Powering generative AI and electrification

Training a transformer model (the "T" in ChatGPT) utilizes approximately 5 GHz of processor clock speed, 3 terabytes of memory, and 700,000 liters of cooling water – producing emissions equivalent to five times those of an average car

The high power (64 to 300 MW) and water demands of generative AI data centers, comparable to small cities, will delay their approvals

1. AI's energy and environmental costs

Generative AI is expected to boost the global GDP by 7% over the next decade, translating to about US$7 trillion [1]. Despite its potential, its immense computation power and memory make datacenters both energy- and water-intensive. For instance, training a transformer model (the "T" in ChatGPT) utilizes approximately 5 GHz of processor clock speed, 3 terabytes of memory, and 700,000 liters of cooling water – producing emissions equivalent to five times those of an average car [2], [3], [4], [5]. A ChatGPT query uses 8 times more power than a Google search, while an AI image uses energy equivalent to a smartphone. 10 to 50 GPT prompts use an equivalent bottle of water (16 oz/473 ml) [4], [5]. Hyperscalers (Google, Microsoft, Amazon, Meta, Apple, Alibaba, Huawei, Baidu, etc) must aim for "more work per watt" for sustainability, as coined by Dipti Vachani, Senior VP and GM, of the automotive division at Arm [4].

The high power (64 to 300 MW) and water demands of generative AI data centers, comparable to small cities, will delay their approvals. Despite this, the global fleet of over 8,000 data centers is expected to grow at a 5.4% CAGR by 2030, boosting power demand and the equipment market into the double-digits [6], [7]. In the US, data center power usage is projected to rise from 2.5% in 2022 to 16% by 2030, enough to power 100 million homes [4]. To support this growth, governments, hyperscalers, utilities, and equipment manufacturers are investing heavily in the power sector. The recently announced Stargate Project intends to invest US$500 billion over the next four years in AI infrastructure, with US$100 billion deployed immediately. The US bipartisan infrastructure deal allocated $65 billion for power upgrades, US utilities are investing US$50 billion, and Hitachi is investing US$6 billion, starting with US$1.5 billion for transformer factory expansion [4], [8], [9], [10].

1.1. Transformative semiconductor innovations

Generative AI is advancing semiconductors while balancing energy and environmental needs. TSMC Chair Mark Liu highlights that integrating chips in 3D on the wafer (CoWoS – chip on wafer on the substrate) or system (SoIC – small outline integrated circuit) densifies transistors beyond the reticle field limit, aiming for a 1 trillion transistor GPU. This is the maximum aperture size of the etching light used on silicon wafers. For typical GPU chips, this limit is around 100 billion transistors [3], [11]. Consequently, with the highest density of vertical connections, is the fastest-growing segment of advanced packaging, expected to triple to US$38 billion by 2029 [12].

Simultaneously, specialized chips are achieving remarkable speeds at lower costs. For instance, Groq's 14 nm chips

