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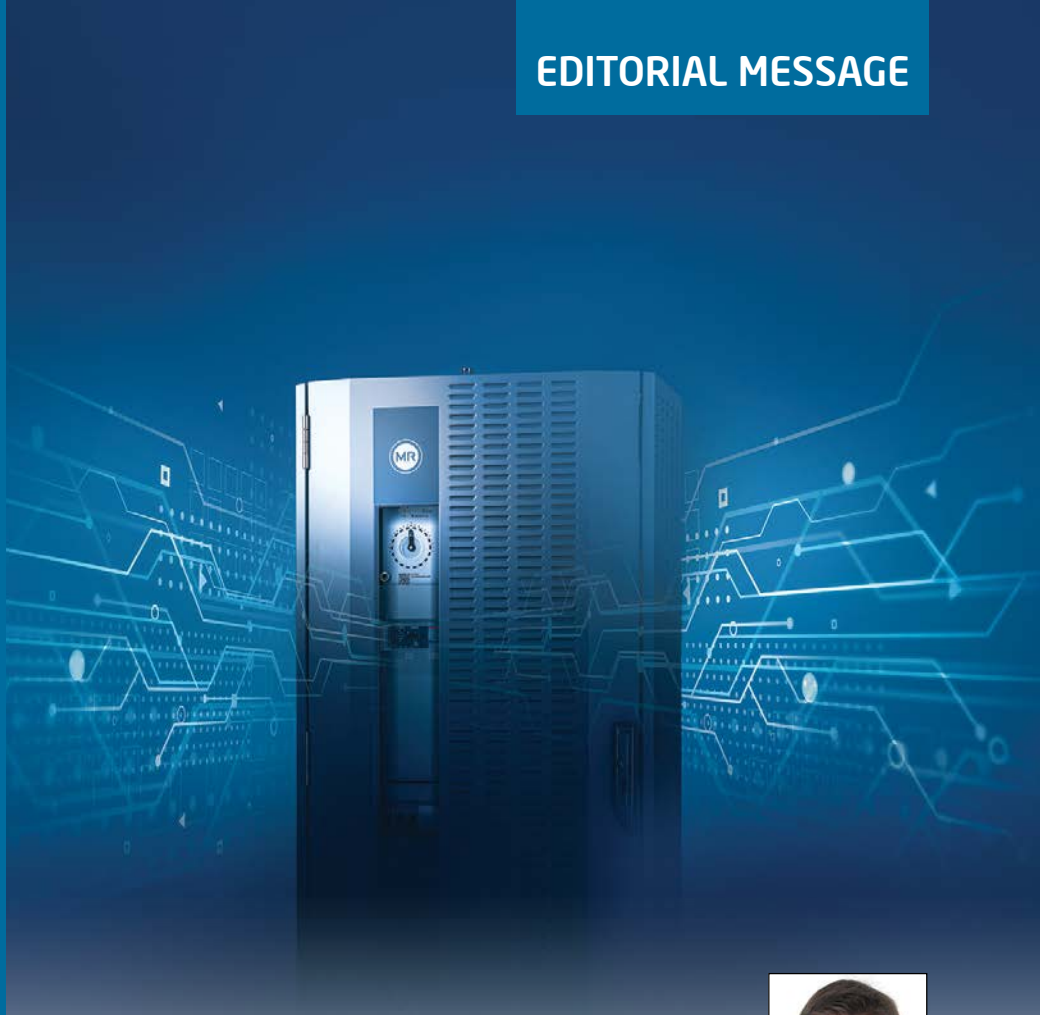

Dear readers,

The goal of this special edition was to shed light on the application of machine learning and artificial intelligence in the transformer industry, contributing to a better understanding of the requirements and available solutions. Expectations from these technologies are high in terms of what they can provide in various fields: monitoring, diagnostics, control, maintenance, perhaps even design, etc. A particular advantage of AI and ML technologies is the ability to predict future conditions, which opens up space for completely new paradigms, especially in maintenance.

