## Technology Summary D.1: Efficient Power Transformers

### Source Country for Data: United States  
**Date:** May, 1994

### Technology Data Type: Best Available Practice

### General Characteristics

**Sector:** Energy Transfer - Electricity transmission and distribution.

**Applications:** To step-up the generator voltage for transmission; to step-down the transmission voltage to intermediate levels for distribution and use in various customer sites.

**Typical Size:** Depends on their power kVA rating; power substation transformers (>2500 kVA); distribution transformers (>2500 kVA); power transformers are housed in special substations. Distribution transformers are either pad or pole mounted.

Transformers are built and tested according to the applicable industry standards. With large power transformers, the standard practice is to design the unit to operate most economically, rather than most efficiently. Maximum efficiency designs may not be the most economic, since increasing the efficiency usually results in an increase in capital cost of the transformer.

**Design Fuels:** Electric.

**Performance Measure:** Operating Efficiency: 98% and higher (for large power transformers).

**Design Lifetime:** 20-30 years.

**Construction and Delivery Timeframe:** Varies depending on size. Pole-mounted distribution transformers are "off the shelf" items; pad-mounted distribution transformers and power transformers are custom built and can require up to 9 months for design and construction.

**Development Status:** Conventional and amorphous core: commercial. Low temperature and high temperature superconducting transformers: development.

### Cost Information

**Location and Year:** U.S., 1991.

**Capital and Installation:** Distribution Transformers: Net price +$2,000-4,000/kW for no-loads + $1,000-2,000/kW for load loss in the U.S. Net price: $700-800 for 37.5 kVA; single phase pole mounted. No net price data is available for pad mounted transformers because the designs are customized.

Power Substation Transformers: Total evaluated price = net price of the transformer + $2,500-3,500; kW no load loss + $1,600-2,500/kW load loss, where the net price is based on the kV and kVA ratings, the temperature and the price of accessories.
TECHNOLOGY SUMMARY D.1: EFFICIENT POWER TRANSFORMERS (Cont’d)

COST INFORMATION (Cont’d)

A conventional 200 MVA grid transformer cost $829,000 in 1989, including the shell ($23,000), core ($331,000), windings ($351,000), shipping ($100,000), and installation ($24,000). Transformers are evaluated in terms of total ownership cost, equal to selling price of transformer (net) and evaluated losses (discounted present value of the future load and no-load losses). Cost of cooling equipment, transportation and civil engineering design must be added to the cost of capital investment.

Non-fuel Operation and Maintenance: None.

Fuel: Not Applicable.

ENVIRONMENTAL CHARACTERISTICS

Waste Streams: PCB in oil: older transformers may contain PCBs; PCBs not used in newer systems. Oil Leaks: proper maintenance and periodic testing can prevent oil spills. Leak-proof oil pits can be built to capture oil.

Air Pollutants: Noise: especially a problem for distribution transformers. Noise emissions are regulated by an ANSI standard C-57 in the U.S.

Carbon Emissions: None.

Site Specific: None.

Emissions Retrofit Potential: None.

IMPLEMENTATION REQUIREMENTS (LABOR AND INFRASTRUCTURE)

Operating Personnel: None required, usually remote operation once installed.

Maintenance Personnel: Experienced journeyman electrician required to perform periodic maintenance and tests on transformers equipment, its auxiliary and cooling system. At an additional cost, an automated monitoring system can be installed at a substation and interfaced with the utility’s SCADA computer. Proper maintenance ensures efficient and safe operation.

Infrastructure Requirements: Transformer design must conform to relevant codes and standards for the given country and region. Design specifications must include specifications for cooling circuits, grounding circuit and in some cases, drainage pit for removing transformer oil.

REFERENCES


## TECHNOLOGY SUMMARY D.2: ELECTRIC POWER TRANSMISSION AND DISTRIBUTION SYSTEMS

**Source Country for Data:** United States  
**Date:** September, 1992  
**Technology Data Type:** Best Available Practice

### GENERAL CHARACTERISTICS

**Sector:** Electric power transfer.  
**Applications:** Electric power transmission and distribution.  
**Typical Size:** Transmission voltage generally 69 kV or higher; primary distribution voltage in the range 4.16-34.5 kV with 12.47 kV, 13.2 kV and 13.8 kV in widest use. Majority of utilities have 34.5 kV, a minority have 23 kV subtransmission voltages for distribution. Primary distribution system supplies distribution transformers that step the primary distribution voltage down to utilization voltages generally in the range of 120-600 V.  
**Design Fuels:** Electrical current.  
**Performance Measure:** Service reliability, operating efficiency. Most industrialized nations experience power losses of approximately 10% between the generating plant and the customer. Efficiencies are hoped to be further increased by superconducting technology and other developments.  
**Design Lifetime:** In perpetuity; replace wooden poles and transformers every 30 years.  
**Construction and Delivery Timeframes:** Depend on the length of the line: local transmission projects can take 2 years to complete; long transmission line projects can take 5-10 years and longer, depending on the permit process.  
**Development Status:** Commercial.