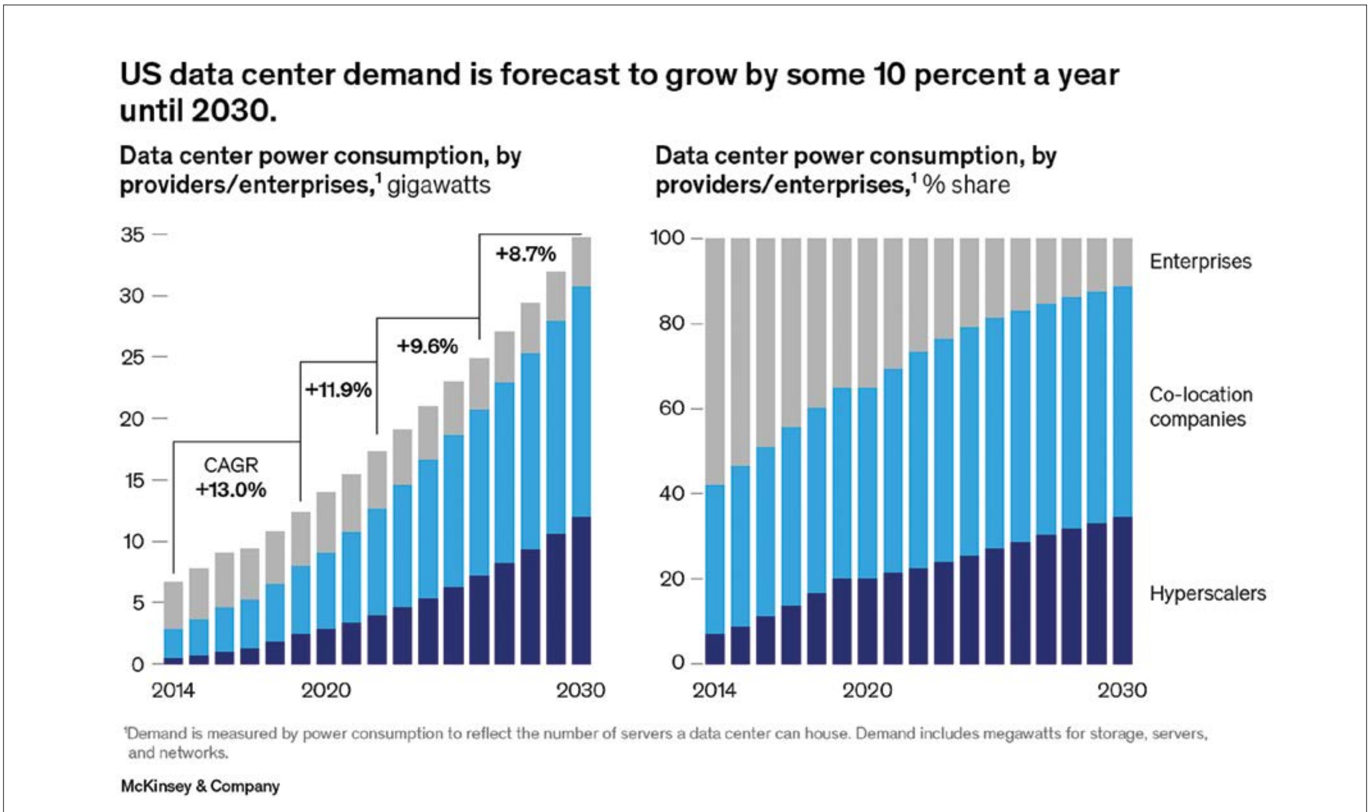

Figure 1. Growth in the US datacenter power demand [6]

are reportedly 18 times faster than the latest 4 nm GPUs from a major GPU manufacturer [13]. In December 2024, the release of DeepSeek-V3, a large language model (LLM), demonstrated superior performance compared to its peers (Llama 3.1 and Qwen 2.5) and matched others (GPT-4o and Claude 3.5 Sonnet) with significantly fewer training resources. Training DeepSeek-V3 reportedly cost US$5.58 million, marking a 94% reduction compared to GPT-4's US$100 million expense [14], [15]. These advancements underscore the principle of "more work per watt."

3D chip integration is expected to enhance computing speed, energy-efficient power (EEP), and power usage effectiveness (PUE). EEP, a measure of energy efficiency with computing speed, is projected to triple every two years [3]. PUE, the ratio of compute to total energy consumption in a data center, ideally equals one [6]. Higher compute speeds and power densities, increase temperature and thermal cycling. This can cause warpage and eventual failure of chip packages and PCBs. Siemens EDA is partnering with TSMC to test Calibre 3D Thermal for verifying 3D integrated circuits [16].

Reducing the energy and environmental footprint of data centers is crucial for their approval and operation

Thermal management accounts for 30-40% of a datacenter's energy use [17]. Advanced cooling methods, like full immersion rack, direct chip, and cold plate cooling, support power densities over 100 kW. AI algorithms can reduce PUE by 20-30% through optimized load sharing and cooling. Recovering datacenter waste heat for district heating, as Amazon does in Dublin, reduces emissions footprints [6]. Reducing the energy and environmental footprint of data centers is crucial for their approval and operation. This requires Simcenter 1D-3D multi-scale energy and thermal system simulations, from chip, PCB, and server-rack levels to building HVAC and cooling systems like chillers and cooling towers. Figure 2 is the thermal analysis of a datacenter building coupled to an external chilling unit, which can be extended to utility-scale energy storage and heat recovery, providing an overall PUE metric.

2. Grid modernization

2.1. Electrification

Electrification of passenger vehicles and home heating and cooling is progressing slower than expected. Palo Alto, California, with the highest EV adoption rates in the US, aims for an 80% emission reduction by 2030 [18], [19]. This requires increasing charging ports from 4,600 to over 30,000 in six years [20]. Assuming a 20% adoption of L2 chargers and heat pumps, the rating of a transformer serving 15 households doubles from 40 to 80 kVA as seen in Figure 3. Palo Alto's grid, originally designed for natural gas cooking and water heating, needs upgrades. Tomm Marshall, Assistant Director for Palo Alto Utility, stated that there are places where a heat pump or EV charger cannot be added without rebuilding that portion of the system [21]. To modernize its grid, in 2022, the City of Palo

