

Pushing the Mathematical Envelope: Case Studies in Solving Modern Electrical Engineering Challenges

Like engineers in every major discipline, electrical engineers are facing mathematical challenges like never before.

Today there is a greater emphasis than ever on issues such as:

- Sustainability – obtaining clean, reliable sources of energy that satisfy geopolitical demands
- Efficiency – as human demands for electricity increase and evolve at different paces
- Smart technology – as consumers demand greater efficiency, control and customization

For electrical engineers, smarter systems that are more efficient and meet higher expectations for cleaner energy – and the complex mathematics that they require – are at the core of meeting these sophisticated, modern challenges. The need to provide sustainable, efficient and smart energy solutions has never been more critical – and difficult. Electrical engineers are facing unprecedented pressure to tackle some of the most cutting-edge problems in the world. The world is experiencing a rapid transformation where people are demanding greater access to renewable sources of energy, and where technology provides solutions before the consumer realizes they have a problem.

When we look at the engineering calculations that can solve these issues, we often find that they are complex and difficult to manage. It is no longer sufficient to have engineering calculations, an organization's intellectual property, locked away in spreadsheets and traditional engineering notebooks.



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Fortunately, mathematical technology has evolved to give engineers solutions that, if used properly, can be very effective. Design and calculation software gives electrical engineers the tools to solve today's most pressing and complex problems, and innovate like never before.

This article will discuss modern electrical engineering projects where complex engineering mathematics has been at the heart of overcoming these new challenges. Specifically, we will look at engineers who are:

- Maximizing the effectiveness of solar energy
- Improving energy grid efficiency to accommodate the demand for electric vehicles and other forms of transportation
- Designing smarter, more powerful, cost-effective embedded electrical systems

Andasol 1–3: A Case Study in Storing Energy from the Sun

Economic and political factors are putting pressure on electrical engineers to make renewable energy sources viable alternatives to fossil fuels. Clean energy, like that generated by the wind or the sun, can reduce air pollution, preserve natural habitats, reduce the need for nuclear power, and help nations become more energy independent.

Electricity can be easily generated from the sun while it's beating down on photovoltaic and solar-thermal panels, but engineers have struggled to find ways to store that energy when night falls or storm clouds roll in.

The process of using Molten Salts, however, is now making it possible keep solar energy farms producing energy 24/7. Salt's high melting point, plus the fact that it doesn't turn to vapor until it gets much hotter, means that it can be used to store the sun's energy as heat.

Andasol 1, which went online near Granada, Spain in 2008, was the first commercial power plant to use parabolic trough solar-thermal technology. The Andasol Plant was developed by Solar Millennium, AG, a German solar company. According to Sven Moormann, a spokesman for Solar Millennium, "The hours of production are nearly double [those of a solar-thermal] power plant without storage."

There are now three operational Andasol plants, each with a gross electricity output of 50 megawatts, and producing about 180 gigawatt-hours per year. Each collector has a surface of 51 hectares (5.5 million sq. ft. or approximately 125 acres) and occupies about 200 hectares (roughly 500 acres) of land.

Andasol's thermal storage system absorbs part of the heat produced in the solar field during the day and stores it in a mixture of sodium nitrate (60 percent) and potassium nitrate (40 percent). A full thermal reservoir holds 1,010 MW-h of heat; this is enough to run a turbine for about 7.5 hours at full-load when direct sunlight is not available.

While there are additional expenses involved in setting up the salt storage system, these costs are balanced out by the additional hours of energy production. Electricity from the Andasol plants costs about the



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same as it does at any solar-thermal power plant—about 13 cents per kilowatt-hour. This is still nearly twice as much as electricity costs from a coal-fired power plant, the least expensive power-generation option not considering environmental impacts of burning coal.