### COST INFORMATION

Costs depend on the voltage, type of pole construction and right-of-way (ROW). At the low end of the cost scale, low voltage, 60 kV transmission line with wooden poles in remote area costs as low as $20/foot, or $100,000/mile. One steel pole costs $10,000.  
Typical costs: $1 million/mile for overhead lines; can be 5 times more expensive in mountainous terrain; about $10 million/mile for underground cables. Superconducting transmission lines currently require cooling with liquid Helium at temperatures around -270 C, causing superconducting transmission be more costly than other technologies at present. Other cooling materials are being developed that will likely reduce the cost of superconducting transmission.

### ENVIRONMENTAL CHARACTERISTICS
**Waste Streams:** Not Applicable.

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**TECHNOLOGY SUMMARY D.2: ELECTRIC POWER TRANSMISSION AND DISTRIBUTION SYSTEMS (Cont'd)**

**ENVIRONMENTAL CHARACTERISTICS (Cont'd)**

**Air Pollutants:** Electric power transmission lines create electromagnetic fields (EMFs). The strength of fields decreases with distance away from the transmission lines. Several states in the U.S. have promulgated rules regulating EMFs associated with high-voltage transmission lines.

**Carbon Emissions:** Although transmission and distribution (T&D) systems do not produce emissions directly, they affect the overall carbon emissions of the utility indirectly, due to the existence of T&D losses. Increased efficiency of the T&D system can reduce carbon emissions of the utility.

**Site Specific:** Electric power transmission lines are linear facilities that will affect the natural and socio-cultural resources. Electric power lines have the greatest impact on land resources. A dedicated power transmission line right-of-way is required. Grazing and other agricultural uses are usually not precluded in ROWs, but other uses are generally precluded. Environmental impacts are caused by construction, operation and maintenance of transmission lines.

**Emissions Retrofit Potential:** Not Applicable.

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**IMPLEMENTATION Retrofit REQUIREMENTS (LABOR AND INFRASTRUCTURE)**

**Maintenance:** Clearing and control of vegetation in rights-of-way is required. Transformer and substation servicing.

**Operating Personnel:** Skilled laborer needed to service substations and transformers.

**Infrastructure Requirements:** Transmission lines are primarily overland systems and can be constructed to span or cross wetlands, streams, rivers, and near shores areas of lakes, bays, etc. Access or maintenance roads are required to service poles, right-of-ways, switchyards and substations.

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**REFERENCES**


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### GENERAL CHARACTERISTICS

**Sector:** End Use - Buildings, Industry; Utilities.

**Applications:** Buildings: Used for generating and storing the daily cooling load of a commercial building during off-peak times of day or when cheaper electricity is available. Industry: load shifting to off-peak electricity rates; permit installation of smaller capacity refrigeration equipment.

**Typical Size:** For storage tank for a typical commercial building with a 30 GJ daily cooling load--approximately 2100 cubic meters for a chilled water system, 275 to 420 cubic meters for an ice storage system, and 1000 cubic meters for a phase change materials system.

**Design Fuels:** Electricity.

**Performance Measure:** These systems are used to offset cooling loads during peak electricity demand periods. Energy consumption per unit of cooling relative to requirements for conventional cooling systems ranges from 10-20 percent more for chilled water systems to as much as 75% more for ice storage systems due to storage losses and colder refrigerant temperatures for ice.

**Design Lifetime:** 15-25 years. Phase change materials systems are a relatively new technology, so there is more uncertainty about their expected lifetimes.

**Construction and Delivery Timeframe:** Ice and phase change system construction times will vary by manufacturer. Some standard-sized systems may be available off the shelf, while custom designed systems may take 3 or 4 months for delivery. Water storage systems are usually constructed on-site as part of a building's cooling system, and may take 2 or 3 months to complete.

**Development Status:** Commercial.

### COST INFORMATION

**Capital and Installation:** Cost is $0.15 to $0.30 per liter ($150 to $300 per cubic meter) of storage capacity for the tank, cost of auxiliary equipment is about 10% to 20% of tank cost, and for ice systems the additional chiller capacity required will cost around $30 to $60 per kW. Many thermal storage applications require utility rates to be cost-effective to the end-user.

