

Design Automation and the Smart Grid

Peter Feldmann, David Kung, and Jinjun Xiong
IBM T. J. Watson Research Center, Yorktown Heights, NY, USA

Notice of Copyright

This material is protected under the copyright laws of the U.S. and other countries and any uses not in conformity with the copyright laws are prohibited. Copyright for this document is held by the creator — authors and sponsoring organizations — of the material, all rights reserved.

DESIGN AUTOMATION CONFERENCE

Article: Electrical Power Systems and Smart Grids

Design Automation and the Smart Grid

Peter Feldmann, David Kung, and Jinjun Xiong

IBM T. J. Watson Research Center, Yorktown Heights, NY USA

Abstract—The current effort to modernize and informatize the century-old national electrical power system infrastructure should benefit from the experience and know-how of the sister discipline of electronic design, which evolved in full symbiosis with the computer era. This article draws attention to, and presents examples of, analogies and potential synergies existing between two electrical engineering disciplines – Electronics and Power Systems Engineering – which so far have followed nearly separate evolutions. The commonality that is most relevant to the Electronic Design Automation community is that both disciplines rely heavily on computational tools for design, analysis, and efficient management. This article, along with the newly created *International Workshop on Synergies between Design Automation and Smart Power Grid*, aims to trigger fruitful, bidirectional exchanges between the respective design tool professionals who, despite their shared theoretical frameworks, have for mainly historical reasons had only limited opportunities to communicate in the past.

Index Terms— design automation, power systems, electronic circuits, smart grid, circuit simulation, load flow, design optimization

I. INTRODUCTION

“Academic Paper in China Sets Off Alarms in U.S.” ran the headline of a *New York Times* story in which a U.S. military strategist warned the House Foreign Affairs committee of a Chinese publication that described how to cause a cascading failure of the entire United States power grid. The strong reaction of some politicians to this incident highlights the importance of the power grid as the lifeline of our country, and the urgency associated with making our power grid “smart”. A smart grid [1] will supply more energy with a reduced carbon footprint; incorporate renewable and distributed sources of energy such as wind, solar and storage technologies; heal itself when compromised; and provide visibility to end consumers for energy and cost savings. Developed economies must meet these ambitious goals mainly through more efficient exploitation of existing infrastructure, rather than heavy investment in new power plants and transmission lines; emerging economies should be empowered to build modern, efficient, clean energy infrastructure at lower costs.

These ambitious goals present many new challenges. The variability and unpredictability of renewable sources will create tremendous control and management challenges whenever they produce significant fractions (over 15%) of the electricity supply. Moreover, the electrical grid will have the problem of transporting this energy over long distances from places abundant in wind or sunshine toward population and industrial centers. Another future challenge comes from the electrification of transportation: chargeable electrical vehicles, when deployed on a large scale, will add terawatts of power demand and overwhelm existing distribution networks. Furthermore, new technologies increasingly favor distributed generation of electricity, from smart buildings and fuel-cell generators to small wind and solar farms. This is a significant departure from the existing centralized network where a few central power generators produce and distribute the electrical energy to a large number of users.

Satisfying the exponential growth of demand and new carbon emission requirements, while maintaining the reliability and security of the electricity supply, would under the existing paradigm require enormous investments in both classic and renewable generation, as well as significant upgrades of transmission and distribution infrastructure. The *Smart Grid* represents a vision of fully exploiting technologies available in the Information Age in order to increase the overall efficiency of the electrical power system and achieve capacity, reliability, environmental, and security goals with significantly reduced investment in physical infrastructure. The Smart Grid vision has been compared to the internet revolution. The old paradigm where power is “broadcast” from several central power generators to a large number of users will be replaced by the Smart Grid, which is capable of routing power “optimally” to respond to a very wide range of conditions, while maintaining reliable, economical, and secure distribution of the electrical energy. To achieve its purpose, the Smart Grid must harness vast amounts of real-time information supplied by sensors, “smart” meters, “smart” appliances, energy market signals, weather data, and social event information. This information will be supplied over secure and resilient communication networks, and then screened, verified, analyzed, digested, and visualized for both human operators and automatic control systems.

II. Potential Synergies between DA and Smart Grid

The Smart Grid presents countless opportunities for the Electronic Design Automation (EDA) community. The deployment of the Smart Grid involves disciplines such as system management, simulation, modeling, optimization, fault detection, and security, all of which are employed at large scales in the design of electronic systems. The modernization of the world's electricity system to achieve the characteristics of a Smart Grid – namely, achieving efficiency, reliability, resiliency, and security through full exploitation of the massive amount of available data – is of highest priority in today's energy-constrained environment. These characteristics are also important metrics for hardware development, and Design Automation has over several decades made substantial progress in improving these metrics. The complexity of large-scale integrated circuit designs is at least on par with, if not worse than, that of upcoming smart power grids. And there are opportunities in the opposite sense as well: it is very likely that methods and techniques used for the analysis, design, and management of electrical power systems will find applications in the design of electronic systems.