Engineers are working to make salt storage systems more effective. Some of the more promising methods include using salt mixtures that melt at lower tem-



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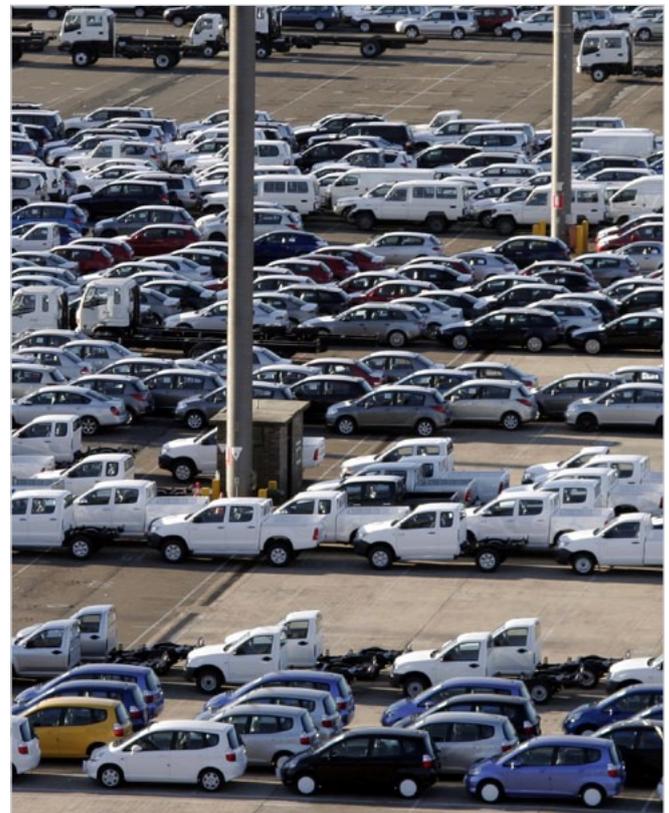
peratures, and concentrating sunlight onto a single tower to increase the temperature of the salts. Technology for storing solar energy using molten salts and converting that stored energy to usable electricity revolves around critical calculations for heat transfer, thermal analysis, and the conversion of melted salt to supersteam. The molten salt mixtures can vary, and typically are comprised of sodium nitrate and potassium nitrate, although calcium nitrate can also be included. Constituting the optimal salt mixture requires extensive calculations using the physical properties of each salt and the ratios of the salts in the mixture. Calculation software is often used for this level of engineering optimization as it facilitates the calculation and analysis process tremendously.

Impact Assessment of Plug-in Hybrid Vehicles: A Case Study in Power Supply and Demand

While some engineers work to generate electricity from new sources, others are studying the impact of increased electricity demand. Researchers from the Pacific Northwest National Laboratory, for example, have been exploring the potential impact an emerging fleet of Plug-in Hybrid Electric Vehicles (PHEV) will have on power systems across the country.

Load flow estimates, overflow probabilities, average capacity measurements and other calculations all helped these engineers address two key questions in a detailed power grid analysis:

- What are the impacts of a plausible penetration of PHEVs on the electricity production cost at a regional level?
- What are the impacts on CO2 intensity at a regional level for a set of selected charging strategies?



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The researchers assumed a year 2030 scenario with 37 million PHEVs on the road, where each vehicle would demand enough energy to travel about 33 miles (53 km) per day. When assessing the energy required to support such a scenario and the feasibility of a power system to accommodate the additional load, engineers must construct mathematical models for evaluating the impact on transmission system components. In addition to fundamental calculations for system load (base load and peak load capabilities) and overall transmission system capability calculations, system stability must also be considered. Occasionally, components such as capacitors or phase-shifting transformers are incorporated to improve stability on long transmission lines. Modeling the stability of a power transmission system requires many complex calculations. A first order stability assessment can be obtained by calculating voltage drop on a line, evaluating heating of conductors, and mathematically determining the impact of adding components such as capacitors and transformers to the design.

In the case of the PHEV study, the total electric energy requirement for the entire electric vehicle fleet was relatively modest; however, the cost impact varied widely by region. High cost sensitivity was predicted in areas where supply is already tight, such as California and the Northeast. In Midwestern regions, which traditionally export power, much smaller cost impacts were indicated. In all regions, cost impacts were twice as much for day charging versus night charging.

