Smart Asset Management:

Digital Power Transformers

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 is part of the transformer system coupled with technical insight helps customers optimize their reliability maintenance and electrical asset lifetime.

Digitalization is all about managed control.

Power transformers are the key components in the electrical grid and as such they are subjected to various stresses – thermal, mechanical, and electrical. These stresses are the reasons why transformers age. The global population of electrical power transformers is aged.

Currently, if transformers do come equipped with sensors, these sensors can only provide an alarm after the condition of the transformer has already started to deteriorate. This makes evaluation of the transformer's health a complex and challenging task.

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Introduction

Digitalization is the addition of remotely connected sensors to a single system. It is the use of unforeseen data relationships from multiple sources to change the value proposition or business model for a specific sector or application.

Digitalization is the cause of large scale and sweeping transformations across multiple aspects of business, providing unparalleled opportunities for value creation and capture, while also representing a major source of risk [1].

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In our industry, this route of digitalization is followed to ensure reliability and maximum lifetime – the transformer condition is monitored continuously and evaluated for appropriate asset management decisions. Asset management needs to be both cost-effective and reliable, sensing solutions that provide asset managers with actionable intelligent data.

There is a global consensus to urgently reduce carbon emissions to assist in the fight against global warming. Because the power industry still uses 75% non-renewable sources such as coal, oil, and natural gas, it is an enormous contributor to these dangerous emissions. The energy industry is obligated to decarbonize and to look beyond the conventional fuel sources to sustainable fuel sources.

Because of the de-centralization of the power system, the entire energy value chain must evolve and rely on small scale renewable energy.

WITH the declining cost of renewable technologies, including batteries, electricity generation is being transformed. The New Energy Outlook (NEO) 2018 published by Bloomberg [2], highlights the following changes:

1. By 2050 half the world's energy will be generated by wind and solar – due to the low cost of renewable energy and batteries.
2. PV, wind, and batteries: The cost of the average PV plant falls by 58% by 2050. Batteries cost is dropping dramatically which enables wind and solar to function when the wind is not blowing, or the sun is not shining.
3. Coal is the biggest loser – estimated to drop by 11% of global electricity generation by 2050.
4. Gas consumption for power generation increases modestly – growth is only expected in China and India.
5. Electrical vehicles add around 3461TWh of new electricity demand.

Below we address four items of the electricity reticulation system where value can be created through digitalization:

