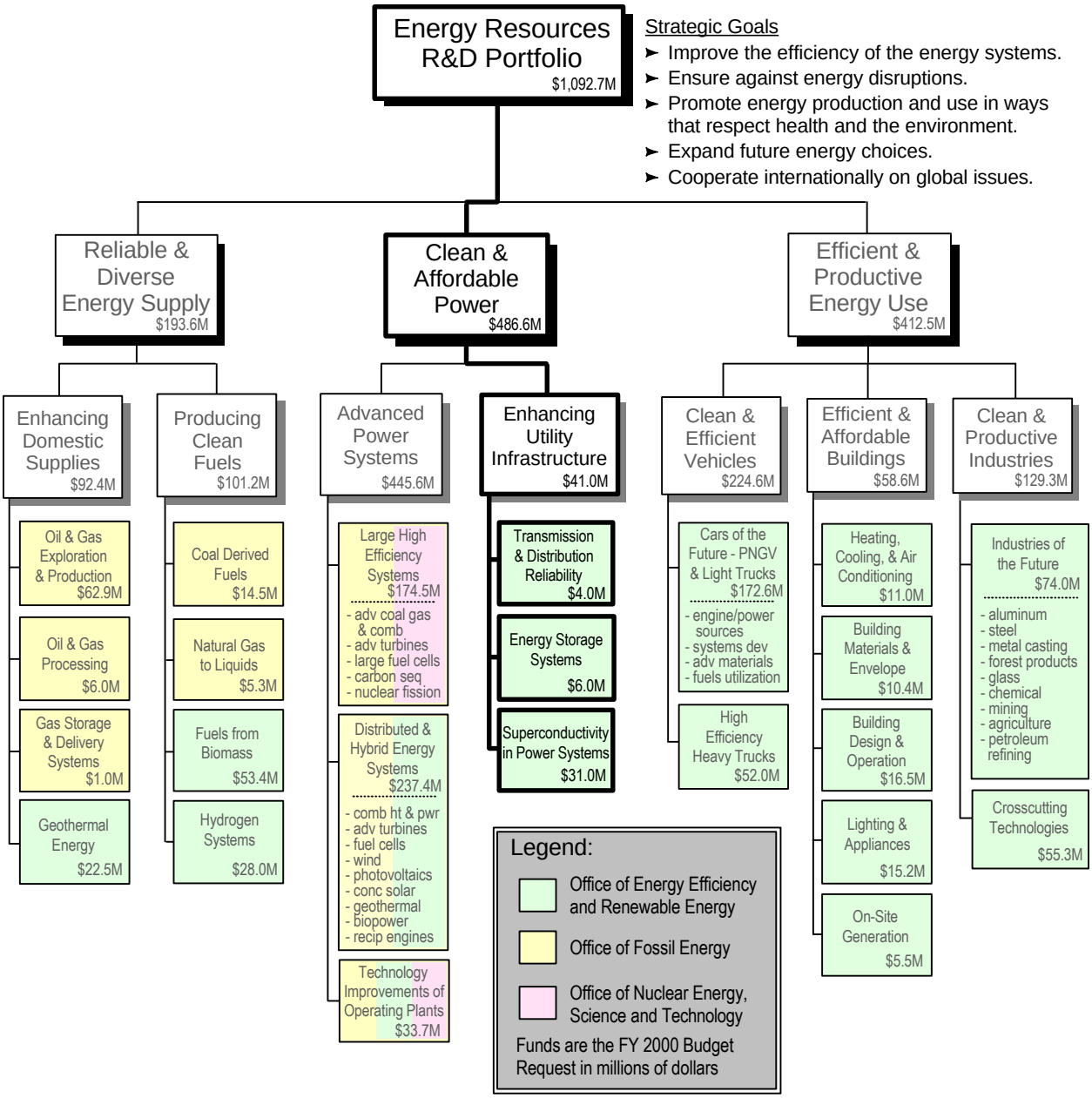
Chapter 6
Enhancing Utility Infrastructure



Chapter 6

Enhancing Utility Infrastructure

Table of Contents

Page

Overview . . . 143
- Definition of Focus Area . . . 143
- National Context and Drivers . . . 143
- Linkage to CNES Goals and Objectives . . . 144
- Uncertainties . . . 145
- Investment Trends and Rationale . . . 145
- Federal Role . . . 147
- Key Accomplishments . . . 149

Transmission and Distribution Reliability . . . 150
- Background . . . 150
- Linkage to CNES Goals and Objectives . . . 150
- Program Description . . . 151
  - Real Time System Control . . . 151
  - Power Electronics . . . 153
  - Distributed Resource Integration . . . 154
  - High Capacity Transmission Technologies . . . 156

Energy Storage Systems . . . 157
- Background . . . 157
- Linkage to CNES Goals and Objectives . . . 158
- Program Description . . . 158
  - Integration . . . 159
  - Components . . . 160
  - Analysis . . . 161

Superconductivity in Power Systems . . . 163
- Background . . . 163
- Linkage to CNES Goals and Objectives . . . 164
- Program Description . . . 165
  - The Superconductivity Partnership Initiative . . . 165
  - The Second Generation Wire Initiative . . . 167
  - Strategic Research . . . 168

Summary Budget Table . . . 170

Overview

Definition of Focus Area

The electricity infrastructure not only delivers over $200 billion worth of electric service to U.S. customers every year, but also powers other critical national service infrastructures such as telecommunications, and water supply that are basic to the functioning of U.S. society. Electricity infrastructure consists principally of the transmission and distribution system, but also extends beyond the utility meter on the customer side, and into the power plant on the production side. Customer equipment such as large motors, power quality management, and load control technologies are included, as well as efficient mechanical equipment for generating electricity. As electric industry restructuring revolutionizes the way electric power is produced and consumed, the continued successful development of regional and interregional competitive markets depends upon the availability of a robust, efficient, reliable electricity infrastructure.

National Context and Drivers

The Nation's electricity infrastructure is being asked to operate in ways for which it was not designed at the same time that new demands for improved performance are being made on it.

- Competitive electric markets operate across far larger geographic areas than the traditional utility service territory. Regional or even national purchase contracts are possible, and national branding campaigns are already underway. Wide area competitive electric markets depend upon reliable transmission with capacity for large scale transfers across long distances.

- The North American Electric Reliability Council (NERC) in its Reliability Assessment (1998-2007) states: "Transmission systems are increasingly challenged to accommodate demands of evolving competitive electricity markets. Market driven changes in usage patterns, the number and complexity of transactions, and the need to deliver replacement power to capacity-deficient areas are causing new transmission limitations to appear in different and unexpected locations."

- Measures taken to limit transmission loading and preserve system reliability were a contributing factor leading to shortages of power on the Midwestern wholesale market during the summer of 1998, resulting in short-term prices in excess of $5.00/kWh.

- The cost of lost production and spoilage suffered by California industry alone for the August 10, 1996, western outage was in the range of $1-3 billion. A 20-minute outage at an integrated circuit fabrication plant can result in loss of a day's production worth $30 million. In our increasingly digital society, disturbances lasting less than a second can be almost as devastating as true outages. Business Week estimates the annual cost of momentary power disturbances to U.S. electric customers to be over $26 billion.

- According to the Energy Information Administration, network inefficiencies annually consume 3 quads of primary energy and produce 50 million metric tons of carbon equivalent in greenhouse gases. Adding in losses on the customer side of the utility meter in equipment such as motors and industrial transformers could double these figures.

- Construction and sometimes reconstruction of transmission facilities are routinely opposed by the public on a number of grounds, including environmental impacts, visual intrusion, property value effects, or concern over the health impacts of electromagnetic fields. Even relatively minor projects can consume years in the permitting process.

