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Status Of Federal And Private
Research And Development Efforts
To Conserve Energy By Reducing
Electric Power Transmission Losses

This study identifies and describes those factors--laws of physics--causing electric power transmission losses and the research and development underway which is designed to reduce such losses.

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ABBREVIATIONS

EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration
K	kelvin
kV	kilovolt
kW	kilowatt
R&D	research and development

PREFACE

Energy conservation has become increasingly important because of the fuel and generating capacity shortages occurring in the Nation. As a result, energy research and development has received more attention. The Congress recently established the Energy Research and Development Administration (Public Law 93-438, dated October 11, 1974) to coordinate the Federal effort. Reducing energy losses in transmitting electricity would contribute to the energy conservation effort.

This study identifies and describes those factors--laws of physics--causing electric power transmission losses and the research and development underway which is designed to reduce such losses.

This study is primarily for the use of General Accounting Office staff members involved in surveys or reviews of national efforts to meet energy needs.

The study is available, also, to those outside the General Accounting Office who may have an interest in electric power transmission losses.

Electricity delivered to customers requires three major system components:

1. Generation--producing power.
2. Transmission--moving power from generation to load centers at high voltages.
3. Distribution--moving power for short distances to customers at low voltages.

On the average, of the total delivered cost of electricity, generation accounts for about 50 percent, transmission for about 13 percent, and distribution for about 37 percent.

During electric power transmission, four factors--resistance (see p. 3), skin effect (see p. 5), corona (see p. 5), and insulation (see p. 6)--cause most of the loss of electric energy. Resistance and skin effect cause most power losses during overhead transmission. These power losses are about 2.5 percent of net generation. The estimated transmission losses during 1975 were equivalent to about 80 million barrels of oil (about a 4.5-day requirement).

The electric utilities, related industries, and the Federal Government conduct research and development in electric transmission and distribution.

The Electric Power Research Institute and the Federal Government, through the Energy Research and Development Administration, are the major supporters of transmission research. The Institute budgeted about \$21 million for fiscal year 1976 transmission research. The Energy Research and Development Administration budgeted about \$11 million for fiscal year 1976 transmission research. The primary goal of transmission research and development is to increase the power-carrying capability of systems and to reduce generation capacity requirements. Also, reductions in electric energy losses during transmission result in additional benefits.

The Electric Power Research Institute and the Energy Research and Development Administration operate cooperatively in areas of mutual interest.

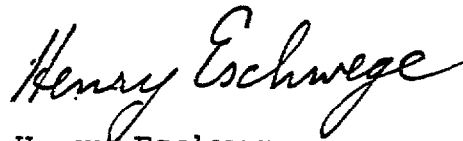
The four factors--resistance, skin effect, corona, and insulation--are laws of physics and therefore will exist when moving electric energy. Theoretically these losses can be reduced by increasing the conductor's cross-section areas, raising transmission voltage levels, and lowering the temperature of the line. Higher voltage transmission allows reduction in the current required and therefore results in lower current losses. Now the level of load demands for bulk amounts of power and construction costs limits the feasibility of raising voltages of existing transmission systems.

Lowering the conductor temperature will also reduce resistance losses. Although resistance losses can be reduced greatly, or in some cases to zero, by operating certain conductor materials at temperatures below 22° kelvin (see pp. 7 and 11), the potential for reducing temperatures is limited by dependability, expense, material fabrication problems, and stability in maintaining the required low temperatures.

Opportunities for large reductions in transmission losses in the near future are limited unless new breakthroughs in technology are obtained.

Future research emphasis may change depending on changing needs. For instance, one factor that is important to the priority assigned to various types of transmission

research is the point at which power is to be generated (i.e., at the load center or at the fuel source). If generation is to be at the fuel source (i.e., at the coal mine), more research probably would be directed toward improving the type of transmission lines needed for long-distance transmission of electricity. However, if generation is to be at the load center (i.e., a city), more research probably would be directed toward improving the type of transmission lines needed for short-distance transmission of electricity.



