National Experts Program
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AI Report

How AI Can Empower Microgrids and Reinvent Electricity Markets

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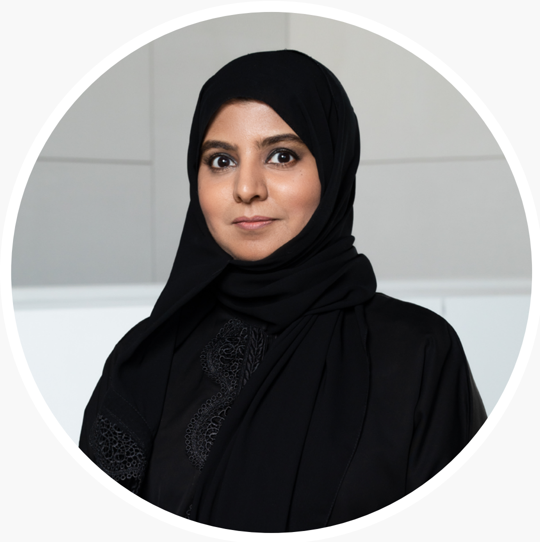

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Dr. Ameena Al-Sumaiti received her doctorate in Electrical and Computer Engineering from the University of Waterloo in 2015. She was a visiting professor at the Massachusetts Institute of Technology in 2017 and is currently teaching at Khalifa University in Abu Dhabi.

She has received more than 34 awards, privileges, and prestigious local and international fellowships, and has made significant contributions to society through capacity-building, education, and research. In 2021, she was listed in the top 2% of scientists in the world, and was shortlisted in a national talent search with 2000 applicants. In 2022, she served as session chair of the “Renewable Energy and Energy Storage” panel at the IEEE Power Electronics Drives and Energy Systems conference in Jaipur.

Dr. Al-Sumaiti is an expert in project management; operations research; energy policy and economics; energy and demand side management; strategic planning of smart cities and the water-electricity-gas-transport nexus; autonomous driving; risk, reliability and uncertainty of engineering systems; and data analytics.

Cities are coming under pressure because of growing electricity demand. This is making efficient electricity grid management absolutely critical—annual losses from grid problems are estimated at **$150 billion** in the US alone.[1]

Artificial intelligence (AI) and a range of other new technologies can solve this, as they provide an opportunity to transition from traditional central grids to microgrids. Microgrids have already been shown to reduce power outages and optimize profitability for utilities while cutting costs for consumers. AI is expected to substantially improve these metrics by enhancing the possibilities for microgrid management.

Some of the challenges associated with microgrids include:

- Predicting power generation and demand accurately
- Ensuring stable and high-quality power supply
- Enabling their participation in the electricity market
- Establishing a reliable communication network
- Leveraging the internet of things (IoT)
- Addressing security concerns
- Predicting natural hazards early
- Enabling predictive maintenance

The good news is that many of these challenges have already been addressed in other sectors.

The microgrid market is expected to grow rapidly in the years ahead (see Figure 1). Globally, it is already estimated to be worth almost **$19 billion**[2], with thousands of projects planned.[3] Microgrids are in place or have been commissioned in numerous countries, including Canada, Australia,[4] India,[5] China,[6] the UAE,[7] and Kenya.[8]