**Non-fuel Operating and Maintenance:** O&M costs will consist of costs to treat and filter the system water, although the incremental cost may be insignificant since the system water of the cooling system would have to be treated regardless of the presence of the storage system. For ice systems that are emptied and not operated off-season, seasonal cleaning may be necessary to prevent tank corrosion.

**Fuel:** Depends on local electricity prices.
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<td><strong>Waste Streams</strong>: Not Applicable.</td>
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<tr>
<td><strong>Air Pollutants</strong>: Not Applicable.</td>
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<td><strong>Carbon Emissions</strong>: None.</td>
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<td><strong>Site Specific</strong>: None.</td>
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<td><strong>Emissions Retrofit Potential</strong>: Not Applicable.</td>
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<td><strong>Operating Personnel</strong>: Storage system daily activation can be automatic, although trained operations personnel are important in making time-of-day strategies successful.</td>
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<td><strong>Maintenance Personnel</strong>: Monitoring and maintenance is required, but should not require additional personnel compared to conventional building cooling system.</td>
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<td><strong>Infrastructure Requirements</strong>: System would need access to both water and electricity, water treatment and filtration required.</td>
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## TECHNOLOGY SUMMARY D.4: HIGH VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION

### Source Country for Data: United States  
**Date:** August, 1994

### Technology Data Type: Best Available Practice

### GENERAL CHARACTERISTICS

**Sector:** Energy Transfer - Electricity Transmission.

**Applications:** For bulk transfer of electricity over large distances at high voltage and in direct current mode.

**Typical Size:**
- The first HVDC project was built in Sweden in 1954 with a power rating of 20 MW and 100 kV over a distance of 96 km.
- The largest HVDC project is in Brazil and was built in 1987 with a power rating of 6300 MW and 600 kV over a distance of 800 km. The total world HVDC capacity as of 1993 is 58 GW and 9 GW is planned.

**Design Fuels:** Electric current.

**Performance Measure:** Service reliability, operating efficiency, and transmission and distribution losses. T&D losses from a typical national grid represent about 8.5% of the total power output. Eighty percent of this loss is resistive and therefore inversely related to voltage according to I²R law. Therefore high voltage decreases T&D losses.

**Design Lifetime:** The transmission lines are perpetual, but the life time of the components such as rectifiers (to convert ac to dc), invertors (from dc to ac), thyristors, and dc circuit breakers is about 30 years.

**Construction and Delivery Timeframe:** Depends on the distance over which power is transmitted. For local transmissions (less than 100 km) the project will take 2 years whereas longer distances may take 5 - 10 years.

**Development Status:** Commercial.

### COST INFORMATION

**Location and Year:** U.S., 1993.

**Capital and Installation:** The total cost of transmission system includes the line costs (conductors, insulators, and tower) plus the right-of-way costs. A dc line with two conductors can carry the same amount power as a three-phase ac line with the same size of the line conductors. A dc tower with only two conductors is simpler and cheaper to construct than three-phase ac tower. Power losses in the dc line are also lower than in the ac line for the same power transmitted. However, HVDC system requires converters at the two ends of the line; hence the terminal costs for dc are higher than for ac. There is a break-even distance over which the total cost of dc transmission is less than ac transmission. For overhead transmission the break-even distance is in the range of 500 - 800 km, for submarine cables in the range of 20 - 50 km, and for underground cables in the range of 40 - 100 km. HVDC is more economical than AC transmission only for distances greater than 500 km.
TECHNOLOGY SUMMARY D.4: HIGH VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION (Cont’d)

COST INFORMATION (Cont’d)

New methods of power generation such as thermoelectric, magnetohydrodynamics and fuel cells, which generate in direct current, will make HVDC more attractive.

Non-fuel Operating and Maintenance: Not available.

Fuel: None.

ENVIRONMENTAL CHARACTERISTICS

Waste Streams: Not applicable.

Air Pollutants: · SO₂: None. · NOₓ: None. · Particulates: None. · Hydrocarbons: None.

Carbon Emissions: DC transmission is more efficient than AC transmission, therefore conserves energy and reduces air emissions, including CO₂ at the power plant.

Site Specific: HVDC transmission systems are very capital intensive; local terrain may increase line costs. Environmental impacts: caused by construction, operation and maintenance of lines.

Emissions Retrofit Potential: Electric power transmission lines create electromagnetic fields. The strength which is proportional to the voltage and inversely proportional to the distance.

IMPLEMENTATION REQUIREMENTS (LABOR AND INFRASTRUCTURE)

Operating Personnel: Skilled technical personnel are needed to service circuit breakers, converters, etc.

Maintenance Personnel: Clearing and control of vegetation in rights-of-way required.

Infrastructure Requirements: Connection to transmission grid.

REFERENCES