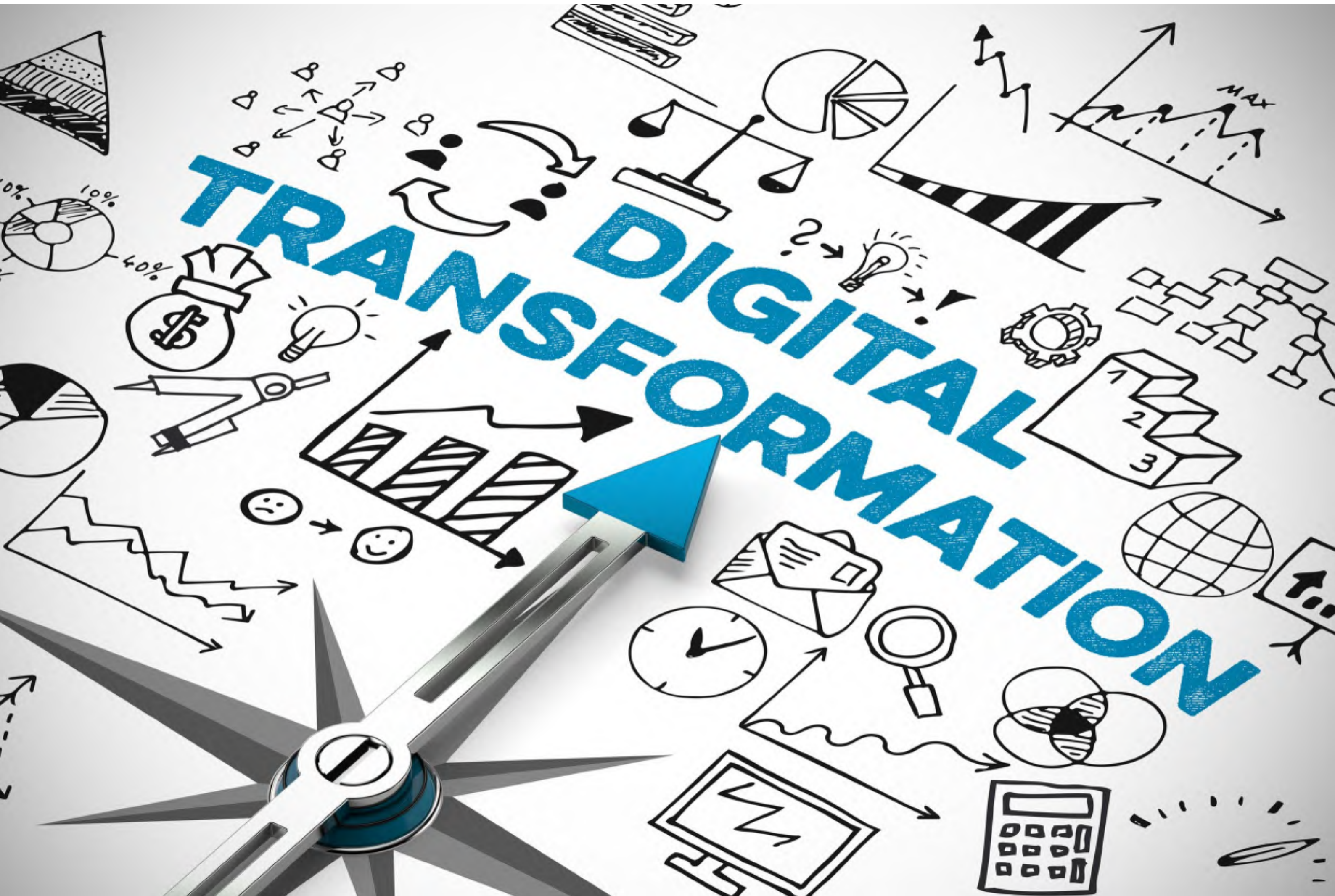
1. **Asset life cycle management:** Real-time, remote-control, or predictive maintenance to extend the life cycle or operating efficiency of the generation, transmission or distribution assets and infrastructure can be enabled by technology solutions [1].
2. **Grid optimization and aggregation:** The optimization of the grid is possible through real-time load balancing, network controls and end-to-end connected markets, enabled by connected assets, machines, devices and advanced monitoring infrastructure.
3. **Integrated customer services:** An integrated customer service can be provided by innovative digitally enabled products and services relating to energy generation and energy management.
4. **Beyond the electron:** Adapting to the customer can be accomplished by hyper-personalized connected services stretching beyond the electricity value chain.

To accommodate these changes, digital technologies must be applied to the energy infrastructure. At this point in time, digital transformation is not well understood. Asset life cycle management, grid optimization and aggregation, and integrated customer services will be central to the digital transformation of the energy sector. We will discuss in-depth how the power transformer can exponentially scale benefits of digitalization across the industry.

We need to re-imagine the design of the energy system, with digital and technological innovations which include predictive forecasting and energy storage.

The "Lego block" approach

There is increased pressure on asset managers to ensure network reliability and profitability, thus an increased pressure to reduce cost and increase efficiencies in the grid itself and the relevant maintenance operations. The database must be able to visualize what is happening to key assets;



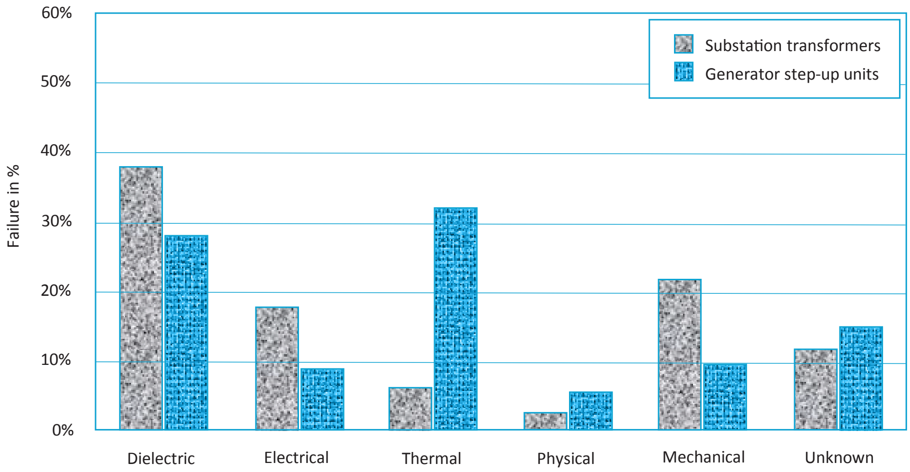
this is vitally important. Transformer failure statistics and historical data must be taken into consideration to provide a failure mode "picture" data model on which recommendations would be based.