There are concrete analogies between the world of energy and the world of chips. The most obvious ones are embodied in the on-chip power grids that must supply good-quality voltage to hundreds of millions of consumers (logic circuits), over a network constrained by real estate (available metal resources), and transmission capability (limitation of pins and wires). All of these challenges resonate with designers of on-Earth electric power grids. In an even closer analogy, on-chip power grid must limit switching noise, and one favorite method for achieving this is by optimally placing decoupling capacitors (decaps). The electric power grid faces a similar challenge to limit disturbances and instabilities in the network, by optimally deploying scarce and very expensive components: capacitors, inductors and storage elements such as batteries or flywheels. The scale of on-chip power grid simulations has reached many hundreds of millions of equations, as demonstrated by the IBM proprietary simulator ALSIM [2] using the WSMP sparse matrix solver [3] in the design of the new Power7 chip. By contrast, there are no reports of production use of electric power grid simulations of this magnitude, and problems involving tens or hundreds of thousands of "buses" are considered very large.

Circuit simulations at the chip level sometimes have different formulations than electrical power grid problems. For example, simulations of on-chip circuits are expressed and solved in terms of time-domain currents and voltages, while power system simulations involve complex power and voltage variables – and even the solution of linear circuits involves solving quadratic equations: $P=YV^2$. Nevertheless, both use very similar mathematical and numerical analysis framework (large systems of algebraic and differential equations; DC, AC and stability analyses; model-order reduction; etc.).

Both on-chip and on-Earth power grids require extensive use of optimization at many levels. In VLSI chip design, a common challenge is to maximize circuit performance subject to area and power constraints. In the design and management of electric power systems, frequent optimization activities entail computation of *optimal power flow* and *economic dispatch*. In optimal power flow, the simulator must calculate the flows in the AC network that result from any given combination of unit commitment and generator megawatt dispatch, and ensure that AC line flows are within both the thermal limits (lines do not overheat) and the voltage and stability constraints. Economic dispatch determines the most efficient, low-cost and reliable operation of a power system by dispatching the available electricity generation resources to supply the load on the system. The primary objective of economic dispatch is to minimize the total cost of generation while honoring the operational constraints of the available generation and transmission resources.

Simulation and optimization are not the only commonalities between the worlds of EDA and power engineering. Significant overlaps exist in other arenas. The Smart Grid will be outfitted with monitors and sensors in generation stations, distribution networks, and consumer households to enable dynamic control and management schemes that optimize both reliability and the quality and cost of service. Similarly, on-chip sensors and monitors are widely deployed in integrated circuits to enable dynamic voltage and frequency scaling schemes for power, performance and reliability optimization. Efficient fault diagnosis in power grids is critical for rapid service restoration and reliability improvement. A smarter power grid supplies orders of magnitude more data from the added sensors and monitors. Sophisticated statistical and data analytic techniques are required to analyze these complex data to identify causes of faults. For integrated circuits, fault diagnosis faces a similar data explosion as a result of the doubling of transistor density with each technology node. For each of these commonalities, it is certainly conceivable that new ideas and approaches can emerge from exploring the synergy between Design Automation and the Smart Grid.

Although there are many similarities between the design of an electric power grid and an on-chip power grid, some significant differences exist that have traditionally set apart the two communities that respectively study and design these objects. From a high-level perspective, one of the major differences can be attributed to the different degrees of controllability and observability in these two systems. A chip is designed once, then manufactured in massive quantities; the on-chip power grid is not modified once the chip is fabricated. An on-chip power grid design is typically static, e.g., with a fixed number of power pads, a fixed power grid topology and size, and fixed decap sizes and locations. Dynamic addition or removal power pads for on-chip power grids has never been reported, while dynamic reconfiguration of decap sizes and locations is rarely used [5] due to cost vs. benefit considerations. In terms of observability, there is no easy way to observe the dynamic on-chip power grid droops (voltage fluctuations). Recently, some researchers have proposed to add on-chip sensors [7,8] to observe certain dynamic characteristics of on-chip power grids, with the sensing data enabling some feedback control mechanism to improve the controllability and stability of the on-chip power grid [6]. But this is still an exotic approach, and its practice has been limited. Because of their limited controllability and observability, on-chip power grids are typically over-designed, i.e., using the static worst case to bound the mostly unlikely worst dynamical scenarios.

