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Realizing Power Plants of the Future through Instrumentation and Controls

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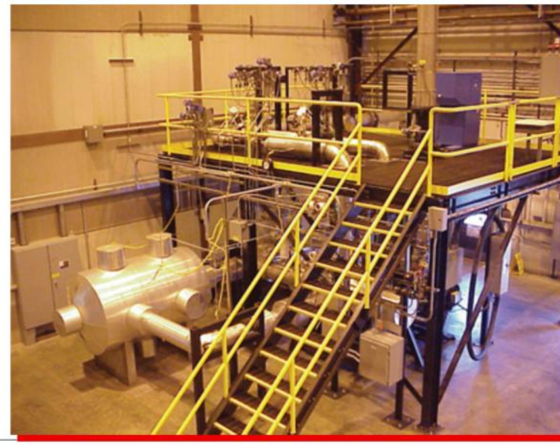

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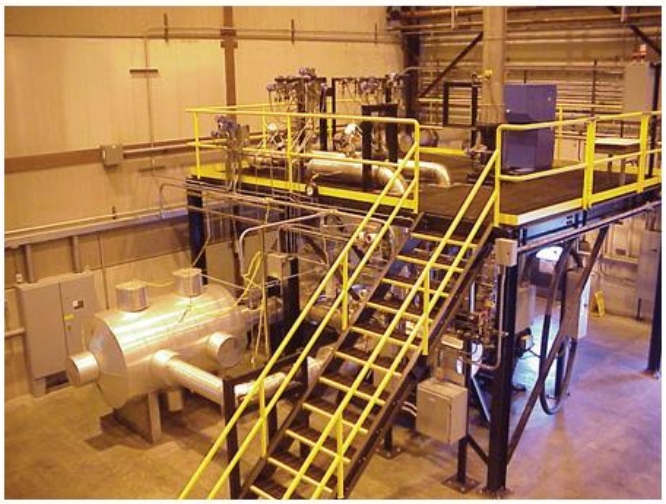
By Sydni Credle



Real-world image of the Hybrid Performance (Hyper) Facility at the National Energy Technology Laboratory. This cyber-physical system (CPS) is used to demonstrate novel controls and virtual simulations. *Photo courtesy: NETL*

Emerging technologies in the field of instrumentation and controls are poised to have a big impact on power production. While some technologies are still in the basic stages of research and development (R&D) and on the cusp of widespread adoption, others are now entering operating rooms to change our industry for the better. Some of the technologies represent major advances on conventional approaches. Others are adaptations from outside industries, and even nature, that are providing game-changing innovations for tomorrow's power generation. Together, these technologies represent the power plant of the future where the most cutting-edge technologies are effectively leveraged to provide clean and efficient power for us all.

Embedded Sensing Through Advanced Manufacturing

Power system efficiency depends upon enhanced process control, which is grounded in acquiring high-quality measurements and information from throughout various energy subsystems including structural components and machinery. For fossil energy-based systems, this means placing sensors in harsh environmental conditions, including high-temperature, high-pressure, corrosive, and erosive environments, that are typical in gas turbines, solid oxide fuel cells, gasifiers, and boilers.

The U.S. Department of Energy's National Energy Technology Laboratory (NETL) is currently supporting projects with the objective of developing innovative materials and packaging techniques that will increase sensor durability and survivability when deployed within the harsh environments of advanced energy systems. NETL is also supporting R&D that investigates advanced manufacturing methods to embed sensor technologies within components, thus removing sensing elements from direct contact with harsh environments. A representative project within this research area is through the University of Texas at El Paso (UTEP). The researchers at UTEP are studying the use of additive manufacturing (AM) in the form of electron beam melting to create "smart" parts, where the sensing elements are directly integrated into metal-based components. Fabrication methods for metals and other extreme environment materials such as ceramics, nickel-based superalloys, and refractory materials are highly complex and non-trivial tasks. Even more challenging is the prospect of embedding sensor elements in a manner that does not compromise the mechanical integrity of the part itself while also allowing for wireless signal processing and data communication out of the component. However, the benefit of these R&D efforts is very high since it enables a new level of insight for the purpose of real-time monitoring of process variables, component health, condition assessment, and life-cycle performance.