Linkage to CNES Goals and Objectives

The Enhanced electric infrastructure program directly supports the five CNES Goals:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems. *(by reducing network and end use losses with superconducting power equipment technologies)*

- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability. *(by developing active system controls, storage technologies, and advanced superconducting applications such as the superconducting fault current limiter)*

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies. *(by development of control and storage technology that could help enable the integration of distributed and renewable resources)*

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options. *(by increasing system capacity, removing bottlenecks, and enabling distributed resource options)*

- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems. *(by working with other countries through the International Energy Agency to promote communications and collaborations)*

The Enhanced Electric Infrastructure program has 3 objectives that support the strategic goals and will be achieved through partnerships with industry. The objectives are (1) provide technical and policy options to enable the operation of large scale, interregional, real time, competitive electricity markets while maintaining system reliability; (2) develop technologies that could reduce by one third the approximately 9 percent of electricity lost to network inefficiency and the associated greenhouse gases produced, by 2020, while system demand increases by 35 percent; and (3) provide network technology options that would allow the electric system to incorporate market-driven penetration by distributed resources, including renewable generation technologies, of up to 25 percent of system peak.

Uncertainties

Both technical and political uncertainties could affect the success of the electricity infrastructure program. Technical challenges (possible barriers to achieving either performance or cost goals) are described in the program planning documents and are summarized in the subsequent R&D challenges sections. Non-technical issues include uncertainty over the nature of incentives for construction of transmission in a competitive electric marketplace. Without assurance of investment recovery in the regulated transmission system, providers may limit involvement in new technologies. Also, with the reduced costs of electricity forecast to result from electric industry restructuring, high efficiency alone will not be sufficient to attract commercial interest to any technology. It is therefore the goal of all the technical components of the Enhancing Utility Infrastructure program to provide performance improvements that justify their cost independent of increased efficiency.

Investment Trends and Rationale

The FY 1998 DOE investment in the Enhancing Utility Infrastructure program was $43.3 million, an amount projected to decline to $40.0 million in FY 1999 and rise to $41.0 million in FY 2000. The changes in overall spending reflect the cessation of funding for the Electric and Magnetic Fields R&D program, and increased emphasis on power system and energy storage technologies.

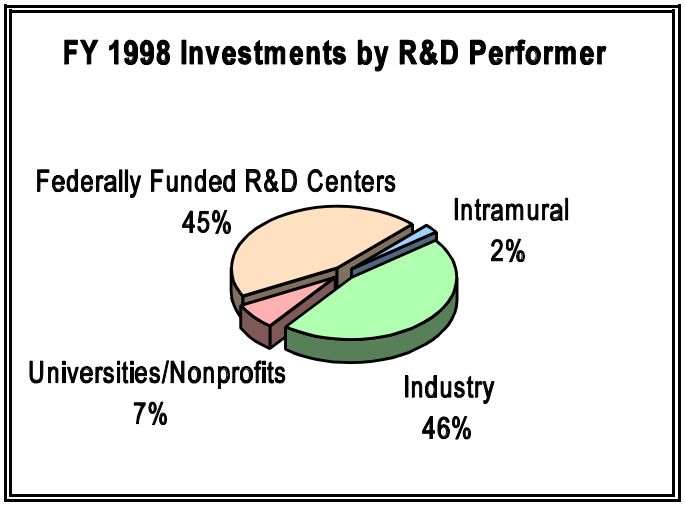
The Electric and Magnetic Fields R&D program studies the biological effects of electromagnetic fields produced by power lines. It was established as a 5-year program by the Energy Policy Act of 1992 and extended for 1 additional year (FY 1998) to permit completion by the National Institutes of Environmental Health Sciences (NIEHS) of a human health risk assessment report. No FY 1999 or FY 2000 funding has been requested. The FY 1998 funding level was $6.8 million.

The Energy Storage Systems program develops storage technologies that enhance power system capacity, power quality, and reliability. Funding for this effort will be augmented from $4.5 to $6.0 million in FY 1999 and FY 2000 to increase focus on advanced storage technologies such as flywheels and superconducting magnetic energy storage (SMES).

The Superconductivity in Power Systems program was charged in 1989 with fostering cooperative research and development with U.S. industry to capture the benefits of high-temperature superconductors for power applications. Six new cost-shared, multi-year partnerships designed to produce operating, pre-commercial power equipment using the best available long-length HTS wires will be underway in FY 1999. In addition, to help accelerate the development of wires based on 1996 National Laboratory discoveries, new cooperative research projects will also be initiated with industry. For these partnerships, funding increased in FY 1998 to the $31.6 million level, and funding will remain at a relatively constant level in FY 1999 and FY 2000 to enable continued progress at the laboratories and within the industry teams.

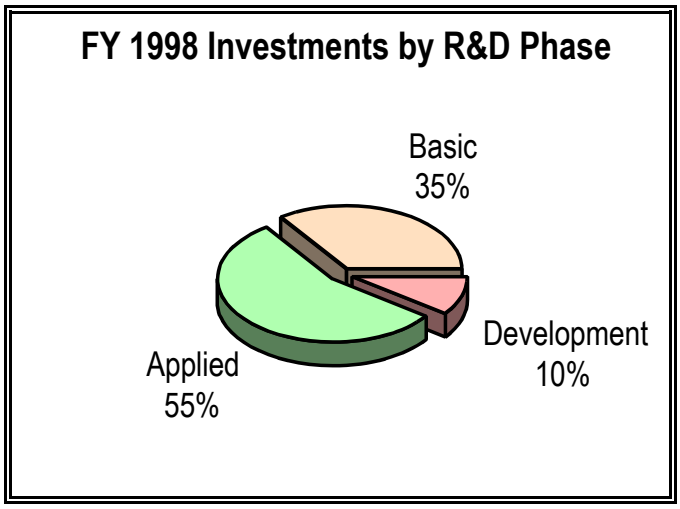
Finally, recognizing the need for a program element focused on the development of system technologies to enable competitive markets and maintain reliability in a restructured utility industry, a new initiative, the Transmission and Distribution Reliability program is proposed in FY 2000. This initiative, with initial funding of $4 million, will focus on development of technologies and policy options to enhance the reliability of the Nation's electric delivery system during the transition to competitive power markets.

The figure below indicates the division of FY 1998 funding between the principle performers of research tasks. Industrial firms account for 46 percent of the program's Federal funding, in line with the applied focus of the program and the desire to use partnerships with industry to hasten the development of necessary private manufacturing infrastructure for eventual commercialization. Pre-commercial pilot projects are selected by a competitive process which solicits cost-shared proposals from integrated teams including users, suppliers of materials and/or components, and systems integrators. This process minimizes public funding requirements, and determines the commitment of the marketplace to the technology. Such projects are cost shared with private sector funding at a level at least equivalent to the Federal share. After industry, the most significant performer is the complex of DOE National Laboratories, representing 45 percent of the Federal funding. The emphasis on National Laboratories reflects the need for sophisticated equipment, extensive facilities, concentrated expertise, and the sustained effort required. Though not counted as research performers, industry experts sitting on steering and oversight committees in all program areas provide important reality checks on the progress and future value of research activities.



The next figure shows the division of effort between basic, applied and development activities. In FY 1998, approximately 90 percent of research funding was devoted to basic or applied activities, reflecting the focus of major parts of the program on the long term development of technologies that enable fundamental shifts in concept for electric power equipment design. The relatively low level of development activities reflect the fact that the majority of the technologies under development have commercial horizons of 5 years or more. Development activities are

also heavily cost shared with the level of Federal funding rarely exceeding 30 percent of total project cost.



Federal Role

If the Nation is to continue to receive the highly reliable electric service it now enjoys, while simultaneously reaping the benefits of the competitive electric marketplace, increasing efficiency, and respecting environmental values, an adequate power delivery system is essential. The very existence of viable large scale markets for electricity depends on the ability to move power over long distances reliably with a minimum of restrictions. New technologies that increase the capability of existing systems while maintaining reliability, and that improve the public acceptability of new facilities are needed to maintain progress toward competitive markets in the electric industry.