Henry Eschwege
Director
Resources and Economic
Development Division

CHAPTER 1

INTRODUCTION

Recent energy shortages and concurrent increases in energy cost have generated increased interest in national efforts to meet energy needs. We reviewed the causes of the loss of electric energy during transmission, the steps necessary to reduce the losses, and the potential for improving the efficiencies of electric transmission systems as a means of conserving energy.

Electricity delivered to customers requires three major system components: (1) generation--producing power, (2) transmission--moving power from generation to load centers over high voltage lines, and (3) distribution--moving power for short distances to customers at low voltages. On the average, the actual cost of generation of electricity accounts for about 50 percent of the delivered cost, transmission for about 13 percent, and distribution for about 37 percent.

Electricity can be transported using one of two types of current--direct current (d.c.) or alternating current (a.c.). However, because the generator output is alternating current, it must be converted if it is to be transported as direct current. Direct current is electric current flowing continuously in one direction, and alternating current is electric current that reverses its direction regularly and continually. Energy transported by direct current is converted to alternating current before it is distributed to the customer whose electrical facilities operate on alternating current. Direct current transmission lines have lower line losses than alternating current transmission lines, but because of the high cost of conversion to or from alternating current lines, direct current lines are usually economical only at high voltages (over 250 kilovolt¹) and over long distances.

Electricity is transported on two types of systems--transmission systems and distribution systems. Generally a transmission system carries electricity from the point of generation to a point where the voltage is reduced for delivery to the customer over a distribution system. In general, a distinction between transmission (to a load center) and distribution (to the customer) is based on voltage level, which varies from system to system, but systems with voltages below 69 kV are usually classed as distribution

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One kilovolt (kV) equals 1,000 volts.

systems. Transmission systems can be designed to carry either alternating current or direct current but not both. Distribution systems in the United States are designed for alternating current and most transmission systems are alternating current.

Transmission lines can be constructed overhead or underground. As of June 30, 1974, there were 413,225 circuit miles of 69 kV and above transmission lines in the United States (about 1 percent is underground lines). Utilities and Federal power agencies have planned construction of 63,695 circuit miles of additional transmission lines by 1984.

Several hundred investor-owned utilities provide about three-quarters of the Nation's electric supply. The remainder is provided by cooperatives or local, State, and Federal governments. Six Federal agencies--Alaska Power Administration, Bonneville Power Administration, Southeastern Power Administration, Southwestern Power Administration, Tennessee Valley Authority, and Bureau of Reclamation--control transfer of power over federally owned transmission lines within their systems as well as lines interconnecting them with other systems. The Federal Power Commission regulates some transmission lines that interconnect both Government and investor-owned utility systems and all transmission lines that cross State lines.

Two organizations provide the bulk of research and development (R&D) for transmission systems--the Electric Power Research Institute (EPRI)--funded primarily by investor-owned utilities--and the Energy Research and Development Administration (ERDA) of the Federal Government.

SCOPE OF STUDY

We examined records and talked with officials of both Federal and non-Federal organizations associated with the utility industry. The Federal organizations included the Bonneville Power Administration, the Bureau of Reclamation, ERDA, and the Federal Power Commission. Non-Federal organizations included EPRI, the Edison Electric Institute, the National Electric Reliability Council, and several investor- and Government-owned utility companies.

We emphasized identifying (1) causes of electrical energy losses during transmission and (2) research designed to reduce transmission losses.

CHAPTER 2

TRANSMISSION LOSSES

Electric energy is lost during transmission because of certain laws of physics which affect electricity in various types of transmission systems. Four factors--resistance, skin effect, corona, and insulation--cause most of the loss of electric energy during transmission. Not all these factors affect alternating current and direct current overhead lines or underground cables to the same extent. Resistance and skin effect account for virtually all loss of energy during transmission. In addition, the power factor¹ has an important effect on resistance losses of alternating current lines. Although corona and insulation factors causing losses are considered when designing transmission lines, each normally accounts for less than 1 percent of the total losses. Large reductions of existing levels of transmission losses will require considerable progress in new technology developments. (See chapter 3.)

