

Grid Storage Launchpad (GSL), the nation's focal point for long-duration energy storage, is under construction on PNNL's campus and expected to start operations in 2024.

will not get us there fast enough to meet the urgencies of some of the climate pressures, on climate extremes and all.

We need to find new ways of working together more effectively between the industry, the state regulators, the policymakers, et cetera. We're working on a national transmission planning study right now with DOE trying to build on top of what industry already does very well. But business as usual will not give us a decarbonized grid by 2035. I'm heartened by a large number of stakeholders, including the industry, the vendor community, the regulators, they all kind of get it. They said, you know, we've got to find ways to innovate our business processes, because we got to move faster. And so, we're working on ways to help make that happen. Ultimately, the states and the utilities are going to build this infrastructure, but we are trying to help them better target and have better capacity to get there faster.

AR You know, Carl, if I were the king of the power development industry, the grid modernization industry, I would take my crown off and hand it to you and say, do what Carl says, because that's brilliant.

Carl, thank you for this interview. I hope we have others about other topics in the future.

CI Thank you, Alan.


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SUBSTATION SOLUTIONS AND POWER SYSTEMS DYNAMICS: ELECTRIFICATION, UNDERGROUND CABLING

The upcoming new edition in August will explore how substations need to adapt to changes in grid edge technologies, security concerns, and weather events to ensure reliability and resilience. It will focus on integrating distributed energy resources, enhancing substation security against cyber threats, and implementing resilient designs to withstand extreme weather conditions.

The edition aims to provide valuable insights and practical guidance for substation operators and engineers to meet the evolving demands of the energy sector.

There is still time for you to add your voice. Contact me at alan.ross@apc.media to add your article or interview.

COMING IN AUGUST ISSUE