Real-Time Data Visualization and Augmented Reality

Measuring energy processes in real-time is critical for attaining greater efficiencies and also for monitoring the health of system components to ensure safe operation. Moreover, with our ever-increasing trend toward big data and large systems of information, synthesizing this data in a meaningful way that provides actionable information is a significant undertaking. Real-time data visualization is a powerful technique that allows for greater insight into complex, non-linear relationships within energy systems as well as greater understanding of physical processes.

Hybrid Performance 1

Graphic illustration of the Hybrid Performance (Hyper) Facility at the National Energy Technology Laboratory. ***Photo courtesy: NETL***

Two companies, Nanosonic Inc. and Sporian Microsystems Inc. are currently investigating low-cost, rapidly deployable sensor technologies for real-time monitoring of heavy metals in water resources. Heavy metals of interest include the Resource Conservation and Recovery Act (RCRA) metals of arsenic, barium, cadmium, selenium, mercury, lead, chromium, and silver. Traditionally, water sampling for these materials is acquired via grab samples and analyzed via in-house or third-party laboratories where results can take up to 3 weeks to process. This lack of real-time information is disadvantageous for power plants seeking to comply with U.S. Environmental Protection Agency's regulations for water quality including the effluent limitation guidelines (ELGs). Sensors that enable real-time feedback information regarding critical water treatment processes, such as flue gas desulphurization, will allow for optimized performance and cost savings in the form of more efficient metering and use of relevant chemicals. Additionally, these real-time sensors may be deployed in a distributed manner that provides both spatial and temporal imaging to enhance control operations and increase efficiency.

The need for real-time sensor measurements extends to other applications beyond water quality management. Tech4Imaging LLC, a small business based in Ohio, is currently developing breakthrough sensor technology in the field of real-time visualizations. The sensors under development are based on electrical capacitance volume tomography in concert with advanced algorithms for image reconstruction. This advanced 3D imaging technique for multi-phase flow measurement is able to distinguish solids, gas, and liquids (3-phase flow) in process streams at high temperatures approaching 900 °C. This represents a first-of-a-kind demonstration for this type of imaging within this high-temperature regime. Applications for this advanced 3D imaging and visualization technology will provide better feedback control and monitoring of high-temperature energy processes.

Recently, Pokémon Go became a cultural phenomenon that overlaid virtual images onto real-world displays of users' immediate surroundings. The technology behind the popular entertainment app is augmented reality (AR), and it is a new horizon for advanced imaging and visualization within the industrial power sector as well. AR brings an unprecedented level of immersion into data. Beyond catching Pokémon, the greater boon has been the raised awareness to using AR technology for practical applications. One example is maintenance, service, and repair of system components. Recently, an app called "eKurzinfo" produced by Audi, has allowed users to access cloud-based AR information, including animated 3D maintenance instructions and how-to information, via a cell phone in real-time. In a similar manner, AR technology can be used to allow plant technicians to use handheld devices, such as a cell phone, to perform image recognition to identify the part under repair and then overlay relevant manuals with virtual annotations of wiring and other components in real-time to facilitate efficient repair.

Beyond the benefit of advanced maintenance practices, an additional prospect for using AR technology within industrial power plants includes the ability to visualize process data from "smart" components in real-time. By using a specialty headset, such as those manufactured by Microsoft's HoloLens or a hand-held device, operators will one day be able to seamlessly interact with wireless sensor technologies embedded within components to reveal the inner workings and operation in a manner that has never before been possible. A real-time "look" inside components by viewing virtual image overlays and holograms of real-world data related to temperature, pressure, cracks, corrosion, and other failure mechanisms will enable step-change comprehension and response to protect the overall health of a plant during operation.

Advanced Controls via Cyber-Physical Systems

With the deeper saturation of renewables onto the grid, fossil energy-based power plants require improved flexibility to meet load-following profiles and stay competitive in an ever-changing power production landscape. The primary way for new (and existing) power plants to meet this new demand will be through adoption of advanced control schemes and use of novel platforms for demonstration.