RESISTANCE

Resistance transforms electric energy into heat, causing a loss of electric energy. Technically, resistance is a property of a conductor (line) which opposes the current (flow of electrons). Resistance losses occur in both alternating current and direct current transmission systems.

The amount of electric energy lost because of resistance (i.e., the quantity transformed to heat) is affected by the magnitude of current, the size of the conductor, the material used in making the line, the distance of transmission, and the temperature of the line.

Although all conductors exhibit the property of resistance, the magnitude of resistance can be reduced by increasing the size (diameter) of the conductor and changing the material from which it is made. Gold, silver, copper, and aluminum exhibit the lowest values of resistance. Most lines today are made of aluminum. Since resistance is a physical property of a conductor, the longer the transmission distance, the greater the resistance losses.

¹The ratio of actual power being supplied by a circuit to the apparent power being supplied. (See p. 4.)

Resistance is minimized and losses are reduced when electricity is transported at low current, low temperature, high voltage, and through large conductors. Technological advancements currently limit voltage levels to about 765 kV.

Resistance losses are also increased as a result of reactive power which is measured by a percentage called the power factor.

Reactive power

In an alternating current transmission system, voltage and current travel along transmission lines like waves, each having peaks and valleys. Ideally, voltage and current should reach their peaks and valleys at the same time. However, two phenomena can cause voltage and current to peak at different times--inductive reactance and capacitive reactance.

When electricity passes through a conductor, a magnetic field develops, producing a voltage acting counter to the voltage produced by the generator and, thereby, opposing current flow. This opposing voltage, however, is usually not significant unless large electric motors are connected which require magnetic fields to operate. This opposing voltage causes current peaks to fall behind voltage peaks. The opposing effect is called inductive reactance.

When current peaks and voltage peaks do not occur at the same time, the apparent power, which is the voltage times the current, is greater than the useable power.

When current peaks and voltage peaks do not occur at the same time, more current is needed to do the same amount of work. Since resistance loss is caused by current flowing in the lines, this additional current increases resistance losses in the line.

Capacitors added to a transmission line, near electric motor loads, can correct inductive reactance by pulling the current peaks in the line back into phase with the voltage peaks. Capacitors resist voltage buildup, thereby causing the current peaks to pull ahead of voltage peaks. When the capacitors balance the motors, the current and voltage peaks occur together and the loss is minimum. If the capacitors are connected when the motors are not in use, the current peaks in the line pull ahead of the voltage peaks, causing increased line losses. To minimize this effect, some capacitors can be switched off. Other ways are to connect shunt reactors which can absorb the excess

reactive power and to disconnect some transmission lines when not needed. However, the first is quite expensive and the latter may reduce system reliability, so these measures must be planned carefully.

The ratio of actual power to apparent power expressed as a percentage is called the power factor. When voltage peaks and current peaks occur at the same time the power factor is 100 percent or unity. The farther the voltage and current peaks are from each, the lower the power factor and the greater the loss in transmission when the same load is served. Transmission system power factors normally range from 75 to 100 percent, but with judicious use of capacitors, power factors of 90 percent and higher are commonplace.

SKIN EFFECT

Resistance decreases with an increase in the size of the conductor. Some benefits of reduced resistance are not fully realized, however, due to the phenomenon known as skin effect. Skin effect losses are found in both alternating current overhead transmission lines and underground cables.

Alternating currents cause electromagnetic forces in conductors which are greater at the center than at the circumference of the line. These forces create a voltage which establishes circulating currents that oppose the main current at the center and add to the main current at the circumference. Thus the current is forced to the outside of the conductor, reducing the effective area of the conductor. This tendency becomes more pronounced as the size of the conductor and frequency of electricity increase. Resistance increase caused by skin effect can approach 10 percent of total resistance losses for large conductors.

Skin effect losses have been reduced by designing transmission lines with larger conductor diameter and by using a central portion of low conductivity. This design reduces the opportunity for electromagnetic forces to form and increase resistance.