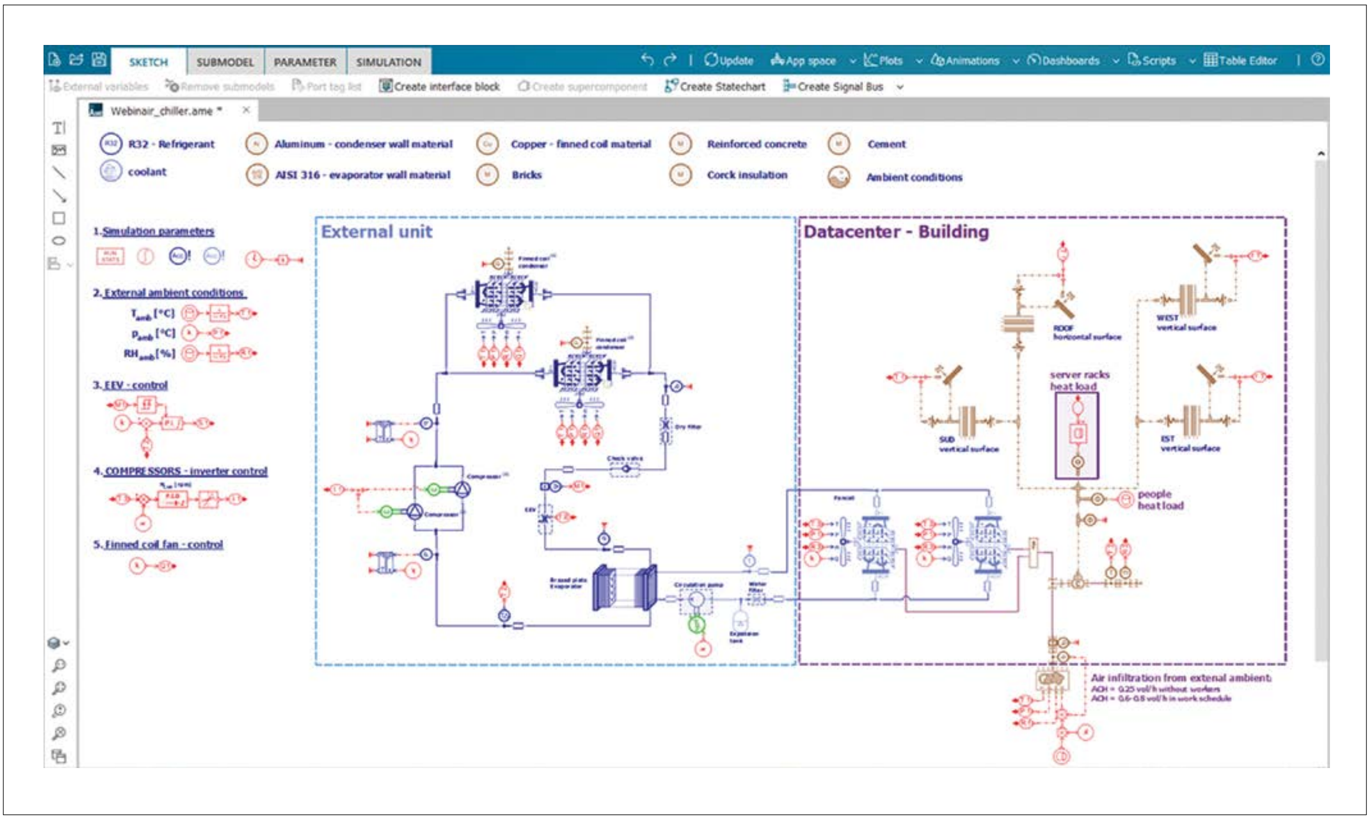

Figure 2. Simcenter system thermal analysis of a datacenter building and chillers

Aging grids and lower maintenance budgets in mature markets require digital twins for improved operations, predictive maintenance, and extended useful life

Alto announced a US$150 million investment – which has grown to US$300 million [22], [23].

2.2. Renewable and lower carbon power integration challenges

Lower-carbon energy sources are essential to reduce emissions from generative AI and electrification. In the US, switching from coal to natural gas has cut emissions by 18% since 2005. In Canada, replacing coal plants with renewable and low-carbon sources is expected to reduce coal's share from 16% in 2005 to less than 1% by 2040 [24]. Hyperscalers are exploring nuclear power, leading to a resurgence in small modular reactors (SMRs). Google and Kairos Power plan to deploy 500 MW from seven SMRs by 2030. Amazon has invested $500 million in X-energy SMR technology, committing to four units deploying 320 MW [25].

To meet its 2030 climate and energy security targets, the EU needs to add 33 GW of wind energy annually. In 2023, it added 18.3 GW, raising wind's contribution to 19%, surpassing hydro (13%), solar (8%), and biomass (3%). Offshore wind, with its higher capacity factor and social acceptance, is expected to surpass onshore installations by 2030 [26].

China reached its 2030 renewable capacity target of 1,200 GW in 2024, six years early. In Q1 2024, thermal additions fell by 45%, while renewables rose by 50%, accounting for 38% of capacity, second to thermal's 46%. Hydro is at 14%, and nuclear at 2% [27]. Despite a 21.6% investment in power grids, equipment utilization dropped, and excess energy dispatch faced challenges [28]. India aims for 50% non-fossil capacity by 2030, reaching 44% in October 2023 [29].

Due to the variability of renewables, charging, and datacenter loads, Hitachi Energy predicts over 30% growth in energy storage, led by utility-scale battery energy storage systems (BESS) [30]. The shift to a bidirectional smart grid is driving active management of generation, transmission, and distribution, necessitating utility digitalization. Additionally, aging grids and lower maintenance budgets in mature markets require digital twins for improved operations, predictive maintenance, and extended useful life.