At the same time that the need for new technology increases, the incentives for privately funded power delivery research in the restructured industry are being reduced. Delivery system research and development has traditionally been driven by the desire to take advantage of generation opportunities. Extra-high voltage transmission was developed in the 1930s to allow the exploitation of Western hydroelectric resources, for instance, and more recently, interconnection system management was perfected to permit generation reserve sharing. However, with the unbundling of the utility industry, generation and delivery system incentives have been separated. While profit opportunities in the competitive marketplace will likely spur generation innovation, the Secretary of Energy Advisory Board (SEAB) Task Force on Electric System Reliability notes that it is " concerned that reliability related R&D with long term focus may be underfunded by market forces." For instance:

- Independent System Operators (ISOs) have been established to take over from utilities the responsibility for reliable operation and planning of the transmission grid while providing equal access to all market players. ISOs have made great strides toward establishing operating arrangements that support competitive markets, but as a result of the transfer of

responsibilities, reliability research efforts funded directly by utilities have largely been terminated and not been replaced.

- Historically, the bulk of public interest R&D on system reliability was carried out by the Electric Power Research Institute (EPRI), a research association funded by the Nation's electric utilities. As a result of changes in the business climate of its members, EPRI's budget has declined by approximately 30 percent since 1994. More importantly, the majority of EPRI effort now focuses on near term, proprietary, commercially viable technology. Projects in longer term strategic research make up less than 15 percent of the total budget, and their public interest value is limited by the proprietary nature of the work.

- State agencies, such as California's Energy Commission (CEC) and the New York State Energy Research and Development Administration (NYSERDA), have funded electric delivery system research and may continue to do so. CEC, with the guidance of the California ISO, funds electric power system reliability research on topics of importance to California consumers. California supports State public benefit research funding through transition charges on electric power sales. Transition funding usually has a limited duration, a focus on immediate benefits as opposed to strategic research, and may not be available to ISO's that cover multiple States.

- Federal support of electric power delivery research is becoming an increasingly important factor. For instance, EPRI leverages its limited strategic research funding by partnering with Federal agencies, exemplified by the collaboration between EPRI and the Defense Advanced Research Projects Agency (DARPA) on advanced power electronics. Delivery system research performed by equipment vendors is also increasingly dependent on leveraging with EPRI or government funding. Agencies such as the Department of Defense (DOD) fund electric delivery system research, usually focused quite specifically on the particular agency's mission. DOD-funded work on utility system modeling, for instance, assesses the security of electric supply to military installations only.

DOE funding of electric infrastructure research is necessary to maintain support for activities that are in the national interest, and to sustain adequate levels of long term development necessary to provide the basis for future industry innovations until new market and/or regulatory structures are developed that provide the incentives for the private sector to assume this work. The realities of electric industry restructuring call for an increased DOE role in power delivery research with both near term goals to assure reliable systems during the transition to competitive markets, and long range goals to develop advanced, enabling technologies.

- Near Term(< 3 yrs.)
  Execution of the recommendations of the SEAB Task Force for evaluation of risk based analytical tools for reliability assessment, examination of alternatives to central station reactive power supply, and monitoring of private research on reliability technologies to assure that gaps do not develop.

- Mid-Term (3-7 yrs.)
  Development of system control technologies that enhance system stability and market performance, distributed resource integration strategies that enhance the flexibility of electric delivery, and transmission technologies for low cost mitigation of bottlenecks.

- Long Term (7-15 yrs.)
  Development of fundamental and enabling technologies for high capacity transmission.

Perhaps as important as defining what is appropriate for DOE infrastructure research is identifying what would not be included. For instance, the immense investment in existing electric delivery facilities means that the introduction of new technology will only slowly change the nature of electric infrastructure. As a consequence, maintenance of existing systems will have a significant effect on electric system reliability especially in the near- and mid-term. Maintenance, however, is the direct responsibility of transmission and distribution service providers and adequate regulatory incentives exist to ensure an appropriate focus on maintenance technology development. For this reason, maintenance technologies will not form a part of the DOE Enhancing Utility Infrastructure program.

Key Accomplishments

DOE began investigating synchronized measurements of power system quantities in 1991 through National Laboratory and university research performers. In 1995, the DOE co-sponsored Wide Area Measurement System (WAMS), an advanced satellite-synchronized monitoring system, entered field trials on the western U.S. power grid. During the western system outages of July and August, 1996, this prototype synchronized measurement system proved its worth by dramatically reducing the time needed to understand the causes and progression of the outages.

In recent years, a number of integrated, multi-benefit energy storage systems have been field tested in collaboration with private partners. For instance, a newly-developed R&D 100 Award winning mobile storage system, operating at a Georgia lithography plant, successfully corrected over 90 percent of the plant's power quality events in its first 6 months of operation. A 3.5 MW storage facility at a heavy metals recycling plant in California carries critical emission control loads in the event of a power outage to eliminate environmental noncompliance. A 1.4 MWh storage system recently installed in Alaska improves power quality in an isolated power system on an Indian reservation. The success of these state-of-the-art systems is helping to address power quality and reliability problems, enable increased use of renewable power generation, and increase the productivity and competitiveness of U.S. industry.

Superconductivity Partnership Initiative (SPI) partners hold world records for high temperature superconducting (HTS) equipment of all types, including fault current limiters, motors, transmission cables, and power transformers. Current-carrying capability of HTS wires has increased 10-fold since 1990, and wire-making costs have decreased substantially as companies gear up for larger orders. A record 6 license agreements have been signed over the last 24 months for industrial use of the innovative second-generation wire technology developed with

DOE support. In addition, 4 R&D 100 Awards have been received for Department-sponsored HTS technology.

Transmission and Distribution Reliability

Budget: FY98-$1.0M, FY99-$3.0M, FY00-$4.0M

Background

The existing electric power grid links nearly 3,500 U.S. utilities operating under the supervision of 150 control areas and 22 security coordinators in 3 functionally and physically independent regional interconnections. It has been characterized as an energy superhighway, though it actually bears more resemblance to the network of two-lane roads that existed before the interstate highway system was built. That system allowed travelers to go from town to town, but those who attempted long distance travel risked delays due to bottlenecks created by local traffic congestion and fragmented, piecemeal routing. Similarly, the electric network has bottlenecks that can become congested and restrict power transfers, while routing for long distance power sales is often fragmented by multiple jurisdictions.

The revolution in system operations resulting from competition has increased pressure to cut costs and to drive the power grids harder, to squeeze as much economic value out of them as possible. Some catastrophic outages in the western system during the summer of 1996 pointed out the fragility of the network in the face of high levels of interregional power transfers. At the same time, the presence of system bottlenecks and the fragmented, independent control structure has made it more difficult for competitive, reliable regional electricity markets and institutions to thrive, and have frustrated attempts to create a national commodity market in electricity.

A major new DOE/industry initiative, Transmission and Distribution Reliability, will address near- and mid-term objectives of the Electric Infrastructure program. It will support a National Laboratory/electric industry partnership to conduct electric system reliability research in the context of competitive markets. The program will collaborate with industrial and academic partners on initiating a research agenda to develop technologies that promote competitive markets, ensure system reliability (adequacy and security), increase network capacity for large scale, long distance power transfers, and promote integration of renewable generation, distributed resources, and storage. Technologies that can automatically control networks over large areas at high speed, and that coordinate operation of distributed resources, offer the potential for creating reliable, interregional markets. Improved high capacity transmission options, and efficient use of distributed resources can eliminate system bottlenecks at minimum cost. This projected five-year program will be reassessed each year to determine the need for Federal involvement depending on the nature and implementation needs of new regulations, and the impact of market forces.

Linkage to CNES Goals and Objectives

The research and development program in Transmission and Distribution Reliability would contribute to the following CNES goals and objectives:

- CNES Goal I, Objective 1 - Support competitive and efficient electric systems.
- CNES Goal II, Objective 2 - Ensure energy system reliability, flexibility, and emergency response capability.
- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.
- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.