CORONA

Significant corona loss occurs only on overhead lines. Corona is the electrical discharge at the conductor's surface and occurs when the intensity of the electric field at the conductor's surface exceeds the electrical breakdown strength of the air. In effect, electricity

leaves the lines.¹ Corona increases with high voltages, large lines, conductor contamination, and wet weather. In wet weather, corona losses may be five times greater than in dry weather.

Corona losses typically account for less than one-tenth of the total power losses. Bundle conductors, consisting of several conductors side by side, are being installed to minimize the effect of corona.

INSULATION

Insulation losses are associated with both alternating current and direct current underground cables. Two types of insulation losses occur during cable transmission.

--Dielectric hysteresis, experienced only with alternating current underground cables, occurs as the voltage is reversed, causing a reversal in the position of the insulation's polar molecules producing heat, thereby causing electrical energy to be lost.

--Conduction currents (leakage currents), the second form of insulation loss, occurs with both alternating current and direct current underground cables. Conduction currents increase when the resistance of the insulation is reduced through increases in the surrounding temperature of the insulation and exposure of the insulation to radiation and certain chemicals. This allows the current to pass through the insulation and power to be lost.

Insulation (air and support insulators) losses on overhead lines are so insignificant they are not considered when computing total transmission losses. Insulation losses at low voltages, on conventional underground cables account for less than one-tenth of the total power losses. However, the losses appreciably increase at high voltages.

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The discharge of electricity from corona is accompanied by a hissing sound and by the odor of ozone. With moisture nitrous acid is produced. Corona on transmission lines causes radio television interference.

These four factors are laws of physics and, therefore, will exist when moving electric energy. Total electrical energy transmission losses resulting from the above factors is about 2.5 percent of net generation.¹ The estimated transmission losses during 1975 were equivalent to about 80 million barrels of oil (about a 4.5-day requirement).

As indicated above, almost all overhead transmission losses are due to resistance. Theoretically, losses can be reduced by increasing the conductor's cross-section area, raising transmission voltage levels, and for underground cables, lowering the temperature of the line. Higher voltage transmission allows reduction in the current required and, therefore, results in lower current losses. Presently, the level of load demands for bulk amounts of power and construction costs limits the feasibility of raising voltages of existing transmission systems.

Lowering the temperature of the conductor will also reduce resistance losses. While resistance losses can be reduced greatly or to zero by operating certain conductor materials at temperatures below 22° K.,² the potential for reducing temperatures is limited by dependability, expense, material fabrication problems, and stability in maintaining the required low temperatures. Improvements in power factors can also reduce transmission losses caused by resistance.

¹Based on a study prepared for ERDA. In addition, the report said that distribution losses are about 5 percent of net generation.

²22° K. is equal to -420° F.

CHAPTER 3

RESEARCH AND DEVELOPMENT

Both the electric utility and related industries and the Federal Government conduct research and development (R&D) in electric transmission systems. The goal of most transmission R&D is to increase the power-carrying capability of new and existing transmission systems. Reductions in electric energy losses during transmission are an additional consideration in such research. The utility industry, through Electric Power Research Institute (EPRI), and the Federal Government, through Energy Research and Development (ERDA), are the major supporters of transmission research.

EPRI and ERDA operate cooperatively in areas of mutual interest. Officials at both organizations said that they communicate with one another about the projects being considered and those projects underway. Additionally, before awarding a research contract from unsolicited proposals by either organization, the other organization receives a copy of the proposed research project on which to comment.

Representatives of EPRI and ERDA meet regularly to review, discuss, and coordinate research. Each organization identifies areas and projects which it supports and research findings are exchanged. Some projects, to which each organization contributes a combined research effort, are also mutually supported.

EPRI

EPRI is an organization funded by direct contributions from about 500 utility companies,¹ and by indirect contributions through cooperative projects with universities and manufacturers. Most funding is accomplished by designating a .115 mill per kilowatt-hour charge to all members' electrical customers. The Tennessee Valley Authority is the only Federal Government organization that is a member.