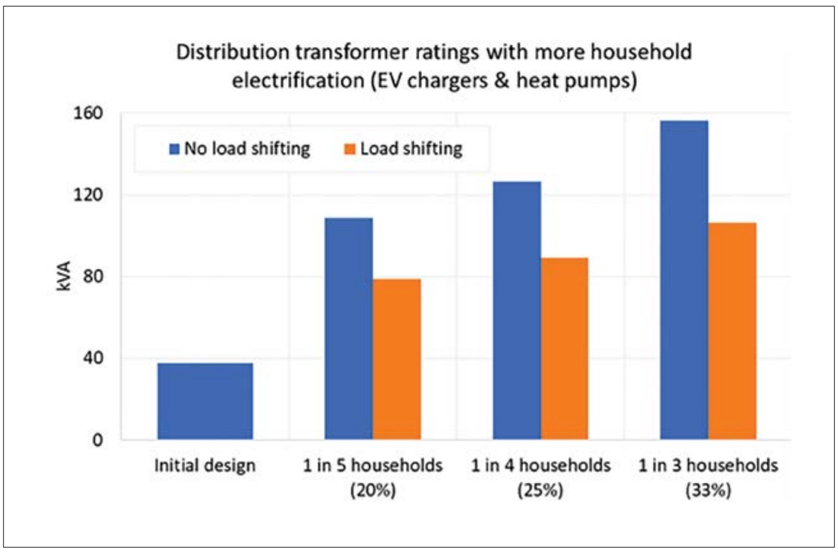

Figure 3. Higher distribution transformer ratings with more electrification of passenger vehicles, home heating, and cooling (initial transformer rating from [18])

3. Evolving role of transformers in AI and grid modernization

3.1. Next-generation transformers

Transformers are crucial for efficient long-distance electrical energy transmission and distribution. This role is even more critical for AI data centers, which present a significant power load to the grid. Transmission loss from generation to the datacenter is a key metric. According to Hitachi-Energy CEO Andreas Schierenbeck, AI data centers have unique power profiles, requiring peak power during AI training without triple redundancies [9]. Therefore, transformers must be redesigned to deliver more power while remaining highly reliable and efficient in a dynamic grid. The requirements are as follows:

1. Design for non-conventional load profiles. Datacenter power consumption can vary by 40-75% within an hour [31]. Similarly, transformer capacity utilization is lower during the day for solar and when the wind blows for turbines. Next-gen designs must balance material use, peak power needs, service life, and efficiency at no and partial loads.

2. Higher-rated distribution transformers that support more electrification (EV charging and heat pumps) without replacing poles and vaults.

3. Bidirectional energy flow that accelerates thermal aging, supporting residential (solar, vehicle-to-grid) and utility-scale battery storage.

4. Strengthened designs for offshore wind and solar applications to withstand wind, waves, and ocean currents.

5. Modular and transportable profiles for expanding centralized EV charging, data centers, wind, solar, and utility-scale battery storage.

A transformer OEM's margins depend on how well its portfolio addresses these requirements within competitive lead times. Medium-voltage transformer lead times have increased from 4-6 months pre-COVID to 18-36 months in 2023, leading to longer lead times for new data centers [7], [32]. They also face expertise gaps due to retirements and a slow development process, affecting SMBs.

Simulation-driven development (SDD) is key to overcoming these challenges. SDD, combined with decades of test data, adapts existing designs to use readily available parts and materials, countering supply chain issues. It enables cost-effective testing of new designs and materials, such as insulation materials, eco-friendly ester coolants, air-cooled designs, and solid-state transformers (SSTs). SSTs, suitable for bidirectional power flow, eliminate the need for standard distribution transformers for EV chargers. Realistic testing in distribution environments will aid their acceptance [33].

A transformer OEM's margins depend on how well its portfolio addresses these requirements within competitive lead times

3.2. Siemens simcenter transformer simulation solution

Siemens Digital Industries Software collaborates with transformer OEMs to virtually validate designs before physical prototyping, reducing costly iterations. Using Simcenter, they extract the transformer's electro-thermal operating envelope for system-level analysis. Initial electrical sizing is done with TrafoSolve, an FEA-based tool for efficiency, insulation, and thermal analysis [34]. It is based on design rules and international standards from Infologic Design, our specialist transformer partner. Once the design is finalized, TrafoSolve exports a 3D geometry to Simcenter 3D, where the entire transformer CAD is assembled. Simcenter 3D synchronizes EMAG, CFD-thermal, structural, and NVH models to the same CAD, enabling faster multi--domain validation [35]. Reduced order models (ROMs) can then be extracted for creating physics-based digital twins.

The transformer workflow, as shown in Figure 4 and trackable through Teamcenter PLM, is easily deployed for major enterprises. For SMBs, which make up nearly 50% of global transformer OEMs, it is deployed through engineering services. While SMBs excel in specific areas, they require multi-domain validation to remain competitive. Simcenter 3D, being CAD-centric with flexible physics licensing, will helps SMBs cost-effectively validate transformer performance. For example, for offshore applications like wind and solar, structural-vibroacoustic analyses must include wind, wave, and ocean current loads, extracted using CFD. Correlating with test data from lower-rated transformers enables the development of higher ratings that cannot be tested on shakers.