Program Description

The Transmission and Distribution Reliability program, in collaboration with the electric industry, proposes initiating a reliability research agenda that would consider technology development in three program areas: Real Time System Control, Power Electronics, and Distributed Resource Integration. Work in High Capacity Transmission Technologies is described below, but no funding is requested in FY 2000. Because the Transmission and Distribution Reliability program is a new initiative, proposed program areas are under review and are subject to change based on industry input on the appropriate content and priority of program elements. As a result, descriptions of program elements are of necessity more general than is the case for programs with a substantial portfolio of ongoing projects. In general, the program initiates definition, fundamental design, and simulation of technologies for monitoring and control concepts identified by the electric industry. These concepts would be supported by work in the broad technology areas outlined below.

Real Time System Control

Budget: FY98-$0.0M, FY99-$2.5M, FY00-$3.4M

Description, Objectives and Performers. Conventional power system control uses off-line models, planned generation dispatch, and anticipated load patterns to identify secure system configurations. With relatively few configurations to monitor, manual control suffices to maintain the system in the secure state. In a competitive marketplace, with a multiplicity of possible generation and load patterns in a constant state of flux, the number of possible system configurations and potential modeling scenarios could become unmanageably large. Agile competitive markets that permit large numbers of long distance power transactions suggest a transition from manual control and off-line modeling to automated, on-line strategies that manage the system in real time. The objective of the Real Time System Control program is to develop technologies leading to automated security assessment and control based upon real time system measurements. High speed communications and distributed intelligent controllers would adjust power electronic network management devices and actively suppress disturbances with only limited human supervision.

Since this program element seeks to introduce a completely new paradigm in system control, initial efforts are expected to rely heavily on university and National Laboratory performers. Work on wide area synchronized measurements, which can be used in existing systems to more accurately investigate disturbances, would be done in cost shared partnerships with electric industry operations partners.

R&D Challenges. Technical developments that are necessary for successful real time control include:

- Measurement systems that extract information that allow calculation of system states in real time.
- Cost effective communications that securely coordinate high speed data exchange under dynamic circumstances.
- Security assessment models that operate in a distributed environment at high speed using system measurement data.
- Autonomous reasoning agents that can carry out secure distributed decision making and issue appropriate control commands.

R&D Activities. Real Time System Control research addresses near- and mid-term research goals of the Electric Infrastructure program. Near term activities include those identified by the SEAB Task Force, while the development of measurement based, automated system controls supports mid-term objectives. The following R&D activity elements describe tools that might meet the challenges.

Wide area synchronized measurements: This program element would extend work on system measurements that proved so useful in the summer of 1996. The existing network of satellite-synchronized transient data recorders could provide measurements to be analyzed using advanced transient analysis methods, such as wavelet decomposition, and correlated with models of known events. This will both improve the value of existing models and identify signatures of disturbances that can be used to guide control actions.

On-line measurement-based security assessment models: This element examines modeling algorithms that operate in a distributed environment to both validate measurements and rapidly screen the hundreds of contingencies represented by the expanded geographic extent of interregional competitive markets.

Adaptive automated control: The advent of power electronics devices capable of actively managing system power flows at high speed creates the need for an automated control capable of coordinating the response of widely dispersed groups of such devices. This research examines development of autonomous reasoning agents that can monitor the state of the system in real time and issue control commands to suppress developing disturbances.

Development of risk assessment planning models for transmission networks: This program element seeks to carry out the SEAB Task Force near-term recommendation by pursuing development of transmission planning models that incorporate real-time control systems and power electronics, as well as extend the accuracy of modeling to larger portions of the grid. Because, in very large systems, conventional deterministic contingency analysis becomes inadequate, the mathematical basis for assessment of transmission capacity through systematic statistical evaluation of a large number of individually unlikely risks could be developed. In order to better define the behavior of very large systems nearing collapse, non-linear modeling methods might also be devised.

Accomplishments. In addition to the WAMS project discussed above, which proved its worth during the summer 1996 western system outages, important successes were achieved in initial steps toward automated system control. A neural network-based voltage controller was developed that could simultaneously optimize the voltage profile and minimize system losses using only a single system measurement point. A multi-path fiber optic communications network for distribution system use was developed that could automatically route messages through damaged and reconfigured networks. The system was licensed to a utility who is currently using it as part of a wide area distribution automation scheme.

Power Electronics

Budget: FY98-$0.0M, FY99-$0.0M, FY00-$0.4M

Description, Objectives and Performers. Inverter based power electronic equipment offers high speed dynamic response and has the ability to manage power quality independent of system conditions. High capacity power electronics can manage power flow on transmission systems, and, under real time control, actively suppress system disturbances.

The objective of the Power Electronics component of the program is to reduce by 50 percent the cost of high capacity power electronic inverters. Performers of the research would include National Laboratories to assess and develop converter designs, and with industrial partners, develop pilot scale systems. Fundamental research on materials would likely be performed by National Laboratories, universities, and other research organizations.

R&D Challenges. Barriers to achieving the desired 50 percent cost reduction goal are as follows:

- Need for high efficiency multi-level voltage source inverter topologies for cost effective application to high voltage operation.

- Need for low cost, controlled turnoff switching devices made from materials that offer higher standoff voltages and better thermal performance than silicon.

R&D Activities. Power Electronics program research activities support the mid-term integration of distributed resources as well as long-term goals for high capacity transmission technology and improved customer power quality options.

Development of high power, high efficiency, low cost inverter topologies: Currently available inverter designs suffer from a series of drawbacks resulting in high cost for high voltage, high power applications. These include the need for series connection of switches, low efficiency for part-load operation, and a requirement for bulky accessories such as filters or interphase transformers to control harmonic distortion. This research activity proposes partnerships between National Laboratories and industry to develop advanced multi-level inverter topologies that are simpler and more efficient than conventional equipment. Funding would be leveraged through cost share, with the bulk of Federal funding applied to improvements in modeling of inverter topologies and in testing of concepts.

Development of economical wide-bandgap semiconductor switching devices: Switching devices made of new semiconductor materials such as silicon carbide and thin-film diamond offer significant improvement in voltage withstand capability and thermal performance compared to conventional silicon-based devices. Anticipated research activity could focus on fabrication of silicon carbide and diamond films with sufficient purity dimensions to be used in development of doping and device fabrication strategies. A consortium of National Laboratories, manufacturers, and material suppliers could be formed to construct a prototype switching device using the new materials. Performance targets for the device might initially be 25kV and 2000 Amps.

Accomplishments. Bench scale prototypes of high efficiency multi-level inverters were developed in a National Laboratory in 1995. One of these designs is now being used in a commercial dynamic reactive power compensator to be marketed by an industrial partner. Important progress had also been made in developing an advanced process for fabricating high purity silicon carbide at rates up to 10 times that possible with conventional techniques.

Distributed Resource Integration

Budget: FY98-$0.0M, FY99-$0.5M, FY00-$0.2M

Description, Objectives and Performers. Distributed resources include a variety of energy production and storage devices, such as small turbines, building-integrated photovoltaics, fuel cells, and energy storage systems with capacities from 1 kW to 10 MW. Another distributed resource is direct control of customer load for system and local benefits. Deployment of such resources on distribution networks could both defer investment in distribution and/or transmission facilities and increase the reliability of power delivery by placing energy sources (either generation or storage) nearer to demand centers. By providing localized reactive power support, distributed resources could improve power quality. By supplementing conventional power delivery systems, distributed generation and storage could offer supply flexibility, including greater use of environmentally benign renewable energy.

The Program will support the integration of distributed resources into the larger power system. Proposed tasks could focus on resolution of control requirements, protection issues, and development of case studies to address barriers to implementation. Research will be performed initially through electric and natural gas industry partners. Eventually, competitively selected cost shared proposals by integrated teams of equipment suppliers,

distribution system owner/operators, and users would field test approaches. National Laboratory and/or university expertise would be utilized to develop the theoretical bases for modeling and control.

R&D Challenges. The principal barriers to large scale deployment of distributed resources are:

- Lack of modeling, monitoring and control methods for planning and operating systems composed of a large number of sources which must be dispatched in accordance with the economics of the larger marketplace, as well as with consideration for local system constraints.