CO₂ intensity as a result of PHEV adoption is also expected to vary by region. In predominantly coal states, the new PHEV load is likely to reduce the CO₂ emission intensity for all charging strategies investigated. In areas that rely more on hydro and renewable energy sources, the CO₂ emission intensity may actually increase if the marginal generation to accommodate the PHEV fleet comes primarily from coal or natural gas.

Based on engineering calculations for electrical power system load and associated transmission and distribution models, the study concluded that the additional energy demand for charging a fleet of 37 million PHEV vehicles in the year 2030 will not have a significant impact on the power grid. Additionally, it

concluded that charging electric vehicles is cleaner at night in the Northeast, the West, and Florida, while day charging is cleaner in the Midwest.

Automotive Infotainment: A Case Study in Embedded Systems

Whether a car runs on electricity, gasoline or a combination of both, it's sure to rely heavily on embedded or smartphone-enabled electronic systems. According to industry estimates, 80 percent of automotive innovation in the premium segment comes from the electronics.

Many of the advances seen throughout the automotive industry—in the areas of safety, emission control, comfort and quality—would not have been possible without the use of advanced computer-based control systems.

Electrical engineers constantly feel pressure to do more with smaller and faster electronic systems. Integrating these systems into design processes that are still managed by people with mechanical engineering backgrounds only adds to the challenge, as do varying customer demands and regulatory requirements. Modernizing and standardizing electronic system architectures is a prerequisite for successful design, industry experts agree. Hans Georg Frischkorn, who leads automotive operations at electronics service provider ESG, believes that standardization will help usher in a new era of networked functions. "It will be very exciting to see the smart car, the smart grid and the smart home all networked together," he says, while warning that the connected car will mean increasing complexity in electronic systems.

Clarion, the US-based division of Japanese electronics group Hitachi, is testing the networked-services arena with a cloud-based infotainment service, "Smart Access", to add to its offering of traditional in-car products. "Smart Access" features smartphone connectivity and the ability to access a wide range of apps, including those for car maintenance, safety management and emergency calling. Telematics executives say that cars will be connected to the Internet through both embedded and smartphone-based



systems. To meet the challenges that come up as a result, Volkswagen, for example, has launched a new company-wide IT academy to attract and retain top electronics and software talent. The goal is to have experts on hand who can manage the different components of embedded systems required for Automotive Infotainment. This includes overseeing embedded software as well as electronic systems. While software engineers must be able to identify and correct software problems, electrical engineers must be able to troubleshoot and resolve electronics-based problems. This requires complete analysis of circuits and their low-level devices. Engineering calculation software that has capabilities to plot magnitude and phase responses, current waveforms through different components, signal transmission, loss and degradation, and calculate other electronics/circuit analytics is a necessity for effective control of embedded systems within the Automotive Infotainment realm.

Conclusion

The extent to which today's electrical engineers can overcome major design challenges will have a tremendous impact on human societies for generations to come.

Improving alternative energy technologies, discovering ways to use energy more efficiently and expanding the capabilities of computing devices will require extraordinary effort and ingenuity.

Engineers will also continue to rely on technological advances to help them meet current and future challenges. Enhanced computing power and design software will increase efficiency, and sophisticated calculation software will help ensure accuracy and mitigate risk.

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Overcoming Electrical Engineering Challenges Requires Sophisticated Calculations

Advances in math calculation software ensure accuracy and mitigate risk.

CHALLENGE	CALCULATIONS REQUIRED
Maximize the effectiveness of solar energy	<ul style="list-style-type: none"> Solar charge controller sizing Battery bank efficiency due to low temperatures Solar irradiance
Improve energy grid efficiency	<ul style="list-style-type: none"> Optimal power flow (OPF) Total transfer capability (TTC) Energy efficiency via enthalpy of formation
Accommodate electric vehicle demand	<ul style="list-style-type: none"> Average capacity/load factor Load flow calculations Grid overload probability
Design more powerful, cost-effective embedded systems	<ul style="list-style-type: none"> Voltage drop RLC circuit analysis Linear superposition Piezoresistance theory

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