3.3. Transformer digital twins

The failure of critical equipment can cripple datacenters, electrical grids, and generating plants, resulting in losses ranging from tens to hundreds of millions of US dollars. For example, Luc Paulhiac, Chief Transformer Expert at EDF, noted that a single power transformer failure can shut down a nuclear plant, costing €3-5 million per day, and up to €20 million in

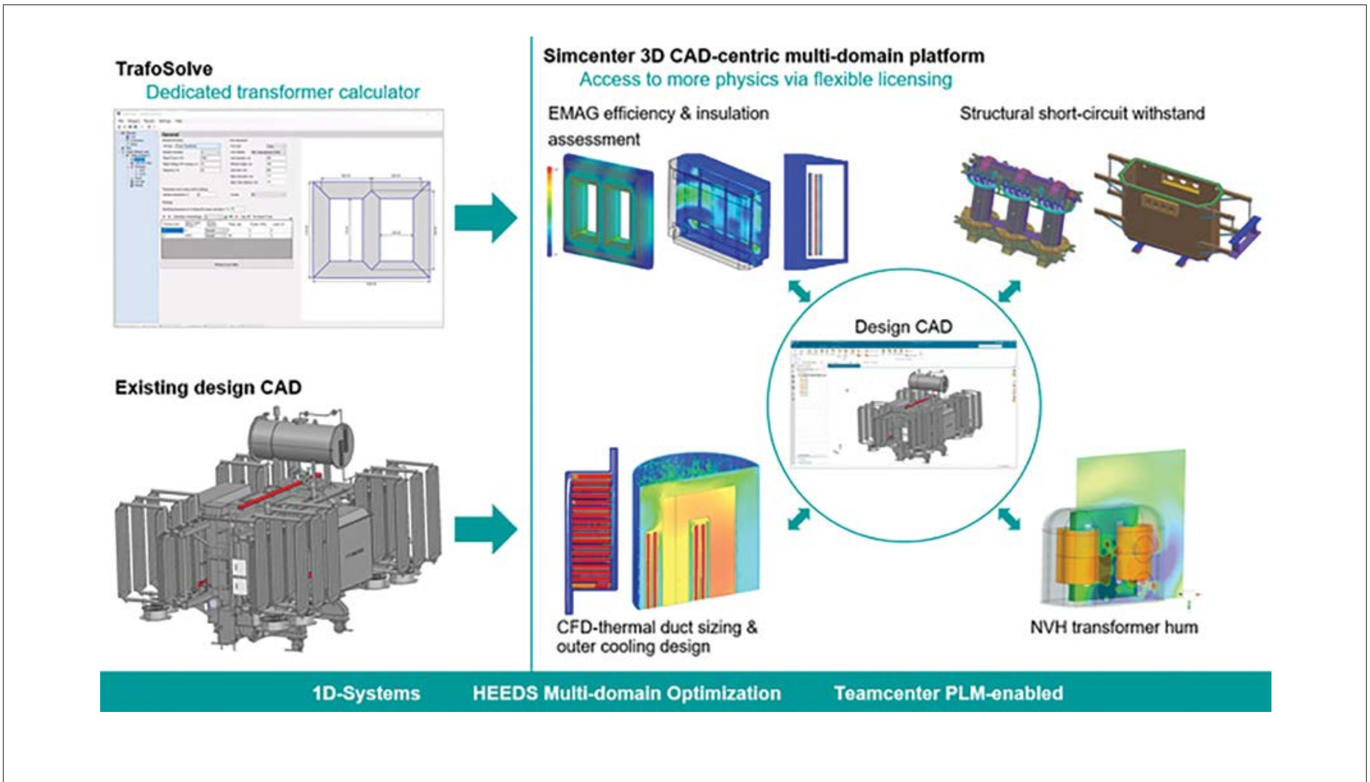

Figure 4. Simcenter transformer simulation solution for early electrical sizing, and detailed electrical and mechanical analysis

The failure of critical equipment can cripple datacenters, electrical grids, and generating plants, resulting in losses ranging from tens to hundreds of millions of US dollar

winter [36]. In 2024, the Point Lepreau Nuclear Generating Station's maintenance shutdown was extended from 98 to 248 days due to a generator problem, costing about CAD$71 million [37]. In 2022, Google and Oracle data centers in the UK went offline due to a heat wave, while Alibaba's in Hong Kong was down due to a cooling failure [38].

To mitigate financial losses, digital twins for monitoring and forecasting are becoming more prevalent. Hydro-Québec monitors the temperature, EMAG, and NVH signatures of hydro turbine-generators during planned shutdowns to minimize downtime [39]. EDF in France is equipping all main transformers with online monitoring [36], which is timely for critical power transformers over 40 years old in mature OECD markets. Due to the growing importance of information services for medical, financial, office, and social applications, data centers are mission-critical. Digital twins are needed to ensure power availability, affecting server load scheduling and thermal requirements and, thus, the data center's footprint. This leads to lower operating costs for remote data centers and renewables by efficiently deploying service crews, managing inventory, and scheduling maintenance.

As shown in Figure 5, a digital twin has two data streams: physical and virtual. Real-time data is processed into a historian-based digital twin. Adding physics and aging models, done on- or offline, allows prediction of non-historical events. For example, Open Grid Europe in Germany leveraged Simcenter Flomaster to evaluate safety risks in the existing gas pipeline network for new requirements and emergency scenarios [40]. According to Oladapo Ogidi, Senior Turbine Technology Engineer at RWE Offshore Wind GmbH, to fully benefit from physics-based digital twins, requires co-creation with OEMs, utilities, and software vendors. OEMs provide CAD and CAE models, qualification, and commissioning data. Utilities offer operational data with aging and event markers. Siemens Digital Industries Software integrates these data streams.

