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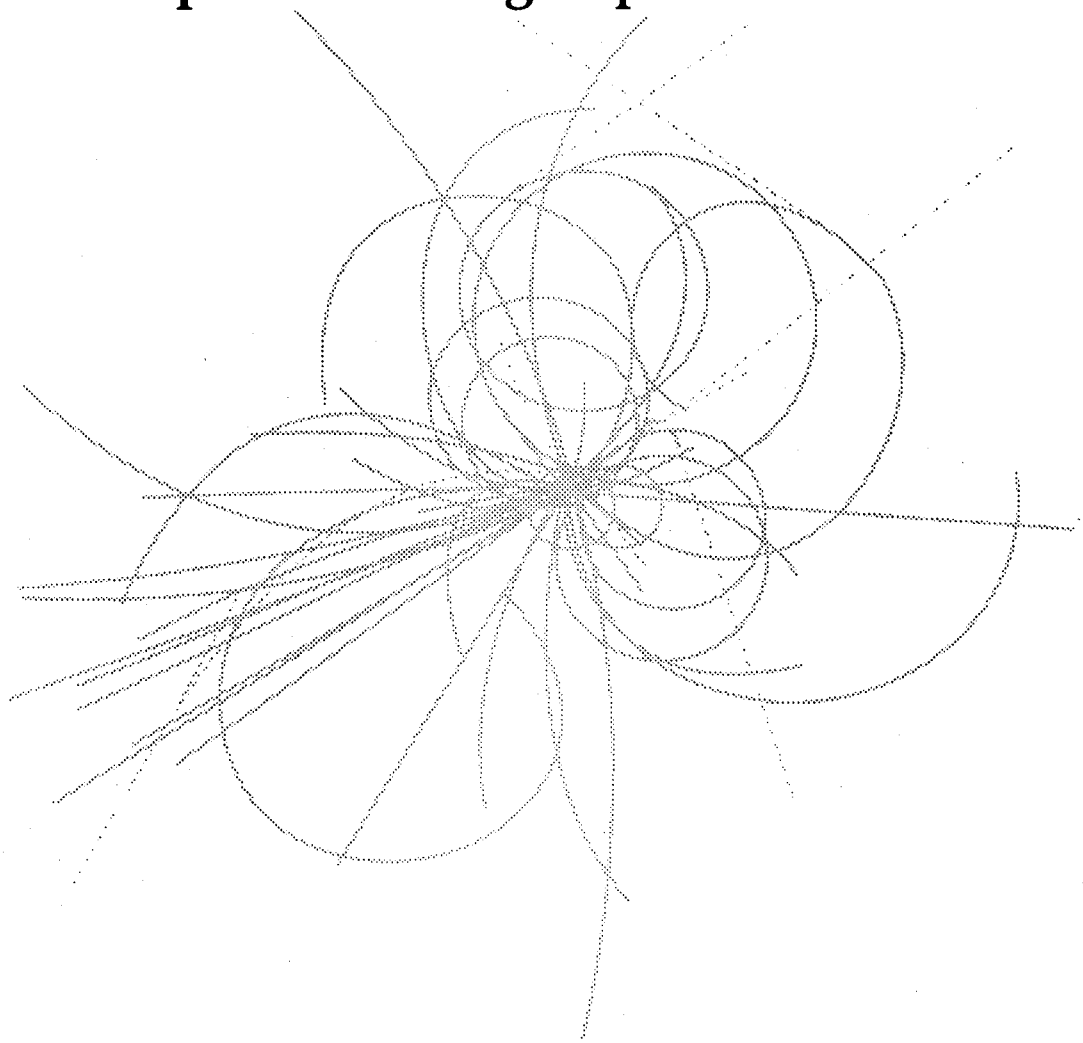

Concept Design of the High Voltage Transmission System for the Collider Tunnel

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CONCEPT DESIGN OF THE HIGH-VOLTAGE TRANSMISSION SYSTEM FOR THE COLLIDER TUNNEL

