Making electric energy systems future-ready through multiple forms of power generation

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Marija Ilic—a senior research scientist at the Laboratory for Information and Decision Systems, affiliate of the MIT Institute for Data, Systems, and Society, senior staff in MIT Lincoln Laboratory's Energy Systems Group, and Carnegie Mellon University professor emerita—is a researcher on a mission: making electric energy systems future-ready.

Since the earliest days of streetcars and public utilities, electric power systems have had a fairly standard structure: for a given area, a few large generation plants produce and distribute electricity to customers. It is a one-directional structure, with the energy plants being the only source of power for many end users.

Today, however, electricity can be generated from many and varied sources—and move through the system in multiple directions. An electric power system may include stands of huge turbines capturing wild ocean winds, for instance. There might be solar farms of a hundred megawatts or more, or houses with solar panels on their roofs that some days make more electricity than occupants need, some days much less. And there are electric cars, their batteries hoarding stored energy overnight. Users may draw electricity from one source or another, or feed it back into the system, all at the same time. Add to that the trend toward open electricity markets, where end users like households can pick and choose the electricity services they buy depending on their needs. How should systems operators integrate all these while keeping the grid stable and ensuring power gets to where it is needed?

To explore this question, Ilic has developed a new way to model complex power systems.

Electric power systems, even traditional ones, are complex and heterogeneous to begin with. They cover wide geographical areas and have legal and political barriers to contend with, such as state borders and energy policies. In addition, all electric power systems have inherent physical limitations. For instance, power does not flow in a set path in an electric grid, but rather along all possible paths connecting supply to demand. To maintain grid stability and quality of service, then, the system must control for the impact of interconnections: a change in supply and demand at one point in a system changes supply and demand for the other points in the system. This means there is much more complexity to manage as new sources of energy (more interconnections) with sometimes unpredictable supply (such as wind or solar power) come into play. Ultimately, however, to maintain stability and quality of service, and to balance supply and demand within the system, it comes down to a relatively simple concept: the power consumed and the rate at which it is consumed (plus whatever is lost along the way), must always equal the power produced and the rate at which it is produced.

Using this simpler concept to manage the complexities and limitations of electric power systems, Ilic is taking a non-traditional approach: She models the systems using information about energy, power, and ramp rate (the rate at which power can increase over time) for each part of the system—distributing decision-making calculations into smaller operational chunks. Doing this streamlines the model but retains information about the system's physical and temporal structure. "That's the minimal information you need to exchange. It's simple and technology-agnostic, but we don't teach systems that way."

She believes regulatory organizations such as the Federal Energy Regulatory Commission and North American Energy Reliability Corporation should have standard protocols for such information exchanges, just as internet protocols govern how data is exchanged on the internet. "If you were to [use a standard set of] specifications like: what is your capacity, how much does it vary over time, how much energy do you need and within what power range—the system operator could integrate different sources in a much simpler way than we are doing now."

Another important aspect of Ilic's work is that her models lend themselves to controlling the system with a layer of sensor and communications technologies. This uses a framework she developed called Dynamic Monitoring and Decision Systems framework, or DyMonDS. The data-enabled decision-making concept has been tested using real data from Portugal's Azores Islands, and since applied to real-world challenges. After so many years it appears that her new modeling approach fittingly supports DyMonDS design, including systematic use of many theoretical concepts used by the LIDS community in their research.

One such challenge included work on Puerto Rico's power grid. Ilic was the technical lead on a Lincoln Laboratory project on designing future architectures and software to make Puerto Rico's electric power grid more resilient without adding much more production capacity or cost. Typically, a power grid's generation capacity is scheduled in a simple, brute-force way, based on weather forecasts and the hottest and coldest days of the year, that doesn't respond sensitively to real-time needs. Making such a system more resilient would mean spending a lot more on generation and transmission and distribution capacity, whereas a more dynamic system that integrates distributed microgrids could tame the cost, Ilic says: "What we are trying to do is to have systematic frameworks for embedding intelligence into small microgrids serving communities, and having them interact with large-scale power grids. People are realizing that you can make many small microgrids to serve communities rather than relying only on large scale electrical power generation."

Although this is one of Ilic's most recent projects, her work on DyMonDS can be traced back four decades, to when she was a student at the University of Belgrade in the former country of Yugoslavia, which sent her to the United States to learn how to use computers to prevent blackouts.

She ended up at Washington University in St. Louis, Missouri, studying with applied mathematician John Zaborszky, a legend in the field who was originally chief engineer of Budapest's municipal power system before moving to the United States. ("The legend goes that in the morning he would teach courses, and in the afternoon he would go and operate Hungarian power system protection by hand.") Under Zaborszky, a systems and control expert, Ilic learned to think in abstract terms as well as in terms of physical power systems and technologies. She became fascinated by the question of how to model, simulate, monitor, and control power systems—and that's where she's been ever since. (Although, she admits as she uncoils to her full height from behind her desk, her first love was actually playing basketball.)

Ilic first arrived at MIT in 1987 to work with the late professor Fred Schweppe on connecting electricity technologies with electricity markets. She stayed on as a senior research scientist until 2002, when she moved to Carnegie Mellon University (CMU) to lead the multidisciplinary Electric Energy Systems Group there. In 2018, after her consulting work for Lincoln Lab ramped up, she retired from CMU to move back to the familiar environs of Cambridge, Massachusetts. CMU's loss has been MIT's gain: In fall 2019, Ilic taught a course in modeling, simulation, and control of electric energy systems, applying her work on streamlined models that use pared-down information.

Addressing the evolving needs of electric power systems has not been a "hot" topic, historically. Traditional power systems are often seen by the academic community as legacy technology with no fundamentally new developments. And yet when new software and systems are developed to help integrate distributed energy generation and storage, commercial systems operators regard them as untested and disruptive. "I've always been a bit on the sidelines from mainstream power and electrical engineering because I'm interested in some of these things," she remarks.

However, Ilic's work is becoming increasingly urgent. Much of today's power system is physically very old and will need to be retired and replaced over the next decade. This presents an opportunity for innovation: the next generation of electric energy systems could be built to integrate renewable and distributed energy resources at scale—addressing the pressing challenge of climate change and making way for further progress.

"That's why I'm still working, even though I should be retired." She smiles. "It supports the evolution of the system to something better."

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