Figure 6 shows the AR real-time visualization of wind turbine blade deformation. Structural FEM analysis identified critical, hard-to-measure locations. Sensors at limited locations generated test data. Deploying an executable ROM that augmented the test, and virtual data gave insights into the stress and deformation of the turbine blade with a lower sensor count. This reduces monitoring costs while capturing data from hard-to-measure locations. It is ideal for offshore wind turbines, where multiple sensors are necessary.

Outlook and challenges

AI is driving a 5% CAGR in datacenter growth, significantly impacting the power sector. Reducing energy and environmental costs is crucial for their opera-

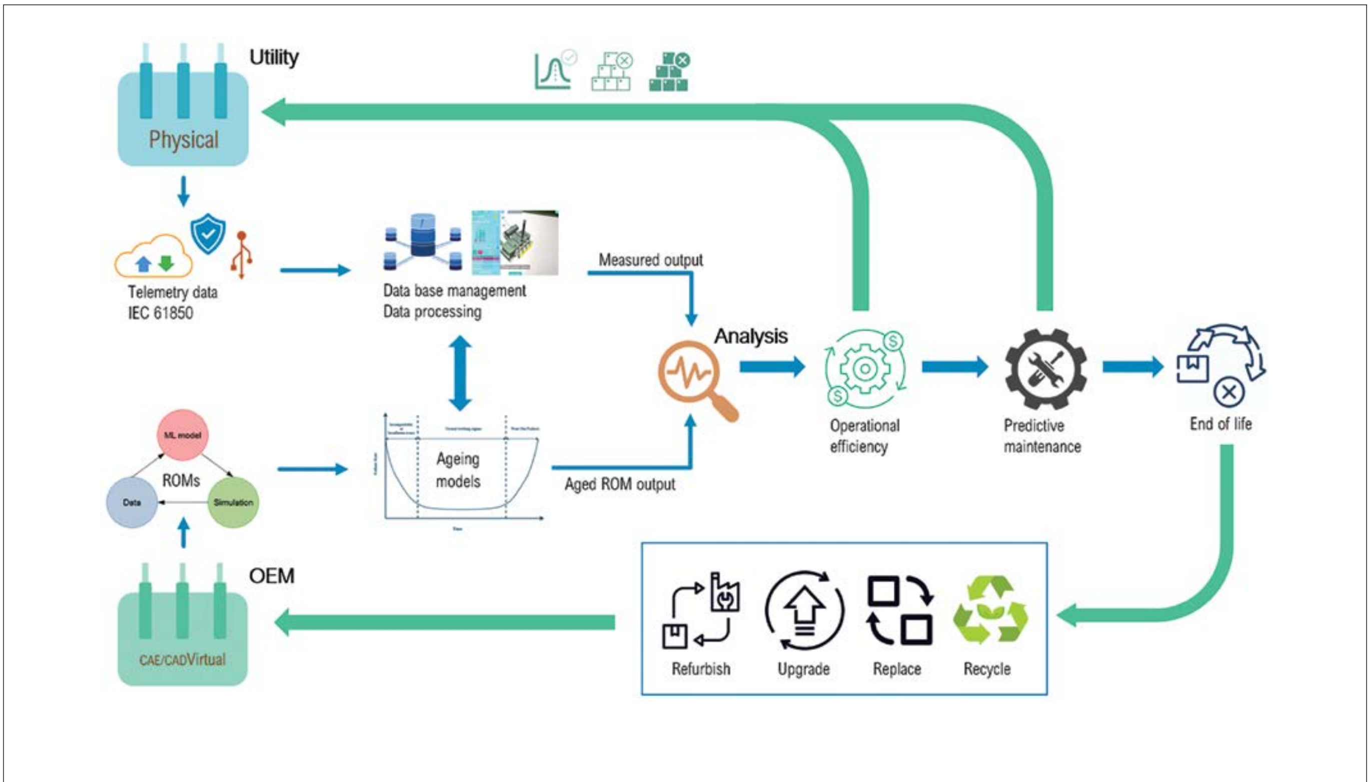

Figure 5. Typical data flow in a power transformer physics-based digital twin

tion. AI sustainability will focus on higher compute speeds, efficient models, and optimized thermal management. Using 3D-integrated and specialized chips like Groq enhances energy efficiency. Efficient LLM models like DeepSeek-V3 will further reduce training costs and emissions. Siemens EDA will continue collaborating with the semiconductor and electronics industry to verify 3D integrated circuits.

Advanced cooling methods, such as full server immersion and optimized algorithms will cut data center thermal energy use, which is 30-40% of total data center consumption. These improvements will drive upgrades, which must be done cost-effectively. Simcenter 1D-3D simulations can be leveraged to analyze energy and thermal loads from chips to cooling towers.

Transformers are crucial for the efficient transmission of the higher power needed for AI and grid modernization, driving their double-digit growth. Modern grids need higher-rated transformers for EV charging, interfacing low-carbon sources, and energy storage. OEMs must redesign transformers for increased power and reliability, facing challenges like investment, longer delivery times post-COVID, and expertise gaps affecting SMBs.

Greater adoption of simulation-driven development (SDD) will adapt existing transformer portfolios and create new designs cost-effectively. For example, to address supply chain constraints by incorporating available materials and parts, Siemens Digital Industries Software is partnering with OEMs for transformer development. TrafoSolve, an FEA-based transformer calculator for early design, and comprehensive multi-domain synchronization to the same design CAD in Simcenter 3D, are being used.