- Lack of an economical approach to distribution system protection and reliability for distributed resources.

R&D Activities. Research activities under this program area will stretch the new paradigm even further, and require examination of technical, economic, institutional, safety, and other issues. More detailed guidance from stakeholders will be sought to completely define this program area. The following elements are proposed as initial areas for investigation in support of near- and mid-term goals. Distributed resources provide a significant alternative to central station reactive power support, and the evaluation of such options is a near-term recommendation of the SEAB Task Force. In the mid-term, distributed resources offer the potential for increased customer choice and improved reliability of the larger system.

Control and protection of distributed resources: This program element will develop high speed multi-variate constrained optimization strategies for dispatching and control of large numbers of distributed resources. It will also assess the availability of cost-effective communications strategies that can accurately and securely exchange data at high speed to economically control large numbers of dispersed resources. This project will also explore options for protective systems that can be retrofitted to existing distribution systems economically and reliably.

Feasibility case studies: A key recommendation of the SEAB Task Force was the evaluation of alternatives to central station reactive power support. Distributed resources offer the most important mechanism for supplying reactive support close to the load. Cooperative efforts with industry will develop case studies assessing the feasibility of distributed resources in specific electric and natural gas systems. Potential partners would include energy producers, distributors, and users such as commercial building owners as well as equipment manufacturers. Case studies would identify the operational characteristics, safety and reliability issues, control system requirements, economic benefits, and emissions performance, as well as supply of reactive power support by distributed generation or storage technologies in an application environment.

Electric and gas systems integration: Most distributed generation is expected to rely on natural gas, at least in the near term. Examples include microturbines and fuel cells, both of

which may be applied either as cogeneration in commercial buildings or as stand-alone electricity sources. Gas infrastructure and supply will therefore be as important as electric system issues in determining the success of the application. A series of regional studies will be conducted with industry to examine the interactions of the gas and electric delivery systems from the perspective of each as a component of an integrated energy system, with special emphasis on decreasing overall emissions and minimizing the cost of the delivered energy services to the customer.

Accomplishments. Two reports were prepared at the request of Congress that used case studies with actual utilities to determine the potential for integration of renewable resources into the electric power transmission and distribution system. The 1994 report assessed the cost and benefits of integrating wind and solar electric generation resources into the electric power distribution system. Wind resources were found to be cost effective for much of the Nation where good wind resources exist, but, for most of the Nation, economic benefits-to-cost ratios for solar applications were low due to their high capital cost. A 1995 report concludes that in general, about 50 megawatts of power from renewable energy sources can be integrated into most existing transmission systems to supply local loads without significant upgrades. However, large remote generation plants might require additional transmission lines that could be a significant part of the system cost of power from these sites.

High Capacity Transmission Technologies

Budget: FY98-$1.0M, FY99-$0.0M, FY00-$0.0M

Description, Objectives and Performers. The objective of the high capacity power transmission program is mid- and long-term development of technologies capable of moving two to six times more power over a given right of way than conventional transmission lines. Likely performers of the research agenda would be industrial partners engaged in the development of electric power equipment, supported by National Laboratories and universities. Eventually, competitively selected industrial teams would present cost-shared proposals for demonstration of promising approaches.

There is no funding for this work in FY 2000, and the option for Federal support beyond FY 2000 will be reassessed in later years.

R&D Challenges. Research challenges in the development of high capacity retrofit technologies include:

- Standard overhead transmission line conductor is a commodity product of proven performance. Alternatives must meet demanding mechanical requirements for decades, possess low resistance or be capable of operating at high temperatures, and be producible at a cost premium consistent with the value of their increased capability.

- Cost reduction of terminal equipment for integrating available line upgrade options into conventional three phase networks. Such options include conversion from three phase to six phase or to high voltage dc operation.

R&D Activities. *High capacity transmission conductors:* This research activity will evaluate, in concert with industry partners, the feasibility of various line conductor designs for high capacity operation, including development and testing of sample conductors.

Assessment transmission options: Options for low-cost line conversion could help alleviate system bottlenecks. Strategies for conversion of three- to six phase could be evaluated, as well as application of advanced inverters developed under the Power Electronics program.

Accomplishments. High phase order transmission systems use 6 or 12 phases over the transmission right-of-way instead of today's 3-phase systems, and can carry 2 and 4 times the power, respectively. In 1992, a 6-phase transmission line was energized as a tie line in a 3-phase system to analyze and demonstrate the performance of high phase order transmission on a utility electric grid. The 1997 final report on the demonstration documented the technical feasibility of high phase order transmission in terms of safety and system protection.

Energy Storage Systems

Budget: FY98-$3.8M, FY99-$4.5M, FY00-$6.0M

Background

Competitive electric market pricing structures will stimulate development of new strategies for controlling electricity use and cost. Sophistication of both high-tech and manufacturing industries makes power quality increasingly important to U.S. productivity. As transmission networks more frequently operate at their stability limits, network operators search for means to increase network capacity at minimum cost. Energy storage systems could effectively address all of these issues. In addition, energy storage increases the value of electricity generated by renewable resources by making it available at any time. Accordingly, the Energy Storage Systems (ESS) Program focuses on three technological thrust areas: reliability, renewables, and productivity.

The ESS Program addresses the multi-billion dollar national power quality problem by developing systems that enable electricity providers to correct instantaneously for power variations. Power quality systems can be installed at a customer site or at a utility substation near customers in need of guaranteed quality power. Larger versions can improve stability and selectively increase capacity of the transmission system.

Large electricity users and providers can achieve important productivity gains and increase competitiveness through distributed siting of storage systems. Often, a single storage system can

be used for multiple purposes and result in substantial cost savings and improved operational efficiency through avoidance of monthly peak demand charges, power quality-induced equipment failure, and peak period overload of utility equipment.

The President's Committee of Advisors on Science and Technology (PCAST) stated that "if intermittent renewable energy technologies are to make very large contributions to electricity supplies in the longer term. .... technologies are needed that would make it possible to store energy for many hours at attractive costs." The ESS Program works with renewable energy system suppliers to optimize storage systems integrated with Photovoltaics (PV) and wind generators.

Linkage to CNES Goals and Objectives

The Energy Storage Systems program supports the following CNES goals and objectives:

- CNES Goal III, Objective 2 - Accelerate the development and market adoption of environmentally friendly technologies.

- CNES Goal V, Objective 1 - Promote development of open, competitive international energy markets, and facilitate the adoption of clean, safe, and efficient energy systems. *(by working with other countries through the International Energy Agency to promote communications and collaborations)*

Focused on the three thrust areas of reliability, renewables and productivity, the ESS Program will continue to team with industry in highly-leveraged agreements to develop improved, integrated, cost-effective storage systems with multiple benefits for electricity providers and users at scales ranging from small remote installations to large industrial facilities.

Application of energy storage technologies will be driven by reduced costs and improved flexibility as the Program develops systems that meet the cost goal of $700 per kW and the energy density goal of 5 kWh per sq. ft. of system footprint while meeting customer needs in the rapidly changing electricity marketplace.

Program Description

Research and development in the ESS Program is organized around three objectives: (1) integration—supporting the near- and mid-term development of complete energy storage systems for diverse applications that make use of modularity, factory integration, and transportability for cost reduction; (2) components—supporting the design, research, and long-term development of batteries, superconducting magnetic energy storage systems (SMES), flywheels, and other advanced energy storage devices along with improved, multi-use power electronics, controls and communications components; and (3) analysis—improving the understanding of application requirements, assisting U.S. industry in identifying high-value energy storage sites through modeling and engineering assessment, and identifying national benefits of storage in a restructured utility industry.

