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Basic Research in Superconductivity for a 21st Century Electric Power Grid

The electric power grid, the backbone of energy delivery in the U.S., faces serious problems in the 21st century. Its capacity is near saturation in the face of rising demand: by 2030, electricity demand is expected to increase by a further 50%. Its reliability and power quality are inadequate: the average customer in the U.S. experiences 214 minutes of power outage per year, versus 53 minutes in France and 6 minutes in Japan. Its efficiency is low: 8% of the power that flows into the grid is lost to resistive heating; this is the equivalent of 40 large coal or nuclear plants and 220 million tons of carbon dioxide emissions. A high capacity, reliable and efficient electric power grid is essential to a secure and sustainable energy future.

Superconductivity enables a 21st century solution for the electric power grid, with a unique level of smart, self-healing performance that is beyond the reach of any other technology.

Capacity: The major bottlenecks in the electric grid are in cities and suburbs, where a high density of people, businesses and industries require a high density of power. The existing infrastructure of underground cables that distribute power to and within cities and suburbs is nearly saturated, creating an urban power bottleneck. Superconducting cables carry up to five times the power of conventional copper cables in the same cross-sectional area. Selectively replacing the existing conventional infrastructure with superconducting cables creates a five-fold increase in capacity, enough to accommodate decades of expansion. The roadblock to widespread deployment of superconducting cables is cost. Increasing the current carrying capacity of superconductors addresses this challenge and could provide a factor of ten in improvement over presently used wire. Raising the current carrying capacity of superconductors requires incorporating nanoscale defects into their structures to stop the motion of magnetic flux. Basic research is needed to understand the relationship between defect structures and current carrying ability, and to develop the processing necessary for their controlled introduction.

Reliability: Power interruptions are caused by the slow reaction of the grid to sudden changes in power flow, often caused by lightning, high winds, ice or falling tree branches disabling a power line. The grid now reacts by opening and closing mechanical breaker switches, a process that takes many minutes and typically requires human intervention. Superconductors provide a fast, smart, self-healing alternative to conventional breakers. Superconductors automatically switch from zero to a high resistance state in a matter of milliseconds, a fraction of one alternating current cycle, intercepting and limiting the flow of dangerously high “fault” currents at speeds much faster than conventional breakers, even with computer control, could ever achieve. Furthermore, superconductors automatically reset to zero resistance in as little as two seconds after the fault current is cleared, whereas conventional breakers require an elaborate process to remake the mechanical connection. This fast, smart, self-healing superconducting fault current limiter performance is beyond the reach of conventional breaker technology. Laboratory demonstrations have proven the principle of superconducting fault current limiters, however basic research is needed to understand the fast switching dynamics of superconductors, the current carrying ability of the resistive state, and the conditions that determine the current levels at which the superconductors switch and reset in order to optimize the power grid system.

Efficiency: 33% of U.S. electric power is used in 22 metro areas. Installing superconducting cables in these cities and suburbs is the fastest and most effective way to reduce losses in the grid. The numbers are impressive – cutting today's losses by only a third would eliminate construction of 13 GW of coal fired or nuclear power plants thereby saving approximately $15B, and equivalent to the additional generating capacity needed for three years of demand growth.

Renewable Electricity Transmission: The U.S. electricity grid faces a major future challenge in adding renewable solar and wind generation resources to meet the need for carbon-free power. U.S. wind resources are optimal in the wind corridor from Texas to the Canadian border, solar resources in the southwest. Most of the US population resides east of Mississippi and on the west coast. Transmission losses prevent transporting large amounts of renewable electricity over these long distances. Superconductors enable long distance transmission by dramatically reducing power losses. However superconducting cables must be cooled, probably by injecting liquid nitrogen coolant into the cable housing every few miles which is technically demanding and costly over very long distances. The best solution for long distance transmission lies in the discovery of superconducting materials that operate at temperatures twice or more higher than the current superconductors. Discovering the next generation of higher temperature superconductors requires basic materials research. Very high temperature superconductors are within reach and there is no known theoretical limit to the superconducting transition temperature.

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