The transformer digital twins service market will grow, reducing costs by managing inventory and service crews and extending life. For data centers, the visibility of critical transformers in load scheduling ensures power availability and optimizes the thermal loads to reduce energy and environmental impact. Co-creation with OEMs, utilities, and software vendors like Siemens Digital Industries Software is essential.

Generative AI and electrification will continue advancing semiconductors, digitalizing utilities, and boosting transformer growth, including energy storage and renewable sources.

References

[1] Goldman Sachs, "Generative AI could raise global GDP by 7%," [Online]. Available: https://www.goldmansachs.com/insights/articles/generative-ai-could-raise-global-gdp-by-7-percent. [Accessed 27 January 2025].

[2] Wikipedia, "Generative artificial intelligence," [Online]. Available: https://en.wikipedia.org/wiki/Generative_artificial_intelligence. [Accessed 02 October 2024].

[3] M. Liu and H. S. Philip Wong, "How We'll Reach a 1 Trillion Transistor GPU," *IEEE Spectrum,* 28 March 2024.

[4] CNBC, "How The Massive Power Draw Of Generative AI Is Overtaxing Our Grid," [Online]. Available: https://www.youtube.com/watch?v=MJQIQJYxey4. [Accessed 02 October 2024].

[5] D. Danelski, "AI programs consume large volumes of scarce water," University

Figure 6. Simcenter real-time AR visualization of the deformation of a wind turbine blade

Generative AI and electrification will continue advancing semiconductors, digitalizing utilities, and boosting transformer growth, including energy storage and renewable sources

of California - Riverside, [Online]. Available: https://news.ucr.edu/articles/2023/04/28/ai-programs-consume-large-volumes-scarce-water. [Accessed 02 October 2024].

[6] S. Bangalore, A. Bhan, A. -D. Miglio, P. Sachdeva, V. Sarma, R. Sharma and B. Srivathsan, "Investing in the rising data center economy," McKinsey & Company, 2023.

[7] M. Banovic and A. Banovic, "Investments 2024 Outlook to 2033," Transformer Magazine, Merit Media Int., 2024.

[8] OpenAI, "Announcing The Stargate Project," [Online]. Available: https://openai.com/index/announcing-the-stargate-project/. [Accessed 27 January 2025].

[9] A. Ross, "Interview with Andreas Schierenbeck, Hitachi Energy CEO," Transformer Technology, 2024.

[10] The White House, "The Bipartisan Infrastructure Deal," [Online]. Available: https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/06/fact-sheet-the-bipartisan-infrastructure-deal/. [Accessed 03 October 2024].

[11] TSMC, "TSMC 3DFabric™ Alliance," [Online]. Available: https://www.tsmc.com/english/dedicatedFoundry/oip/3dfabric_alliance. [Accessed 20 January 2025].

[12] S. K. Moore, "Hybrid Bonding is the 3D-Chip Tech that's Saving Moore's Law," *IEEE Spectrum,* pp. 34-39, September 2024.

[13] BBC News, "AI chip makers battle for dominance," [Online]. Available: https://www.youtube.com/watch?v=wvFhr13J1kE&list=PLXVEiQojTEVuIOpeTksebUMON2yKASQh&index=3. [Accessed 02 October 2024].

[14] Wikipedia, "DeepSeek," [Online]. Available: https://en.wikipedia.org/wiki/DeepSeek. [Accessed 20 January 2025].

[15] Wikipedia, "GPT-4," [Online]. Available: https://en.wikipedia.org/wiki/GPT-4. [Accessed 20 January 2025].

[16] Siemens Digital Industries Software, "Siemens extends collaboration with TSMC to advance integrated circuit and systems design," [Online]. Available: https://newsroom.sw.siemens.com/en-US/siemens-tsmc-oip-na-2024/. [Accessed 14 January 2025].

[17] T. Mann, "Intel plans immersion lab to chill its power-hungry chips," The Register, [Online]. Available: https://www.theregister.com/2022/05/19/intel_immersion_lab/. [Accessed 17 January 2025].

[18] City of Palo Alto, "Sustainability and Climate Action Plan (S/CAP)," [Online]. Available: https://www.cityofpaloalto.org/City-Hall/Sustainability/SCAP. [Accessed 26 March 2024].

[19] City of Palo Alto, "Electrify Your Drive," [Online]. Available: https://www.cityofpaloalto.org/Departments/Utilities/Sustainability/Electric-Vehicle. [Accessed 26 March 2024].

[20] R. N. Charette, "The EV Transition Is Harder Than Anyone Thinks," *IEEE Spectrum,* 28 March 2023.

[21] P. Pradhan, I. Ahmad, D. Habibi, G. Kothapalli and M. A. S. Masoum, "Reducing the Impacts of Electric Vehicle Charging on Power Distribution Transformers," *IEEE Access,* vol. 8, pp. 210183-210193, 2020.

[22] J. Xia, "Council plans $150 million electric grid renovation," [Online]. Available: https://thecampanile.org/25820/news/council-plans-150-million-electric-grid-renovation/. [Accessed 03 October 2024].