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INTRODUCTION

In order to provide electrical service to the Superconducting Super Collider Laboratory (SSCL) 54-mile-circumference collider of 125 MVA at 69 kV or 155 MVA at 138 kV of distributed power, it must be demonstrated that the concept design for a high-voltage transmission system can meet the distribution requirements of the collider electrical system with its cryogenic system's large motor loads and its pulsed power technical systems. It is a practical design, safe for operating personnel and cost-effective. The normal high-voltage transmission techniques of overhead and underground around the 54-mile collider tunnel could not be applied because of technical and physical constraints, or was environmentally unacceptable. The approach taken to solve these problems is the installation of 69-kV or 138-kV exposed solid dielectric transmission cable inside the collider tunnel with the superconducting magnets, cryogenic piping, electrical medium, and low-voltage distribution systems, and electronic/instrumentation wiring systems. This mixed-use approach has never been attempted in a collider tunnel. Research into all aspects of the engineering and installation problems and consultation with transmission cable manufacturers, electrical utilities, and European entities with similar installations—such as the Channel Tunnel—demonstrate that the concept design is feasible and practical.

This paper presents a history of the evolution of the concept design. Design studies are underway to determine the system configuration and voltages. Included in this report are tunnel transmission cable system considerations and evaluation of solid dielectric high-voltage cable design.

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PROJECT LAYOUT

The project electrical service will supply two (2) main areas—the West and East Complexes—and ten (10) service areas equally distributed around the 54-mile collider ring at the surface.

The West Complex includes the injector facilities, made up of the LINAC, Low Energy Booster, Medium Energy Booster, and High Energy Booster (HEB), the west main substation, two experimental areas, and the campus. The campus includes technical support buildings, warehouses, workshops, and emergency services facilities.

The East Complex has two large experimental areas with industrial buildings, the east main substation, and emergency services facilities. The collider ring is divided into ten sectors, each with its own service area and electrical substation at the surface. These sector service areas are 5.4 mile apart. The surface facilities include buildings to house control electronics, magnet power supplies, cryogenic equipment, gas storage tanks, tunnel air conditioning, and ventilation equipment, and cooling pond. The service area substation provides all power to the service area and tunnel power for that sector. Halfway between each sector service area is an emergency exit shaft that provides personnel emergency egress and a location for air conditioning and ventilation equipment. See Figure 1.