This is in sharp contrast with the on-Earth power grid design. First, the electricity power grid is designed and modified over a long period of time: its topologies, power generation sources (i.e., number of generators and types of generators), decoupling capacitor banks, and power line capacities are under continuous repair and improvement. The reason is simple: we do not have the luxury of having multiple copies of the electricity power grid – there is only one instance. Second, the electricity power grid provides great flexibility in terms of controllability and observability. For example, load shaping is used to control the amount of loading on the grid by price incentives and, in extreme conditions, by intentionally shutting off certain users in certain geographical areas from access to electrical power. Switches and relays are all frequently used in substations to control the smooth operation of electricity power grid. Besides traditional meters or even recent smart meters, there are also many systematically placed SCADA (Supervisory Control And Data Acquisition) sensors and PMUs (Phasor Measurement Units) in the power grid. These sensors provide continuous observations of the operational status of the grid, such as fully synchronized phasor information. Thanks to this high degree of controllability and observability of the electricity power grids, we can comprehend in real time and in great detail the dynamic nature of power grid operations. Ironically, all of these flexibilities are far from being fully exploited to achieve optimal electrical power grid design and operation. On the contrary, the electrical power grid is currently designed and operated even more conservatively than an on-chip power grid, where worst-case design is the norm. Such

conservatism stems from the enormous societal importance of reliable electricity service – measured in its economic impact and the human lives dependent on it – along with the lack of good analysis tools, and the absence of backup solutions (there is but one electricity power grid).

The grand challenge facing Smart Grids is how to utilize the past and present observable power grid status, along with other available information sources such as weather or market data, renewable sources, pluggable electric cars, etc. to provide accurate control of the operational “smart” grid without compromising its reliability. This grand challenge is further broken down into six major research challenges that we believe are instrumental to the success of smart power grid: (1) large scale power grid simulation, (2) power grid optimization, (3) real-time power and load management, (4) effective power contingency analysis and fault simulation, (5) continuous power grid improvement, and (6) secure power grid operation. All of these challenges are traditional topics that the EDA community has tackled since its inception, culminating with today's billion-gate chip designs. Hence our belief that the new *International Workshop on Synergies between Design Automation and Smart Power Grid*, organized around these challenges, will provide a valuable forum to bridge the gap between the Electronic Design Automation and Smart Power Grid communities.

III. Conclusion

In conclusion, we have noted numerous analogies and areas of overlap between the disciplines of designing large-scale integrated circuits and designing electrical power systems. It would be extremely beneficial for the EDA community to better understand the challenges of smart power grids, and for the Power Engineering community to get a glimpse of the technical expertise that is well-established in the field of Electronic Design Automation. Collaboration between the two communities on cross-disciplinary research problems is bound to both accelerate the progress of Smart Grids and expand the scope of DA.

REFERENCES

- [1] *Smart Grid System Report*, U.S. Department of Energy, July 2009.
- [2] S. Nassif and J. Kozhaya, “Fast Power Grid Simulation”, *Proc. Design Automation Conference*, 2000, pp. 156-161.
- [3] A. Gupta, “WSMP: Watson Sparse Matrix Package”, *Technical Report*, IBM Research Division, 2000.
<http://www-users.cs.umn.edu/~agupta/wsmp.html>.
- [4] J. Xu, P. Hazucha, M. Huang, P. Aseron, F. Paillet, G. Schrom, J. Tschanz, C. Zhao, V. De, T. Karnik and G. Taylor, “On-Die Supply-Resonance Suppression Using Band-Limited Active Damping”, *Proc. IEEE Intl. Solid-State Circuits Conf.*, 2007, pp. 286–288.
- [5] M. Ang, R. Salem and A. Taylor, “An On-Chip Voltage Regulator Using Switched Decoupling Capacitors”, *Proc. IEEE Intl. Solid-State Circuits Conf.*, 2000.
- [6] Y. Shi, J. Xiong, H. Chen and L. He, “Stochastic Current Prediction Enabled Frequency Actuator for Runtime Resonance Noise Reduction”, *Proc. Asia and South Pacific Design Automation Conference*, 2009.
- [7] J. Liu and R. Makki, “SRAM Test Using On-Chip Dynamic Power Supply Current Sensor”, *Proc. Intl. Workshop on Memory Technology, Design and Testing*, 1998.
- [8] Y. Lechga, R. Mozuelos, M. Martinez and S. Bracho, “Built-in Dynamic Current Sensor for Hard-to-Detect Faults in Mixed-Signal ICs”, *Proc. Design Automation and Test Europe (DATE)*, 2002.