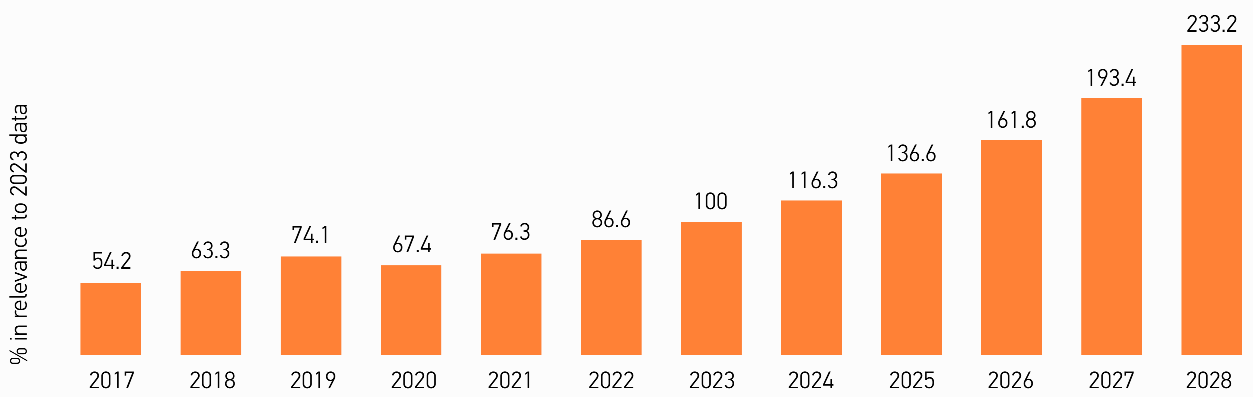

Figure 1: Microgrid Market: History & Growth Rate

To realize the market potential, AI developers and power producers need to work together to develop strategies for microgrid management. This report draws on recent publications and builds on current approaches to illustrate exactly how AI can help electric utilities improve their microgrid management.

Managing microgrids with AI

Microgrids have to be configured with a range of energy infrastructure, such as renewables plants, energy storage systems, power lines. They also need to take into account power loads elsewhere on the network. Balancing these demands requires an energy manager to ensure reliable, secure operations and to communicate any potential problems.

AI can transform microgrid operations, but to do so, four areas will need to be addressed:

01 **Fostering research and development projects.** AI features prominently on the research and development agenda for microgrids as it can play a pivotal role in driving technological advancements and fostering future projects. This work can feed into the buildout of smart cities, particularly around long-term infrastructure planning and short-term operational planning.

02 Creating microgrid databases. Real-time data streaming eliminates the need for a complementary analytics layer.[10] However, the selection of appropriate AI algorithms will depend on the volume of data and its application. Machine learning could also be deployed to reduce currently extensive coding times for databases.[10]

03 Stimulating new market opportunities. AI can drive new market opportunities for both electric utilities and consumers. In traditional centralized power grids, end users can sell surplus energy to the main grid. With decentralized microgrids, users and operators could sell and buy electricity from other microgrids. Startups as well as larger businesses could benefit from this. Consultancy firms could also benefit.

04 Enabling value chains. Microgrids can connect to larger grids or operate off-grid. AI can improve operations in both cases by enabling real-time information streaming, data analysis, and communication between grids.

How AI can scale up microgrid innovation

Smart microgrids are a vital component of smart cities. AI could create autonomous microgrids that can monitor and control operations, ensuring steady electricity supplies for users (see Figure 2).

Microgrid feature	Before AI	After AI
Power form	Bulk	Distributed generation
Power flow	Uni-directional	Bi-directional
Power value	Predictable	Uncertain

Figure 2

Construction costs for microgrids vary, depending on project scope, but tend to range from **$2 million** to **$4 million** per megawatt.[12] AI could help define the optimal locations and sizes for microgrids, saving not just money, but also time spent on adding junctions to networks, for example.

AI can also support microgrids by offering predictive maintenance.[13] Machine learning algorithms can predict when components may need replacing or other repairs may be needed, as well as gauging the time needed for maintenance. Again, this can save not just money, but also time.

> **“As the smart homes market grows,[14] there will be increased data on how and when customers use electricity. Linking these homes with AI predictive controls, intelligent communication networks, and autonomous microgrids offers huge potential.”**

Improving energy management could not just reduce energy use, but also cut emissions.[15]

AI and machine learning are already helping around a third of commercial building vendors to offer energy management and sustainability services.[16] IBM's Watson IoT platform is allowing facility management that can improve energy efficiency in buildings, while Verdigris and Bidgely focus on energy data analytics.[15]

Finding the right roles for AI in energy management

The global value of AI in the energy management market was estimated at **$4.4 billion** in 2018, but this is forecast to grow to **$12.2 billion** by 2024.[17] The integration of IoT is already happening at pace,[18] and North America and Europe accounted for over **50%** of the use of AI for energy management in 2018.[17] But realizing the market's potential will depend on identifying where AI offers the best value and biggest opportunities. It will also depend on tackling current challenges, such as the need for accurate estimations of renewable power generation—which is intermittent by nature—and the variability of load demand. Ensuring security around the grid and its energy transactions with consumers will also be critical.