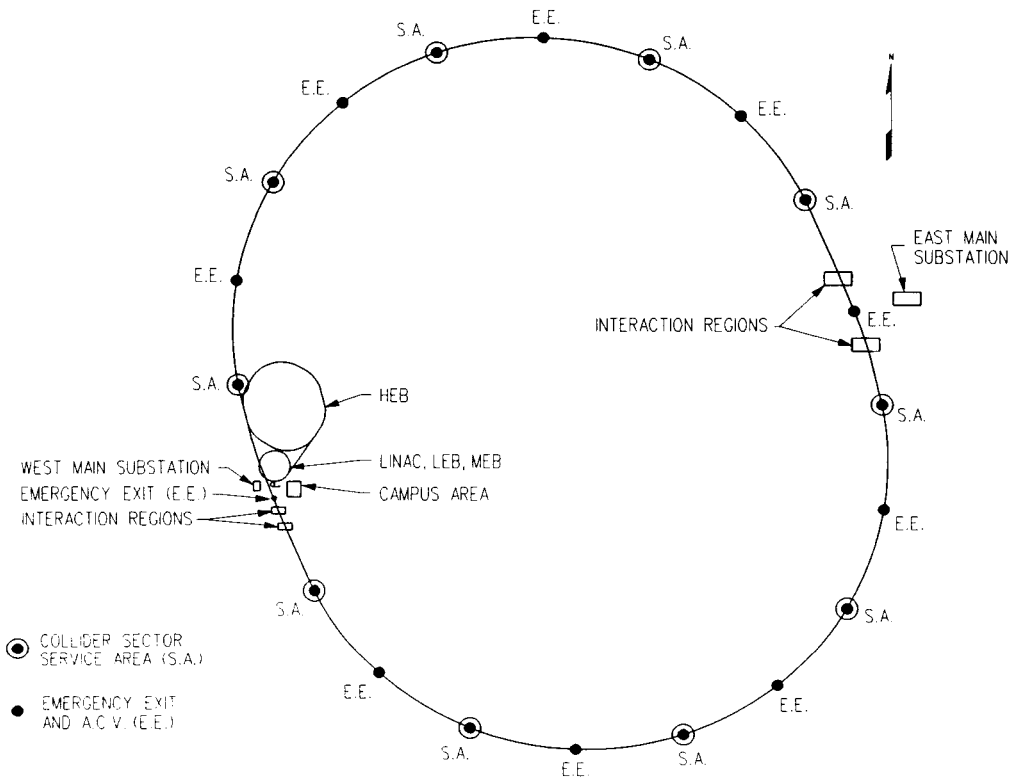

Figure 1. SSCL Project Layout.

CONCEPT DESIGN HISTORY

1983–1987

During this period, the first studies and concept designs for the requirements of an electrical system were performed. This was before a specific site within the United States had been selected for the SSCL. Design groups and consultants looked at all of the technical requirements of the collider, using as a basis the Fermi National Accelerator Laboratory experience with its large pulsing and ramping loads. The Fermi collider is approximately one-half the size of the SSCL HEB. The SSC collider main ring has no equivalent in size or power requirements; it will be the largest in the world.

Conclusions reached by the design groups were that the minimum system, with an expected average total system load of 107 MVA and a peak load of 162 MVA, would require a single utility grid of 230 kV, a 69-kV transmission system around the collider ring, and 13.8 kV for surface distribution. An emergency feed of 69 kV for the collider and HEB cryogenics systems would be required, as power must be maintained to these systems.

1988–1990

The State of Texas was chosen as the site of the SSCL. Studies and concept designs were then modified with the now-known transmission system that is available in the area around the SSCL. Also, total system loads increased to 185 MVA average and 225 MVA peak.

The concept design proposed that the SSCL be served from 345-kV lines available on each side of the SSCL project, with transmission around the inside of the collider at 69 kV to the service areas and 12.47 kV for surface distribution.

1991–1992

Reviews of the SSCL concept design were conducted by design consultants, the utility company, and an expert advisory board. The design consultants recommended an all 25-kV system. The utility company recommended an intermediate voltage of 138 kV (between 345 kV and 69 kV) and 12.47-kV distribution voltages in the substations. The advisory board agreed with the intermediate voltage of 138 kV in the substation, and recommended 138 kV around the collider ring. The board also recommended eliminating the East 345-kV substation and using existing local 138-kV transmission lines for emergency service.

Figure 2 shows the SSCL concept design with the adoption of the 138-kV intermediate voltage recommended by both the utility company and the advisory board in the substations, and 69 kV around the collider ring.