In Cigre's failure mode analysis [3], the failure modes were identified as:

1. Dielectric: Partial discharge, arching, etc.
2. Electrical: Short circuit, poor joints, poor contacts
3. Thermal: General overheating, localized hot spot
4. Physical chemistry: Contamination, corrosion etc.

Dielectric failures were the most prominent failures for substation transformers. Thermal and dielectric failures were most common for GSU transformers. This clearly indicates that thermal analysis of transformers can provide critical information about transformer condition and can be used to identify inception of faults or to better manage transformer loading.

Figure 1. Failure mode analysis: Cigre WG A2.37 [3]



Asset life cycle management, grid optimization and aggregation, and integrated customer services will be central to the digital transformation of the energy sector.

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Applying the "Lego block" approach [4], temperature monitoring is the first Lego block of the digital power transformer. Electric and thermal faults break down the oil molecule and the insulation paper molecules, resulting in the formation of dissolved gas formation – thus making dissolved gas analysis (DGA) the second Lego block:

1. **Temperature monitoring.** Using temperature monitoring devices on power transformers is not a recent phenomenon. Most transformers are equipped with a current transformer based winding temperature indicator (WTI) and utilize a PT100 fitted in a pocket to monitor top oil temperature, which usually is the oil temperature (OTI). Please note that temperature varies throughout the transformer, with the hottest part of the transformer being at the top. It is important to take into consideration the ambient temperature to forecast possible overloading and thus overheating, which in turn can decrease the lifetime of the transformer. Other devices like the Bucholz-relay data, oil level, pressure relief device and, if fitted, DGA data should be available to see the whole picture. All of these indicator's data should be taken into consideration to ensure a healthy operating system. This data should be available online to get a real time indication of the situation and to build a picture of what the data should look like when everything is normal. As soon as any deviations are noted, they should be evaluated and a decision should be made, either to monitor the situation if not critical, or to take immediate action if need be to save cost on downtime and maintenance.

2. **DGA monitoring.** DGA is one of the most common techniques used for fault diagnosis because its non-intrusive and the unit does not need to be de-energized. There are various DGA analysis methods available in the industry. The DGA profile gives us an indication of the transformer condition.
   It is vitally important that the interpretation of the DGA is done by a technical specialist that can correctly apply all the variants and relations to come to an accurate indication of the condition of the power transformer. The quality of the testing laboratory and the sample is of the utmost importance as this can cause major inaccuracies leading to inadequate control measures, thus useless data, and a waste of money.

If correctly done, DGA analysis will identify possible faults in the transformer and indicate how serious the problem is. This traditional method leaves a lot up to chance and a lot of expertise is needed to come to the correct answer. If any part of the process does not meet the highest quality, the maintenance manager might end up with the wrong data. This can cause an incorrect action to be implemented and a unit might be lost. Most utilities follow a maintenance strategy requiring them to take an oil sample every 6 to 12 months, which is good enough to build up a history for the unit and to create a unit specific normal profile.

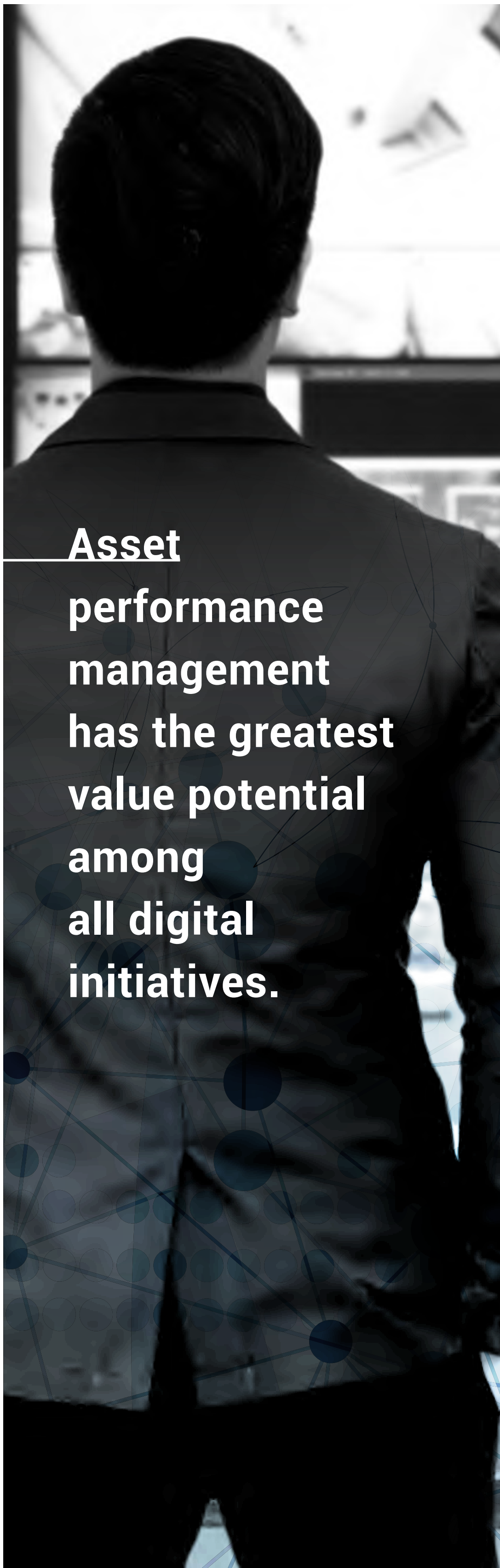
However, since the day-to-day health of the unit is not monitored, if a problem should arise between two sampling cycles, one that is quite serious, within a few days or months the problem might escalate making the repair bill much higher and the repair time consuming. Having real-time data would alert the manager to a problem.