AI and ML technologies are also highly related to digitalization as a dominant global trend, which facilitates agile business models that respond to challenges within emerging markets. Digitalization also leads to a surge in data generation and accumulation, and with proper analysis, these data are expected to significantly secure and improve the grid performance and resolve various customer demands. This is also why we need solutions for understanding the data and learning from it.

In addition, the speed and reliability of obtained information become essential, so all these trends are greatly supporting each other. Therefore, significant growth in investments and businesses related to this field is expected in near future.

However, there are also challenges such as testing, deployability, scalability, transparency, affordability, and cyber security.

I'm glad that a group of great authors together with our respectable Guest Editorial team have prepared high-quality articles this issue brings, addressing the above-mentioned key aspects.

I hope you will enjoy your reading.

Mladen Banovic, Editor-in-Chief

The transition towards a low-carbon economy, along with the ever-increasing development of intelligent solutions for the smart grid, presents new challenges, and opportunities for the efficient and reliable operation of transformers.

Artificial intelligence and machine learning-based methods are supporting the emergence of intelligent health monitoring and design optimization solutions. These methods are widely used for transformer prognostics and health management (PHM) tasks, which integrate ageing models with operation, design, and control strategies, to develop anomaly detection, diagnostics, prognostic and intelligent maintenance applications.

To assess the impact of the integration of renewables and smart grid solutions on transformers, the development of intelligent solutions asks for diverse modelling methods, which integrate PHM applications with, e.g., meteorological forecasting models and demand forecasting models. In this direction, hybrid modelling solutions are emerging as promising solutions, which bring together machine learning, physics-based modelling and engineering solutions to support transformer lifetime decision-making for different operation contexts.

Jose I. Aizpurua

In the aftermath of the Paris Agreement 2015, new businesses are manoeuvring competitive low-carbon solutions to reduce 70% of global emissions from the power sector alone by 2030. Obviously, decarbonization, decentralization, and digitalization of power systems are pivotal for this energy transition. It is imperative to interlink digitalization with sustainability for better performance and a higher return on investment from such business models. However, the ultimate goal of this transition is to achieve carbon neutrality.

Artificial intelligence (AI) is the heart of all potential, explainable, and sustainable solutions. It can contribute substantially to ease decision-making and boost the productivity / efficiency of systems. AI-driven energy transition may be swift, but it does require a substantial investment. This means innovative transparent and user-friendly solutions to integrate physical systems and their data-driven twins within a common data environment. These digital twins will provide valuable insights for the integrated management of assets, energy and a company in general.

Sruti Chakraborty

The industry faces an unprecedented and multi-faceted change with the irreversible trend in digitalization, new loads such as electric vehicles, new forms of energy generation and transactions, such as in distributed wind and solar power, robotization of manufacturing processes and customer services, e-commerce, and cybersecurity, to name a few. The incredible amount of data flowing through the existing IT infrastructures in the form of numbers, indices, and images, is overwhelming. It requires new and faster tools to support experts and asset managers alike, providing timely actionable information, and improving systems reliability and efficiency. Transformers are not an exception to this trend. Manufacturers and users are applying and testing new solutions and algorithms that have fortunately been made available, as public domain tools, by a thriving community of data scientists and artificial intelligence experts, worldwide.

Dr. Luiz V. Cheim

Although it is considered that data science and algorithms belong to the last decades or the "smartphone epoch", it is of course much older, at least 80 years. We may even trace it thousands of years back. However, AI & ML are easier to implement with today's powerful and fast hardware and software. On the other hand, the quantity of data that requires processing is much higher. Just like any modern industry, the power transformer industry also tries to utilize those new concepts, but the users should be aware of the obstacles and challenges of implementing AI & ML techniques for the diagnosis and maintenance of this precious equipment. Of course, cyber security should be carefully considered in our turbulent times, as well as a simple question of whether or not human intelligence will be replaced by machine intelligence. Just as we will not rely on self-driven cars, it is better to reconsider the race to rely on such tools. They may be very useful in everyday work for dealing with operational data, but users should know their limitations. This special edition of Transformers Magazine will help readers gain some clarity on the advantages and limitations of implementing AI & ML.