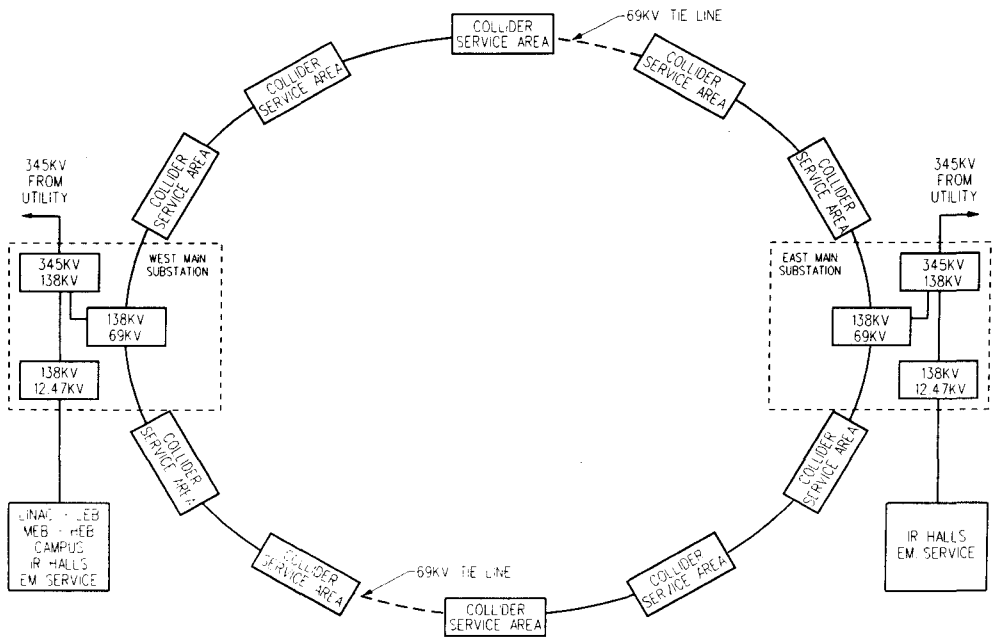

Figure 2. SSCL Concept Design with 69 kV Around Collider.

Figure 3 shows the advisory board concept of one substation of 345 kV to 138 kV for the substation intermediate and the collider ring voltage, with existing local 138-kV transmission for emergency service.

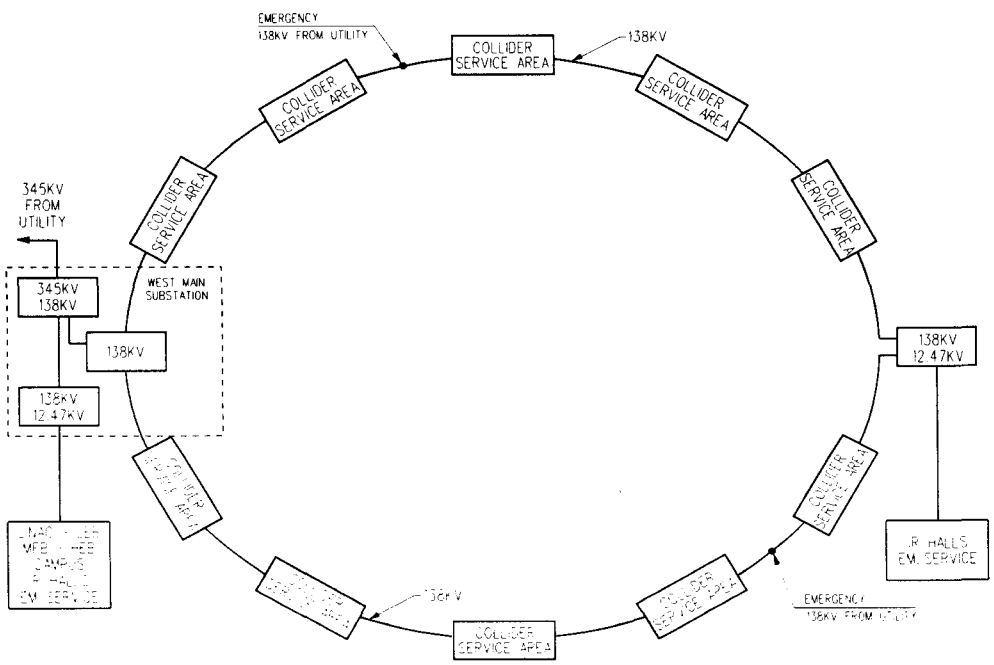

Figure 3. Advisory Board Concept with 138 kV Around Collider.

DESIGN STUDIES

Design studies now in progress are evaluating final load requirements, reliability, short circuit, load flow, motor starting, operating philosophy, and construction costs. These studies are now being performed on both systems shown in Figures 1 and 2 as well as with 25-kV surface distribution. A study for 25-kV distribution for the injectors, only, is also being performed. The studies are due for completion by late April 1992. The results of these studies will allow the SSCL to make a final determination of system configuration, collider transmission, and surface distribution voltages.