Online DGA can be programmed to sample automatically at pre-set intervals, in a closed-loop measurement system. The system needs to have measurement repeatability, no cross-interference between gases and no calibration required. It needs to detect all the gases for complete transformer analysis and health profile compilation.

Pattern recognition algorithms are built into the software database according to the data in historic database files of transformers that displayed a certain problem, e.g. partial discharge, overheating, discharge fault, or another problem, although expert input might be required for final assessment [4].

Smart asset management

In a study by the U.S. Department of Energy, it was found that 75% of breakdowns have been eliminated by an actively implemented predictive maintenance plan based on digitalization. Asset performance management has the greatest value potential among all digital initiatives.



If digital initiatives like condition monitoring, predictive forecasting, and smart sensors are deployed, it will lead to a marginally lower maintenance costs, lower downtime of assets, and fewer critical breakdowns. Digitalization supplies real-time data by means of connected sensors and algorithms, which enables the maintenance manager to make informed decisions and take corrective action. Asset managers can identify problems and take action to prevent unplanned downtime. A futuristic approach can be implemented, for instance, "When does it make sense to operate a transformer above its nameplate rating?", rather than the conservative approach of operating at less than half the capacity. This can only be done with continuous data at hand.

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Studies found that short time overload conditions (100%-120%) for about 10 hours should not potentially harm the transformer if no partial discharge or hotspots are present in the transformer because there is, in actual fact, no real thermal overload. In comparing load versus temperature versus time, the formation of hydrogen should be monitored as this might be the first indicator of possible electrical faults in the unit.

Traditionally, transformers have been conservatively rated and operated to reduce risk of failure in unforeseen and unpredictable adverse circumstances. However, by continuously and effectively monitoring the load, operating environment and transformer condition in real time, while having control over cooling systems and online tap changers, the typical power transformer can be safely operated by up to 20% above its nameplate value, since it will still be operating within predefined standard design limits, in terms of current and thermal properties. This is known as dynamic rating.

In addition, online condition monitoring devices connected to the online transformer management system permit continuous assessment of condition and can be utilized to provide early warning of deteriorating components or to adjust dynamic rating limits. Most important parameters commonly monitored include fault gases, moisture in oil, bushing power factor, temperature, cooling system functionality, and tap changer utilization. Insulation life consumption can also be monitored on a continuous basis.

Utilization of condition monitoring digitalization also permits condition-based maintenance with attendant benefits in reduced maintenance resource requirements and cost reductions, along with fewer outages.

By combining these capabilities into one Transformer Management System device, we have a "better tool" as required for managing power transformers for maximized output, but in a completely safe and fully controlled manner [3].

How does digitalization apply to utility?

1. System wide data integration and new business models: Provides a system wide view of devices inside the network, as well as analysis of device performances. New business models become possible because of the broad visibility of data and the historical analysed data ensuring maximum application of equipment – optimum use.
2. Fleet level analytics, services and remote management: Improved customer value and experience of the overall product. This enables asset managers to take control of the entire network and ensure maximum potential is reached, creating a wider range of service available to the end user.
3. Station level communication and serviceability: Once the whole base is digitally enabled, cost effective connectivity and remote managing of equipment becomes a reality.
4. Device level sensing and data acquisition: Data is continuously captured, formatted and analysed from all the devices linked to the system, which makes interpretation and decision making much easier.