Marius Grisaru

Machine learning (ML) and artificial intelligence (AI) have transformed the entire data analytics industry, and equipment health monitoring has seen a surge in its applications. Monitoring transformer health is critical for any utility, manufacturing sector, and other users. There are various offline and online monitoring methods for detecting faults such as winding faults, hotspot temperature rise, oil leakage, oil degradation, bushing damage, estimating health index, etc. With the increasing digitalization of transformers, data are becoming increasingly available. With a large amount of data, ML and AI methods can easily be applied with an existing methodology to develop system-agnostic analytics, both for individual transformers and transformer fleets. Recently, many researchers have published papers on using ML and AI with transformer condition monitoring.

Dr. Bubathi Muruganantham

In the last 10 years, we have seen how the words AI and ML appear frequently in the hundreds of titles of the various transformer publications. With these tools, various aspects of transformers are analysed, such as power loss analysis, fault detection, online monitoring, design, fault classification, oil quality evaluation, predictive maintenance, health index, capacity to withstand short-circuit forces, estimation of moisture content, prediction of the concentration of furan compounds, prediction of mechanical stress, overload analysis, improvement of the cybersecurity of differential protections, estimation of internal parameters, and others. From a search carried out in Scopus, it was detected that the word ML and transformers appear more frequently than the word AL and transformers and the three countries with the most publications are China, India and the United States. And one trend is that a large percentage of publications are open access. These investigations will certainly continue to grow in the future.

Dr. Juan Carlos Olivares Galván

Digitalisation is a key driver of the electric power system transformation, enabling the conversion of large amounts of data into value. Power transformers, as an essential element of the power system, is not an exception. Digitalisation is often seen as a framework for the implementation of such emerging technologies as artificial intelligence (AI), machine learning (ML), industrial internet of things (IIoT), and digital tweens, to name a few. These technological advances are increasingly used instead of, or in addition to, conventional approaches and decision-making processes of the past. Conventional models based on first principles are often limited, oversimplistic and not adequately representative of complex processes observed in the design and operation of the modern power grid. These shortfalls open the path for more extensive use of sensors, telecommunication means, and intelligent wireless solutions. Continuous online monitoring demands large volumes of data that must be converted into valuable information, so asset managers, planning and plant operation engineers can utilise it in their daily lives. AI, ML and IIoT are definitely the future of the development and digital transformation of the electrical grid, where a transformer is one of the most critical assets.

Dr. Oleg Roizman

Artificial intelligence (AI), machine learning (ML), and big data (BD) techniques are currently widely used in different parts of the electrical engineering sector due to their privileges for being used in smarter manufacturing as well as accurate and efficient operating of electric devices. Power and distribution transformers are vital and expensive assets in the power network, where their consistent and fault-free operation greatly impacts the reliability of the whole system. The AI techniques, digital twins, digitization, and digitalization have the potential to fully modernize the power network in near future with their invincible advantages, including effectively addressing future tasks and issues, related to four distinctive life-cycle phases of transformers, i.e., design, operation, maintenance / condition monitoring, and asset management stages. AI and ML methods can be used for a range of applications including optimal construction design, smart fault techniques, hotspot detection, smart asset management, smart manufacturing, etc. Special edition of Transformers Magazine on AI and ML is a great opportunity to share the latest development in the implementation of AI techniques for the transformer industry with a greater community.

Dr. Mohammad Yazdani-Asrami

Executive Editor

Dr. Bhaba P. Das is the Lead Digital Business Developer for Transformers Business Line, HUB (Asia-Pacific, Middle East and Africa), ABB Power Grids, based in Singapore. He is part of the Application Engineering Team and spearheads the digital transformation efforts of transformers in the Asia Pacific region. Prior to ABB Power Grids, he worked as an R&D engineer for a major transformer manufacturer in New Zealand. He was awarded the Young Engineer of the Year 2017 by the Electricity Engineers Association of New Zealand for his work on the design and development of smart distribution transformers, fibre optics-based sensors for transformers, and diagnostic software for fleet condition monitoring. He is a Senior Member of IEEE and Young Professional of IEC. He completed his PhD in Electrical Engineering at the University of Canterbury, New Zealand.