TUNNEL CABLE SYSTEM

The 69-kV SSCL concept design provides the 54-mile collider with 125 MVA of distributed power—12.5 MVA at each of the 10 service areas around the collider from four feeders, as shown in Figure 2. If the 138-kV system is adopted, the load around the collider would increase to 155 MVA, as it would then also serve the East Campus from the two collider feeders from the west substation (see Figure 3). The normal high-voltage transmission techniques of overhead and underground transmission could not be applied because of technical and physical constraints; nor was it environmentally acceptable. Overhead transmission was not considered viable because lightning strikes could cause line disturbances resulting in lost experiments. Other-weather related problems such as tornados and ice storms can also cause long outages. Obtaining a right-of-way for a transmission line around the collider would be very difficult and would be environmentally unacceptable to the SSCL and the local community. Underground transmission cable for 54 miles was considered very impractical, and the cost was prohibitive. The approach taken to solve these problems was the installation of exposed solid dielectric transmission cable attached to the collider tunnel roof. The electrical medium- and low-voltage distribution systems and electronic/instrumentation wiring systems are also installed in the tunnel attached to the roof. Cable installation design has to be practical, cost-effective, and safe for operating and maintenance personnel. Various designs were developed, using manhole and duct systems in the tunnel floor, which proved impractical and very expensive. Cable tray systems are practical but require excessive access space and are also very expensive for 54 miles. Exposed high-voltage cables gave some concerns about personnel safety; however, after explanation of modern cable design, manufacturing, installation procedures, protection systems, and the policy of very limited access to the tunnel only during maintenance periods, these concerns were abated.

The SSCL had discussions with various American cable manufacturers on the application of exposed high-voltage cable in tunnels used not for utilities but for other purposes, such as transportation or process industry, where limited personnel access was standard. It became very apparent that such an application has been used very little in the United States but extensively and very successfully in Europe. There is no code or technical reason in the United States preventing this application—only custom.

European installations have requirements similar to the collider tunnel installation. After visits to installations and meetings with European design and installation engineers and with manufacturers of installed cables in those locations (*e.g.*, the channel tunnel), the design concept for a solid dielectric high-voltage transmission system for the collider tunnel has been verified as a good engineering concept. It is a practical, safe and effective application of an exposed cable system. Favorable engineering and cost recommendations were made by those involved in the meetings.

Figure 4 illustrates the concept of the cable installation in the collider tunnel.