Integration

Budget: FY98-$2.0M, FY99-$2.2M, FY00-$3.0M

Description, Objectives, and Performers. By viewing a storage system as a single product, rather than a custom designed project composed of parts procured from various sources, major savings in construction cost and improvements in performance can be achieved. Benefits include cost savings of 30 to 50 percent through reduction of custom engineering and on-site installation labor, as well as reduced start up times. Standardized components, designed to optimize system performance, offer the potential for further cost reduction and longer life. Integrated hybrid systems, consisting of a renewable generator (PV or wind), storage system, and a diesel generator or gas turbine, offer increased flexibility to meet energy supply needs. Development of multiple integrated systems in a coordinated effort allows the program to leverage private and public resources through coordination of parallel R&D activities.

R&D Challenges. Experience has proven that good integration leads to optimal performance at the lowest cost compared to off the shelf or one-of-a-kind engineered designs. The major obstacle to greater levels of integration is the cost associated with low production volumes. Without further support for high-cost, high-risk prototypes and demonstrations, it will be impossible to generate the wide-spread interest and support necessary to optimize designs at a low enough cost to reap reliability and productivity benefits.

R&D Activities. *Transportable systems:* A mobile version of the award winning PQ2000 factory integrated battery-based power quality system is being developed. Mobile PQ2000 is a 2-MW/15-second system developed in collaboration with Omnion Power Engineering Co. that is currently being tested by Virginia Electric Power Company and at 3 other sites over the next 2 years.

Advanced battery systems: The ESS Program continues to work on development of zinc-bromine battery systems, which have 4 times the energy density of lead acid batteries. The Advanced Battery Energy Storage System (ABESS) is a high-risk, 3-year, 50-50 cost-shared project with ZBB to develop a transportable, modular zinc/bromine battery storage system, scheduled to begin a multi-year test at a utility or customer site by 2000.

Renewable generation and storage: The ESS Program works with the photovoltaic and wind industries to improve the compatibility and reliability of hybrid renewable generation and storage (RGS) systems while lowering system cost and maintenance requirements. In 1998, three studies commenced that will define the present and future needs of users of RGS systems, determine their application requirements, and help guide development of integrated system components.

Accomplishments. The PQ2000 system developed by the ESS Program and its industrial partners earned an R&D 100 Award as the first installation of a complete integrated power quality protection system with master control by the electric utility. The system meets the power quality needs of one of Oglethorpe Power Corporation's industrial customers, a

lithography plant in Homerville, GA. During the first six months of operation, the system corrected over 90 percent of the plant's power quality events.

A factory integrated 1.4 MWh, multiple benefit storage system by was developed by ESS and an industrial partner. Installed on the Annette Island Reserve, in southeast Alaska, the system absorbs the large load spikes caused by the local lumber mill. By displacing the output of a 3.3 MW diesel engine formerly operated at light load to control power swings, it reduced diesel fuel use by 180,000 gallons and cost by $310,000 in the first 8 months of operation. It greatly improved power quality for the island residents, the 1,700-member Tsimpshean Native American Indian tribe.

A 3.5 MWh storage system co-developed by the ESS Program and GNB provides multiple benefits at a lead-acid battery recycling plant in Vernon, California. The system's primary benefit is its ability to carry critical loads during power outages, ensuring that pollution control equipment remains operational. Additional benefits include peak-shaving and uninterruptible power.

Components

Budget: FY98-$1.4M, FY99-$1.4M, FY00-$2.1M

Description, Objectives, and Performers. The ESS Program works with industry partners to carry out fundamental research on advanced storage elements and power conversion equipment components that cost less, have higher performance, are smaller, and are better integrated with the other parts of the system. A great deal of the evaluation of prototype energy storage components is conducted in-house at Sandia National Laboratories. The Program also draws on the expertise and resources of a diverse group of partners including representatives from industry and an industry research association, a utility trade association, two engineering and consulting firms, and several university groups.

R&D Challenges. Materials and processing limit the life, and hence, the cost effectiveness of advanced storage equipment. For example, work must be done to identify electrochemical failure mechanisms in valve regulated lead acid (VRLA) batteries and find ways to delay failure. Key issues include loss of cell seal integrity, loss of conductivity due to changes in separator mechanical characteristics, and sensitivity to temperature extremes. Similarly, successful commercialization of advanced zinc bromine batteries requires improvements in the microporous polyethylene separator, increases in the rate capability of the bromine electrode activation layer, and in the robustness of the electrochemical cell stack.

Research is also needed on SMES, flywheels and power conversion systems. SMES requires low cost materials and cryogenics. Flywheels need high strength composite rotor materials and improved bearings. Power conversion systems require development of advanced, high power, low cost semiconductor switches, hybrid power controller software, and advanced converters.

R&D Activities. *VRLA batteries:* Low-maintenance, spill-proof, and more compact than conventional batteries, VRLA batteries have been commercially available for more than ten years. The ESS Program, using the extensive field data now available, will build on past work with industrial partners by collaborating on a VRLA reliability improvement project with the International Lead Zinc Research Organization. Studies will be conducted to define opportunities in existing VRLA designs for further improvement under typical utility battery operating conditions and use modes. Similar projects are in the planning stages for SMES and flywheels.

Power conversion systems (PCS): The ESS Program is teaming with power electronics firms, universities, and energy research institutions to develop power controller electronics and software for use in several advanced storage applications such as remote backup systems. The ESS Program supports testing at the Arizona Public Service Solar Test and Research Center of a state-of-the-art PV/battery hybrid controller developed by Trace Technologies. Results from the characterization testing will be used to develop operation strategies for village hybrid systems. ESS is also participating with the International Lead Zinc Association in a cost shared effort to develop testing requirements for remote area power systems. This project will greatly improve the reliability of modular renewable energy systems not tied to electric grids.

Accomplishments. Recently, the ESS Program completed development of a prototype 33 kW, 3-hour prototype zinc/bromine battery that exhibits four times the energy density of current lead acid batteries. This highly successful prototype is the basis for the ESS Program's ongoing ABESS project that will result in the development and demonstration of a transportable 300-kW/2-hour integrated system designed to showcase the potential of zinc bromine technology for peak shaving and other customer-side applications.

In 1998, the ESS Program completed an assessment of system configurations, cost, and standards for PCS use in the utility industry with recommendations for future R&D activities. This report will form the basis of future R&D work on a single PCS topology to serve the needs of batteries, flywheels, SMES, and renewable generation sources.

Analysis

Budget: FY98-$0.5M, FY99-$0.9M, FY00-$0.9M

Description, Objectives, and Performers. Projects conducted within the analysis program area are designed to improve the understanding of application requirements and assist industry in identifying high-value energy storage sites using models and engineering assessment tools. This work often forms the basis for R&D projects undertaken by the ESS Program and/or its partners.

R&D Challenges. Currently, the greatest source of uncertainty in the development of energy storage and other distributed resources is the future of the electricity industry. The emergence of a competitive marketplace for electricity will bring about many technological changes in the way electricity is generated, delivered and sold. A restructured electricity

marketplace is expected to lead to many opportunities for increased efficiency, resource utilization, flexibility and reliability through energy storage as utilities begin to tap the potential benefits of distributed resources. Understanding how the dynamics of this new marketplace will drive end user needs and quantifying the many potential benefits of energy storage are the major challenges confronting the energy storage community.

R&D Activities. *Hybrid system handbook:* In order for a hybrid system to demonstrate optimal performance at the lowest cost, components must be integrated in a configuration that meets the specific application requirements of that particular system. Requirements for a village system, for instance, are quite different than for a telecommunications application. In order to address this problem, the ESS Program is developing a handbook on energy storage for renewable applications. The handbook will provide technical guidelines to members of the renewable generation and storage communities for improved integration of energy storage with renewables. The completed handbook will include the results of a technology characterization testing existing renewable/storage hybrid systems.

Energy storage in a restructured environment: As electric industry restructuring proceeds, it will become increasingly important that electricity providers and related service companies understand the role energy storage can play in maintaining the reliability of the electricity infrastructure. The ESS Program will conduct a quantitative analysis of the impact of energy storage on reliability. This study will help determine the direction of development of integrated energy storage systems for reliability applications.