EPRI budgeted about \$21 million for fiscal year 1976 in transmission research. EPRI's research advisory committee, appointed by the board of directors and composed of 20 utility executives, meets regularly to assess and define

¹Additionally the American Public Power Association which comprises publically owned utility systems participates in EPRI.

the broad R&D needs of the industry. A functional division committee assists each technical division director in evaluating priorities and recommending program emphasis. In addition, within each functional division, task forces aid divisional personnel in program assessment and review. There are no written criteria used to set priorities for research. Rather, committee members base decisions on their perceptions of what the industry needs most. Recommendations of the research advisory committee are subject to the approval of the board of directors.

Short-term projects

EPRI's transmission research is administered by its Transmission and Distribution Division which is organized into functional areas--alternating current overhead transmission; direct current overhead and underground transmission; underground transmission; distribution; and system planning, control, and security. The division's immediate objectives in alternating current overhead transmission and distribution are research on conductors, towers, breakers, transformers, and other equipment used in bulk power transmission lines and substations.

The potential to reduce transmission losses primarily depends on the overall feasibility of lines operating at a voltage higher than 765 kV. For example, the losses on a 1,500-kV line will have about one-fourth the losses of a 765-kV line as a percentage of the total power transmitted.

The largest research project in this area as of 1974 was Project UHV (ultra high voltage). The project involves designing, constructing, and testing overhead transmission lines rated up to 1,500 kV. EPRI is now funding tests of a short length of a complete three-phase line. Corona research will be conducted in conjunction with this project.¹

Electric power transmission networks are currently operating at voltages up to 765 kV. The Director of the Transmission and Distribution Division told us that the state-of-the-art advances in electrical engineering have gradually improved the efficiencies and thus have reduced the losses of each new transmission system over previous systems. He said that opportunities for large reductions in transmission losses in the near future are limited unless significant progress in new technology developments are obtained.

¹ERDA and the Bonneville Power Administration also provide funding.

One obstacle to implementing higher voltages (up to 1,500 kV) is the high-intensity electric fields that may result. EPRI is now sponsoring a project studying the effects of these high-intensity electric fields on plants and animals.

Mid-term projects

EPRI's mid-term projects are concentrated principally on reducing the environmental impact of bulk power transmission facilities and to increase the number of long-distance transmission circuits. EPRI has concentrated its research efforts on direct current transmission and underground transmission.

Direct current transmission

The direct current transmission program is directed toward scaling down the size of terminal equipment, decreasing costs, increasing reliability, and reducing thermal losses in converter valves. At present, direct current transmission is advantageous for long overhead lines and underground cables. EPRI is sponsoring direct current transmission research in three areas: high-voltage transmission lines, converter-station miniaturization, and direct current circuit breaker development. In the near future, they plan research on +1,200 kV (or 2,400 kV line-to-line) transmission lines.

One direct current transmission line research project is developing design data for +600 kV (or 1,200 kV line-to-line) transmission lines. Performance of line and station insulation and corona losses are a part of this research.

Underground transmission

High cost and the limited high-voltage ratings of the lines must be overcome before underground transmission systems become practical for bulk power transmission. EPRI has 39 projects in the underground transmission field, including research in compressed gas-insulated cables, taped cables, and direct current cables. An ERDA official said that it is cofunding many of these projects.

A compressed-gas transmission system is a conductor held by insulators in the center of a gas-filled pipe. Among its useful properties are an inherent high insulating strength, good heat transfer characteristics, and a low loss resulting from dielectric hysteresis. (See p. 6.)

EPRI's project to develop a synthetic insulated cable, which is laminated, has the objective of developing cables for 500 kV and higher.

Long-term projects

After the year 2000, very high-capacity energy transmission methods will probably be required to meet electric energy needs. Two possible long-term solutions to problems of bulk power transmission lie in developing low temperature (cryogenics) cable systems or superconducting cable systems which could be rated at 10,000 megawatts and above.

