Overview of the Transformer Resilience and Advanced Components (TRAC) Program

Vision Statement

Technologies and approaches will be developed that help maximize the value and lifetimes of existing grid components, and enable the next-generation of grid hardware to be more adaptive, more flexible, self-healing, resilient to all-hazards, reliable, and cost-effective compared to technologies available today.

Program Motivation and Goals

To date, much of the “smart grid” transformation has focused on applying advanced digital information and communication technologies to the power grid to improve the system’s reliability, resiliency, efficiency, flexibility, and security. To realize the full potential of a modernized grid, advances in the grid’s physical hardware are also needed. One prime example is the development and use of utility-scale energy storage systems. Next-generation grid components can improve equipment performance and lifetimes over current designs, simplify integration of advanced technologies, and provide new capabilities required for the future grid. The activities identified in this overview can help accelerate grid modernization, increasing controllability, flexibility, and resilience, and realize the vision of the TRAC program.

The TRAC program has two primary goals:

- Increase the resilience of aging assets and identify new requirements for future grid components
- Accelerate the research, development, and field validation of next-generation grid hardware technologies

Program Scope and Focus

The TRAC program supports activities in high-impact focus areas where federal resources, subject to Congressional appropriations, can play an important role in filling critical R&D gaps. The application areas highlighted in Figure 1 were identified through meetings and discussions with various stakeholder groups representing industry, academia, and national laboratories, and through the U.S. Department of Energy’s Quadrennial Technology Review process.[1] Under each application area are specific technologies that (see Table 1), if objectives are met, can address some of the major challenges facing the industry, establish capabilities needed in the future, and enable new operational paradigms.

[1] U.S. Department of Energy. *Quadrennial Technology Review 2015,* accessed April 5, 2018, http://energy.gov/under-secretary-science-and-energy/quadrennial-technology-review-2015.

Across the various application areas, there are several desired attributes associated with the design of next-generation transmission and distribution (T&D) grid technologies that will influence and shape the R&D activities within the TRAC program portfolio, including the following:

- Modularity and scalability
- Local intelligence and adaptability
- Inherent cyber-physical security
- Manufacturability and sustainability

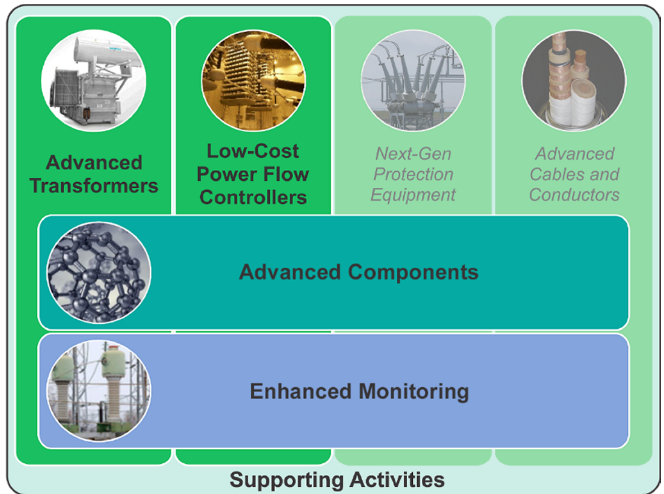

Figure 1 – Application Areas in the TRAC Program Scope

Standardized designs do not exist for many T&D grid components, and their customized nature drives up equipment and installation costs. Modular and scalable designs would enable greater standardization and allow for more cost-effective capacity expansion. Additionally, local intelligence with embedded sensors, data processing, and communications would enable real-time health monitoring, reducing maintenance costs and enhancing system reliability by preventing failures.

With increased intelligence, future T&D grid components will have much stronger connectivity to communication and information technology networks. To mitigate vulnerabilities from evolving threats, cyber and physical security measures must be considered simultaneously and incorporated into the design of each component, rather than added as an afterthought. Finally, as new T&D grid components are designed and developed, it is important to consider the manufacturing processes and lifecycle impact of these technologies.