Non-grid applications: The need for distributed energy storage technology is particularly acute in remote areas not connected to utility grids. Congress highlighted this need in 1998 by requesting that DOE develop and demonstrate cost competitive, modular renewable energy technologies to "focus near-term research on the development of reliable systems for remote applications in occasionally hostile climates." The ESS Program is currently working with the International Lead and Zinc Research Organization on a feasibility study of hybrid photovoltaic/storage systems for use in remote villages in Peru. Results from this study will be used to assist in conducting a series of demonstration projects showcasing this technology.

Accomplishments. Recent progress in the development of both superconducting magnetic energy storage (SMES) and flywheel energy storage has made these technologies increasingly viable energy storage options in the United States. In order to further development of these advanced storage technologies, the ESS Program completed an analytical study that identifies areas of analysis and R&D necessary to advance SMES and flywheel technologies. Included in the study is a modeling tool that links cost and performance of SMES and flywheels over time and an updated definition of application requirements and potential markets.

A recent survey by Arizona State University supported by ESS and the Photovoltaic Program quantified sales of photovoltaic batteries domestically and world-wide in 1995, identifying market weaknesses and information needs. The information contained in the report has helped to improve the information exchange between the various industry groups involved in the development and manufacturing of PV/storage hybrid systems.

Superconductivity in Power Systems

Budget: FY98-$31.6M, FY99-$32.5M, FY00-$31.0M

Background

High temperature superconductivity (HTS) or the ability of some ceramic materials to become lossless carriers of electricity when cooled to the temperature of liquid nitrogen, was discovered in 1986. Materials that become superconducting at the much lower temperature of liquid helium are used in medical applications, but costs of refrigeration have made them unattractive for power equipment applications. HTS not only presents opportunities for constructing compact, high efficiency, high capacity power equipment but also opens possibilities for development of equipment, such as fault current limiters, that offer entirely new capabilities. HTS, in fact, has the potential to impact the production, delivery, and use of electricity as profoundly as fiber optics has impacted communications. Superconducting wires, with 100 times the current carrying capacity of copper wires, will result in transmission cables with five times the capacity of conventional cables. HTS motors, generators, and transformers will have half the energy losses and be half the size and weight of conventional systems. Superconductivity in Power Systems constitutes the principal long-term development effort for the Enhancing Utility Infrastructure program.

HTS offers many national benefits. HTS cables offer an alternative to new rights of way for overhead lines which are difficult to obtain, without the oil spill exposure that limits interest in conventional oil filled cables. Retrofitting HTS cable into existing ducts could increase transmission capacity of rights of way by up to five times with no environmental risks.

HTS motors and generators pack nearly three times the power into the same space as conventional machines and coordinate well with power electronic inverters to provide a double benefit of controllability as well as increased power density.

HTS fault current limiters ameliorate concern for added short-circuit current caused by system growth. Limiting fault currents to lower levels also enhances system stability, reliability, and safety, and improves power quality. The ability to efficiently control currents also offers new operating possibilities for power flow control.

HTS transformers offer utilities oil-free, fire-proof performance and the absence of a thermal aging mechanism, as well as high efficiency. HTS transformers can also be operated for long periods at up to double their rated capacity without loss of life, a capability not available in conventional units. Finally, the HTS transformer will likely have low-impedance, making it easier for utilities to maintain output voltage levels over a wide range of power levels, and they will incorporate fault current-limiting winding concepts to provide additional benefits. HTS transformers truly represent the first major hardware innovation in this mature industry since the development of oriented core steel.

HTS bearings for flywheel systems could be attractive to tomorrow’s utilities and large industrial

customers seeking diurnal storage efficiencies approaching 90 percent.

HTS magnetic separator technology is important both for the chemical industry and for hazardous waste processing.

The annual world market for HTS power technologies is estimated to be at least $30 billion by 2020. DOE leads the world in superconductor technology development and with the SPI projects described below, DOE and U.S. industry are partnered to move a step closer to being the world leader in sales.

Linkage to CNES Goals and Objectives

The Superconductivity in Power Systems program supports the following CNES goal and objective:

- CNES Goal IV, Objective 2 - Develop technologies that expand long-term energy options.

In 1988, DOE mobilized the resources of U.S. industry, National Laboratories and universities to accomplish two major technological goals: (1) solve the difficult problem of manufacturing electrical wires from the family of brittle ceramic superconducting materials discovered in 1986, and (2) develop practical equipment designs for efficient, pre-commercial electric equipment such as motors, transmission cables, generators, transformers, and current limiters that use these wires.

To accomplish these program objectives, specific goals must be met for superconducting wire, as well as for pre-commercial prototypes of power equipment using the wires. The wire goal is to achieve an operating capacity of 1000 amperes per square millimeter of wire cross-sectional area at a cost of 1 cent per ampere-meter. Goals for equipment are specific to individual technologies, but are met through operational tests of prototypes that prove the technology is ready to provide the specified performance advantages. Generally, devices will have only half the energy losses of conventional alternatives. In addition, it is the goal of the Superconductivity Program that, by 2004, U.S. industry will begin supplying the international electric power sector with the first HTS transmission cables, transformers, motors, and current controllers.

Program goals are achieved through a national effort that partners Federal and State agencies, universities, National Laboratories, and private industry in cost shared, industry led consortia focused on producing marketable products. HTS equipment will achieve market penetration not only based on efficiency, but also on superior performance, small size, and environmental benefits when compared with conventional equipment.

Program Description

The Superconductivity Power Systems program marries the entrepreneurial drive of high-tech companies with the vast technological resources of DOE's National Laboratories to meet the complex research challenge of long-term development of HTS technology for electric power. The HTS program contains three program elements: The Superconductivity Partnership Initiative (SPI), The Second Generation Wire Initiative, and Strategic Research.

The Superconductivity Partnership Initiative (SPI)

Budget: FY98-$14.0M, FY99-$14.5M, FY00-$14.0M

Description, Objectives, and Performers. The SPI competitively solicits aggressive industry-led projects to design and operate pre-commercial HTS electric power equipment. SPI projects include transformers, motors, cables, current limiters, flywheel energy storage, generators, and magnetic separation systems. A unique SPI feature is that each project must be carried out by a vertically integrated team, typically including an electric utility, a system manufacturer and a superconducting wire supplier, and National Laboratories. This vertical integration has proven to be a powerful way to quickly develop mature end user systems while leveraging resources.

The SPI program promotes cost-shared development by manufacturers of equipment design technologies necessary to take commercial advantage of advances in HTS wire technology. By the end of the program, it is expected that SPI teams will have built and operated refined HTS versions of all of the major power equipment technologies that could represent a significant benefit for the electric utility infrastructure.

A total of 9 SPI projects either are or will soon be under way. Performance teams include 17 manufacturers, 6 utilities, 2 utility research associations, 5 National Laboratories, and a State research organization. Projects cover the entire program range including a 15kV current limiter, a 5000 Hp motor, 2 power transformers and 2 cables, as well as a magnetic separator and a flywheel energy storage system.

R&D Challenges. SPI teams must resolve a number of key technical challenges including:

- Conductor availability, performance, configuration, and cost.
- Electrical and thermal insulation performance and durability.
- Interface between the ambient environment (room temperature, atmospheric pressure) and the cryogenic temperature, high-pressure environment.
- Cooling system research, design, reliability, and performance.

R&D Activities. *Cable projects:* Activities are underway to determine the optimum configuration for wrapping the HTS tapes to assure the lowest possible alternating current (ac) losses. Such losses can add substantially to the heat load of the cryogenic system required to keep the cable cold. In addition, two candidate dielectric systems are being evaluated by different teams. One system, based on room temperature, extruded dielectric material, takes advantage of the large base of conventional cable experience, while another, based on a novel cryogenic temperature dielectric, offers potential for reduced ac losses.

The characterization and measurement of ac losses is complex for cables and the SPI cable teams are developing two alternative methods for these measurements. Either a transport or a calorimetric method is used and the teams have made good progress toward developing a detailed understanding of the ac loss phenomenon.

Low cost, reliable cryogenic systems to keep the cable cold are of crucial importance to the success of HTS cable technology and both teams are also evaluating options for increasing the cable length between cooling stations.