In all conductors, as temperature is lowered, resistance becomes smaller and current will flow with less energy loss and consequently, less heat generation. This means that cables at low temperatures can carry more power than they can at normal temperatures.

At very low temperatures, certain materials undergo a change in physical properties and offer no resistance at all to the flow of electric current. In these superconductors, with their zero resistivity, there are no energy losses and very large currents can be carried in relatively small cables. Research in the field of superconductivity is seeking materials which can undergo the transition to the superconductivity state at higher temperatures--the best materials known to date must be cooled below 22° K. which requires refrigeration with liquid hydrogen or liquid helium. Developing materials which become superconductive at temperatures above 77° K. (the temperature of liquid nitrogen) would make superconductive cables more practical. To date, the use of liquid nitrogen refrigeration is only applicable to cryogenic cables made of the common metals (e.g., aluminum and copper). In either case, cryogenic or superconducting cables will require energy for refrigeration systems to maintain their low temperatures.

EPRI currently is sponsoring a number of projects on superconductivity, the goal of which is to solve the problem of carrying a higher power density, with lower losses, over greater distances. Cryogenic and superconducting cables with rated capacities on the order of 1,000 to 10,000 megavolt amperes¹ are the development objectives of this research. Cryogenic and superconducting transmission projects include research to develop:

¹Megavolt amperes is the same as megawatts without a power factor reduction.

- A rigid superconducting cable that can carry massive amounts of power over one small three-phase line with essentially no losses. This system would use pressurized liquid helium as a cooling agent. The operating temperature would be approximately 5° K. and would require refrigeration stations every 5 miles.
- Multilayered thin-film superconducting material for alternating current lines. This would allow an operating temperature of 10° K. and would reduce transmission losses.
- Feasibility studies for a versatile high-capacity liquid helium refrigeration system.

While cryogenic or superconductive cables would reduce transmission losses greatly, or to zero for the latter, there are a number of problems associated with these types of systems. The systems are very susceptible to the presence of metallic particles, even as fine as dust, which might get into the system and cause a breakdown. Spacers for holding the conductor in the center of the outer tube are very expensive and an obstacle to implementation.

Practicality is the primary obstacle to implementing cryogenic or superconducting transmission systems, according to the Director of EPRI's Transmission and Distribution Division. He said that this type of transmission system might be practical only for power levels above 10,000 megawatts,¹ a power level the Nation may not need for 25 years. Additionally, the need for cryogenic and all ultra-high-voltage-types of transmission depends, in part, on future decisions on powerplant sitings. If future generation is concentrated in power parks, superconductive transmission systems might be feasible. If generation is near the load, however, conventional or cryogenic transmission systems may be adequate. (See p. 15.)

According to an EPRI official, superconducting transmission lines are very expensive. It is estimated that they would cost at least twice that of conventional transmission lines. The amount of energy expended to cool the system to 22° K. and below and the effects of a refrigeration system failure are two major obstacles to superconductivity. Power required to refrigerate the line would be very costly in both dollars and energy. Also, there is danger that if the conductors warm up and go from a state of no resistance to their normal state of finite resistance, the extreme power levels would burn up the lines immediately.

¹ One million watts equals one megawatt.

ERDA

The Energy Reorganization Act of 1974 established ERDA to insure that the Nation's short-term and long-term energy needs will be met by full exploitation of fuel resources. As part of this effort, the Congress has directed ERDA to conduct research and development in energy conservation.

Under current plans, the Assistant Administrator for Energy Conservation Research and Development will have authority over five major programs, one of which is Electric Energy Systems. One of its subprograms is electric power transmission. This subprogram is comprised of the former Atomic Energy Commission and the Department of the Interior R&D programs in transmission and distribution. ERDA's program includes R&D of both overhead and underground transmission technologies to meet the increasing demands for higher power transfer capability.

ERDA meets regularly with EPRI's utility advisory committees to obtain their input on research needs and to insure coordination of research.