Cyber-Physical Systems 2

Graphic illustration of underlying themes that form the basis of cyber-physical systems (CPS) research. ***Photo Courtesy: NETL***

Cyber-physical systems (CPS), platforms that integrate real-world hardware with simulated components, represent a low-risk mechanism for testing advanced controls algorithms that leverage real-time data and process variables. NETL's Hybrid Performance (Hyper) Facility in Morgantown, WV, houses a pilot-scale CPS capability to investigate novel control schemes for highly coupled energy systems such as solid oxide fuel cell-gas turbine hybrid systems. This unique facility draws collaborators from around the world, including the University of Genoa, DLR (German Aerospace Research Center), and Ames Research Laboratory. The highly specialized Hyper Facility is the only hardware-based simulator in the world focused on transient operation and dynamic control of hybrid systems.

To date, NETL has investigated a host of multivariable, advanced distributed control strategies including distributed proportional-integral-derivative, system identification (neuro-evolutionary algorithms, etc.), multiple-input multiple-output with state space as well as agent-based stigmergy, and biomimetic-based frameworks. Biomimetic-based methods use computational algorithms that reflect highly efficient processes occurring in nature such as the human nervous systems and ant foraging techniques. In collaboration with NETL, researchers at Case Western Reserve University (CWRU) have successfully used the latter technique as a way to detect faults for in-situ condition monitoring of energy systems. Using nature as a guide-in this case, ant foraging behavior-the CWRU team is able to analyze information pathways between sensors and actuators within a power system in a way that is analogous to the pheromone trails that ants use to find food. By analyzing the topology of these sensor information paths, changes may be detected that provide advanced warning of both sensor and component failures, which is essential to avoiding unplanned outages, planning repairs, and maintaining service life of components. This advanced topological deconstruction of the information structures within systems is just one way in which controls are evolving to meet the challenges of tomorrow.

Blockchain for Cybersecurity

As components become more and more intelligent, with the aid of embedded technology and wireless communication coupled with advanced controls, we can push closer to realizing a fully autonomous capability that leverages constructs such as the Internet of Things (IoT), also known as the “Industrial Internet.” IoT is the wave of the future, but issues may arise regarding the security of power systems resources and susceptibility to outside forces. Current events such as the recent Distributed Denial of Service (DDoS) attack, which used internet-connected devices to disrupt international media sites such as Amazon, Twitter, Spotify, and others, drives home the necessity of exploring novel ideas that will aid in protecting IoT components, which may one day include critical resource infrastructure for power plants. The power plant of the future must be equipped with cybersecurity in a manner that minimizes the vulnerabilities posed by being IoT connected.

Novel techniques that leverage well-established R&D areas of encryption, firewalls, and authentication must be created and deployed to meet this challenge. NETL is currently investigating the use of blockchain technology as a cybersecurity tool to maintain the robustness of integrated energy systems of the future. Blockchain is the term for the infrastructure that relies on a distributed ledger of transactions within a network. Virtual currencies such as Bitcoin use blockchain as the underlying protocol to ensure financial transactions. If you think of digital money like digital information, then blockchain is analogous to hypertext transfer protocol (http). In the late 1980s when http and digital information was invented, the true impact (email, smart phones, big data, virtual reality, etc.) of this disruptive technology was unimaginable. With digital money such as Bitcoin, we are already seeing the disruptive power of blockchain on the financial sector by using it to make reliable, secure transactions. The energy sector is now poised to have the same disruption via blockchain. The exact manner in which blockchain-based energy systems will impact cybersecurity for the power plant sector is unknown at this time. However, new R&D efforts will explore how blockchain can be incorporated with sensor networks and advanced controls architectures to mitigate vulnerabilities of future IoT-enabled components, thus realizing safe and robust operation for energy systems.

Conclusion

The power plant of the future will continue to provide reliable, affordable, abundant energy to the nation, but it will do so in a totally new way. Instrumentation and measurements will include meaningful, real-time data streams from new sources including "smart" components that feature embedded intelligence, advanced 3D imaging, and immersive data visualization enabled by new technologies such as augmented reality. This newly acquired information can be leveraged to develop novel controls strategies based on rapid feedback that will enable robust, flexible power generation systems able to function with unprecedented efficiency. Technologies borrowed from gaming, finance, and nature will offer unique solutions to complex challenges that will reshape how the power generation sector thinks about plant operation. Together, these technologies will usher in a new and better way of doing business in the power plant industry.

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