Conclusion

The thermal management focus might provide the tools to overcome future challenges of the evolving power grid and the demands placed on the power transformer [5]. According to IEC standards, normal ageing is defined as the loss of 24 hours of life on a power transformer after 24 hours of continued operation. Abnormal ageing occurs when more than 24 hours of lifetime is lost in a power transformer after 24 hours of continued operation. Some studies have shown that under certain conditions, overloading transformers to 120% did not thermally stress the transformer. The goal should be to overload with acceptable loss of life, and such operations should not pressure design margins of accessories like bushings, tap changers, cable connections, etc. This is only possible under continued monitoring circumstances, getting all the data every second of the day.

Using transformer intelligence enables asset owners to extract all available capacity of transformers; it also helps them reduce investment cost, prevent high over-capacity specs for budgets and tenders, utilize ambient conditions that are favorable for long-term or short-term operation above nameplate rating, monitor vital parameters using smart sensors, and make informed maintenance decisions [6].

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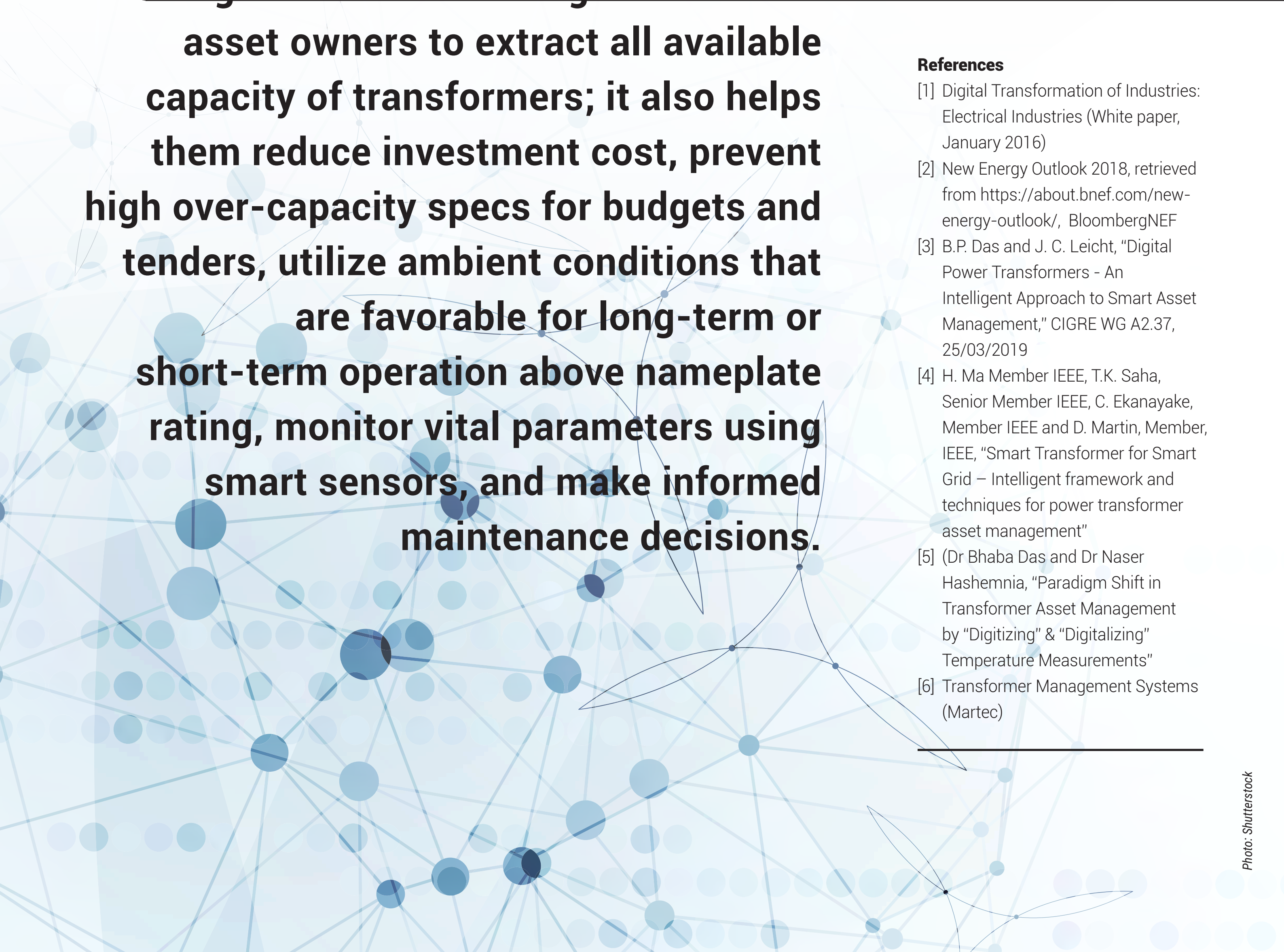

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