Guest Editors

Amr A. Adly received B.Sc. and M.Sc. degrees in Electrical Power Engineering from Cairo University and a PhD degree in Elect. Eng. from the University of Maryland, College Park, USA. He worked as a Senior Magnetics Design Scientist at LDJ Electronics, Michigan, USA, during 1993–1994. In 1994 he joined Cairo University as a faculty member and was promoted to Full Professor in 2004. He also worked in the USA as a Visiting Professor at the University of Maryland during the summers of 1996–2000. He established and directed the R&D Division of the Egyptian Industrial Modernization Centre and worked as a design consultant for several motor and transformer plants in Egypt. Professor Adly is an IEEE Fellow and is currently an Associate Editor for several scientific journals including the IEEE Transactions on Magnetics. He published more than 130 reviewed papers and holds one US patent and was awarded numerous prestigious prizes and awards including the University of Maryland ECE Department Distinguished Alumnus Award. Prof. Adly has served as the PI of several joint international projects and previously as Cairo University Vice President for Graduate Studies and Research.

Jose I. Aizpurua finished his Telecommunication Engineering studies at Mondragon University (MU) in 2010. He got his PhD from MU in 01/2015 in the area of Information & Communication Technologies. During his PhD, he was a visiting researcher at a major Spanish railway company and at the University of Hull (UK). He has been a postdoctoral researcher for 4 years at the University of Strathclyde (Glasgow, UK). During this period, he designed, developed and delivered prognostics & health management (PHM) applications for the power & energy industry. Since 02/2019 he has been a Lecturer and Researcher at MU and an Ikerbasque Research Fellow since 09/2020. Dr Aizpurua is a Senior IEEE member and member of PES and Reliability Societies, and his research interests include the development and deployment of intelligent PHM and dependability solutions for the power and energy sector.

Dr. Bubathi Muruganantham received a B.E degree (Electrical Engineering) in 2007 from Anna University India and PhD (Engineering Science) in 2013 from Homi Bhabha National Institute, India (Indira Gandhi Centre for Atomic Research, Kalpakkam).

Currently, he is working as a Lead Engineer in Eaton Research Labs at Eaton India Innovation Centre, Pune developing prognostic and health monitoring solutions for the Electrical and Aerospace business. Previously, he has worked with GE Global Research Centre, Bangalore and ONYX Insight, Chennai. Overall, he has 8 years of work experience and 7 years in the Industry 4.0 domain.

His expertise includes condition monitoring of electrical & mechanical systems, signal processing and machine learning.

Dr. Juan Carlos Olivares-Galvan was born in Mexico in 1969. He received a PhD in electrical engineering at CINVESTAV, Guadalajara, Mexico in 2003. He was a Visiting Scholar at Virginia Tech, Blacksburg, USA, in 2001 (12 months). Furthermore, he was a Visiting Professor at the University of Alberta, Edmonton, Alberta, Canada in 2014 (12 months). Dr. Olivares-Galvan is Senior Member of IEEE. He was a transformer design engineer for eight years at Electromanufacturas S.A. de C.V. (Electromanufacturas operated as a subsidiary of Eaton Corporation plc.). He is currently a professor at the Universidad Autonoma Metropolitana (Departamento de Energia, Azcapotzalco Campus). In addition, he is a reviewer of various journals such as IEEE Transaction on Power Delivery, Electric Power Components and Systems, International Transactions on Electrical Energy Systems, IEEE Transactions on Magnetics, IEEE Transactions on Industrial Electronics, IET Electric Power Applications, IET Generation, Transmission & Distribution, IET Circuits, Devices & Systems, Swarm and Evolutionary and Electric Power Systems Research, The International Journal for Computation and Mathematics in Electrical and Electronic Engineering Computation, Electrical Engineering.