ERDA's electric power transmission objectives are to:

- Develop technology for special bulk power transfer applications.
- Develop technology and reduce constraints to use of high-voltage direct current transmission.
- Develop underground transmission systems capable of matching overhead lines in voltage and power capacity and reduce cost relative to that of overhead systems.
- Develop technology and reduce constraints to use of 1,200 kV alternating current transmission.

The program involves industrial and university contractors and national laboratories, with an emphasis on technology transfer to industry. The following is a summary of ERDA's estimated expenditures by subprogram.¹

¹ERDA's estimated budget for distribution is \$200,000 and \$1,000,000 for fiscal years 1975 and 1976, respectively.

	<u>Actual</u> FY 1974	<u>Estimate</u> FY 1975	<u>Estimate</u> FY 1976
	(000 omitted)		
Underground transmission	\$1,600	\$5,412	\$3,000
Overhead alternating current transmission	-	500	2,000
Overhead direct current transmission	-	400	2,000
Advanced energy delivery concepts	-	200	4,000
Total electric power transmission program	<u>\$1,600</u>	<u>\$6,512</u>	<u>\$11,000</u>

ERDA's underground transmission subprogram concentrates on developing technologies for reducing power losses, lowering capital and operating costs, substantially increasing power capability, and increasing reliability. The major areas of emphasis for fiscal year 1976 include developing cryogenic and superconducting cable systems, bulk power gas-insulated cable, and direct current cable systems.

ERDA's overhead alternating current transmission program is directed toward 1,200 kV bulk power transmission and gas-insulated substations, to reducing losses, increasing power transmission capability, reducing costs, and assessing and mitigating negative environmental impacts. The primary thrust of this program is in 1,200 kV transmission line research, compact and miniaturized lines and stations, and development of ancillary equipment for bulk power applications, such as circuit breakers and transformers.

The objective of the subprogram related to overhead direct current transmission is the solution of the technical problems and constraints that prevent broader application of direct current overhead transmission. Direct current lines have lower power losses from the absence of reactive power¹ flow and skin effect. If lower cost, more efficient, miniaturized terminal stations could be devised, there would be greater incentive for these lines. This subprogram's major areas of emphasis lie in the development of (1) miniaturized alternating current/direct current converter

¹The ratio of actual power being used in a current (watts) to the apparent power being drawn from the line. Thus it is the nonworking part of total power delivered.

station prototypes, (2) direct current system components, (3) ultra-high-voltage direct current systems, and (4) analysis simulation of advanced direct current systems. Reduction in losses, furthermore, would enhance the power capability of direct current underground cables. The unique advantage of much greater power transfer capability makes underground direct current transmission attractive because of the absence of certain factors (e.g. dielectric hysteresis).

ERDA emphasizes more than such industry long-term projects as superconductivity. In fiscal year 1976, ERDA plans to continue developing alternating current and direct current superconducting cables. Specifically, ERDA is pursuing (1) flexible and rigid cable designs and (2) an advanced refrigeration system designed for cooling superconducting cables. ERDA plans to continue studies with utility companies to identify potential applications for superconducting cables.

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The state-of-the-art advances in electrical engineering have gradually improved the efficiencies and thus have reduced the losses of each new transmission system over previous systems. Opportunities for large reductions in transmission losses in the near future are limited unless significant progress in technology developments are obtained.

The non-Federal (EPRI) and the Federal (ERDA) transmission research and development is coordinated.

Both EPRI and ERDA are new organizations--EPRI was established in 1972, while ERDA's scope was expanded in 1974. Substantial benefits resulting from their R&D efforts are yet to be realized.

Future research emphasis may change depending on changing needs. For instance, one factor that is important to the priority assigned to various types of transmission research is the point at which power is to be generated (i.e., at the load center or at the fuel source). If generation is to be at the fuel source (i.e., at the coal mine), more research probably would be directed toward improving the type of transmission lines needed for long-distance transmission of electricity. However, if generation is to be at the load center (i.e., a city), more research probably would be directed toward improving the type of transmission lines needed for short-distance transmission of electricity.

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