In addition to the R&D needed for these application areas, there are a range of supporting activities and issues that will require consideration and attention to achieve broader adoption of innovations. These activities and issues are organized into five key categories: (1) testing and model validation; (2) simulations and analyses; (3) architectures, interoperability, and standards; (4) manufacturing and supply chain; and (5) education and training. Efforts in these supporting areas will be coordinated with R&D to amplify results that can lead to benefits, including:

- Increased energy efficiency
- Improved operations
- Enhanced asset utilization and management
- Increased system resilience
- More domestic manufacturing and jobs

Federally sponsored R&D, along with supporting activities, can complement industry efforts and help (1) promote innovation, (2) de-risk technologies that could provide significant value to the nation, and (3) facilitate broader adoption of new technologies and approaches.

The investment cycle needed to replace, upgrade, and expand the U.S. transmission and distribution (T&D) systems has already begun, with annual spending increasing from $28 billion in 2010 to $44 billion in 2013. Missing this window of opportunity to develop and install the next-generation of T&D components required for a future grid could slow its transformation and impose significant opportunity costs to society.

Through basic and applied R&D that effectively address industry's need for enhanced T&D hardware performance and capabilities, the TRAC program will support advancement of more reliable, resilient, and flexible grid component technologies by leveraging innovative designs with power electronics, new materials, and embedded sensors and intelligence.

Table 1: Summary of TRAC R&D Focus Areas and Objectives

R&D Focus Areas	Application Areas	Technologies	Objectives
Power Electronics	**Advanced Transformers**	Flexible and Adaptable Large Power Transformers	• Costs comparable to conventional units (e.g., \$10–\$15 per kilovolt-amps [kVA]) • Efficiency > 99% at all levels of loading • 25% reduction in size, weight, and footprint compared to conventional units • Controllable impedance range of 5%–21%
		Power Electronics Augmented Distribution Transformers	• Costs comparable to conventional units (e.g., \$25–\$35 per kVA) • Efficiency greater than prescribed standards at all levels of loading • Double the power density compared to conventional units • Self-protected against switching failures
		Solid State Power Substations	• System capital costs of \$80–\$100 per kVA • Efficiency > 97% at all levels of loading • Module galvanic isolation > 100 kV at high frequencies • Half the footprint of a conventional substation
	Low-Cost Power Flow Controllers	Advanced Power Routers	• System capital costs of \$10–\$40 per kVA • Impedance control in the range of 10%–20% of power rating • Response times < 5 milliseconds
		Medium-Voltage Direct Current Converters	• Installed system costs < \$100 per kVA • Efficiency > 99% at all levels of loading • Half the footprint of a converter station built with conventional converter technologies
Materials	**Advanced Components**	Dielectrics and Insulators	• Dielectric strength of > 300 V/mil (> 120 kV/cm) at the same price as conventional materials • Dielectric loss angle (tan delta) of < 0.05% at 60 hertz (Hz) at upper limit of operating conditions • Enhanced material properties remain stable over useful life of assets (e.g., 20–40 years) • Temperature withstand > 130°C in continuous operation, > 180°C in emergency situations
		Magnetics	• 50% reduction in energy losses for line frequency transformers compare to silicon steel at the same flux density

R&D Focus Areas	Application Areas	Technologies	Objectives
			• 50% reduction in eddy current losses for high power (kilowatts to megawatts), high frequency (10–100 kHz) transformers compared to state-of-the art materials • Costs comparable to materials used today
		Electrical Conductors	• Electric conductivity 50% better compared to copper or aluminum • Mechanical strength and thermal conductivity 25% better compared to copper or aluminum • Costs comparable to copper or aluminum
		Semiconductor Devices	• Packaged diodes and transistors that cost < $0.10/amp at 1,200 V • Packaged diodes and transistors that can block > 5 kV and carry > 20 A • Packaged transistors with switching frequencies up to 100 kHz and low losses
Sensors	**Enhanced Monitoring**	Sensing Elements	• Accuracy better than 1% of critical value of interest • Capital cost < $1 per sensing element for ubiquitous sensors • Sensor capital cost and lifetime commensurate with instrumented equipment and application
		Integrated Data Processing and Communications	• Installed costs < $100 per sensor system • Installed costs < $10,000 per instrumented grid node (e.g., substation and facility) • Support up to 10,000 nodes without performance degradation • Communication latency < 1 millisecond within 10 miles
		Analytics and Applications	• Autonomous adjustment and control to prevent unwanted events in < 5 milliseconds • Better than 99% success rates in the detection of and the protection against targeted events • Improved analytics result in > 5% savings in asset management on average