[23] City of Palo Alto, "Grid Modernization for Electrification," [Online]. Available: https://www.cityofpaloalto.org/Departments/Utilities/Utilities-Services-Safety/Utilities-Projects/Grid-Modernization-for-Electrification. [Accessed 03 October 2024].

[24] Canada Energy Regulator, "Market Snapshot: Canada's retiring coal-fired power plants will be replaced by renewable and low-carbon energy sources," 29 January 2020. [Online]. Available: https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2020/market-snapshot-canadas-retiring-coal-fired-power-plants-will-be-replaced-renewable-low-carbon-energy-sources.html. [Accessed 04 October 2024].

[25] D. Chernicoff and M. Vincent, "Google and Amazon Make Major Inroads with SMRs to Bring Nuclear Energy to Data Centers," DATA CENTER Frontier, [Online]. Available: https://www.datacenterfrontier.com/energy/article/55235902/google-and-amazon-make-major-inroads-with-smrs-to-bring-nuclear-energy-to-data-centers. [Accessed 14 January 2025].

[26] WindEurope, "Wind energy in Europe: 2023 Statistics and the outlook for 2024-2030," WindEurope asbl/vzw, Brussels, 2024.

[27] X. Dong, "China to Achieve its 2030 Installed Clean Energy Target in July 2024," Climate Energy Finance, 2024.

[28] F. Chen and J. Siqi, "China's renewable energy 'fluctuations and volatility' could see Beijing supercharge power reforms," South China Morning Post, 28 June 2024. [Online]. Available: https://www.scmp.com/economy/economic-indicators/article/3268474/chinas-renewable-energy-fluctuations-and-volatility-could-see-beijing-supercharge-power-reforms?module=inline&pgtype=article. [Accessed 04 October 2024].

[29] Ministry of New and Renewable Energy, India, "Non-fossil fuel sources account for nearly 44 per cent of India's total installed electricity generation capacity," 06 December 2023. [Online].

Available: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1983201. [Accessed 04 October 2024].

[30] A. Timbus, J.-P. Gracia and K. Fant, "Transformer Connect: Renewable Energy Solutions," Hitachi Energy, [Online]. Available: https://www.hitachienergy.com/us/en/products-and-solutions/transformers/transformer-connect. [Accessed 04 October 2024].

[31] G. Ghatikar, M. Piette, S. Fujita, A. McKane, J. Dudley, A. M. K. Radspieler and D. Shroyer, "Demand Response and Open Automated Demand Response Opportunities for Data Centers," California Energy Commission, PIER Program and Pacific Gas and Electric Company (PG&E), 2010.

[32] A. Green, H. Tai, J. Noffsinger, P. Sachdeva, A. Bhan and R. Sharma, "How data centers and the energy sector can sate AI's hunger for power," McKinsey & Company, 2024.

[33] G. Mantov, "EPRI and 6 Utilities Demo SSPs' Solid State Powerhub," Solid State Power, [Online]. Available: https://www.solidstatepower.net/page6news.html#header2-d. [Accessed 15 January 2025].

[34] Infologic Design, "TrafoSolve," [Online]. Available: https://www.infologicdesign.co.uk/trafosolve. [Accessed 10 October 2024].

[35] Siemens Digital Industries Software, "Simcenter 3D software," [Online]. Available: https://plm.sw.siemens.com/en-US/simcenter/mechanical-simulation/simcenter-3d/. [Accessed 10 October 2024].

[36] L. Paullhiac, "Interview with Luc PAULHIAC Chief Transformer Expert at EDF," *Transformer Magazine,* 2024.

[37] R. Jones, "N.B. Power facing $71M bill for generator troubles at idle nuclear plant," CBC, [Online]. Available: https://www.cbc.ca/news/canada/new-brunswick/nb-power-bill-generator-trouble-point-lepreau-1.7271720. [Accessed 17 January 2025].

[38] T. Mann, "Refrigeration failure at Hong Kong datacenter takes out Alibaba Cloud and others," The Register, [Online]. Available: https://www.theregister.com/2022/12/20/alibaba_cloud_hong_kong_outage/. [Accessed 17 January 2025].

[39] F. Lafleur, "Hydro-Quebec Canadian energy provider uses Simcenter testing solutions to optimize power output," Siemens Digital Industries Software.

[40] SMART Engineering GmbH, "OGE leverages 1D CFD to design safe gas infrastructure and assess readiness for energy transition," Siemens Digital Industries Software.

[41] K. Quach, "Google, Oracle cloud servers wilt in UK heatwave take down websites," The Register, [Online]. Available: https://www.theregister.com/2022/07/19/google_oracle_cloud/. [Accessed 17 January 2025].

PEER REVIEWED

Author

John Wanjiku, PhD, is a Product Manager at Siemens Digital Industries Software. He has over 10 years of experience in the EMAG FEA analysis of electric and electromechanical devices, such as e-machines,

Other interests include the electro-thermal analysis for electronics packaging (3D-ICs and power converters), energy-thermal analysis for data centers, utility-scale battery energy storage, and centralized EV charging.

John is a Senior Member of IEEE, and its Industrial Application Society (IAS)

LinkedIn: https://www.linkedin.com/in/jwanjiku/