AI appears best suited to help with energy management in five key areas:

01 Accurate forecasting of load demand and renewable energy generation. Forecasting demand and supply is

Load forecasting

Short term	Medium term	Long term
1 hour – 1 week	1 week – 1 year	>1 year

Applications: (Short term)
- Demand side management
- Power generator monitoring
- Dispatching electricity generation

Applications: (Medium term)
- Microgrid maintenance
- Setting prices of electricity
- Specifying approaches for power distribution

Applications: (Long term)
- Estimating needed power capacity
- Network expansion

Figure 3

crucial for balancing any grid or microgrid.[19] Historical and probabilistic data can be used for this and could make short, medium, or long-term forecasts (see Figure 3).[20-22]

AI algorithms would be able to filter out inaccurate statistical models, thereby preventing inaccurate forecasting that could result in electricity shortages and extra power purchases, creating financial burdens for grid operators. This could also prevent the production of surplus power. [23]

Similarly, forecasting levels of renewable energy generation would optimize decisions around energy storage, energy supply scheduling, and peer-to-peer energy trading.

> **AI can examine factors that will influence energy production—temperature variability, solar irradiance, wind speeds[24]—and could also predict and prevent generation losses, for instance by scheduling robotic cleaning of dirty solar photovoltaic panels.**

AI forecasting could also help determine the right size for a microgrid at the design stage.[25] It could consider not just present-day issues, but also future developments such as population growth, load demand forecasts, and the availability of funding for more renewable energy in the area.

02 Improved microgrid stability, power quality, and protection. Voltage, frequency control, power sharing, and power balances all influence microgrid stability.[26] The parameters of other system equipment also have an influence.

The increasing penetration of renewable energy into microgrids and the rising use of power inverters that can turn direct current into alternating current create issues around grid inertia and power stability.[27] Traditional stability evaluations consider the physical qualities of the system and combine this with mathematical calculations. With its higher levels of accuracy and efficiency, AI could help resolve stability problems. It could directly track numerous physical parameters in real time and react accordingly.[28] Its data-based models can replace complicated power system models.[29]

Power quality can also be boosted with AI. Power quality is the degree to which the voltage, frequency, and waveform of power supply meet set specifications.[30] Inadequate power quality can result in equipment malfunctions—creating a need for repairs or replacements—and potential instability in power supplies.[31] Traditional power quality assessments rely on time-consuming visual inspections, combined with complex mathematical analysis. Using monitoring equipment for data collection is a first step to allowing AI to assess power quality.

AI tools such as expert systems, fuzzy logic, and neural networks can quickly analyze power lines and power quality. They can also complement existing analytical methods such as wavelet transform analysis.[32-33] Moreover, AI can support computational systems in detecting substantial variations in power systems and can subsequently adjust system settings to respond as situations arise. [34] A system that can do this has been developed at the University of St. Thomas in the US;[35] real-time simulation of AI-based fault detection for a microgrid has also been demonstrated.[36]

03 Communication, IoT, and security. The shift towards smart microgrids will only be possible with intelligent communication infrastructure. These networks establish connections between microgrid components and allow rapid responses to variations in power generation, load demand, voltage, current, and frequency. Ultimately, this is what drives more effective energy management within microgrids.