Terminations and splices are a special topic of research in the cable SPI projects. Most failures in today's conventional cables occur in either the terminations or the splices. Electrical, thermal, and mechanical stresses on materials must be balanced.

Transformer projects: Research activities in the transformer SPI projects include the development of appropriate conductor geometries, dielectrics, and the cooling system. Investigation of low-loss conductor and winding configurations are essential as ac losses, like thermal losses, must be carried away by the cryogenic refrigeration system. The core design and core cooling systems are active areas of research.

HTS motor project: The SPI motor team is focusing on innovative fluid transfer coupling technology for entry and exit of cryogen at the motor/refrigerator interface. They are also developing the wire and motor coil technology necessary for cost-effective, 3-Tesla operation at temperatures near 30°K. Another active area of research is the concept of cryocooling in a rotating reference frame. Sophisticated high power test beds have also been developed for full scale characterization of HTS motor performance.

Accomplishments. World record performances were achieved by SPI teams. The 200-horsepower motor exceeded the design goal by 50 percent during tests in 1997, and the world's first superconducting current limiter met its technical goals during testing at a utility substation in FY 1998. The next version will feature the world's largest HTS coil and operate long-term on a utility grid, a first for the SPI program. The world's largest HTS transformer commenced testing in FY 1998, and the world's longest HTS cable completed its tests successfully.

The Second Generation Wire Initiative

Budget: FY98-$8.0M, FY99-$8.0M, FY00-$8.0M

Description, Objectives, and Performers. The Second Generation Wire Initiative is exploiting 1996 research breakthroughs at Los Alamos and Oak Ridge National Laboratories that promise unprecedented current-carrying capacity in high-temperature superconducting wires. These breakthroughs, which made headlines worldwide, will allow long wire lengths to behave as a single crystal, thus eliminating internal barriers to current flow that may limit use of wires now being manufactured. The interest in second generation wires for energy applications is enormous. A total of nine high-performance project teams involving six national labs and nine industrial partners are at work to further develop the wire technology.

R&D Challenges. Moderate lengths (1 to 10 meters) of coated conductors are needed for use in coils and device prototypes during FY 1999-2000. The performance goals for such moderate length wires are: critical current (I_c)= 50 amps and engineering current density (J_e) =20,000 amps per sq. centimeter. R&D challenges include scale-up of promising short sample results to produce substrates, verification of superconductor film growth by a number of industrially scalable techniques, demonstration of adequate texture and epitaxy over length, and development of simpler, and more robust buffer layer systems.

R&D Activities. *Substrate development:* This project investigates two methods of making buffered, textured metallic substrates, ion-beam assisted deposition ("IBAD"), and rolling-assisted, biaxially-textured substrates ("RABiTS"), both developed by National Laboratories. An industrial partner is developing electron-beam evaporation for depositing the superconducting layer upon either of two substrates. Concerns are process conditions for buffer layer deposition, adequate texture in the rolled nickel metal foil, and thickness of the superconducting layer while maintaining acceptable levels of critical current density.

Buffer layer development: A team led by an industrial partner is developing a non-vacuum buffer layer technology for deformation textured metal substrates. Such a structure could offer cost and performance advantages over conventional vacuum deposition of these layers. The work includes measurement of buffer layer texture, deposition of buffers and superconductor, and electrical characterization.

Alternative superconductors: A team of National Laboratories and industrial partners have also been working together to scale up yttrium-based (YBCO) coated conductors. Tasks include nonmagnetic deformation textured substrate development, substrate preparation, buffer layer development, IBAD sample testing, investigation of strain tolerance, statistical analysis of defects, environmental stability, microstructural studies, and measurements of critical current and critical current density. Near-term goals are a critical current density of 1 MA/cm^2 at 77^oK on a nonmagnetic, deformation textured substrate 1 meter long. The team has the ultimate goal of demonstrating the commercial feasibility of the coated conductor technology.

Accomplishments. Initial FY 1998 scale-up goals were met for wire processing breakthroughs. The first 2-cm lengths of coated conductor were produced in FY 1998 using an *ex-situ* deposition process.

Strategic Research

Budget: FY98-$9.6M, FY99-$10.0M, FY00-$9.0M

Description, Objectives, and Performers. The Strategic Research R&D area focuses on developing underlying knowledge needed for the success of industry-led projects. The Second Generation Wire Initiative evolved from five years of strategic research that achieved world record performance in short wire samples. In addition, research and analysis will be conducted on issues associated with integration of superconducting systems into an increasingly competitive and restructured industry framework. Strategic Research performers include four DOE National Laboratories, two Department of Commerce labs, seven universities, and two industrial partners.

R&D Challenges. Strategic research challenges include development of powder-in-tube wire that meets cost and performance needs of pre-commercial prototype developers, novel processing to increase pinning and connectivity to raise field and temperature operating windows for the HTS wire. Coils must be fashioned from the first lengths of second-generation wire, and the properties of these coils must be measured to provide input to system developers. An understanding of HTS material phase assemblage is critical to developing cost-effective HTS wire processes.

R&D Activities. Strategic research activities include bismuth/oxide (BSCCO) wire development research by two teams. The research includes development of novel means to produce high critical current density HTS tapes, including the new "coated BSCCO" approach that already has demonstrated over 40,000 A/cm^2 in short samples. The group studies the effects of processing conditions on the critical current and microstructure of the resultant wires.

Efforts to scale up the short sample BSCCO results to long lengths are conducted under several CRADAs. This research enables U.S. industry to use the National Laboratories' special facilities and staff resources to solve key technical issues of filament uniformity, grain growth (bridging) between filaments, ac conductor losses, and others.

Research is also conducted by the laboratories and several universities to exploit the higher critical temperatures of the thallium and mercury compounds. National Laboratories and universities, for example, are working to deposit and characterize thallium HTS on RABiTS. Results of the order 0.5 MA/cm^2 have been obtained on short samples.

Phase diagram research enables the National Laboratories and industry to understand the physical and chemical properties of HTS compounds. This research is cost-shared with the Department of Commerce. In another cost-shared effort, the mechanical properties of the

new laboratory-developed coated conductors are being examined, with plans underway to measure the private industry materials, as well, starting with the BSCCO tapes.

Strategic research also includes the fabrication and testing of small research magnets using the BSCCO compound (now) and the coated conductors when lengths of material become available. The understanding of normal zone propagation and quench characteristics of the new coated conductor in coil form will be needed if these wires are to be useful in electrical devices.

University research explores the physics of deposition of buffer layers and superconductor by electron beam evaporation, including the development of rate-monitoring apparatus, the nature of current flow through grain boundaries, and novel, high rate deposition of buffer layers.

Accomplishments. In FY 1998, the industry-led Wire Development Group achieved a record critical current density in BSCCO powder-in-tube wires of 71,500 A/cm^2. The average critical current in HTS wire made in FY 1998 for cables exceeds 100 amperes per tape in liquid nitrogen, a new record for commercially available wire.

Summary Budget Table (000$)

Enhancing Utility Infrastructure Research Areas	FY 1998 Appropriated	FY 1999 Appropriated	FY 2000 Request
Transmission and Distribution Reliability	**1,000**	**3,000**	**4,000**
Real Time System Control	0	2,500	3,400
Power Electronics	0	0	400
Distributed Resource Integration	0	500	200
High Capacity Transmission Technologies	1,000	0	0
Energy Storage Systems	**3,839**	**4,500**	**6,000**
Integration	1,950	2,200	3,000
Components	1,350	1,400	2,100
Analysis	539	900	900
Superconductivity in Power Systems	**31,579**	**32,500**	**31,000**
The Superconductivity Partnership Initiative	14,000	14,500	14,000
The Second Generation Wire Initiative	8,000	8,000	8,000
Strategic Research	9,579	10,000	9,000
Electric and Magnetic Fields R&D	**6,844**	**0**	**0**
Total	**43,262**	**40,000**	**41,000**