Sruti Chakraborty is a research engineer and budding entrepreneur with a PhD in Chemical Engineering from Malaviya National Institute of Technology-Jaipur, INDIA. She is the co-founder of Seetalabs SRL, an innovative tech start-up located in Turin, Italy. She develops low-cost solutions for risk management and failure mitigation of industrial assets including power transformers. She is hugely passionate about optimizing asset reliability and reducing data complexities in transformer industry using artificial intelligence (AI). She works closely with industry partners and other organizations to improve their transformer asset management experiences. She also hosts periodic tech-talks with industry professionals on various challenges and solutions in the field of clean technology, AI, cyber-security, and smart grids.

Dr. Luiz Cheim has been with Hitachi Energy as a Sr. Principal R&D Engineer for a number of years, having over 30 years of experience in the power transformers industry. His major activities as part of a global R&D team are in the development of transformers condition assessment and performance models and algorithms, as well as the development of new sensors and state-of-the-art monitoring technologies. Dr. Cheim is the proponent of the Hitachi Energy Transformer Inspection Robot (TXploreTM). In August 2018 Luiz was granted the Best Paper Award by the Cigre organization in Paris, Study Committee A2/PS2 on the use of AI/Machine Learning techniques in support of transformer diagnostics. Luiz is in the editorial board of the new Cigre Green Book on Transformer Life Management, a member of the Cigre WG D2.52 AI Application and Technology in the Power Industry, and responsible for Chapter 5 – Applicability and Maturity of AI Technologies. Dr. Cheim has filed over 20 patents in the last 10 years alone, including the most recently granted by the US Patent Office on AI Superminds (reference 5).

Marius Grisaru holds an MSc in Electro-Analytical Chemistry from the Israel Institute of Technology. He has almost 30 years of intense experience in almost all transformer oil test chains, from planning, sampling and diagnosis to recommendations and treatments, mainly in Israel but also in other parts of the world. He is responsible for establishing test strategies and procedures and creating acceptance criteria for insulating liquids and materials based on current standardization and field experience. In addition, he trains and educates electrical staff on insulating matrix issues from a chemical point of view. He is an active member of relevant Working Groups of IEC, CIGRE, and a former member of ASTM. He is also the author and co-author of many papers, CIGRE brochures, and presentations at prestigious international conferences on insulation oil tests, focusing on DGA, analytical chemistry of insulating oil, and advantageous maintenance policy for oil and new transformers.

Dr. Oleg Roizman is a founder and Managing Director of Intellpower Pty. Ltd. in Australia, an engineering consulting and services company with emphasis on continuous online monitoring and diagnostics of power transformers.

Having over 30 years of experience, Oleg is world renowned for the development of intelligent solutions for power electrical engineering in the field of diagnostics, monitoring and life management of electrical plants.

Dr. Roizman holds a PhD in Electrical Engineering and a BSc in Electrical Engineering and Economics (Hons.). Oleg is a sought-after speaker, educator, a member of IEEE Transformer Committee, a member of various CIGRE working groups and has written over 30 technical papers.

Dr. Mohammad Yazdani-Asrami holds a PhD in electrical power engineering. He spent the last 12 years on research works and projects related to transformers, electric machines, and harmonics in four different countries, including Iran, Italy, New Zealand, and the UK. His transformer-related research was focused on hot spot temperature determination and loss evaluation of conventional transformers under voltage and current harmonics, as well as the optimal design of transformers for power and high frequencies. He also worked on a project for the design development and fabrication of a fault-tolerant superconducting transformer at Robinson Research Institute, Victoria University of Wellington, New Zealand, which holds the world record on fault-withstanding time for HTS transformers. His current research interests are electromagnetic design and the development of conventional and superconducting electrical machines such as superconducting transformers, fault current limiters and permanent magnet machines for terrestrial power networks and aircraft applications. He is currently working as „a lecturer in electrically powered aircraft and operations“ at the University of Glasgow, Glasgow, United Kingdom.

He is a member of IEEE (MIEEE), member of IET (MIET), member of the British Cryogenic Council (BCC), and member of the Cryogenic Society of America (CSA). He is an editor at Transformers Magazine (TM). He also served as guest editor for several special issues in „IEEE Transactions on Applied Superconductivity“ and „Superconductor Science and Technology“ journals.