AI could not only be involved in the running of these communication networks, but could also design, analyze, and maintain them. The Catalonia Energy Research Institute (IREC) follows an international standard defining communication protocols for smart electronic devices of electrical substations

(IEC 61850). Elements of this microgrid communicate over the communication network through a Controller Area Network (CAN bus) or Modbus [37], a protocol developed for enabling communication among automated devices.[38] In addition, a flagship 6G program has begun at Finland's University of Oulu, aiming for global adoption of the technology by 2030.[39] Integrating this with renewable energy systems and microgrids could enable faster, more reliable, and more secure communications.[40]

Applying IoT in microgrids can also improve energy management as it allows real-time analysis of electricity usage.[41] AI can support IoT in deriving insights from this data while ensuring data privacy and security.[42] AI's capabilities in data learning could also help optimize 6G network performance, boosting opportunities around IoT communications.[43]

On the security front, AI can be trained to understand system operations, identify vulnerabilities in defense mechanisms, and suggest enhancements to security measures. AI could also learn advanced encryption techniques to help counter concerns around data privacy related to smart meters.

04 **Electricity market competition.** AI has the potential to restructure electricity markets, pushing them away from centralized monopolies toward a series of microgrids that operate as competing utilities. Algorithms could oversee energy pricing mechanisms, amending them in line with supply and demand dynamics.

AI is a possible game-changer for energy price forecasting and facilitating peer-to-peer energy trading. The Brooklyn Microgrid in the US was the first to show the potential of peer-to-peer microgrids in 2016, and was expanded after a year to include additional neighborhoods.[44] Another attempt to scale peer-to-peer energy trading is taking place in Thailand with a platform that buys and sells electricity from factories fitted with rooftop solar panels.[45] The Sonnen Community in Germany is using a peer-to-peer energy trading platform alongside energy storage technology.[46]

Peer-to-peer energy trading reduces electricity costs for consumers compared with grid purchases, as while grids charge transportation costs, microgrids are located close to consumers.[47]

From a climate perspective, peer-to-peer energy trading can accelerate the transition from fossil fuels to green energy by using AI to identify and predict potential variations in renewable generation, creating estimates of power purchase volumes and times.

05 **Prediction of natural disasters, plus predictive maintenance.** As has been seen in the US with hurricanes, natural disasters can damage infrastructure.[48] NASA's Jet Propulsion Laboratory has developed an AI algorithm that predicts the intensification of tropical storms and hurricanes,[49] while an open AI model based on a support-vector classifier has been shown to predict electrical outages caused by storms with **81%** accuracy.[50]

> **"AI can also analyze images of equipment to assess whether maintenance is needed, potentially saving companies large amounts of money."**

Fires damage around **3,000 electric utility** poles every year in the US, largely as a result of leaks and other damage not being addressed quickly enough. Each fire costs utility companies an average of **$25,000**. AI technology that analyzes digital images to identify defects, abnormalities, and other potential maintenance risks can allow companies to address issues before damage occurs.

The next steps for AI in microgrid management

Governments, regulators, policymakers, utilities, and downstream industries are key players contributing to how microgrids operate. They must work together to define a framework for the integration of AI into microgrid operations.

Governments can have a principal role in the early deployment of AI. Roadmaps setting out strategies for the implementation of AI must be focused on what final outcomes need to be achieved. They should also identify potential investment sources and teams to support implementation of the technology.

Microgrid utilities will benefit from AI as it can help them define optimal configurations and analyze operational data to improve energy management. AI is essentially a physician that can assess the health of a microgrid and provide suggestions to both improve the system as it stands and prevent future problems.

End users can use AI to better understand their own behavior, allowing them to adjust their energy use and electricity bills.

Policymakers and energy utilities can work together to minimize energy consumption and greenhouse gas emissions. Downstream industries can use AI to improve equipment and system designs to align with energy use and environmental standards.

All stakeholders need strategies to outline the potential opportunities and how they can capture them. Investments in AI technology can be recovered through long-term cost reductions in operations, energy trading, and maintenance. AI can also mitigate risk around electricity price fluctuations.

There are multiple opportunities, but there are also risks that should not be ignored. While AI could open new research, job, and market opportunities in energy management, diligence will be required around the accuracy of AI algorithms. Data bias is another potential problem, and data privacy is a critical concern, with increased data use creating increased risks around cyberattacks and data theft.

The best way forward is stakeholder collaboration, developing best practice, and constantly reassessing this as the market evolves.

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