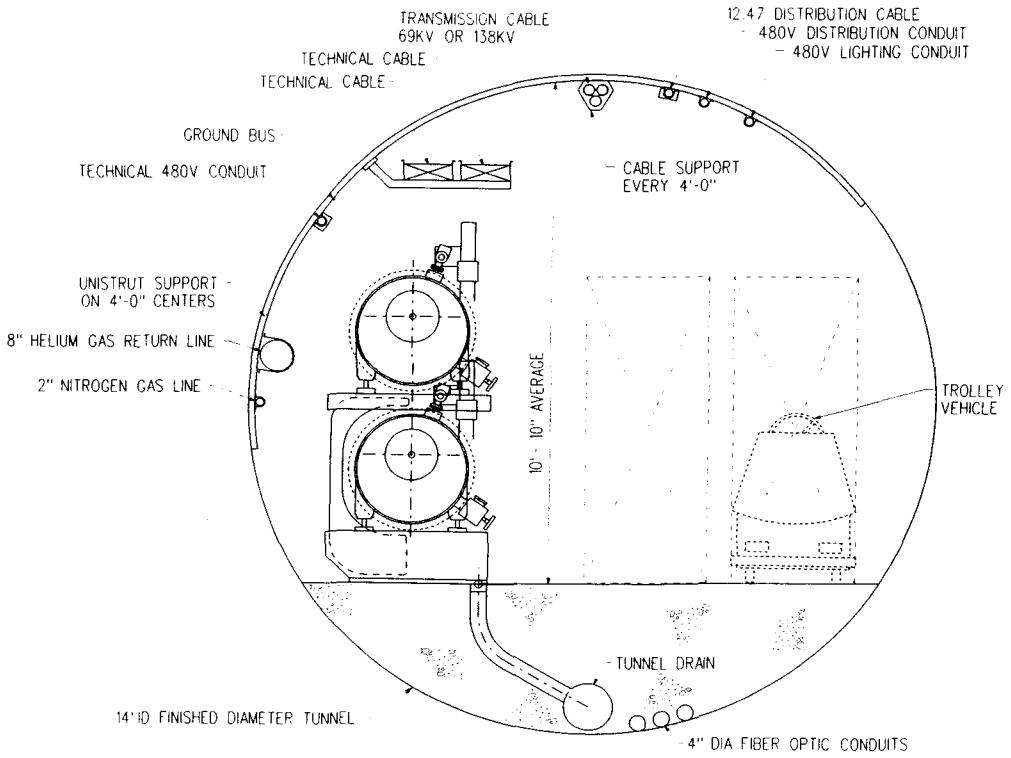

Figure 4. Tunnel Cable Installation.

CABLE DESIGN

The function of insulation in electrical cable, both physically and electrically, is to provide separation of the conductor from its surroundings. Thus the insulation system must possess the mechanical strength to support a physical load and the electrical strength to separate the charges with minimum loss of energy. Also involved are load and temperature changes. Manufacturing considerations are very important, including the purity and cleanliness of the insulation material, and the extrusion and curing methods employed during cable manufacture.

A solid dielectric cable is more than simply a conductor and insulation; it is a system that also includes semiconductive shields to provide smooth isopotential interfaces between the conductor and the insulation; grounding shields; and metal and extruded jackets to provide physical protection and to minimize the entrance of moisture.

Pure, high-molecular-weight thermoplastic polyethylene (PE) has the best overall electrical properties, as well as the highest electrical breakdown strength and the lowest electrical losses. However, its useful temperature range is limited, and it is sensitive to moisture. PE has been modified by various means to improve one or more of its characteristics. However, compromise must always be accepted in the formulation of materials. Low-density PE can be crosslinked with organic peroxide to form crosslinked polyethylene (XLPE). Or, it can be copolymerized with monomers and other materials to make ethylene propylene rubber (EPR) insulation. XLPE can be further modified to make a moisture-resistant insulation called tree retardant crosslinked polyethylene (TRXLPE). These three insulations make up the vast majority of cable produced in the United States and the world.

Cable insulation selection from among XLPE, TRXLPE, and EPR is one of the most critical determinations to be made for the SSCL's high voltage cable system. Other variables in cable design are not as controversial as this issue. SSCL findings to date on the features of the various insulations in cables are set forth in Table 1.

XLPE	Best use when no moisture is present Excellent for high-voltage cables Cost-effective initial and operating
TRXLPE	Best use when moisture conditions are expected Cost-effective initial (1.1 × XLPE) and operating
EPR	Best use when overloading is likely Best use when flexibility is important Best use when conditions indicate cost (2 × XLPE) justification

Table 1. Findings Summary.

FEATURE	XLPE	TRXLPE	EPR
Cost (XLPE = 1)	1	1.1	2.0
Insulation Material Formulation Standard	Good	Good	Many Formulations
Insulation Material Quality Variability	Good	Good	Many Producers
Variability Insulation Material Manufacturing	Good	Good	Hard to Detect
Cable Flexibility	Good	Better	Excellent
AC Breakdown Strength (Initial)	Good	Good	Lower
AC Breakdown Strength Retention after Aging	Lower	Good	Good
Impulse Breakdown Strength	Good	Good	Lower
Accelerated Cable Life Test	Good	Good–Excellent	Excellent
40-Year Expected Life	Good	Good	Excellent
Coefficient of Thermal Expansion	Non-linear	Non-linear	Linear
Dielectric Constant	Excellent	Better	Lower
Dissipation Factor	Excellent	Better	Lower
Overload Condition	Good	Good	Better
Insulation	Poor	Lower	Better
Strippable Shield	Good	Good	Poor